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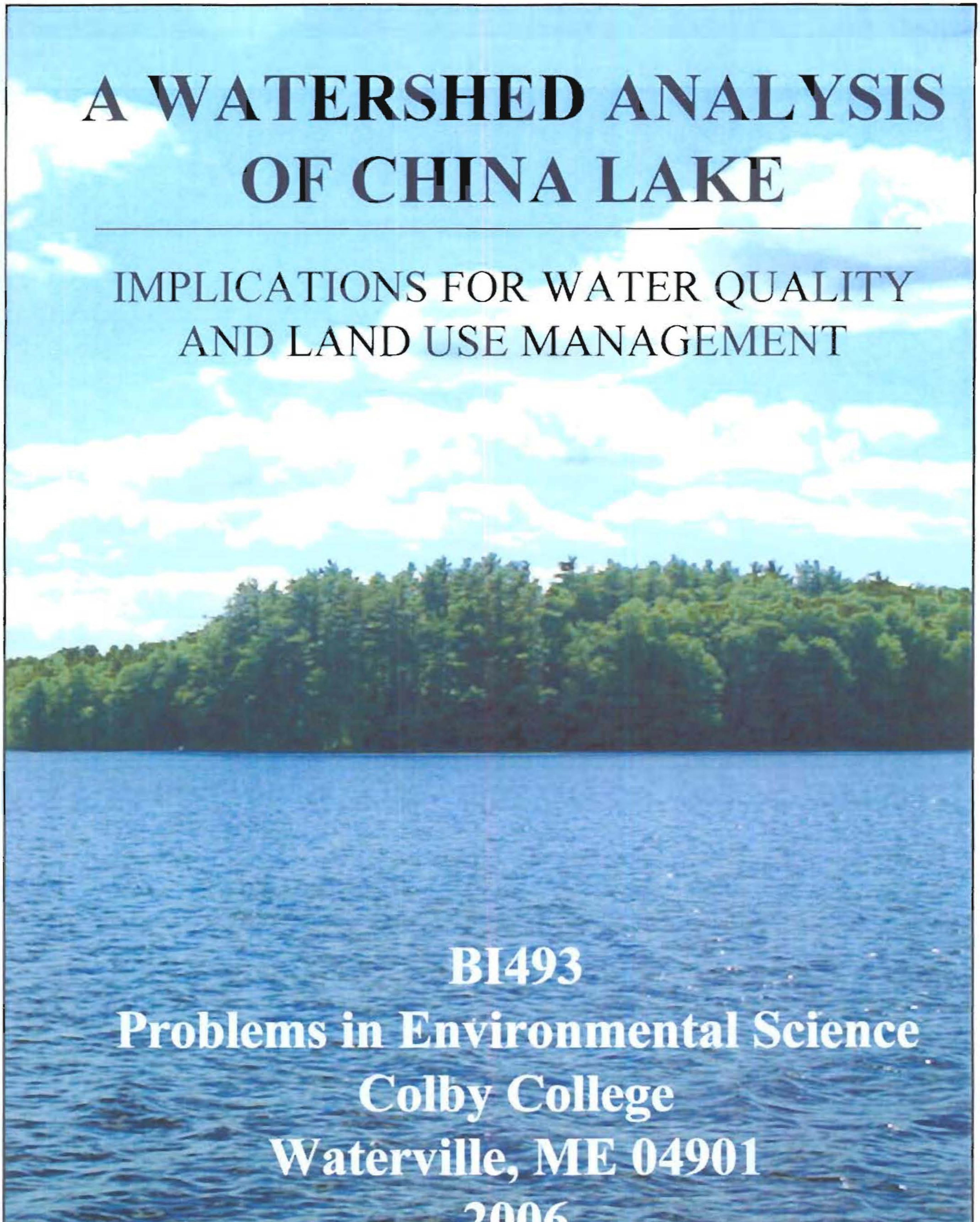
A Watershed Analysis of China Lake

Colby Environmental Assessment Team, Colby College

Problems in Environmental Science course (Biology 493), Colby College

A WATERSHED ANALYSIS OF CHINA LAKE

IMPLICATIONS FOR WATER QUALITY AND LAND USE MANAGEMENT



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WATERSHED ASSESSMENT INTRODUCTION

EXECUTIVE SUMMARY

CEAT investigated the water quality of China Lake, located in China and Vassalboro Maine, from June through December 2005. The group analyzed physical, chemical, and biological water quality parameters from samples taken on China Lake and from tributaries flowing into the lake. An analysis of land use patterns, especially the impact of residential, commercial, municipal, and institutional development in this watershed, enabled CEAT to study their impact on water quality trends. Data collected by CEAT in 2005 were compared to historic data from the Maine Department of Environmental Protection (MDEP) to gain a historical perspective of lake water quality. The phosphorus model created from these data enabled CEAT to identify the sources of phosphorus that most threaten the current and future water quality of China Lake.

CEAT confirmed that the accumulation of phosphorus resulting from surface runoff, shoreline erosion, and internal nutrient loading negatively affects water quality of China Lake. Once the phosphorus concentration passes a threshold of 12 to 15 parts per billion (ppb), a lake may undergo algal blooms that decrease the aesthetic, recreational, ecological, and economic value of the lake and adjacent shoreline properties. Water quality improves with reductions of external phosphorus loading and sediment release of phosphorus caused by anoxic water conditions.

A brief summary of CEAT findings in the China Lake study:

- Using a water budget, CEAT calculated the flushing rate at 0.35 flushes per year. This value indicates that 35% of the water in China Lake is replaced each year, and all the water is theoretically replaced every 2.86 years. The relatively large size of China Lake and the relatively small watershed size contribute to the low flushing rate.
- The dissolved oxygen level in China Lake has decreased substantially since the first recorded algal bloom in 1983. No trends in dissolved oxygen concentrations exist in recent data, but concentrations in all recent years are lower than the levels historically found in the lake, particularly in deep water.

- Phosphorus concentrations over the summer of 2005 ranged from 11.4 to 199.3 ppb with a surface mean (± SE) of 22.5 ± 2.0 ppb and a hypolimnion mean of 55.7 ± 13.3 ppb. The high phosphorus concentration results in China Lake being classified as a eutrophic lake.
- Aerial photographs of the China Lake watershed from 1965 and 2003 were analyzed to determine changes in land use. One trend observed was an increase in development near the shoreline, including the rise of residential, municipal, and commercial lands.
- Buffer strips serve as the last boundary between surface runoff and the lake. A study of the 460 developed lots along China Lake indicated that 12% had buffer strips rated unacceptable, 34% were rated poor, 40% were rated fair, and 11% were rated good. Buffer strips covering the entire shoreline distance of each lot with multiple layers of vegetation extending at least 75 feet from the lake are recommended on the China Lake shoreline where possible.
- Camp roads cover 18.0 hectares (44.5 acres) of the China Lake watershed and are estimated to contribute approximately 3.40 kg of phosphorus per hectare per year to the lake. State roads cover 58.5 ha (144.6 acres) and contribute less phosphorus, approximately 1.50 kg/ha/yr. Of the camp roads, 21% of the acreage covered was rated good, 43% fair, 26% poor, and 10% unacceptable.
- CEAT identified 40 problem areas during road surveys. These surveys identified problems such as the lack of culverts, crowns, or ditches as well as the presence of berms. Camp roads accounted for 39 of these problem sites, possibly due to the lack of state funded or mandated repairs.
- No invasive species have been found in China Lake, but the presence of large areas of shallow water and the three public boat launches make an infestation of Eurasian Water Milfoil, Variable-Leaf Milfoil, *Hydrilla*, or another invasive macrophyte species possible.

Successful water quality remediation begins with a reduction in the amount of nutrients entering China Lake. Maintaining roads, improving buffer strips, reducing shoreline erosion, and limiting development in areas with high erosion potential will help reduce the quantity of nutrients entering the lake. However, reducing external nutrient loading alone will not return China Lake to a clear water lake because of the advanced state of eutrophication and the significant phosphorus release from lake sediments during anoxic periods. Some form of in-lake

mitigation needs to be taken. The most effective way to remove phosphorus-laden sediments would be to dredge the lake, but this alternative is both prohibitively expensive and ecologically destructive. Although expensive, the most cost effective solution is an alum treatment. Drawdowns are a less expensive, long-term, potential remediation technique but would be difficult with this large, two basin lake with a low flushing rate. The powerpoint presentation given on December 8th along with data summaries can be viewed at http://www.colby.edu/biology/BI493/BI493.html.

GENERAL NATURE OF STUDY

Lakes are one of the most important natural resources in Maine, providing necessary habitat for aquatic plants and wildlife, and important economic, aesthetic, and recreational resources for humans. Maintaining the ecological and economic value of Maine lakes depends on preserving pristine water quality. Unfortunately, human activities often alter lake habitats and detrimentally affect water quality.

Lakes undergo an aging process called eutrophication. Young lakes are nutrient poor (oligotrophic); over time they accumulate nutrients from a variety of sources and eventually reach a nutrient rich (eutrophic) state (Beeton 1965). Erosion from shorefront properties and roads, and decaying organic matter are potential sources of nutrient loading into lakes. Although the accumulation of nutrients is a natural process, human activities can significantly accelerate eutrophication significantly. In typical Maine lakes and other freshwater ecosystems, phosphorus is the limiting nutrient for plant growth (Dodds and Welch 2000). High levels of phosphorus entering a lake as a result of human activities can lead to abundant growth of aquatic plants and algae. Dense plant growth, and their subsequent death and decay, often harm other species by decreasing dissolved oxygen levels in the water (Carpenter et al. 1998), causing ecological and economic harm from reducing wildlife habitat, lowering levels of biodiversity, decreasing property values, and ending productive fisheries.

The 2005 Colby Environmental Assessment Team (CEAT) conducted a study of the China Lake watershed. The watershed includes land in China, Vassalboro, and Albion, Maine while the lake itself is located in the towns of Vassalboro and China. China Lake is relatively large, covering 1,604 ha (3,963 acres) and is extremely important in the region. It serves as a local drinking water source and a popular recreation area for fishermen, boaters, and swimmers. The area has been developed for many years and numerous year-round and seasonal houses cover its shoreline. The long history of development in the watershed has led to a decline of water quality and annual algal blooms.

The purpose of this study was to evaluate the water quality of China Lake and assess the impact of human activities and development in the watershed on water quality. CEAT measured and analyzed physical, chemical, and biological parameters of the lake, and compared these findings to historical data. Land use was evaluated within the watershed with particular attention paid to those land uses with a high potential to increase nutrient loading of the lake, such as

development of residential and commercial properties, septic systems, and roads. Geographic Information System (GIS) software was used to map physical features of the watershed, land use patterns, and model soil erosion potential and septic sustainability in the watershed. CEAT used calculations of the water and phosphorus budgets of the lake to predict future phosphorus loading and potential eutrophication. With these data, CEAT identified specific problems in the watershed and suggested remediation techniques to improve water quality.

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)

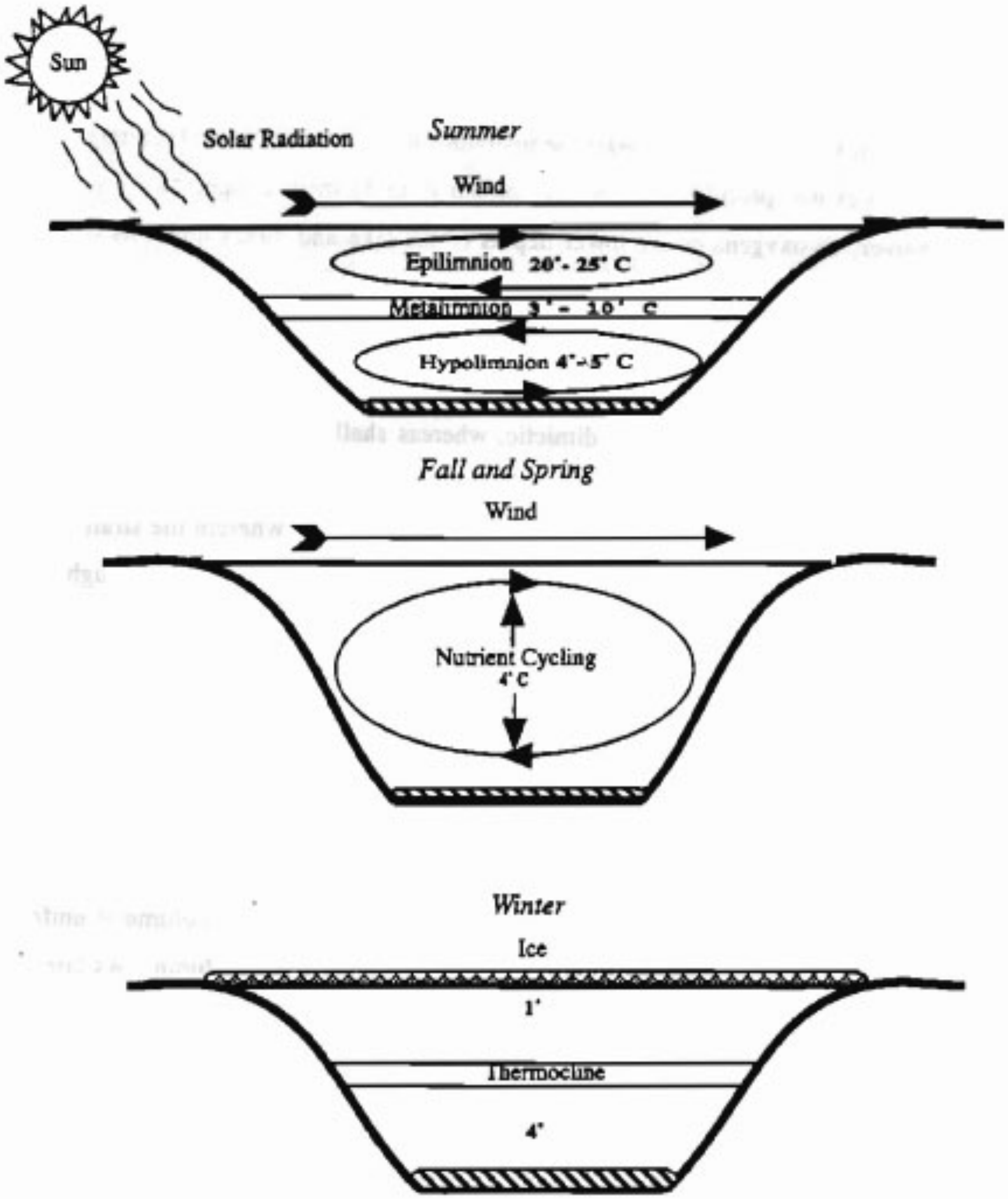

Figure 1. Mixing by means of lake turnover in dimictic lakes. During the summer, lakes are stratified into three layers (epilimnion, metalimnion, and hypolimnion). During the fall and spring, the isothermal temperature and density facilitate the lake turnover and redistribution of nutrients. In the winter, 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.

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

They are low in suspended solids such as nitrates and more importantly phosphorus, the limiting nutrient for plant productivity in most freshwater ecosystems. The shape of a lake can also influence its productivity. Steep-sided oligotrophic lakes are not conducive to extensive growth of rooted vegetation because there is 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

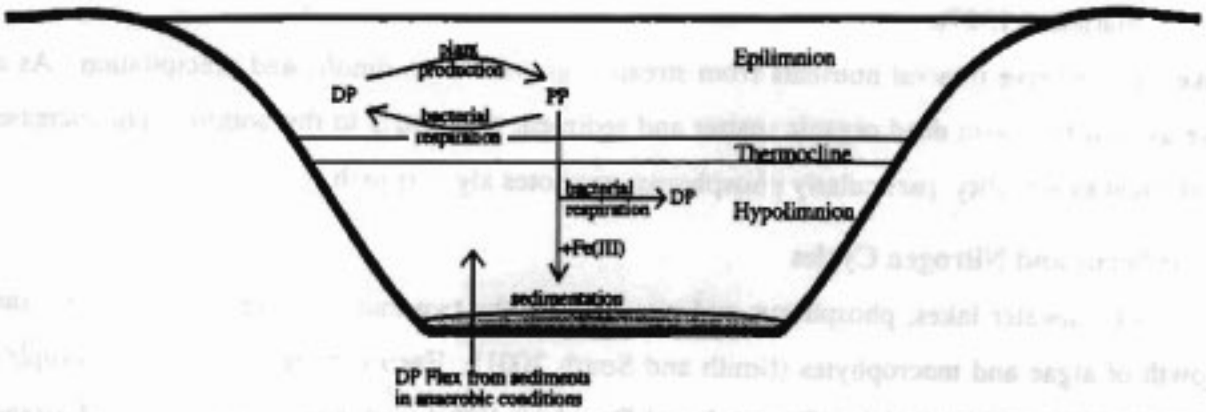

Figure 2. A model of the cycle of the major forms of phosphorus, dissolved (DP) and particulate (PP), within a lake ecosystem. The sedimentation of DP through complexation with Fe (III) contributes to the build-up of DP in the sediments. Note the production of DP in the hypolimnion due to bacterial decomposition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

levels at the sediment-water interface, resulting in the release of DP. The ferric phosphate complex, combined with the anaerobic bacterial conversion of PP to DP, can lead to a significant build-up of DP in anoxic sediments.

The sediments of a lake can have phosphorus concentrations of 50 to 500 times the concentration of phosphorus in the water (Henderson-Sellers and Markland 1987). Sediments can be an even larger source of phosphorus than external inputs. Nutrients are 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).

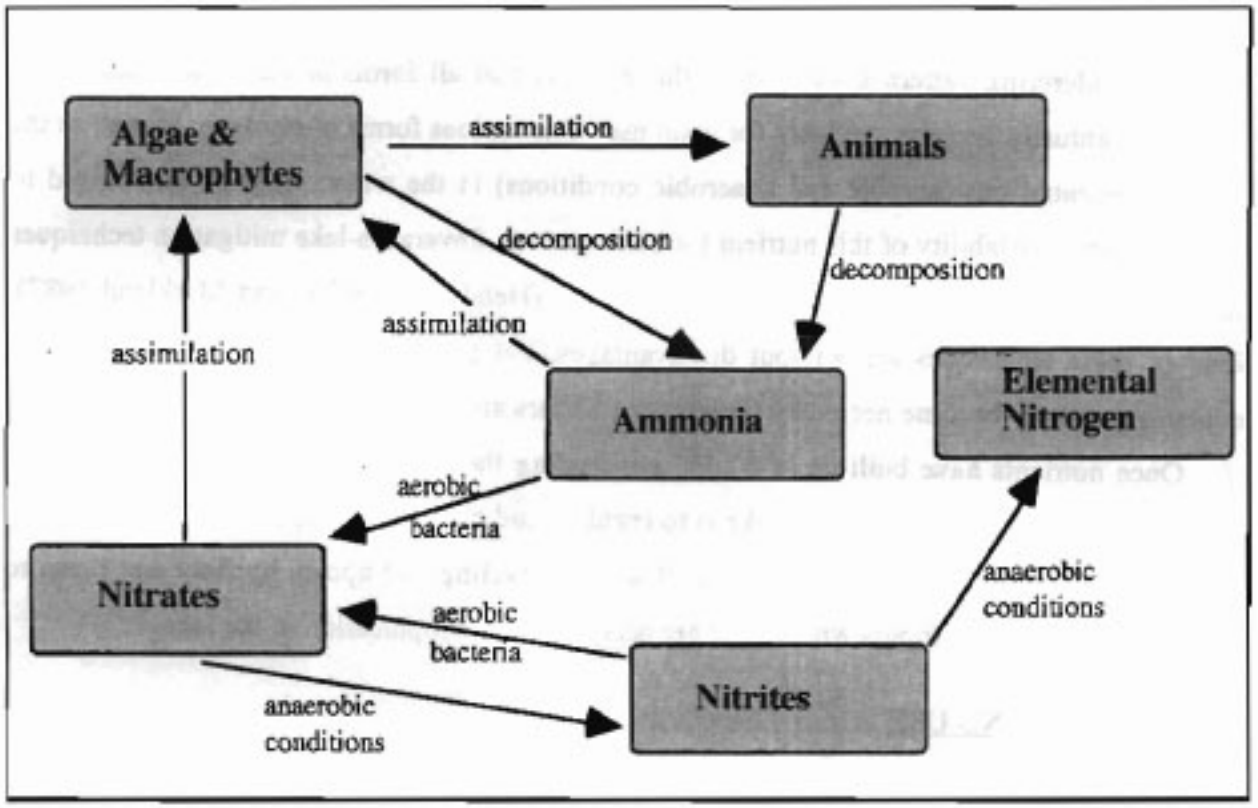

Figure 3. A diagram of the various forms of nitrogen that occur in the nitrogen cycle within a lake ecosystem. It is important to note that in aerobic conditions both ammonia and nitrites are converted to nitrates, which are available for use by plants.

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 can be affected by natural and anthropogenic processes (Hem 1970). Human activity usually accelerates the loading of nutrients and sediments into a lake the water quality can be adversely affected in a short period of time.

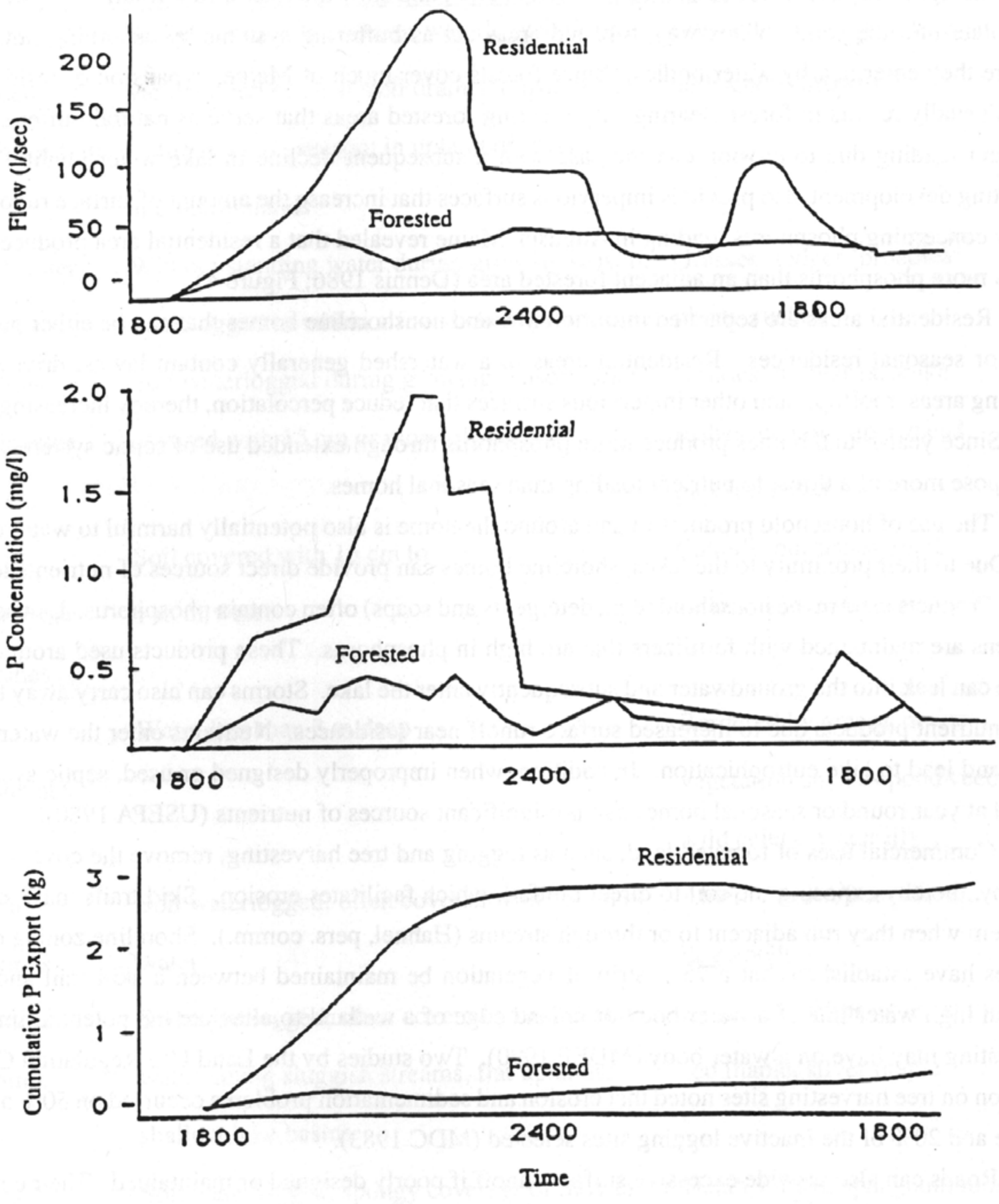

Figure 4. Comparisons of runoff after an April rain storm in two neighboring watersheds near Augusta, ME. Top: volume of immediate runoff over a 12 hour period; Middle: phosphorus concentration in the runoff; Bottom: total amount of phosphorus exported into local streams and lakes from the storm (Dennis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

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. 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% 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).

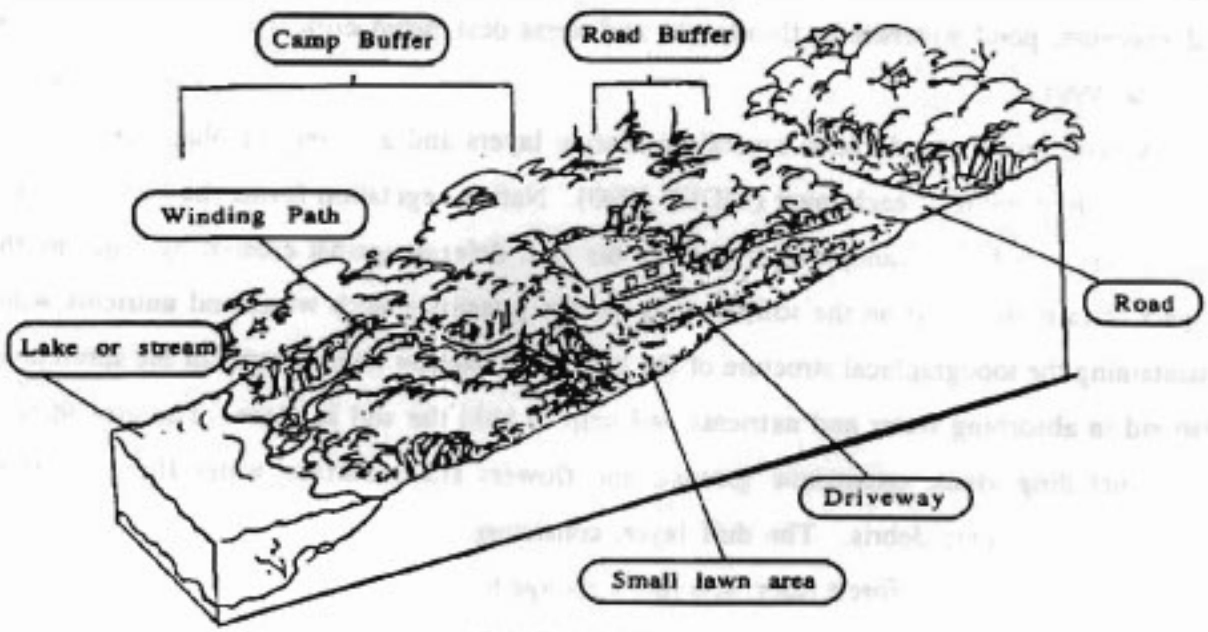

Figure 5. Diagram of an ideally buffered home.

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.

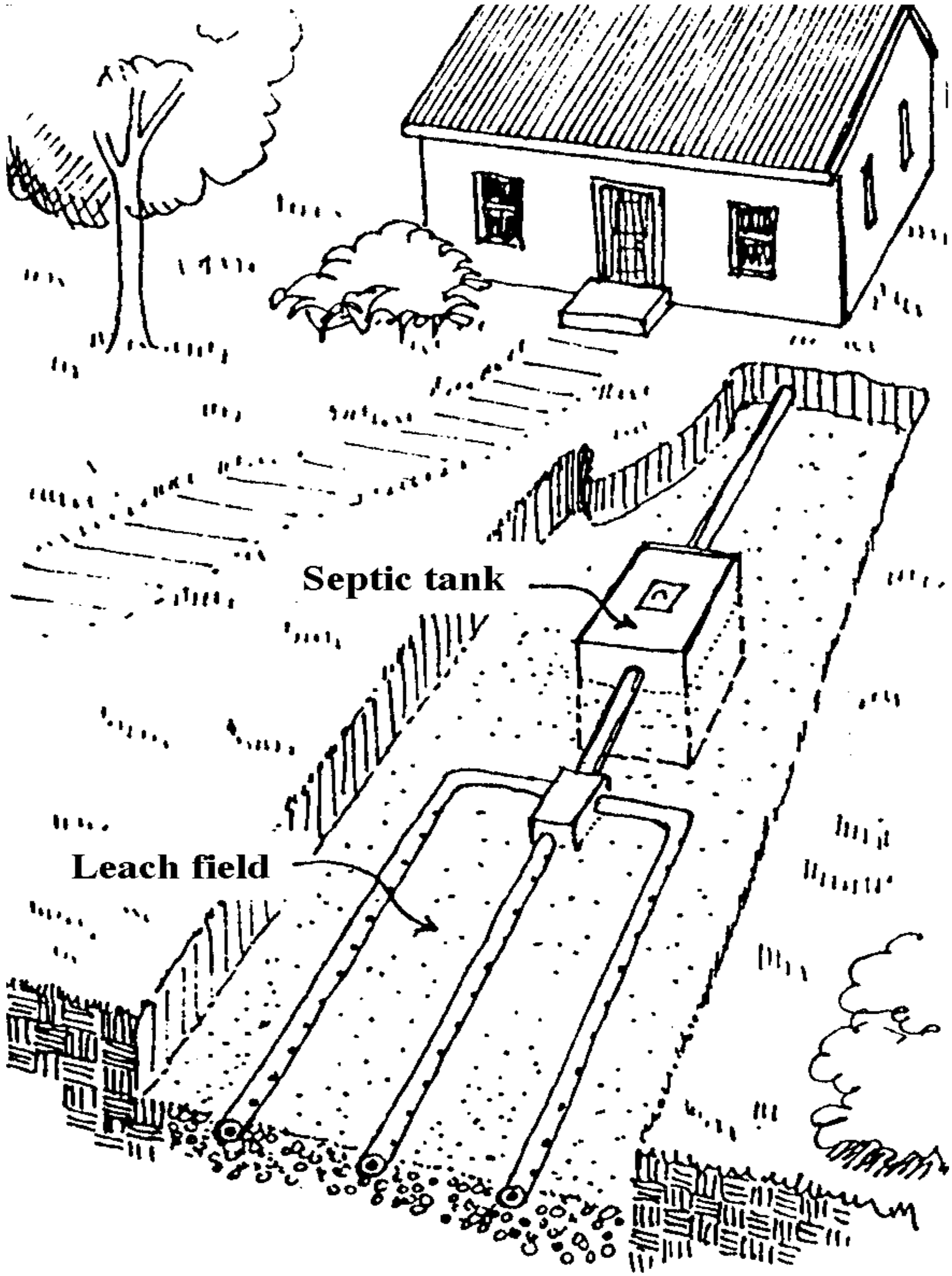

Figure 6. The layout of a typical septic system (Williams 1992).

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).

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).

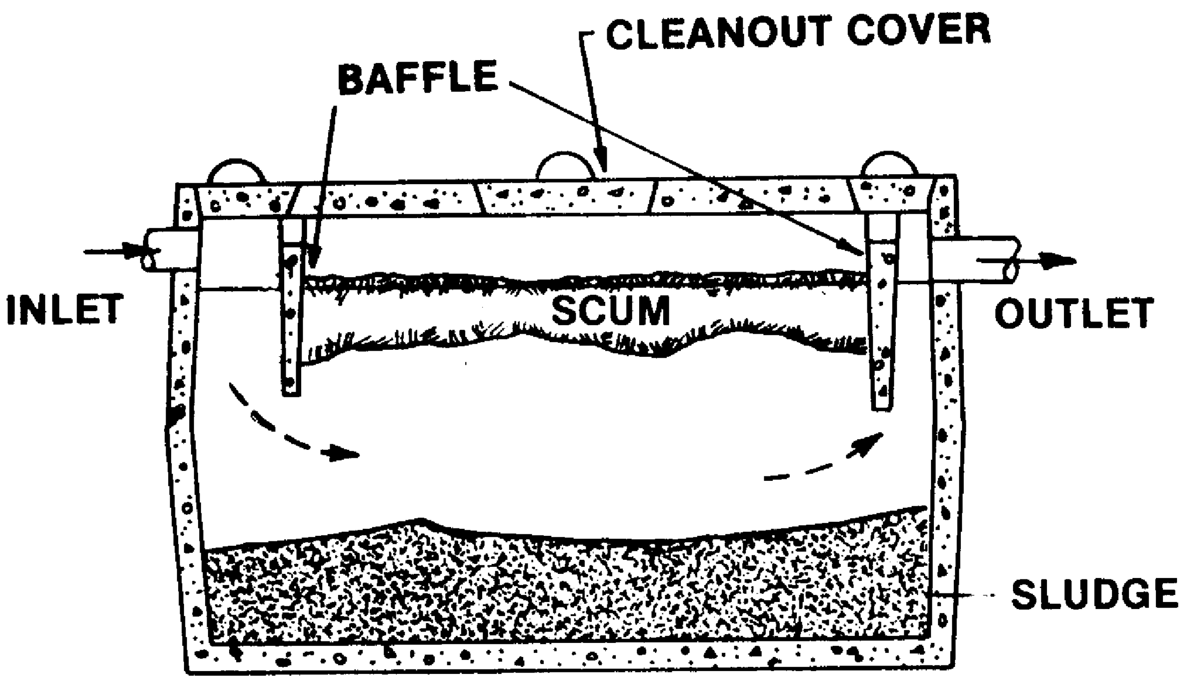

Figure 7. The cross-section of a typical treatment tank showing the movement of effluent through the tank as well as the separation of the scum and sludge (MDHS 1983).

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.

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%) 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% 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% (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 China Lake 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% 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

CHINA LAKE CHARACTERISITCS

<u>WATERSHED DESCRIPTION</u>

The China Lake watershed is located in Kennebec County, Maine, and is situated within the townships of China, Vassalboro, and Albion (Figure 8). The lake is classified by the Maine Information Display Analysis System (MIDAS) as MIDAS #5448 (PEARL 2005a). This classification system assigns unique four-digit codes to identify all lakes and ponds in Maine. China Lake is located 44.25° N and 69.33° W, at an elevation of 59.1 m (194 ft), and covers a surface area of 1,604 ha (3,963 acres) (PEARL 2005a). China is classified geographically as a two basin lake, with an East Basin and West Basin (PEARL 2005a). Bathymetrically, China Lake is described as a three basin lake, with three deep holes forming the western, southeastern, and northeastern basins (Manthey, pers. comm.). China Lake has an average depth of 10.1 m (33.1 ft), a maximum depth of 28.2 m (92.4 ft), and a volume of 120,001,704 m^3 (97,286.4 acre-ft) (PEARL 2005a). The water within China Lake flows from input to output at an annual rate of 0.35 flushes per year. There are several small islands within China Lake, most notably Indian Island, Green Island, Bradley Island, and Moody Island. China Lake is dimictic, experiencing thermal stratification in the summer with turnovers occurring each spring and fall. Algal blooms have been reported yearly since 1983 and the Maine Department of Environmental Protection (MDEP) currently describes China Lake as a “frequently blooming” lake. This classification means that the lake commonly experiences late summer and early fall reductions in water transparency due to algal blooms (MDEP 2005a).

The China Lake watershed boundary used in this study was obtained from the Maine Office of GIS (MEGIS), and includes the direct drainage area of China Lake and the small sub-watersheds of Evans Pond and Hunter Brook (MEGIS 2005). The drainage area of the China Lake watershed (not including China Lake itself) covers an area of 6,911 ha (17,077 acres). The topography within the 6,911 ha of the watershed is a mixture of rolling hills surrounding wetland and pond basins, each of which drains into China Lake. The highest of these hills, Barmeter Hill, is 197 m (646 ft) in elevation and situated on the southeast edge of the watershed boundary.

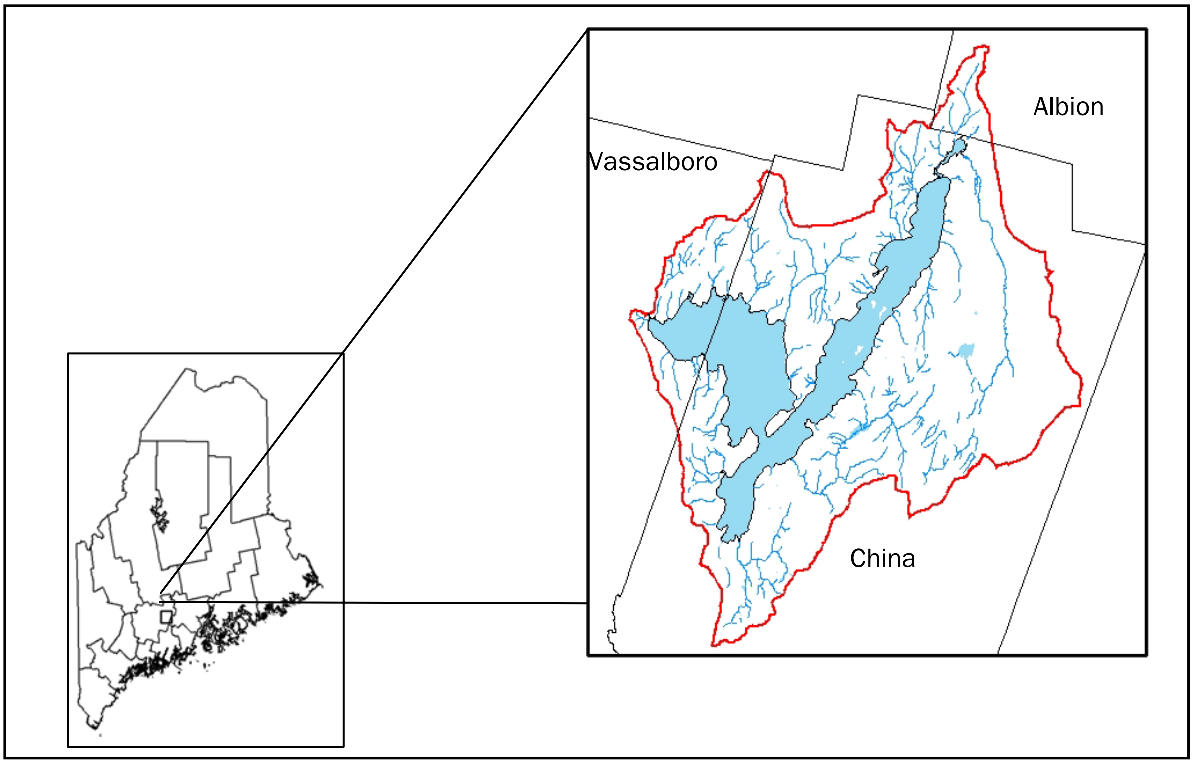

Figure 8. Location of China Lake and the China Lake Watershed within the towns of China, Vassalboro, and Albion, ME.

China Lake is a naturally formed, glacial-basin lake that was enlarged by raising dam outflow levels in 1969. Originally constructed during the Civil War era, the dam at the outflow of China Lake at Vassalboro was restructured by MDEP in 1969, raising the lake level approximately 1.2 m (4 ft). The outflow of the dam is currently under the management of the Town of Vassalboro, but will be transferred to the Kennebec Water District in 2006 (Manthey, pers. comm.). The Kennebec Water District gained control of the dam because the West Basin serves as the water supply for the greater Fairfield, Oakland, Vassalboro, Waterville, and Winslow area.

The majority of the water input to China Lake comes from Hunter brook via the Muldoon (wetlands) at the northern terminus of the lake, Clark Brook in the southeastern portion of the East Basin, and inflow from Jones Brook at the southern terminus of the lake. There are several other small unnamed tributaries along the eastern shore of the East Basin, and northern shore of the West Basin. However, due to their ephemeral nature, the flows of the smaller tributaries were minor or nonexistent during the field period of the study. The waters of China Lake flow north to south in the East Basin, and east to west in the West Basin, where the Outlet Stream is the

only distributary for China Lake. The Outlet Stream ultimately empties into the Sebasticook River, and shortly thereafter the Sebasticook empties into the lower Kennebec River (PEARL 2005a; see Analytical Procedure and Analysis: Water Budget).

GEOLOGICAL AND HYDROLOGICAL PERSPECTIVE

During the Pleistocene Epoch (25,000 to 20,000 years ago), Maine was covered completely by the Laurentide Ice Sheet, which extended from Labrador and Newfoundland through New England, reaching its southernmost point near Long Island, New York at the peak of glaciation (Marvinney and Thompson 2000). The ice sheet moved in a south-southeastern direction and spread beyond the present coast of Maine and onto the continental shelf. The motion of the ice shaped the landscape of Maine as sediments were lifted and deposited, previous waterways were destroyed, and hundreds of new lakes and ponds were left in their place following the recession of the ice sheet (Marvinney and Thompson 2000).

Approximately 21,000 years ago, climatic warming began to melt the Laurentide ice sheet. By 10,000 years ago, the ice sheet had nearly completely receded from Maine (Davis et al. 1978, Marvinney and Thompson 2000). Glacial recession caused further deposition of sediments, leaving a glaciomarine clay-silt and glacial till substrate over bedrock throughout Maine. This substrate now characterizes the typical lake basin in the state, most of which have a southeasterly orientation due to the direction of glacial movement up the coast (Davis et al. 1978). These lakes are considered young by geologic standards, having formed less than 10,000 years ago, and many are naturally nutrient poor because of underlying characteristic substrate. This combination of young age and naturally low nutrient levels would predict that most Maine lakes would be oligotrophic. While historically oligotrophic, the current status of Maine lakes is changing as a large number of lakes are now eutrophic due to the acceleration of the natural aging process by human activity (Davis et al. 1978; see China Lake Characteristics: Biological Perspective: Trophic Status).

HISTORICAL PERSPECTIVE

Regional Land Use Trends

The historical land use trends in Maine reflect changing agricultural activity of the region. Prior to human settlement, Maine was nearly completely forested (Irland 1998). However,

timber harvesting and settlement in the seventeenth, eighteenth, and nineteenth centuries dramatically changed the landscape of Maine. By 1872, forested areas of Maine had reached an all time low, only 53.2% of total land area (Plantinga et al. 1999). Since that point, agricultural activity and timber harvesting have declined in Maine, taking a sharp downward turn in the twentieth century. From 1950 to 1999, cropland area declined by 288,544 ha (713,000 acres), pasture land by 70,416 ha (174,000 acres), but forested area within Maine increased by nearly 162,000 ha (~400,000 acres) (Plantinga et al. 1999). The increase in forested area can be attributed to the decline in agricultural activity (Plantinga et al. 1999). Demographic shifts away from agriculture left former agricultural lands fallow and these lands have largely reverted to forest or are in the process of reversion. In contrast to the decline of agricultural land, municipal and residential lands in Maine increased in area during the twentieth century. Shifts toward town and urban centers and a new focus on tourism have led to an increase in human-based infrastructure for these land use types (City of Oakland 2005).

The land use history of China and Vassalboro mirror historical regional trends within Maine and New England in general. Settlement of the China Lake region by European settlers began in 1760 in the Vassalboro area (Varney 1886). Initially a part of Sidney on the Kennebec River, Vassalboro was incorporated later in 1771. American soldiers from the Revolutionary War denied land bounties for their military services traveled north in search of land and squatted in the China/Vassalboro area (Grow 1975). Initially wilderness, the area was developed for human uses. Land was cleared, plowed, tilled, and leveled for agricultural and residential uses. Organized by Quakers in 1776 under the name of Harlem, China grew to be the fourth largest incorporated town in Maine by 1820 (Grow 1975). Incorporated after Vassalboro, the population of China soon exceeded that of its neighbor on the West Basin. The dramatic change in land use reflects the remarkable growth of China in this period. By the turn of the nineteenth century approximately 60% of forests in Kennebec County had been cut down (Grow 1975). Agriculture and industry continued through the nineteenth century, yet by the turn of the century these efforts began to decline when settlers began moving westward seeking more arable lands. The abandoned and fallow lands left behind began the process of succession into forest. Interestingly, in the same period, tourism emerged as an economic force in China, and greater attention was paid to recreating a pristine wilderness area to support the burgeoning industry (Manthey, pers. comm.). In the twentieth century, state, county, and local governments began

regulating land use and restricting development. As a result, forested areas increased by approximately 250% between 1880 and 1995 in Kennebec County (Irland 1998).

The changes in land use within the China Lake watershed match the predictable progression typical within Maine and New England. Initially pristine wilderness, land was largely deforested in the nineteenth century under the expansion of agricultural and industrial production. With the recession of these forces in Maine in the mid twentieth century, forested areas made significant resurgences. Currently, residential, commercial, and municipal developments represent the largest potential sources of land use change in the region.

Water Quality

Maine is home to more than 6,000 lakes (MDEP 2005b). These lakes are as much a part of the landscape as they are a part of the Maine lifestyle. Lake water quality affects drinking water, the recreational and intrinsic value of the lake, and property value and the economic status of entire communities (MDEP 2005b).

Each year as many as 600,000 people, or two thirds of all Maine adults, use lakes (MDEP 2005b). While half of these uses are for swimming, 400,000 people use the lakes for drinking water. Non-residents also enjoy the use of Maine's lakes, including many children who attend youth camps each year. When factoring in nonresident users, recreational user days of Maine lakes exceeds 12 million each year (MDEP 2005b).

A survey conducted by the University of Maine and MDEP linked a decline in water quality with a decline in local property values. A decline in water quality can reduce property values as much as $200 per frontage foot, which represents hundreds of millions of dollars in lost value (MDEP 2005b). Researchers at the University of Maine at Orono conducted a study to quantify the value of water quality by looking at property values (MDEP 2005b). They found that properties on China Lake sold for an average of $107,070, with 15% of this amount ($15,996) being dependent on water quality. These findings indicate that properties located on lakes with good water quality can sell for as much as 15% more than properties on lakes with impaired water, purely by virtue of the water quality. An additional loss in property values in excess of $16 million could occur if conditions continue to decline on China Lake (MDEP 2005b). In general, lake users prefer large, clear lakes to small, algae laden waterbodies. Models based on survey results from 143 of Maine's most popular lakes suggest that when water clarity decreases by 0.50 m there is a corresponding loss in net economic benefit, or user

satisfaction, of as much as $0.5 million and a decrease in total sales activity associated with those lakes of $1.6 million (MDEP 2005b). Water clarity has the largest impact on people's enjoyment of lakes (MDEP 2005b).

In Maine, lakes located in more highly developed watersheds have higher total phosphorus levels than lakes located in less developed watersheds (Smith and Witherill 1999). Phosphorus entering lakes from erosion runoff increases five to ten times when natural watersheds are converted for commercial and agricultural uses (Smith and Witherill 1999). Increased phosphorus loading potentially results in algal blooms, which turn lakes green and are associated with foul odors and bad tasting water. Repeated algal blooms, and the associated decrease in dissolved oxygen, may result in fish kills and can drastically affect the deep, cold-water fisheries (Smith and Witherill 1999).

The first recorded algal bloom on China Lake occurred in 1983. MDEP now lists China Lake as a lake that frequently blooms (MDEP 2005b). China Lake typically blooms three times, once each in the spring, summer, and fall (Van Bourg, pers. comm.). The spring and fall blooms are most likely the result of turnover redistributing phosphorus and dissolved oxygen within the lake. The phosphorus brought to the surface becomes available for use by primary producers and results in an algal bloom.

Several treatments exist to combat total phosphorus concentrations in lakes. One treatment option involves applying alum to a lake. The alum prevents phosphorus release from the sediment, preventing internal phosphorus loading. An alum treatment was applied to Threemile Pond in 1988 to prevent internal loading of phosphorus (CEAT 2004). This program appeared to be successful and China Lake was set to be treated next. However, in 1994, Threemile Pond bloomed again. Rather than invest in a treatment that might not work, an alum treatment feasibility study was conducted to determine if the treatment would succeed on China Lake (Bouchard, pers. comm.). Study results indicated that internal loading accounts for three times as much phosphorus in the lake as external sources. It was thought that at best, the treatment would prevent algal blooms in the China Basin for eight years (Walker 1994). Since the treatment was going to cost $1 million and did not guarantee success, MDEP did not recommend an alum treatment for China Lake (Bouchard, pers. comm.).

Local communities have taken many innovative steps to improve the water quality of China Lake. The China Region Lakes Alliance and China Lake Friends work to raise awareness of

issues relevant to water quality and organize remediation actions (CRLA 2005a). Federal funding in the form of a Community Development Block Grant was dedicated for point source remediation (Bouchard, pers. comm.). The first Youth Conservation Corps in Maine was founded to address water quality issues of China Lake . Many programs have involved the local communities in making improvements to the watershed to help prevent harmful runoff from entering the lake. Though the water quality has not been restored to pre-1980 levels, the actions taken by the community have stabilized the water quality (Bouchard, pers. comm.). This study compares all current findings to historic data to examine the effectiveness of these programs and to help make remediation recommendations for the future.

Dam and Water Level

The China Lake outlet dam predates the Civil War, but the lake level was not raised to its current level until 1969 (Althenn 2005a). Since 1969, there has been a lot of controversy over the water level, largely revolving around the source of nutrient loading into the lake. According to the Friends of China Lake, a private organization that manages a website to help people find information on China Lake and the causes of its eutrophication, the higher water level is the main cause of China Lake’s current nutrient loading problem. Others, such as MDEP hold that non point-source pollution is to blame.

Large-scale shifts in processes of water level stability can degrade habitat quantity and quality for fish and aquatic mammals (Pegg et al. 2005). Aquatic habitat quality issues that translate into negative impacts on biota can be directly correlated to extreme water level fluctuations at unnatural times of the year (Leyer 2005). River dams alter natural water level fluctuation patterns and considerably reduce seasonal flow variability and peak flows, potentially impacting fisheries (Leyer 2005). Draining lakes is known to affect macroinvertebrate communities directly and indirectly, and can cause many macroinvertebrates to go locally extinct (Van De Meutter et al. 2005). Variations in lake level can potentially affect smelt spawning success by reducing the total amount of smelt spawning habitat in the lake littoral zone (Van De Meutter et al. 2005).

Water level management on a lake can affect water quality, wetland conditions, plant and animal species, and their habitats (Bouchard 2005). In some lakes, significant drawdowns are used to reduce high total phosphorus levels in the water column. These drawdowns are generally not useful in controlling shoreline erosion, unless they target the prevention of springtime ice

damage (MDEP 2005e). Drawdowns present a significant disadvantage because lowering the lake level exposes large areas of previously stable fine sediment to drying, which results in the release of nutrients and increased turbidity in the lake when the water level rises (Bouchard 2005). To control erosion, it is usually best to maintain constant water levels, because significant fluctuations can be highly disruptive to a number of flora and fauna.

The Friends of China Lake desire a lower water level in China Lake similar to historical levels pre 1969 (Althenn 2005a). They believe that the increase in water level in 1969 led to the first algal blooms in the early 1980s, primarily as a result of submerged wetlands contributing nutrients. The MDEP contends that the algal blooms are primarily due to non point-source pollution, not submerged wetlands (Bouchard 2005). The Friends of China Lake claim that the dam holds the water at an unnaturally high level, keeping the lake from its natural seasonal fluctuations, as well as raising the local water table, which increases the potential of septic contamination. The organization contends that MDEP failed to inform the Town of China that they really increased the water level to maintain sufficient flow past the Vassalboro sewage plant (Althenn 2005b). Friends of China Lake also state that the large, sudden event of raising the water level caused the lake to have algal blooms. The MDEP states that years of accumulation of total phosphorus in the sediment caused the algal blooms.

BIOLOGICAL PERSPECTIVE

Native Fish of China Lake

The lakes in the Androscoggin and Kennebec River drainage systems are well stocked with fish and highly developed as fishing areas (Cooper 1941). Most of the fish populations are relatively unstable due to heavy fishing and the effects of introduced species. The China Lake East Basin shore is heavily developed, and the effect of human activities, including the introduction of nonnative species, has been to reduce or eliminate many species of native fish (Werner 2004). Exotics are frequently more tolerant of various environmental stresses than native species (Schofield and Driscoll 1987).

The Maine Department of Inland Fish and Wildlife (MDIFW) manages the fisheries and fish stocking of China Lake. Warmwater and coldwater fish of China Lake are listed in Table 3. Although China Lake is fairly deep, it is a eutrophic lake (MDIFW 1987). The warmwater fishing is good in China Lake, but the coldwater fishery is no longer self-sustaining (Cooper

1941). The principal warmwater fisheries in China Lake are Largemouth Bass, Smallmouth Bass, Brown Bullhead, White Perch, Yellow Perch, and Chain Pickerel, and the principal coldwater fishery is Brown Trout, which is stocked (MDIFW 2005). Fishing regulations in China Lake limit the take of smelt to hook and line fishing, and state that no smelt are to be taken from tributaries (MDIFW 2005). The minimum length of Brown Trout that can be taken is 14 inches in both open water and ice fishing season.

Table 3. Existing warmwater and coldwater game fishes in China Lake, China, Maine (MDIFW 2005).

Coldwater Fishes	Warmwater Fishes	Minnows
Brown Trout *Salmo trutta*	Smallmouth Bass *Micropterus dolomieu*	Creek Chub *Semotilus atromaculatus*
Brook Trout *Salvelinus fontinalis*	Largemouth Bass *Micropterus salmoides*	Redbelly Dace *Phoxinus eos*
Rainbow Smelt *Osmerus mordax*	White Perch *Morone Americana*	Common Shiner *Luxilus cornutus*
American Eel *Anguilla rostrata*	Yellow Perch *Perca flavescens*	Golden Shiner *Notemigonus crysoleucas*
	Chain Pickerel *Esox niger*	Blacknose Dace *Rhinichthys atratulus*
	Brown Bullhead *Ameiurus nebulosus*	Banded Killifish *Fundulus diaphanus*
	Pumpkinseed Sunfish *Lepomis gibbous*	Threespine Stickleback *Gasterostreus aculeatus*
	Redbreast Sunfish *Lepomis auritus*	Fourspine Stickleback *Apeltes quadracus*
		Ninespine Stickleback *Pungitius pungitius*
		White Sucker *Catestamers commersoni*

Coldwater fish require certain conditions for survival that have not been met in China Lake since the algal blooms started in 1983 (CRLA 2005a). Salmon and trout generally need water colder than 21° C, although Brook Trout can handle warmer water when there are no competing warmwater game fish, such as perch, bass, or pickerel (Cooper 1941). All coldwater fish require a dissolved oxygen level of at least 5 ppm to survive. Trout can also handle much more acidic water than salmon. Togue need colder waters than trout and salmon, and are seldom found in lakes shallower than 50 feet. A self-sustaining smelt population is an absolute necessity for the success of large landlocked trout and salmon because smelt are the only small fish living deep enough to serve as prey (Cooper 1941). Cooper (1941) found that it is impossible to have more than three to six species of warmwater fish, if good fishing for trout, togue, or salmon is desired.

Warmwater fish can inhabit all of Maine's lakes, and China Lake is no exception (Cooper 1941). China Lake is now known best for its bass fishing and several trophy-size bass have been caught in recent years (MDIFW 2005). Largemouth Bass can be found in weeds, while sunfish and crappies stay in open water (Eddy and Surber 1947). Smallmouth Bass do best in fairly deep, cold lakes with little vegetation and rocky shores (Cooper 1941). The nonnative warmwater fish in China Lake include Black Bass, Black Crappie, and Northern Pike (MDIFW 2005).

There have not been any reports of large fish kills in China Lake as a result of poor water quality, although a fish kill is always a potential problem in the spring and in hot summers (Van-Riper, pers. comm.). It is hard to pin down the cause of a fish kill in any lake, but fish kills have not been a problem in the history of China Lake.

Fish Stocking

The Maine Department of Fish and Wildlife (MDIFW) stocks China Lake for recreational fishing and management practices concentrate on Brown Trout. Fish stocking involves putting fish into a lake or river, often with the hope of establishing a self-sustaining population. Stocking in China Lake exists for the purpose of creating a recreational coldwater fishery. The fish currently stocked in China Lake are Brown Trout and Brook Trout at 3900 fish per year for Brown Trout (MDIFW 2004). Historically, China Lake supported populations of salmon and togue (Lake Trout), and these species had been stocked until 1978 (Figure 9). Sporadic returns from heavy stocking of small Brown Trout led to an attempt to re-establish a landlocked salmon fishery in the early 1970s (unpublished data, Maine Department of Inland Fish and Wildlife

1987). Salmon stocking, which commenced in 1969, was terminated in 1978 (Figure 9), due to anoxia in the hypolimnion where salmon live.

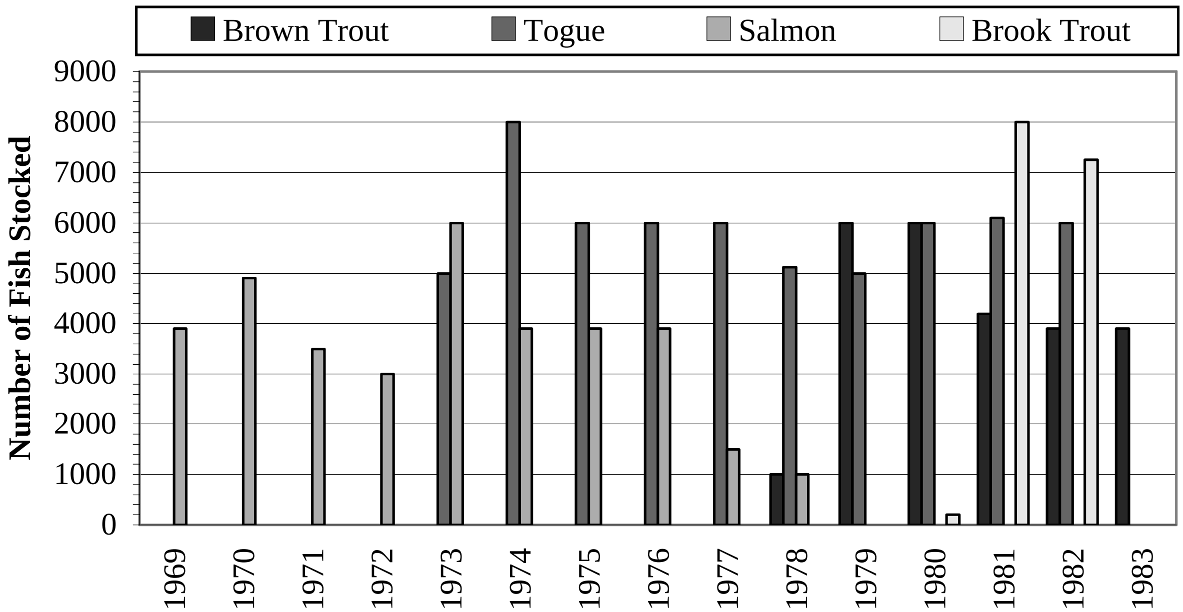

Figure 9. History of fish stocking in China Lake during the attempt to establish a self-sustaining Togue fishery from 1969 to 1983 when the lake started blooming. Since 1983 only Brown Trout and Brook Trout have been stocked (MDIFW 2005).

High public support led to an attempt to establish a togue fishery in the 1970s (MDIFW 1987). In the early 1980s, when the water quality began to deteriorate, the MDIFW had to stop stocking togue, because togue inhabit deep water and need high levels of dissolved oxygen. Until water quality improves, togue cannot survive in China Lake (unpublished data, Maine Department of Inland Fish and Wildlife 1987).

In 1978, MDIFW made a new attempt to manage China Lake for Brown Trout, with yearly stockings of fall yearlings (unpublished data, MDIFW 1987). This program provided a basis for a successful, highly popular Brown Trout fishery, although not entirely self-sustaining. In the late 1980s, trout stocking was determined to be unwise due to the low flushing rate of China Lake, the anoxic conditions in the hypolimnion, and the algal blooms, all of which limit trout reproductive success. However, trout stocking continues despite the poor water quality (MDIFW 2004). Figure 9 shows the rise and fall of the salmon and the togue stocking; since 1983 only Brown Trout have been stocked (MDIFW 2004).

Brown Trout are stocked from the shore in China Lake, primarily from the Four Season's Club Boat Launch on the West Basin, but also from secondary sites at the South China boat launch and a private launch on Fire Road 29 (MDIFW 2004). The MDIFW hopes to get some reproductive success from Brown Trout, although they recognize that trout have difficulty surviving in the hypolimnion when water quality is particularly bad (Van-Riper, pers. comm.). In the case of Brook Trout, the MDIFW manages a "put and take" fishery, expecting no reproduction (Van-Riper, pers. comm.). "Put and take" means that no survival is expected and the only purpose of putting fish into the lake is for recreational fishing. There is a low likelihood for the fish to reproduce successfully since they require improved water quality. Although they can survive in the anoxic waters, they are unable to spawn successfully in tributaries to China Lake.

There were no reports of illegal stocking in China Lake until 2003, when Sea-Run Alewifes were found near the China Lake outlet (MDIFW 2004). Alewifes are problematic if they cannot leave the lake as adults, because they die in the lake, creating a water quality and health problem. Finding alewifes near the outlet dam is particularly problematic because that is where the Kennebec Water District takes its water. To avoid accidental stocking of unwanted fish, MDIFW prohibits using spiny-rayed fish as bait in China Lake (Van-Riper, pers. comm.). Unwanted stocking would result if live bait fish got into the lake and began to reproduce. Illegal stocking occurs when an individual puts fish into the lake, usually for recreational fishing, in the hopes of establishing a population. The fine for illegal stocking in Maine is $10,000, yet enforcing this law has proven difficult (Van-Riper, pers. comm.). Fish stocking provides China Lake with coldwater fish that would otherwise no longer inhabit the lake and MDIFW is doing all it can to keep the coldwater fishing satisfactory.

Native Plants of China Lake

Macrophytes are an integral component to healthy pristine lakes. Macrophytes are either submergent, emergent, or floating aquatic plants often found in shallow, nutrient rich waters (USEPA 2005). Common macrophytic species to Maine lakes include, cattails (*Typha latifolia*), water lilies (*Nymphaea* family), grasses, sedges, and rushes (*Commelinidae*), and pickerel weed (*Pontederia cordata*) (Williams 1997). Natural macrophytes serve to enhance habitat heterogeneity greatly (Woodcock et al. 2005). Macrophytes serve several integral roles in lake ecosystems. Macrophytes increase oxygen levels, provide food, and shelter fish. Presence of

macrophytes root systems that bind shoreline soil and nutrients reduces shoreline erosion and prevents nutrient resuspension in shallow areas (Williams 1997). Macrophytes populations suffer greatly, both in quantity of individuals and quality of existing individuals, with a water quality decrease (USEPA 2005). Because of their important role in the lake ecosystem, the health and species richness of the macrophyte populations serves as a good indicator of the lake's water quality (USEPA 2005).

Invasive Plants

China Lake does not contain any of the eleven species classified as aquatic invasive species for Maine (MDEP 2005c). Executive Order 13112 of 1999 defines invasive species as both non-native and posing an economic, environmental, or health threat (Presidential Document 1999). While Maine remains one of the states least affected by aquatic invasive species, infestations are slowly increasing in Maine lakes. Once invasive species establish themselves, eradication becomes a near impossibility (MDIFW 2005). Aquatic invasive species have aggressive growth and reproductive habits and they will quickly, sometimes completely, out-compete and replace native species, reducing biodiversity. Aquatic invasive species clog waterways by creating dense mats that block sunlight, lower oxygen levels, and decrease available nutrients, hampering both aquatic plant and fish populations. The compilation of effects from invasive species cause drastic environmental and economic repercussions by reducing biodiversity, and decreasing commercial and recreational value of the infected lakes, streams, or ponds (MDIFW 2005).

Executive Order 13112 delegates power for monitoring, management, and control of invasive species within Maine to the Maine Department of Conservation, MDIFW, and MDEP (Presidential Document 1999). Within Maine, there have only been five invasive species identified and recorded: Variable-leaf Milfoil *(Myriophyllum heterophyllum),* Eurasian Milfoil *(Myriophyllum spicatum), Hydrilla (Hydrilla verticillata),* and Curly-leaved Pondweed *(Potamogeton crispus)* (MDEP 2005c). The infected areas are primarily concentrated in southern Maine. The proximity of some infestations, and the rapidly spreading nature of others, presents an immediate threat to the waters of China Lake (Figure 10).

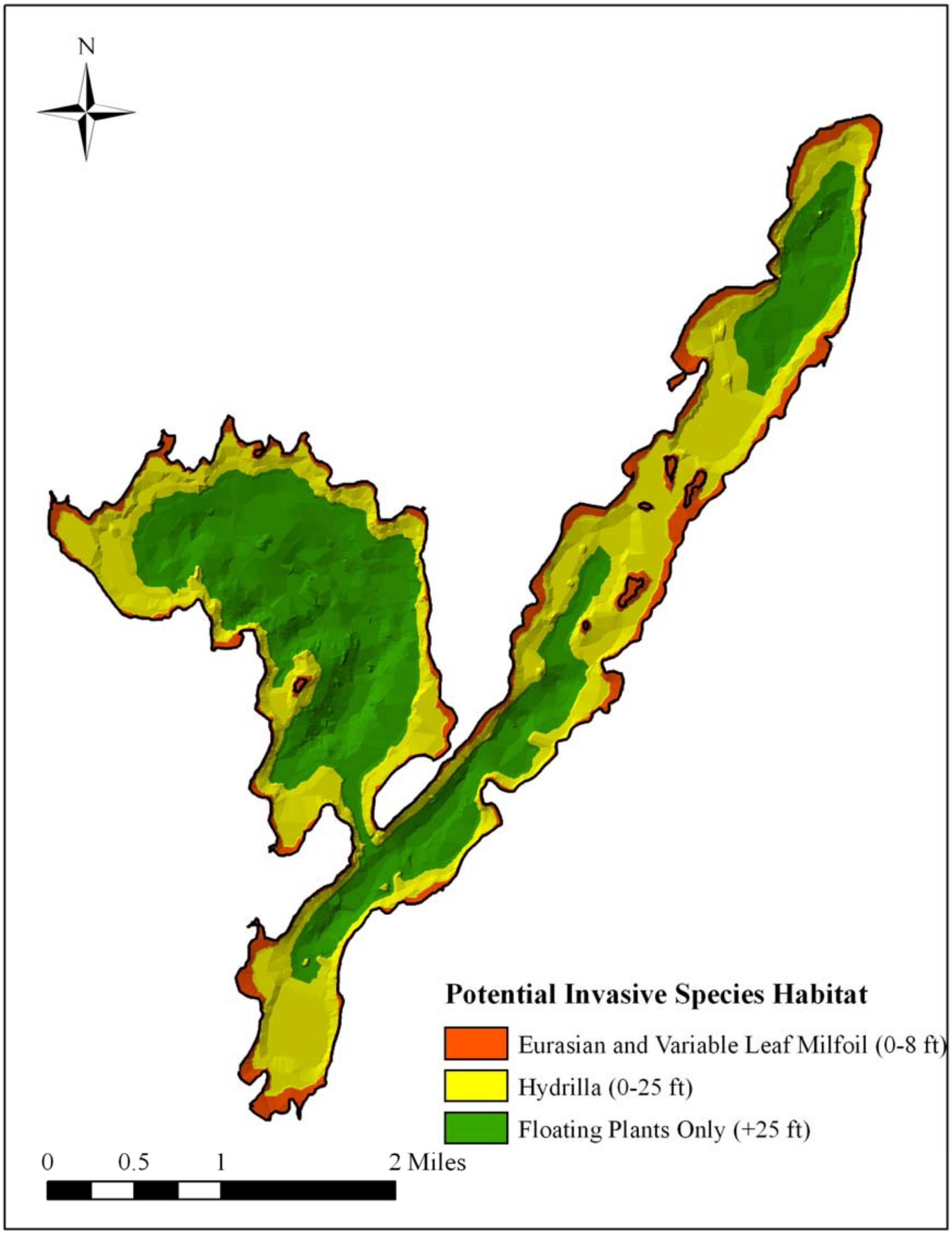

Figure 10. Suitable depths for selected invasive aquatic plant species. Colored areas show species maximum potential habitat range. Eurasian Water and Variable-Leaf Milfoil grow in less than 8 ft and hydrilla grows in up to 25 ft of water (UMExt 2005a, UMExt 2005b, USACE 2005)

Variable-leaf Milfoil and Eurasian Milfoil represent the most eminent threats to China Lake for aquatic invasive species infestation (MDEP 2005c). The China Lake watershed is already infested with the non-native plant Purple Loosestrife (*Lythrum salicaria*); however, this species is not listed as an invasive species in Maine. Purple Loosestrife lowers biodiversity and alters the environment in the shallow shoreline waters and the wetlands at the north end of the East Basin. The waters throughout China Lake under twenty-five feet in depth are susceptible to aquatic invasive species infestations. Variable-leaf Milfoil grows in waters up to six feet and Eurasian Milfoil can grow in depths of up to eight feet. Hydrilla represents an even greater threat, as it will grow anywhere ranging from one foot of water out to depths of twenty-five feet; these depths represent approximately 53% of the total area of China Lake's.

The main cause of the spread of invasive species is anthropogenic, namely the introduction of species resulting from boating activities, such as contaminated propellers (MDIFW 2005). The infeasibility of eradicating established invasive species causes most control methods to be targeted at prevention, primarily through education and monitoring of human activity. The MDEP and MDIFW have established an inspection and registration program for all boating activities in Maine (MDIFW 2005). Private organizations, such as the Maine Volunteer Lake Monitoring Program and Maine Center for Invasive Aquatic Plants, run identification workshops both at the basic and advanced patrol levels (VLMP 2005). As a final deterrent, transport of invasive species has been made illegal with penalties ranging from $500 to $5000 (MDIFW 2005).

Algal Blooms

Algal blooms, often caused by cyanobacteria (prokaryotic), are a common occurrence in many lakes in Maine and across the country. Algae are aquatic, eukaryotic, photosynthetic organisms ranging in size from single-celled forms to giant kelp. Algae dynamics are important to study because algae are associated with many water quality problems, such as ecological imbalances, physical impacts on the aquatic system, water quality alteration, aesthetic impairment, taste, odor, and toxicity (Wagner 2004).

Algal blooms occur when excess phosphorus is introduced to the lake ecosystem. Phosphorus is the limiting nutrient when determining the rate of growth of algae in typical Maine lakes (Tietjen 1988). Primary production is controlled by light and nutrients; when conditions are favorable rapid algal growth may occur and there can be a bloom. As nutrient levels

decrease, the algae die and begin to be decomposed by aerobic bacteria, using the remaining oxygen in the water, turning the lower levels of the lake anoxic. In anoxic conditions, the deep-water sediments release phosphorus into the lake instead of absorbing them. This process of growth and decomposition decreases suitable aquatic habitats and can kill fish (Wagner 2004).

China Lake was considered a healthy lake before its first algal bloom in 1983 (Tietjen 1988). Human land use practices throughout the watershed caused accelerated eutrophication. The majority of the phosphorus entering China Lake is generated from non-point sources, such as residential development and agriculture (Tietjen 1988).

There are many different species of algae that bloom in China Lake. The most common are blue-green algae (cyanobacteria), which thrive in an aquatic habitat with high phosphorus concentrations. Of the seven major algae that normally bloom in China Lake, three are blue-green algae (*Anabaena, Aphanizomenon,* and *Microcystis*), one green algae (*Melosira*), and three diatoms (*Asterionella, Fragilaria,* and *Tabellaria)* (Van Bourg, pers. comm.; Thurlow, Davis, and Sasseville 1975).

In 1995, the Kennebec Water District began measuring the turbidity of China Lake to determine when blooms occurred and sampled water to determine what species caused the blooms. These data have been compiled into a graph showing the turbidity of China Lake (Figure 11). Typically, China Lake blooms three times a year, once in the spring, once in the summer, and once in the fall. Notice the three peaks are particularly clear in 1995, 1997, 1999, 2000, and 2001 (Figure 11). The spring bloom is usually a diatom bloom, followed by blue-green algal blooms in the summer and fall.

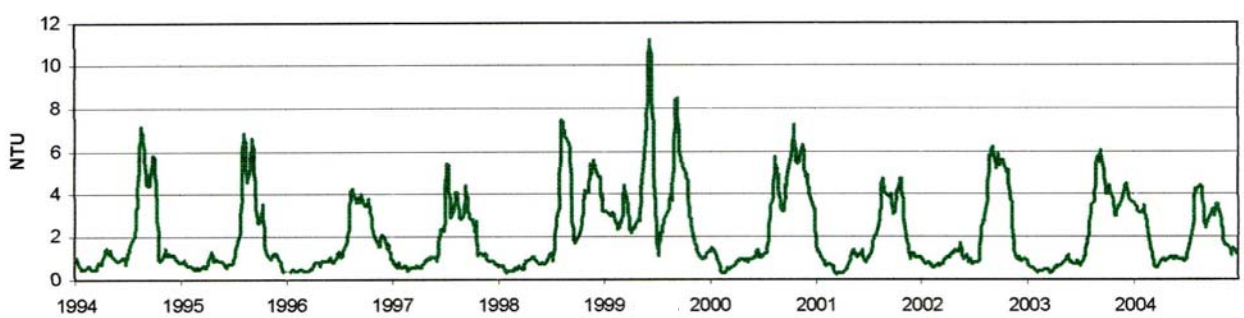

Figure 11. China Lake turbidity (NTU) from 1994 to 2005. Significant peaks in turbidity are generally caused by algal blooms (unpublished data, Van Bourg).

The green algae bloom overlaps with the blue-green algae. Both 1998-1999 and 2003-2004 were drought years; due to the lack of precipitation there was little erosion and the majority

of the phosphorus came from internal recycling. In drought years, there was little snow cover to stop the algal bloom because light can penetrated the ice-covered lake and supported algal growth. In the winters of 1998 and 2003, algal blooms that began in August continued through March of the following year (Van Bourg, pers. comm.). High algae populations are particularly problematic for the Kennebec Water District because they make purifying water for public use difficult. In 2001, there was a distinct diatom bloom in the spring, followed by summer and fall blooms of blue-green algae. This pattern is for China Lake (Van Bourg, pers. comm.). These blooms have occurred since 1983 and will continue in the future unless strong action is taken.

Economic Impact of Bloom

Over 6,000 lakes in Maine are at high risk for water quality degradation (MDEP 2005b). The repercussions of lowered water quality, decreased clarity due to algal blooms, have consequences far beyond the biological and ecological degradation. The Maine economy relies heavily on lakes for their recreational value, estimated at 90 million dollars annually. Maine lakes also provide approximately 3,000 jobs as well as drinking water for 400,000 people (MDEP 2005b). Impaired water quality represents a severe threat to Maine's lake dependent economy, and can cost Maine and its residents millions of dollars in lost revenue (MDEP 2005b).

Maine lakes are valued at over 6.7 billion dollars in net economic value (MDEP 2005d). This figure incorporates all uses: recreational, drinking water, and jobs created. Approximately 2.8 billion dollars are spent in economic activity in and around Maine lakes, resulting in 1.2 billion dollars annual income for the approximately 50,000 jobs associated with all lake uses. Statewide, lakes with algal blooms can result in a net economic value loss of approximately two billion dollars annually (MDEP 2005d). These losses result from lowered recreational and fishery activity as well as property value losses.

Lakefront property values are integrally tied to lake water quality (MDEP 2005b). On China Lake, 15% of the property value is directly dependent on water quality. Approximately 60% of tax revenue of a typical Maine lakeside communities comes directly from shoreline property value taxes (MDEP 2005d). A MDEP study showed declining water quality would significantly reduce property values, and subsequently tax revenues from shoreline properties. On China Lake one meter decreased visibility from present conditions measured by Secchi disk could exceed losses 16 million dollars in tax revenue (MDEP 2005d).

The economic losses from the presence of algal blooms cannot be ignored. Billions of dollars in revenue for the State of Maine and its residents are at stake every year. Conversely, improvement of water quality potentially increases both direct and indirect revenue for lake communities. Improvement of water quality, increasing transparency by one meter from present conditions in China Lake (determined by Secchi disk) could increase property tax revenue over $9 million (MDEP 2005d). The added effects of increased recreational use, increased employment, direct and indirect economic benefits to the immediate vicinity of the lakes, and drinking water value could easily restore Maine lakes to their estimated net economic value, which exceeds 6.7 billion dollars (MDEP 2005d).

Trophic Status

A lake's trophic status is a measure of the efficiency of nutrient use in a lake ecosystem (Chapman 1992). The trophic status specifically measures the total biomass production at the primary production level, which is comprised of aquatic plants and algae. Lakes with a high trophic status have few consumer species including zooplankton and fish. These species are capable of reducing the biomass of primary producers. When nutrient levels increase, phytoplankton and macrophyte levels increase to a level that cannot be controlled by the consumer population. The buildup of nutrients results in an increased amount of dead biomass. During anoxic periods these nutrients are released back into the lake ecosystem leading to increased algal growth (Chapman 1992).

There are four trophic status categories for lakes: oligotrophic, mesotrophic, eutrophic, and dystrophic (see Background: Lake Characteristics: Trophic Status of Lakes). As a lake acquires nutrients over time through eutrophication, its trophic status changes. Secchi disk transparency, chlorophyll-*a*, and total phosphorus concentration are frequently used to determine the degree of eutrophication, or trophic status, of a lake (EPA 2003). Biologists and volunteers can calculate the trophic status of a lake by using a combination of techniques, including monitoring transparency, total phosphorus, or chlorophyll-*a* readings taken over a period of at least five months in a given season (MDEP 1986).

A trophic state index is a convenient way to quantify the relationship among transparency, total phosphorus, and chlorophyll-*a*. One common index, developed by Dr. Robert Carlson of Kent State University, uses a log transformation of secchi disk values as a measure of algal biomass (EPA 2003). An oligotrophic lake is characterized by above average transparency (>8 m

Secchi Disk Transparency (SDT)), deficient phosphorus (<6 ppb Total Phosphorus (TP)), and low productivity (<1.0 ppb Chlorophyll-*a*). A mesotrophic lake has average transparency (2 to 4 m SDT), moderate phosphorus levels (12 to 24 ppb TP), and moderate productivity (2.6 to 7.3 ppb Chl-*a*). A eutrophic lake has below average transparency (<2 m SDT), high phosphorus levels (>24 ppb TP), and high productivity (>7.3 ppb Chl-*a);* (Carlson et al. 1996). The hypolimnia of shallow lakes may become anoxic at depths below 4 m (Carlson et al. 1996). In the most severe cases, a lake is considered dystrophic when the internal generation of organic matter is extremely high, recreational water use becomes severely impaired, and anoxia occurs often in the hypolimnion during summer stratification (Chapman 1992). Using this classification system, China Lake is considered eutrophic (see Analytical Procedures: Water Quality).

MDEP designed a classification system to assess the vulnerability of water quality to future impacts of changing land use. Lakes high in nutrients are eutrophic according to the MDEP classification scheme and continued degradation increases the chance that eutrophic lakes will become unsuitable for both aquatic species and human recreation (see: Background: Lake Characteristics: Trophic Status of Lakes). In general, eutrophic lakes have large populations of a few dominant phytoplankton species, high surface oxygenation and low benthic oxygenation, many fish species, and high levels of suspended solids (Chapman 1992).

STUDY OBJECTIVES

WATER QUALITY ASSESSMENT

The primary purpose of this study was to determine the ecological health of China Lake and make recommendations for improving water quality. The Colby Environmental Assessment Team (CEAT) analyzed the trophic state of the lake, capacity to sustain aquatic wildlife, and ability to support the current and future levels of development. Pollution from commercial land use can include chemicals, excess nutrients, and sediment runoff, all of which lower water quality and increase the rate of eutrophication. The goal was to identify non-point pollution sources, such as roads, agriculture fields, lawns, and septic systems, and assess their impact on the water quality of China Lake.

General water quality is the best indicator of the nutrient load from non-point pollution sources and the ecological condition of the lake (Chapman et al. 1996). CEAT analyzed multiple physical, chemical, and biological water quality parameters. To determine how water quality changed in relation to seasonal changes, CEAT collected water samples during the summer and fall at sites on the lake and tributaries. The findings were compared to water quality analyses performed by the Maine Department of Environmental Protection (MDEP) in previous years to examine the effects of human activity on the trophic status of China Lake.

LAND USE ASSESSMENT

Land use patterns in a watershed have a significant impact on the health of associated water bodies. Different land uses produce different types and amounts of anthropogenic and natural pollutants. For example, forested land adjacent to a water body is highly desirable because it filters runoff and traps sediment that would otherwise drain into the lake. In contrast, a commercial property located near a water body constitutes a large area of impervious surface, contributes to surface runoff of sediments, and may generate chemical or nutrient pollutants. Sediments are a concern for water quality because they carry nutrients (most importantly phosphorus) that accelerate lake eutrophication.

The goal of the land use assessment was to identify and quantify the current patterns of land use in the China Lake watershed through the use of aerial photography, ArcGIS® 9 software, and ground truthing. The surveying objectives were to identify specific locations on

roads where improvements could mitigate runoff problems, to determine the intensity of residential land development, and to assess areas along the shore where landscaping changes could protect the lake from direct runoff and sedimentation. The analysis goals were to create an erosion potential model, septic suitability model, and phosphorus budget to project the impact of future development in various areas of the watershed.

FUTURE TRENDS

One important purpose of monitoring water quality is to enable informed planning for future development and protection of the lake. CEAT developed a water budget and Phosphorus Loading Model to predict the effects of further land use changes on nutrient loading in China Lake. Comparisons of land use patterns in 1965 aerial photographs, 2003 Digital Orthophotoquads (DOQs), and analysis of demographic statistics of the area were used to understand past changes of land use. CEAT analyzed historic land use patterns to help predict future trends and how they would impact the lake.

REMEDIATION TECHNIQUES

After identifying the most important issues for lake quality and land use, it is essential to learn how to improve upon them. In the recommendation section of this report, CEAT presents a variety of commonly used mitigation techniques for improving lakes with poor water quality. While some of these strategies may be ineffective in China Lake for various ecological and economic reasons, there are several approaches that may be useful for watershed residents interested in improving the quality of the lake. These remediation techniques serve as an educational recommendation that can lead to positive action for China Lake watershed residents.

ANALYTICAL PROCEDURES AND RESULTS

WATER QUALITY STUDY SITES

Eleven study sites were chosen for water quality testing on China Lake. Sites 1, 2, and 3, which were used by the Maine Department of Environmental Protection (MDEP), are referred to as comprehensive sites. All tests were performed at these sites to develop a complete understanding of water quality at a few representative points in the lake. Water profiles were collected at Sites 1, 2, and 3 to obtain an accurate view of water quality, dissolved oxygen concentrations, and temperature at all depths. A limited number of tests were performed at the spot sites (sites 4-8) and tributary sites (sites 9-11) (see Appendix A). Spot sites were chosen to study potential differences in water quality and to investigate potential problem areas, such as areas of high development or with local farms. Three tributaries were tested to determine what they were carrying into the lake. Storm monitoring stations were set up in these streams to ascertain what was being carried into the water during storm flow conditions.

During the summer months of June and August 2005, sampling was conducted at Sites 1, 2, and 3. On 19-Sep-05, sampling was conducted at all sites. Physical (dissolved oxygen, temperature, turbidity, color, and conductivity) and chemical (pH, alkalinity, nitrates, and total phosphorus) parameters were measured at all 11 sites. Relative abundance of chlorophyll-*a* was only recorded at the comprehensive sites (see Appendix A). These tests were used to characterize the water quality of China Lake and to identify potential problem areas.

GPS points were taken at each of the sampling sites to create the study site map (Figure 12). These coordinates were superimposed onto the study site map using GIS (see GIS: Introduction). The most common coordinate system for taking GPS points, Universal Transverse Mercator (UTM), was used to plot our sample site locations. GPS points were recorded with Northing (the number of meters north of the equator) and Easting (the number of meters east of the Prime Meridian) coordinates for each site.

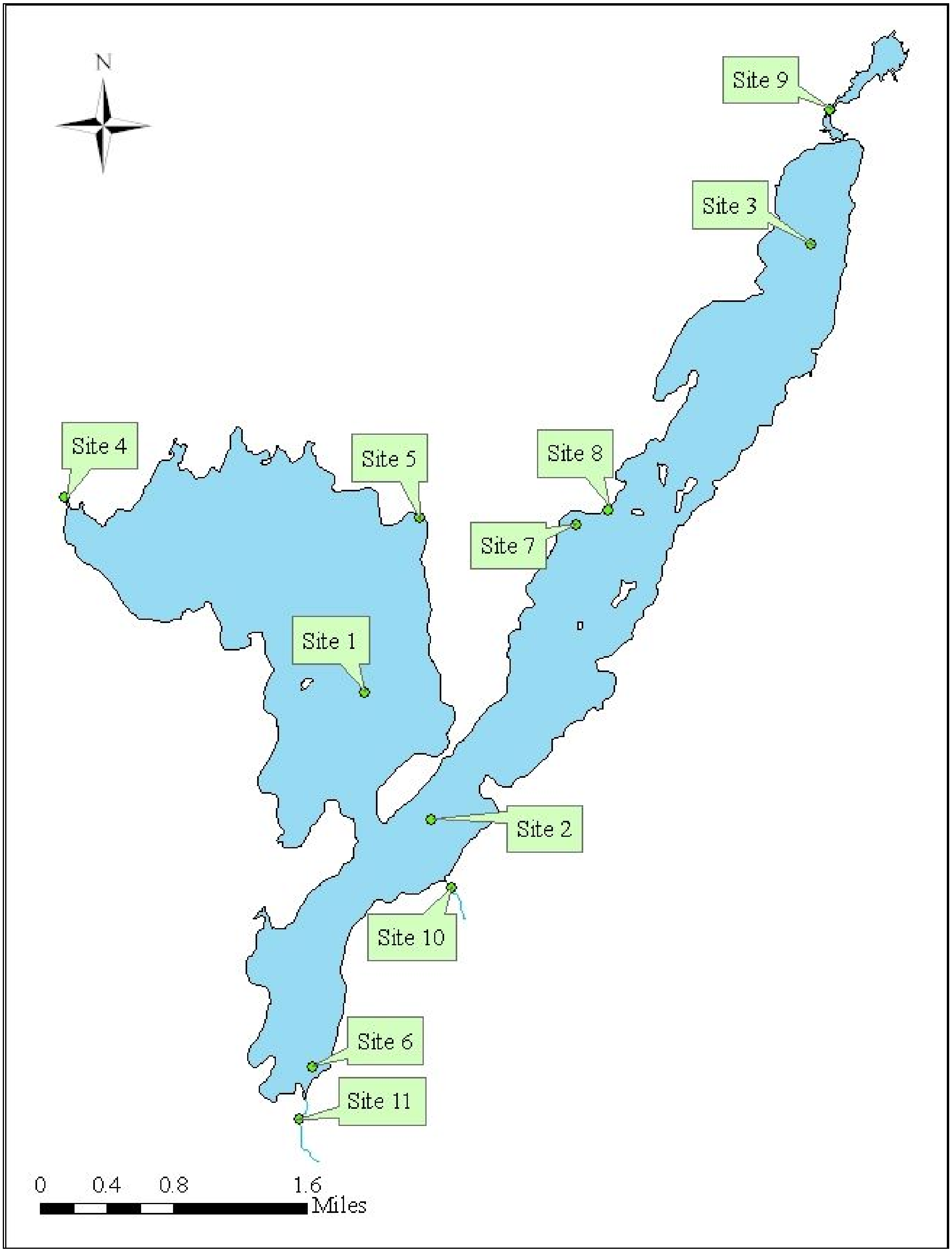

Figure 12. Site map displaying the locations of the water chemistry sampling sites on China Lake.

COMPREHENSIVE SITES

MDEP has used sites 1, 2, and 3 for sampling is past studies, which was useful for making historical comparisons to this study.

Site 1: Northing: 4920148 Easting: 0454862 Depth: 27.5 m

Site located in the West Basin.

Site 2: Northing: 4918933 Easting: 0455432 Depth: 8.7 m

Site located at the south end of the East Basin, just north of the entrance to the West Basin.

Site 3: Northing: 4924273 Easting: 0459109 Depth: 16.0 m

Site located at the north end of the East Basin.

SPOT SITES

Site 4: Northing: 4921730 Easting: 0451831 Depth: 1.0 m

Site located at the dam where water drains from the West Basin. Samples were taken from the lakeside of the dam to characterize the water leaving the lake.

Site 5: Northing: 4921539 Easting: 0455255 Depth: 1.0 m

Site located on the north shore of the West Basin. Samples were collected where Ward Brook enters China Lake. Ward Brook is a tributary that runs from an agricultural area, through a buffer zone and into the lake. Samples from this site were used to determine the impact of agricultural land on local water quality.

Site 6: Northing: 4916232 Easting: 0454237 Depth: 1.5 m

Site located at the southern most end of the East Basin. Samples from this site were used to determine the impact of a public boat launch on local water quality.

Site 7: Northing: 4921476 Easting: 0456753 Depth: 1.5 m

Site located on the west bank of the East Basin, near the base of the farms. Samples from this site were used to determine the impact of agricultural land on local water quality.

Site 8: Northing: 4921609 Easting: 0457072

Site located on the west bank of the East Basin, just south of Green and Taconnet Islands. Samples were collected in front of a cluster of older houses to determine their potential impact on water quality.

TRIBUTARIES

Site 9: Northing: 4925513 Easting: 0459224

Site located at the major inlet on the north end of China Lake. Samples were taken from the streamside of the Route 201 bridge.

Site 10: Northing: 4917971 Easting: 0455555

Site located in Starkey Brook, which enters the lake from the east side of the East Basin, across from the entrance to the West Basin. Samples were taken from the stream, close to where it enters the lake.

Site 11: Northing: 4915720 Easting: 0454085

Site located in Jones Brook, which enters the East Basin at the southern end. Samples were taken from the brook, close to where it enters the lake.

WATER QUALITY

PHYSICAL PARAMETERS

Dissolved Oxygen and Temperature

Introduction

The concentration of Dissolved Oxygen (DO) in a water body depends on physical, chemical, and biological factors, so measuring DO is a good indicator of water quality. Changes in DO concentrations can serve as an early indication of changes of water quality in a lake (Bartram and Balance 1996). DO decreases with increases in temperature because gas solubility decreases with increases in temperature. Higher temperatures reduce the dissolved oxygen available to organisms, and since the metabolic rate of organisms increases with increases in temperature, higher temperatures result in a lower percentage of the metabolic demand being satisfied (Henderson-Sellers and Markland 1987).

Biomass distribution and changes affect dissolved oxygen concentrations. DO concentration is also restricted by the effect of thermal stratification, which limits the rate of oxygen transfer from the surface to greater depths (Henderson-Sellers and Markland 1987). Low biomass concentrations and relatively high turbulence levels result in the mixing of nutrients, allowing for a homogenous oxygen concentration from surface to depth. The DO profile reflects the thermal stratification of a lake with a reduction in DO observed below the thermocline (Henderson-Sellers and Markland 1987). DO stratification occurs because the main sources of oxygen are in the epilimnion and the main sinks for oxygen are in the hypoliminion. Thermal stratification prevents mixing of DO between the epilimnion and the hypolimnion. As DO is depleted by decomposers in the hypolimnion and stratification prevents its replenishmen the DO profile becomes similar to that of temperature for a waterbody (Henderson-Sellers and Markland 1987).

Most organisms are dependent on oxygen for life, so low levels of oxygen in a water body can decrease the diversity of aquatic life. Water with DO concentrations below 1 ppm is considered anoxic and DO levels below 5 ppm are life-threatening to most cold water fish (PEARL 2005b).

Methods

The Colby Environmental Assessment Team (CEAT) took DO and temperature measurements at Site 1, 2, and 3 on 7-Jun-05, 22-Jun-05, 3-Aug-05, 16-Aug-05, and 19-Sep-05. Measurements were taken using a YSI 650 MDS Sonde at one meter intervals from the lake surface to within one meter of the bottom. Temperature was measured in degrees Celsius (°C) and DO was measured in parts per million (ppm). Historical data were obtained from the MDEP and the Volunteer Lakes Monitoring Program.

Results and Discussion

At Site 1, DO ranged from 10.85 ppm at the surface to 7.95 ppm at a depth of 27 m on 7-Jun-05 (Figure 13). By mid-August the water had gone anoxic (<1.0 ppm) at 25 m. The lake had become anoxic at 11 m by 19-Sep-05. On 19-Sep-05 the DO dropped from 8.72 ppm to 2.83 ppm between 8 and 9 m. This dramatic decrease resulted from the thermocline, which had been in place since late June. Stratification of the water column prevents the replenishment of dissolved oxygen in the hypoliminion. The high activity of decomposers due to high food levels resulting from algae dying and sinking to the bottom where it is decomposed, uses up the oxygen in the hypolimnion.

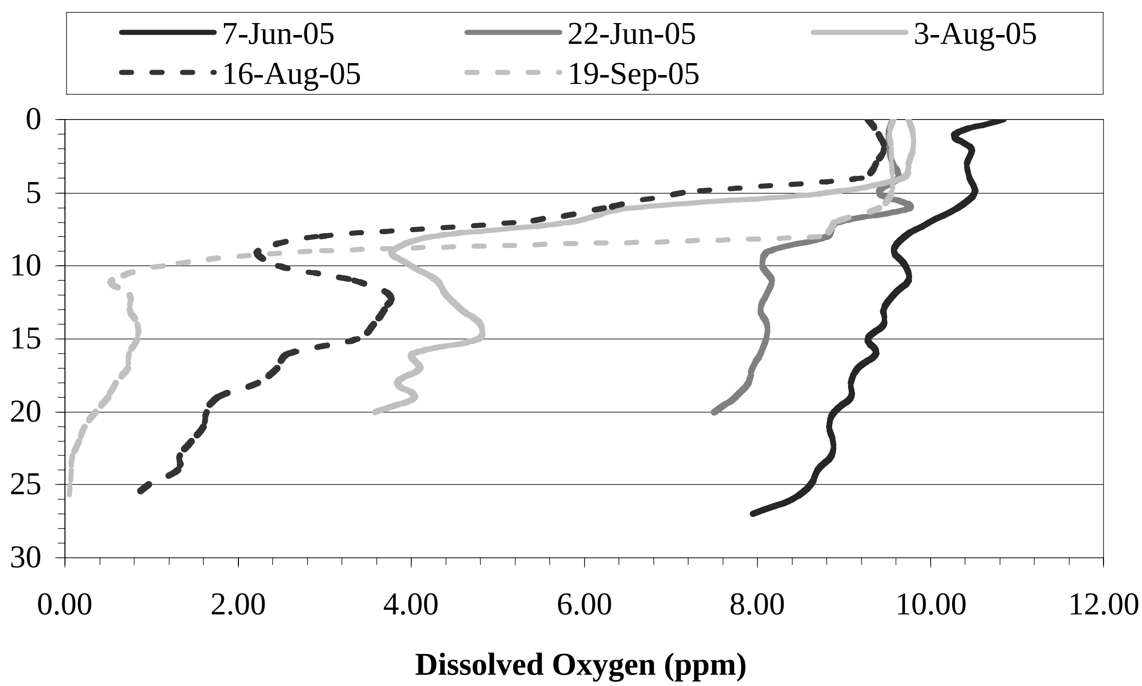

Figure 13. Dissolved oxygen profile at Site 1 of China Lake during the summer of 2005. See Figure 12 for site location.

At Site 2, DO levels ranged from 10.21 ppm at 3 m to 8.04 ppm at 16 m on 7-Jun-05 (Figure 13). Benthic DO levels decreased through the end of the monitoring, to 0.07 ppm on 19-Sept-05. Site 2 at China Lake first turned anoxic on 16-Aug-05 at a depth of 11 m. Stratification between the epillimnion and the hypolimnion occurred at a depth of 6 to 8 m.

The DO profile at Site 3 on 7-Jun-05 ranged from 9.58 ppm at the surface to 7.81 pmm at the bottom (Figure 13**)**. The bottom readings decreased as the summer progressed and from 3-Aug-05 though the last sample day on 19-Sep-05, DO was measured at 0.07 ppm at 16 m. The lake turned anoxic between 8 and 11 m at Site 3 on these sampling days. Higher levels of DO were observed at depth in early June, before the lake stratified. Temperature declined with depth on the June sampling days, however, due to the recent spring turnover event, strong stratification of the lake was not yet observed. The lake had become distinctly stratified by August and September DO and temperature measures indicate a thermocline between 5 and 10 m. The thermocline is an area of rapid change in temperature. DO declines below the thermocline because the thermocline prevents the circulation of gases between the epilimnion and the the hypolimnion. DO depleted by decomposers at depth cannot be replenished by surface DO because of this thermocline, resulting in water to become anoxic below the thermocline.

In 1982, the lake water never turned anoxic (Figure 14). Historical data were from Site 1. However, similar to the observations made by CEAT, in September of 1987, 1992, and 1997, the lake became anoxic below the thermocline. In 1997, DO levels remained above 1.0 ppm into deeper water (17 m) than in 1992 (10 m), indicating that a smaller volume of the lake became anoxic in 1997. The anoxic conditions observed at depth indicate that internal phosphorus loading could be an important factor in China Lake. From the months of June to September 2005, temperature ranged from 24.8° C at the surface to 9.8° C at 27 m at Site 1 (Figure 15). In early June, temperature profiles indicate weak stratification, which increased as the summer progressed.

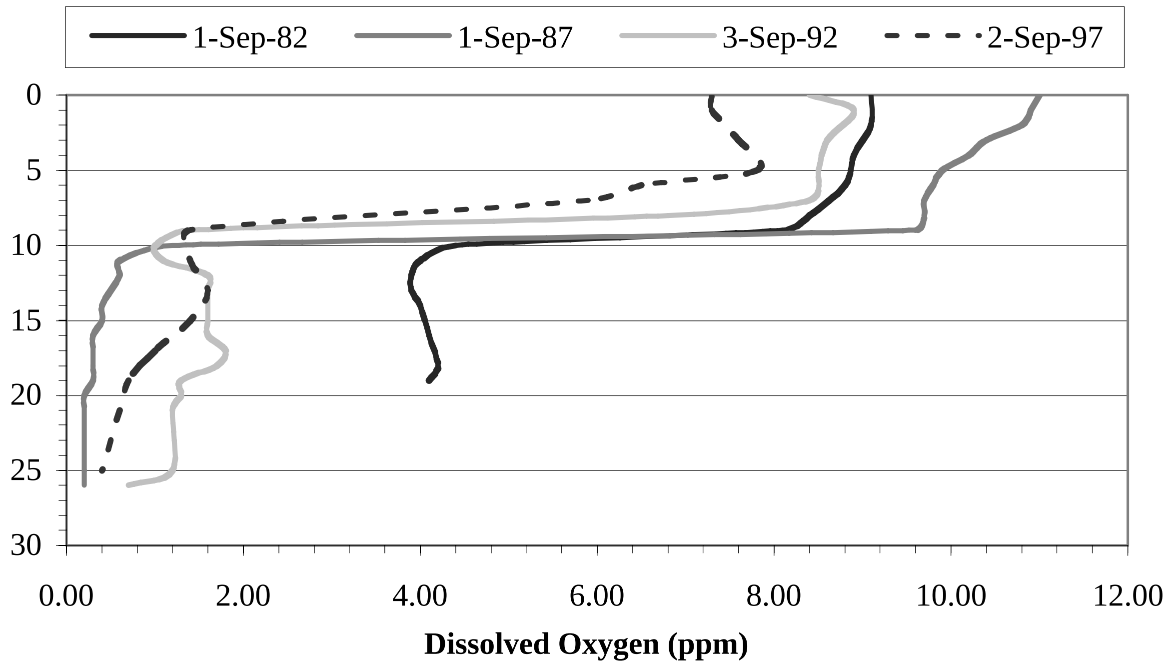

Figure 14. Historic dissolved oxygen profiles at Site 1 of China Lake (MDEP 2005c). See Figure 12 for site location.

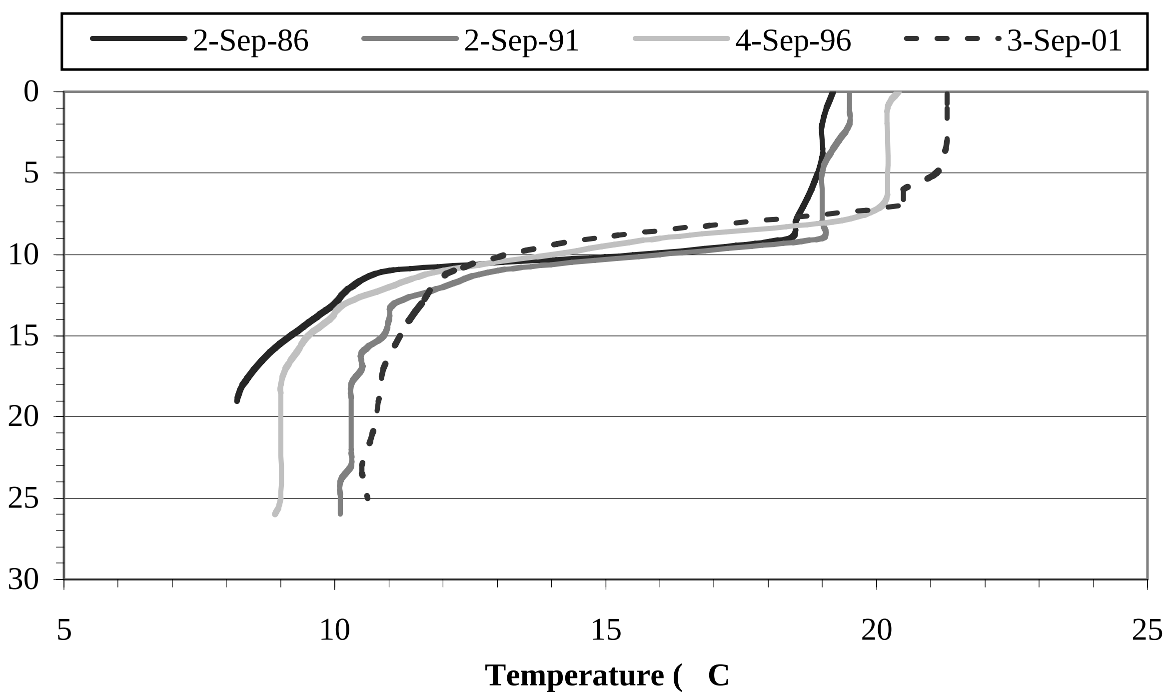

Figure 15. Historic temperature profiles at Site 1 of China Lake (MDEP 2005c). See Figure 12 for site location.

Transparency

Introduction

Transparency measures visibility in the water column, which is affected by suspended matter in the water (Chapman 1996). Color and turbidity, as well as light intensity and the equipment used, cause variation in this measurement (Bartram & Balance 1996). In addition, transparency can change daily. However, transparency measurements provide a quick way to estimate the water quality and trophic state of a lake and can be used to track water quality over time (Pearl 2005c).

Water color, silt, algae, and zooplankton reduce clarity. Algae are the most abundant of these factors, so transparency is an indirect measurement of algal productivity. In Maine lakes, average transparency is 4.9 m, but it varies from 0.4 m to 20.0 m (Pearl 2005c). When transparency dips below 2.0 m, the lake is considered to be undergoing an algal bloom (PEARL 2005c). A lake is considered eutrophic when the average transparency is less than 2.0 m for more than three years of a ten-year period, and has color readings greater than 25 Standard Platinum Units (SPU) (PEARL 2005d). Lake transparency decreases as productivity increases. Low transparency limits photosynthetic activity below the surface of the water and leads to oxygen depletion. Transparency can also adversely affect visual predators. Low transparency impairs the ability of an organism to find food affecting the whole ecosystem of the lake (PEARL 2005d).

Methods

CEAT measured transparency at Sites 1, 2, and 3 using a Secchi disk with an Aqua-Scope on 7-Jun-05, 22-Jun-05, 3-Aug-05, 16-Aug-05, and 19-Sep-05. MDEP used the same method to do their water quality sampling. Historic data were obtained from the MDEP and the Volunteer Lakes Monitoring Program (MDEP 2005b).

Results and Discussion

CEAT observed decreasing transparency from June to August. Mean (± SE) transparency for China Lake over all of the sampling dates was 2.90 ± 0.40 m, which is similar to that recorded at Threemile Pond (Table 4). The transparency was below 2 m on both sampling dates in August (Figure 16). This transparency corresponds with algal blooms, with transparency

decreasing as the severity of the bloom increased in the late summer. Transparency in China Lake varied from 6.10 m at Site 1 at the beginning of the summer to 1.20 in late August, indicating the occurrence of an algal bloom at this time.

Table 4. Comparison of China Lake physical parameters (mean ± SE) to five nearby lakes (CEAT 1995, 1997, 2000, 2004, 2005).

Lake	Transparency	Turbidity (NTU)	Color (SPU)	Conductivity (μMHOs/cm)
China Lake	2.90 ± 0.40 (n = 15)	2.64 ± 0.38 (n = 50)	11.88 ± 0.77 (n = 8)	72.0 ± 8.90 (n = 11)
Threemile Pond	2.9 ± 0.04	1.6 ± 0.81	14.85 ± 8.5	48 ± 5.8
Webber Pond	1.3 ± 0.1	5.9 ± 2.7	19 ± 0.36	39 ± 1.0
East Pond	3.25 (n = 12)	8.0	16.9 (n = 8)	27.5 (n = 9)
Great Pond	5.9 ± 0.2 (n = 13)	4.34 ± 1.84 (n = 10)	13 ± 2 (n = 15)	32.2 ± 1.0 (n = 10)
Long Pond North Basin	6.2 ± 0.4 (n = 14)	3.33 ± 0.17 (n = 9)	12 ± 1 (n = 9)	28.9 ± 0.7 (n = 5)

Mean transparency decreased steadily from 1980 to the present with the 1999 mean being below 2.0 m (Figure 17). The maximum transparency has fluctuated since 1980 with a reoccurring pattern of increased transparency followed by a decreased transparency over a three year period (Figure 17). Since 1983, with the exception of 1989 and 1990, the minimum transparency has been below 2.0 m, indicating that an algal bloom occurred in China Lake during all of these years.

Turbidity

Introduction

Suspended matter in the water column affects turbidity readings. Turbidity results from the scattering and absorption of light, and changes daily similar to transparency. Spring runoff and rain can affect turbidity. Turbidity is lower when suspended organic and/or inorganic matter,

silt, clay, or plankton is present in the water column. Low turbidity indicates that there is low light penetration resulting in low rates of photosynthetic activity in a lake (Chapman 1996).

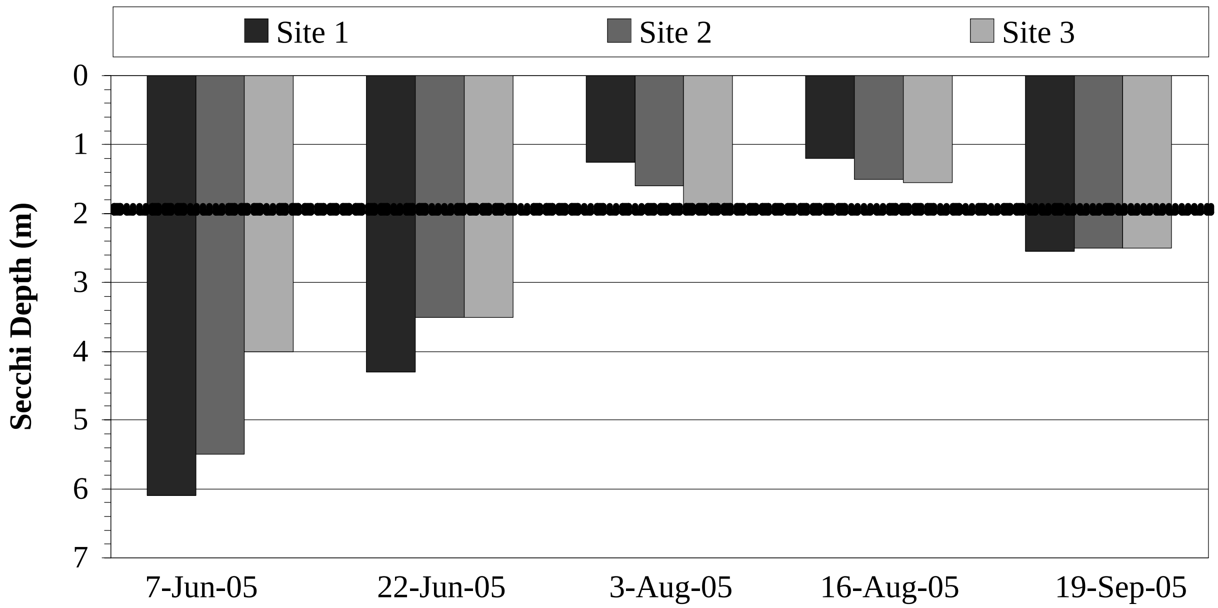

Figure 16. Mean Secchi depth transparency at Site 1, 2, and 3 of China Lake during the summer of 2005. Minimum transparency below a depth of 2 meters (dotted line) indicates the occurrence of an algal bloom. See Figure 12 for site locations.

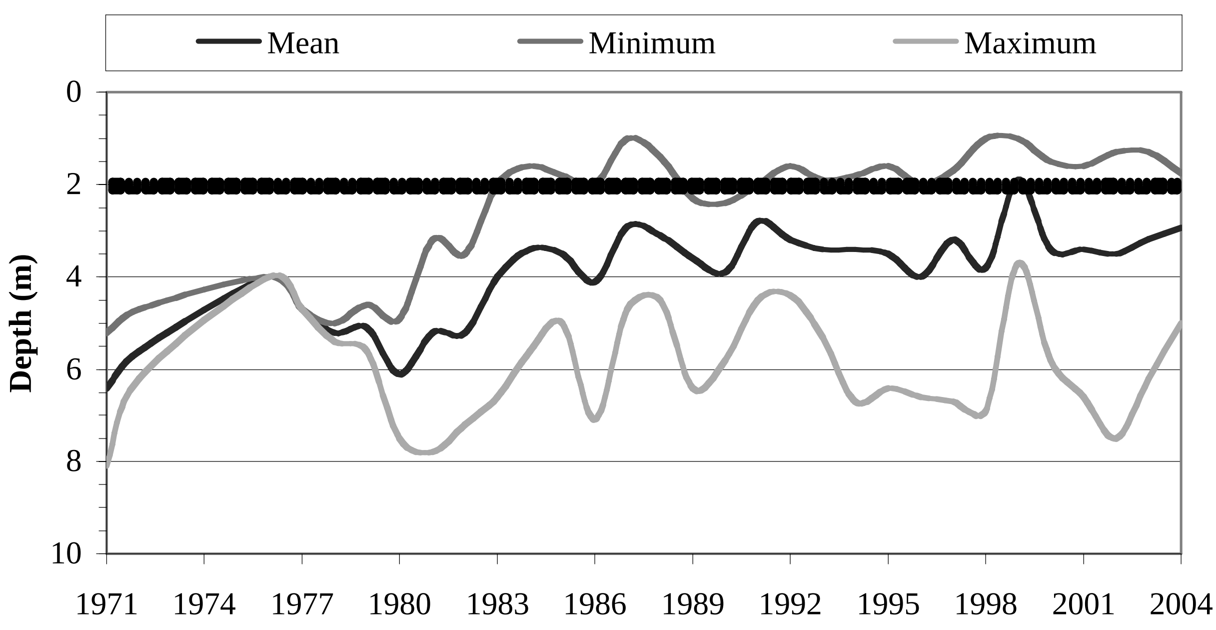

Figure 17. Mean, minimum, and maximum transparency of China Lake

measured at Site 1 from 1971-2004 with Secchi disk (MDEP 2005c). Minimum transparency below a depth of 2 meters (dotted line) indicates the occurrence of an algal bloom. See Figure 12 for site location.

Methods

Turbidity was measured from surface, mid, and bottom samples from Site 1, 2, and 3 on several dates between 7-Jun-05 and 19-Sep-05 (See Appendix A). Surface samples were tested at Sites 4, 5, 6, 7, and 8 by CEAT on 19-Sep-05. Turbidity was measured in Nephalometric Turbidity Units (NTU) using a Hach™ 2100P Turbidimeter. Turbidity can range from 1-1000 NTU, but most samples are below 50 NTU (Chapman 1996).

Results and Discussion

Throughout the summer and fall monitoring, surface turbidity at Site 1 ranged from 0.68 to 6.42 NTU. The mean surface turbidity (± SE) was 3.18 ± 0.35 (Table 4). Surface data collected during the summer revealed an increase in surface turbidity at Site 1 from 1.8 NTU on 7-Jun-05 to 6.42 NTU on 16-Aug-05. Between mid-August and 19-Sep-05 the surface turbidity decreased to 4.27 NTU. Turbidity increases as a result of more suspended matter in the water. The increase in turbidity observed in the late summer is most likely due to the algal bloom the proceeding decline in turbidity indicates the ending of the bloom event.

Color

Introduction

Color measures suspended particles and dissolved substances in the water column. Suspended materials may be from natural or human causes. Vegetation cover within the watershed, weathered geologic material, and land-use strategies influence the type and amount of dissolved and suspended materials present in a waterbody (PEARL 2005e). CEAT filtered water before measuring to determine True Color; apparent color measurements use unfiltered water to determine the effect of suspended matter refraction and reflection of light. True color varies from 0 - 300 Standard Platinum Units (SPUs), with an average of 28 SPU for Maine lakes (PEARL 2005e).

Methods

Water samples were collected from the surface at all study sites on 19-Sep-05 and true color measurements were performed in the Colby Environmental Analysis Center (CEAC). Samples were collected and kept on ice until returned to the laboratory where they were refrigerated until they were analyzed. Samples were returned to room temperature before analyses. True Color analyses were conducted within 24 hours of sampling, using a HACH™ DR/4000 Spectrophotometer™.

Results and Discussion

True Color ranged from 10 SPU to 175 SPU on 19-Sep-05. The mean (± SE) surface SPU for all samples was 35.82 ± 15.19 SPU (Table 4). The mean for Sites 1 - 8 was 11.88 ± 0.77 SPU and ranged from 10 - 16 SPU. The tributary sites ranged from 58 - 175 SPU resulting in the high mean. High color in the tributaries results from higher levels of sediments from runoff and erosion. Historic true color measurements, obtained from the MDEP and the Volunteer Lakes Monitoring Project, range from 10 SPU to 49 SPU at Site 1 in 1999. The mean (± SE) true color from 1982 to 2004 was 26.64 ± 3.06 SPU (Figure 18). Color readings were similar to those seen at nearby lakes (Table 4**)**. Higher color would indicate the occurrence of an algal bloom.

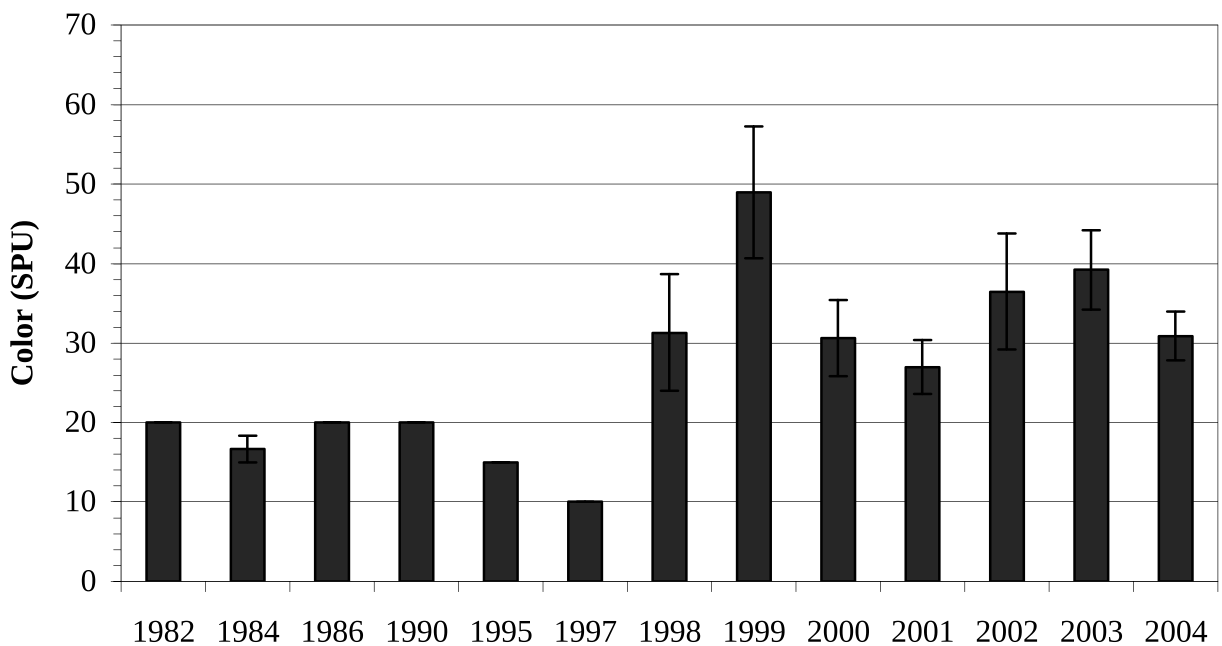

Figure 18. Historic mean (± SE) color for selected years at Site 1 of China Lake (MDEP 2005c). See Figure 12 for site location.

Conductivity

Introduction

Conductivity is the ability of water to conduct an electric current. The concentration of ions in solution influences conductivity (Bartram and Balance 1996). Conductivity is measured in millisiemens per meter (1 mSm^{-1} = 10 $\mu S\ cm^{-1}$ = 10 $\mu mhos\ cm^{-1}$). Measurements should be made in the field immediately after obtaining the sample because conductivity changes with storage time. Conductivity is also temperature dependent, so if the conductivity meter is not equipped with automatic temperature correction the temperature of the sample should be measured and recorded (Bartram and Balance 1996).

Methods

CEAT recorded conductivity profiles at Sites 1, 2, and 3 on 3-Aug-05, 16-Aug-05, and 19-Sep-05 using an YSI 650 MDS Sonde. Conductivities of surface samples from all sites on 19-Sep-05 were collected and kept on ice until return to thee laboratory where they were immediately analyzed. Conductivity was measured using YSI Model 31S Conductance Bridge (see Appendix B) at CEAC.

Results and Discussion

Conductance reflected stratification at Site 1 on all three sample dates. At Site 1, conductivity ranged from 90 μMHOs/cm at the surface to 61 μMHOs/cm at 15 m in August. In September, conductivity ranged from 84 μMHOs/cm at the surface to 67 μMHOs/cm at 26 m. The conductivities of Site 2 samples taken in August were similar to those recorded for Site 1. The 19-Sep-05 profile for Site 2 had less variation, varying from 82 μMHOs/cm at the surface, to 79 μMHOs/cm between 10 and 13 m and 81 μMHOs/cm at 15 m. Site 3 had conductivity profiles similar to those found at Site 2 for all dates.

On 19-Sep-05, surface conductivity ranged from 50 μMHOs/cm at Site 2 to 142.9 μMHOs/cm at Site 11. Results for conductivity at Sites 1, 2, and 3 obtained using the Conductivity Bridge were about 25-30 μMHOs/cm lower than results obtained using the Sonde

for those same sites. Samples were stored on ice and transported to the lab, but were not returned to room temperature before testing. Since conductivity is temperature dependent, the data collected in the lab using the Conductance Bridge is only comparable to other data obtained using the same methods on the same day. Sites 4 and 9 had a conductivity of 76.9 μMHOs/cm and Sites 10 and 11 had conductivities greater than 100 μMHOs/cm. The remaining sites all had conductivities between 50 and 58.8 μMHOs/cm. The mean (± SE) conductivity for all sites on 19-Sep-05, using the Conductivity Bridge method, was 72 ± 8.90 μMHOs/cm (Table 4). Historical conductivity means ranged from 63 μMHOs/cm in 1984 to a peak of 161.44 ± 0.25 μMHOs/cm in 2000 (Figure 19).

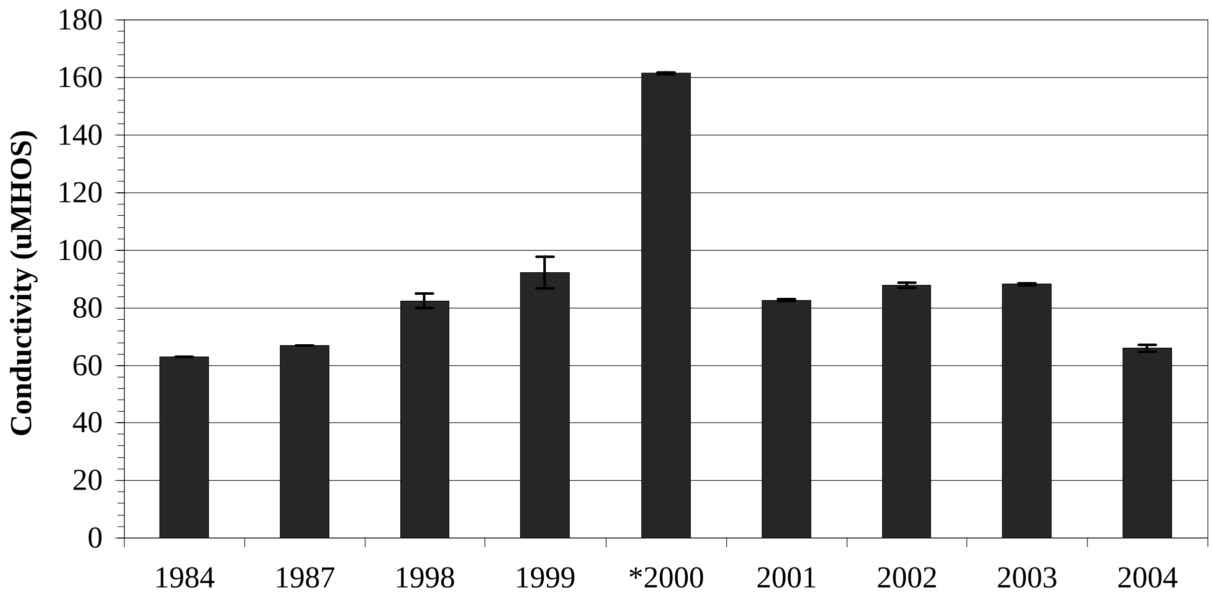

Figure 19. Historic mean (± SE) conductivity for selected years at Site 1 of China Lake (MDEP 2005c). Asterisk indicates removal of an outlier data point to calculate the mean for that year. See Figure 12 for site location.

<u>CHEMICAL PARAMETERS</u>

pH

Introduction

The concentration of hydrogen ions (H^+) in water is measured by pH. Values range from less than 1 (extremely acidic) to 14 (extremely basic) with pH of 7 indicating neutral acidity (Kalff 2002). pH is measured on a logarithmic scale - a change of 1 unit indicates a change of

H^+ concentration by a factor of ten. Lake water pH fluctuates naturally with the level primary productivity and unnaturally as a result of pollutants, such as acid rain. The degree of change of pH as a result of acid rain is influenced by alkalinity (see Water Quality: Alkalinity). However, pH also changes as a result of photosynthesis. As plants use carbon dioxide during photosynthesis, pH increases. High pH can indicate an algal bloom. pH is an important parameter in lake water quality because it influences which plant and animal species are able to live in the lake; different organisms have specific pH ranges in which they can survive (MDEP 1996). In addition, the pH level of China Lake is important because most processes involved in mitigating water quality problems (such as chemical coagulation, disinfection, softening, and corrosion control) are pH dependent (Tomar 1999).

Methods

Surface water samples were collected on 22-Sep-05 from each comprehensive site (Sites 1, 2, 3), each spot site (Sites 4, 5, 6, 7, 8), and two tributary sites (Sites 9, 11) to measure pH. See Figure 12 for site locations. Tributary Site 10 (Starky Brook) was not analyzed because the stream flow was prohibitively high for sampling. The samples were placed on ice and taken back to the Colby Environmental Analysis Center (CEAC) for analysis. Surface pH of each site was measured with an Accumet Basic pH meter. Also, pH profiles were taken at the three comprehensive sites using the YSI 650 MDS Sonde on 3-Aug-05, 16-Aug-05, and 19-Sep-05. Both instruments were calibrated before use (see Appendix B). Finally, mean pH for China Lake was compared to other local lakes in Maine to put China Lake in geographic context. Threemile Pond, Webber Pond, and East Pond, are of similar trophic status as China Lake, Great Pond is showing signs of eutrophication and Long Pond, North Basin is an example of a local lake in good condition.

Results and Discussion

On 22-Sep-05, the mean surface pH was approximately neutral (pH = 7) across the entire lake (Table 5). The pH profiles for each of the comprehensive sites show that surface pH was substantially more basic than benthic pH (Figure 20). Each of the three comprehensive sites showed similar trends. On 3-Aug-05 and 16-Aug-05, surface pH reached levels greater than 9. On 19-Sep-05, surface pH was slightly basic, but not as dramatically basic as the August levels.

Mean pH values have been measured on China Lake regularly since 1982 (MDEP 2005c). Yearly means have ranged from nearly 7.5 in 1986 to just over 6.8 in 2004 (Figure 21). Surrounding lakes, including Threemile Pond, Webber Pond, East Pond, Great Pond, and Long Pond, North Basin, also have relatively neutral mean (± SE) surface pH (Table 5).

The historic pH in China Lake has been consistently neutral, however CEAT found that when pH is investigated more closely, annual means might prove insufficient in evaluating water quality. Certain remediation techniques have very specific pH requirements and seasonal fluctuations or variations due to depth may be enough to limit the success of a treatment.

pH can fluctuate with depth and season for a variety of reasons. The most likely cause of pH change in China Lake, are the seasonal algal blooms. The removal of CO_2 from the water due to photosynthesis causes an increase in pH. The photosynthetic rate during an algal bloom rises dramatically, so the spike in pH in the late summer is due primarily to the increased algae content.

Table 5. Comparison of China Lake water quality chemical parameters (mean ± SE) to five nearby lakes (CEAT 1995, 1997, 2000, 2004, 2005).

Lake	pH (surface)	Alkalinity (mg/L; surface)	Nitrates (ppm; surface)	Total Phosphorus (ppb; epicore)
China Lakes Region				
China Lake	7.95 ± 0.19 (n = 19)	19.60 ± 1.61 (n = 10)	0.04 ± 0.01 (n = 11)	17.69 ± 0.79 (n = 16)
Threemile Pond	6.97 ± 0.21 (n = 11)	42.30 ± 4.75 (n = 3)	0.15 ± 0.04 (n = 4)	40 ± 2 (n = 2)
Webber Pond	7.13 ± 0.31 (n = 10)	37.37 ± 12.93 (n = 3)	0.11 ± 0.04 (n = 11)	24.90 ± 2.80 (n = 8)
Belgrade Lakes Region				
East Pond	7.43 ± 0.23 (n = 34)	11.2 ± 0.72 (n = 5)	0.04 (n = 7)	21.81 ± 0.88 (n = 42)
Great Pond	6.97 ± 0.11 (n = 17)	9.0 ± 0.58 (n = 3)	< 0.02	14.16 ± 3.50 (n = 38)
Long Pond North Basin	6.90 ± 0.25 (n = 4)	-	0.05 ± 0.01 (n = 9)	6.27 ± 1.09 (n = 7)

The basic surface pH of China Lake in the summer is significant to note because extremely basic pH levels can cause the release of phosphorus from the shallow water sediments. In China Lake, the pH remained around 9 for approximately the first five meters of depth. This implies that around the perimeter of the lake, phosphorus may have been released from the shallow sediments (0 – 5 m) during the late summer algal bloom.

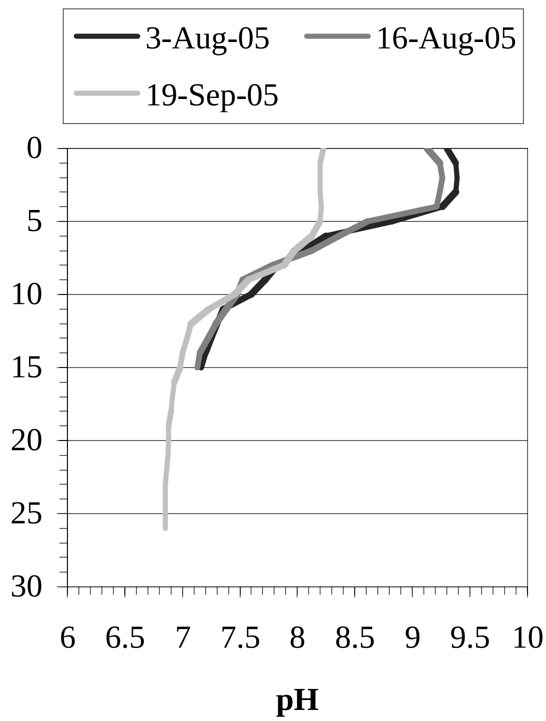

Figure 20. pH profile at Site 1 of China Lake during the summer of 2005. 19-Sep-05 measures pH to 26 m because prior to that date, the cable on the sonde was only 15 m long. See Figure 12 for site locations.

At pH 5-7, phosphorus retention and sorption to ferric compounds is maximized. pH is also an important factor when considering remediation techniques. At pH levels greater than 8, phosphorus is released from aluminum salts (one of the primary components in alum treatments). At pH 9, calcium carbonate sorbs phosphorus but needs aeration or complete mixing on a continual basis (Cooke et al. 1993). Although yearly mean pH may be consistently neutral, seasonal fluctuations are important to consider when evaluating viable remediation techniques.

Alkalinity

Introduction

Alkalinity is the acid neutralizing capacity of a body of water (Kalff 2002) or the ability of a lake to sustain the addition of acid without causing a change in the overall pH (Novotny 2003). It is the measure of calcium carbonate ($CaCO_3$) in a body of water. Alkalinity in Maine lakes varies from 0.3 milligrams per liter (mg/L) to 150.3 mg/L, with an average of 12.2 mg/L (MDEP 1996). The most important factors in determining alkalinity are land composition, changes in pH, and wastewater (Murphy 2002). Of these, land composition has the greatest bearing on

alkalinity in lakes. The soil and rock composition of the watershed determines the natural quantity of calcium carbonate in the water. For example, limestone and sedimentary rocks are high in carbonate, while granite is low in carbonate. pH and alkalinity are closely related (see Water Quality: pH) so changes in pH can cause changes in alkalinity.

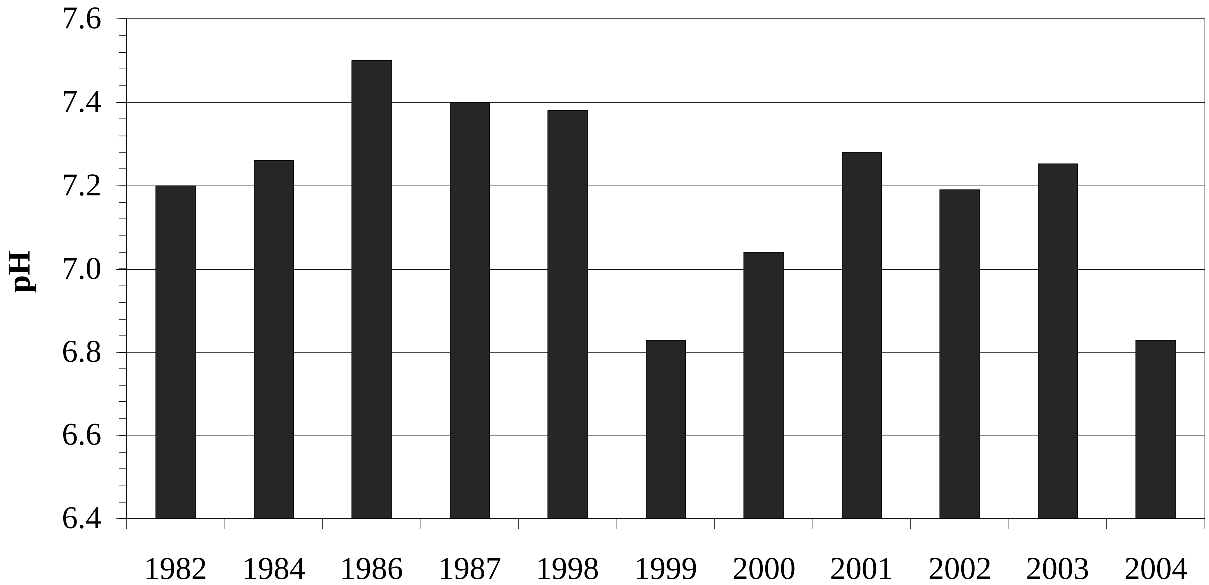

Figure 21. Historic mean pH for selected years at Site 1 of China Lake (MDEP 2005c). See Figure 12 for site location.

Wastewater from residential land often has elevated levels of carbonate due to home cleaning agents and food waste (Murphy 2002). Maine lakes have a relatively high alkalinity and substantial buffering capacity and are relatively resistant to changes in pH.

Methods

Surface water samples were collected on 22-Sep-05 from each comprehensive site (Sites 1, 2, 3), each spot site (Sites 4, 5, 6, 7, 8), and two tributary sites (Sites 9, 11) to measure alkalinity. Tributary Site 10 (Starky Brook) was not sampled because the stream flow was prohibitively high. See Figure 12 for site locations. The samples were placed on ice and taken back to CEAC for analysis. Alkalinity values were measured in milligrams of $CaCO_3$ by titration with 0.02 N sulfuric acid (see Appendix B). Finally, mean alkalinity was compared to other local lakes to put China Lake in geographic context. Threemile Pond, Webber Pond, and East Pond, are of similar trophic status as China Lake, Great Pond is showing signs of eutrophication and Long Pond, North Basin is an example of a local lake in good condition.

Results and Discussion

The mean (± SE) surface alkalinity was high at all sites across the lake in 2005, measuring just over 19 mg/L. Historically the alkalinity of China Lake has been high. The values have ranged from approximately 12 mg/L in 2003 to greater than 20 mg/L in 1987 (MDEP 2005c). The recorded value for 2005, of 19.60 ± 1.61 mg/L, fits reasonably into that range (Figure 22) and does not seem extraordinarily high for the area (Table 5).

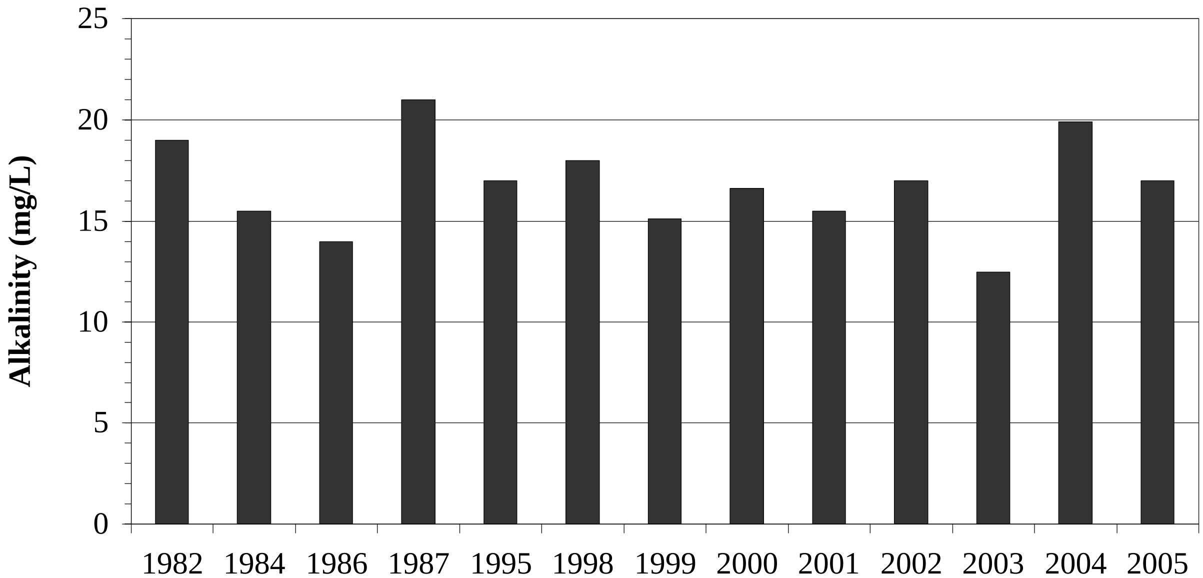

Figure 22. Historic alkalinity for selected years at Site 1 of China Lake. Alkalinity recorded for 2005 was measured by CEAT, all other years before (MDEP 2005c). See Figure 12 for site location.

Although higher than average across China Lake, in 2005 the alkalinity at the tributary sites was substantially higher than either the comprehensive sites or the spot sites, due in large part to the high sediment loading in the streams.

Nitrates

Introduction

Nitrates are an essential nutrient for plant growth. Nitrogen undergoes a series of redox reactions depending on the presence or absence of oxygen to produce various derivatives such as ammonia, nitrites, and nitrates (Tomar 1999). In fresh water, nitrate (NO_3^-) is the most common form of nitrogen. Nitrate concentrations in the lake can be increased by development within the

watershed, specifically from municipal and industrial wastewaters, waste disposal sites, sanitary landfills, and inorganic nitrate fertilizers are potential sources of excess nitrogen (Chapman 1996).

Methods

Surface nitrate concentrations were measured in the lab from water samples collected from all sites (Sites 1 – 11) on 19-Sep-05. See Figure 12 for site locations. The samples were placed on ice and taken back to CEAC for analysis. Nitrate profiles were also taken in the field at the three comprehensive sites (Sites 1, 2, and 3) using the YSI 650 MDS Sonde on 22-Jun-05, 3-Aug-05, 16-Aug-05, and 19-Sep-05 (see Appendix B). Finally, mean nitrate concentration was compared to other local lakes to put China Lake in geographic context. Threemile Pond, Webber Pond, and East Pond are of similar trophic status as China Lake, Great Pond is showing signs of eutrophication and Long Pond, North Basin is an example of a local lake in good condition.

Results and Discussion

Mean (± SE) surface nitrate concentration at the comprehensive sites was 0.04 ± 0.01 mg/L (n = 3), at the spot sites it was 0.05 ± 0.01 mg/L (n = 5), and at the tributary sites it was 0.04 ± 0.01 mg/L (n = 3). These surface means are comparable to surface mean nitrate concentration from nearby lakes, including Threemile Pond, Webber Pond, East Pond, Great Pond, and Long Pond, North Basin (Table 5).

From the mean surface concentration, it is not possible to distinguish between the sites on China Lake. However, when broken down by site, it became clear that Sites 7 and 8 had elevated surface nitrate concentrations (Figure 23). These elevated levels could be a result of the specific land uses adjacent to Sites 7 and 8. CEAT noticed a farm located adjacent to Site 7 and a high density of grandfathered houses located at the shoreline adjacent to Site 8. These areas should receive special attention when considering remediation techniques

The surface nitrate concentrations measured in the field with the Sonde and in the laboratory yielded similar trends. It is important to avoid value comparison between the two sets of data, because different analytical procedures were used. Nitrate profiles were measured at the three comprehensive sites on 22-Jun-05, 3-Aug-05, 16-Aug-05, and 19-Sep-05. The nitrate concentrations were highest during the late summer at the surface of the lake. Figure 24

illustrates the nitrate profile at Site 1, which is representative of the other two sites as they all expressed similar profiles (see Appendix C).

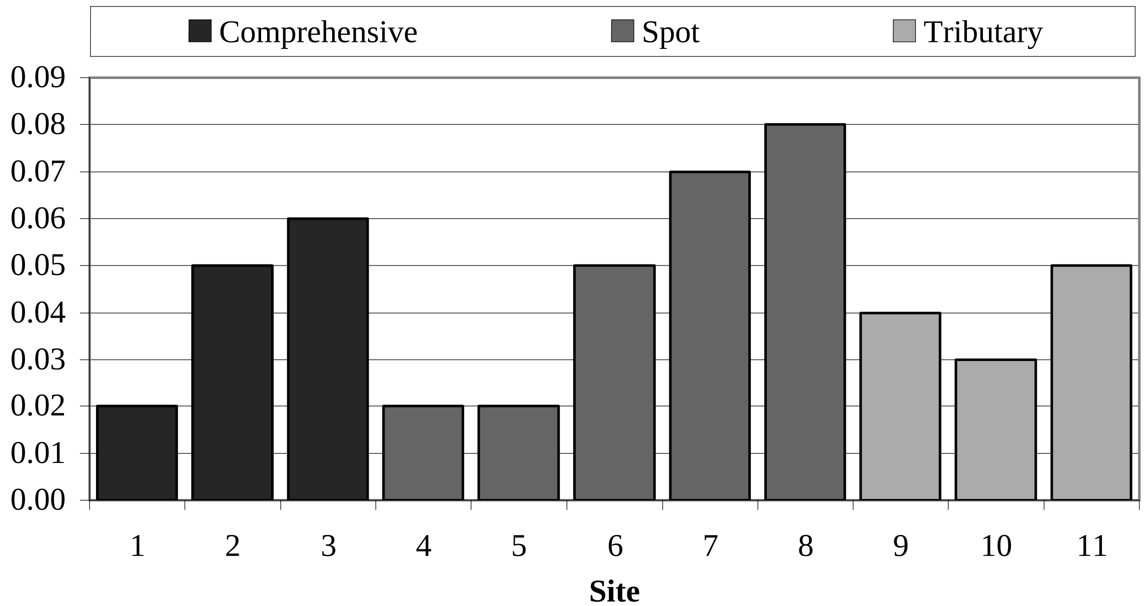

Figure 23. Surface nitrates measured at each comprehensive site, spot site, and tributary site of China Lake on 19-Sep-05. See Figure 12 for site location.

Total Phosphorus

Introduction

Phosphorus is considered one of the most important nutrients in freshwater systems because phytoplankton growth is limited by phosphorus abundance (Effler et al. 1996). In addition, phosphorus is required in the synthesis and decay of organic materials and helps in the production, storage, and utilization of chemical energy during vital activities (Tomar 1999). For these reasons, phosphorus is considered the limiting nutrient in freshwater systems.

Elevated levels of phosphorus in freshwater lakes increase phytoplankton abundance causing deleterious consequences, such as reduced water clarity from algal blooms (see China Lake Characteristics: Algal Blooms) and reduced dissolved oxygen. Phosphorus is the key nutrient driving algal production, making lake water phosphorus concentration the most important factor in causing the algal bloom in a lake.

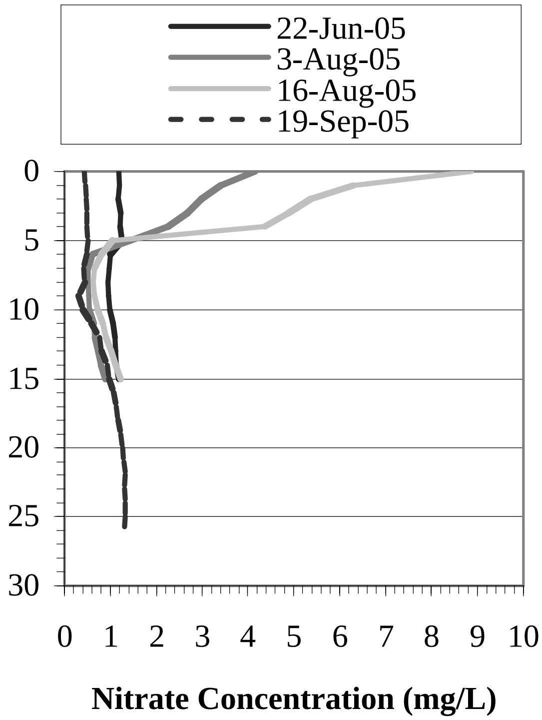

Figure 24. Nitrate profile at Site 1 of China Lake, measured by CEAT during the summer 2005. 19-Sep-05 measures Nitrates to 26 m because prior to that date, the cable on the sonde was only 15 m long. See Figure 12 for site location.

Phosphorus occurs naturally in sediments, decomposing leaf litter and other organic materials, so some phosphorus in the ecosystem is inevitable. However, human land-uses, recreational activities, and runoff contribute to the excess phosphorus loading of lakes (Novotny 2003). The Maine Department of Environmental Protection describes lakes with phosphorus concentrations of 12 – 15 parts per billion (ppb) as at risk for algal blooms (Bouchard, pers. comm.; see Background: Phosphorus and Nitrogen Cycles).

Methods

CEAT measured total phosphorus concentration on 07-Jun-05, 22-Jun-05, 03-Aug-05, 16-Aug-05, and 19-Sep-05 (see Appendix C). Comprehensive Site 2 was remeasured on 6-Oct-05 due to incorrect location of the first sample on 19-Sep-05. See Figure 12 for site locations. At the comprehensive sites (Sites 1, 2, and 3), samples were taken from the surface, mid-depth, epicore, and bottom of the lake. Surface samples were taken at all spot sites and tributary sites. After collection, all samples were placed on ice and taken back to CEAC for analysis (see Appendix B). CEAT also measured the phosphorus contribution of two of the tributary sites (Sites 9 and 11) after a storm. A Global Water Stormwater Sampler SS201, placed in the two sites, was programmed to begin sampling after 0.5 inches of rain fell during a storm. One hose collected water from the tributary and filled the sample bottle completely (4 liters) as soon as 0.5 inches of rain fell; this sample was referred to as the continuous sample. The other hose collected water from the tributary every 10 minutes, until the sample bottle filled completely (4 L); this sample is referred to as the staggered sample.

All samples were digested using 1.0 mL of 1.75 N ammonium peroxysulfate and 1.0 mL 11 N sulfuric acid (per 50 mL sample) in an autoclave at 15 lbs/in^2 and120^o C for 30 minutes. The digestion process converts all organic phosphorus bound with phytoplankton, algae, or other organisms into its inorganic form. Post-digestion, samples were brought to pH 6 and a combined reagent was added for analysis (see Appendix B). The color produced by the combined reagent reacting with the phosphorus was measured using a Milton Roy Thermospectronic Aquamate Spectrometer and converted to phosphorus concentration measured in parts per billion (see Appendix B). Finally, mean total phosphorus concentration was compared to other local lakes to put China Lake in geographic context. Threemile Pond, Webber Pond, and East Pond, are of similar trophic status as China Lake, Great Pond is showing signs of eutrophication and Long Pond, North Basin is an example of a local lake in good condition.

Results and Discussion

In 2005, mean (± SE) surface concentration of phosphorus was 16.5 ± 0.6 ppb, mean mid-depth concentration was 15.3 ± 0.2 ppb, mean bottom concentration was 55.7 ± 13.3 ppb, and mean epicore phosphorus concentration was 17.7 ± 0.8 ppb. Across all three of the comprehensive sites (Sites 1, 2, and 3), surface phosphorus concentration was fairly consistent and ranged from 13.4 to 19.8 ppb. See Figure 12 for site locations. With the exception of the tributary sites (which had substantially higher concentrations; see Appendix C), all of the sites sampled had similar surface total phosphorus concentrations. When sampled on 19-Sep-05, CEAT measured surface phosphorus concentrations, at two of the tributary sites (Sites 10 and 11), and recorded 63.3 ppb, and 43.6 ppb respectively. It is likely that tributary sites had higher phosphorus concentrations because of water turbulence and resulting increased sediment loading.

From the stormwater sampler placed at tributary Sites 9 and 11, CEAT found that the first flush sample measured 25.3 ppb (Site 9) and 16.7 ppb (Site 11), and that the time weighted composite sample measured 46.1 ppb (Site 9) and 20.9 ppb (Site 11). These results indicate a pulse of phosphorus as a result of a storm event. Phosphorus collects on the land throughout the watershed and during a storm, this phosphorus is flushed into the tributaries and carried into the lake. This suggests that much of the phosphorus loading is the result of storm events rather than consistent loading.

The results for phosphorus concentrations in China Lake are consistent with recorded mean epicore total phosphorus for surrounding lakes (Table 5). Mean epicore values were compared

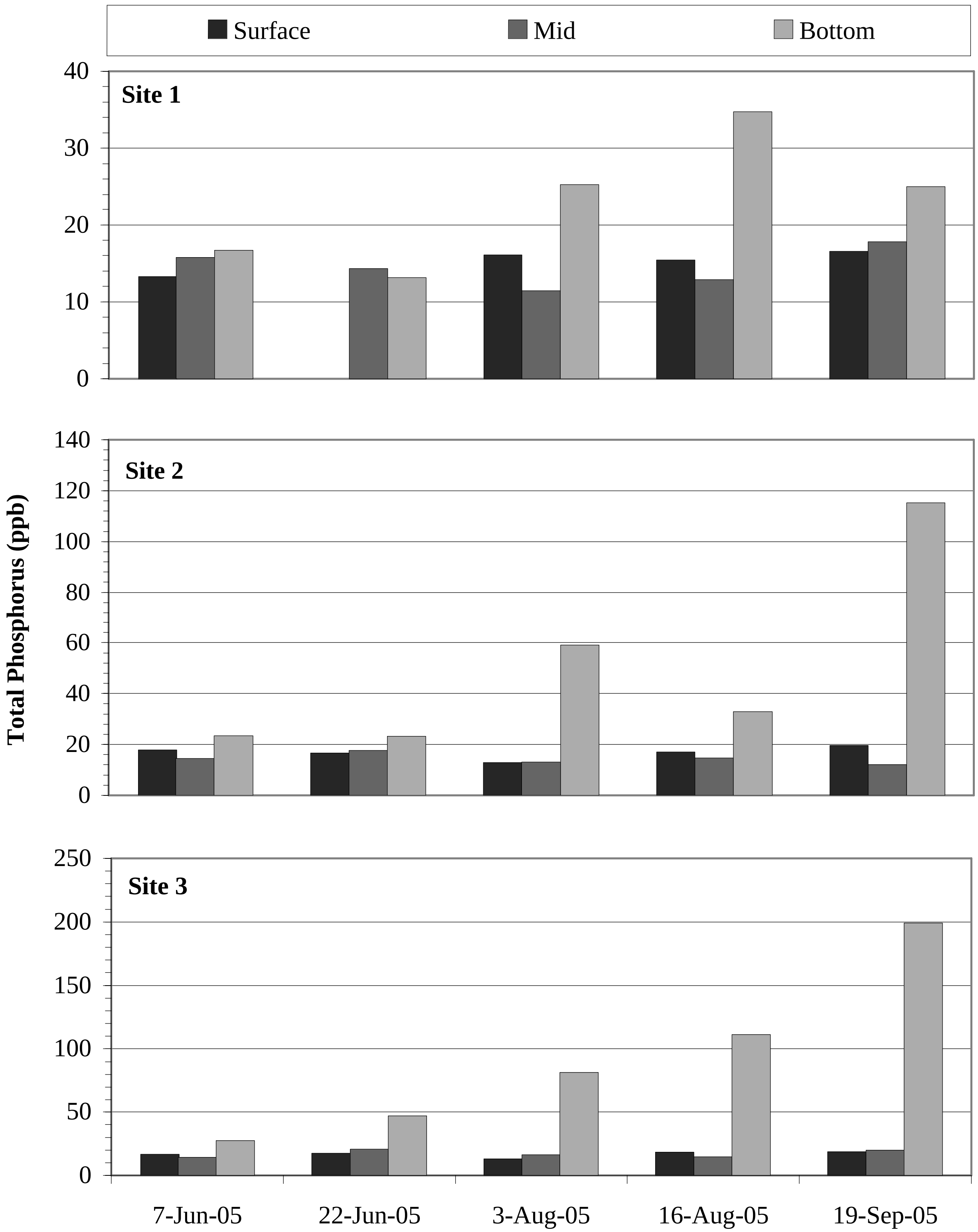

Figure 25. Total phosphorus at varying depths compared among Site 1, 2, and 3 of China Lake as measured by CEAT during summer 2005. Note that the y-axis scale differs for each site. See Figure 12 for site location.

to represent the most comprehensive value of total phosphorus in the top strata of the lakes. Threemile Pond measured 40 ± 2 ppb (CEAT 2004), Webber Pond measured 24.9 ± 2.8 ppb (CEAT 2003), East Pond measured 21.8 ± 0.9 ppb (CEAT 1999), Great Pond measured 14.2 ± 3.5 ppb (CEAT 1999), and Long Pond, North Basin measured 6.3 ± 1.1 ppb (CEAT 1995). The comparative values of mean surface total phosphorus are consistent with the trophic status of the six lakes, with China Lake, Threemile Pond, Webber Pond, and East Pond being the most eutrophic with the highest concentration of total phosphorus, Great Pond having slightly lower, and Long Pond, North Basin having the lowest total phosphorus concentrations.

The peak phosphorus concentration at Site 1 of China Lake occurred at the bottom of the lake on 16-Aug-05 and measured approximately 35 ppb. The peak concentration at Site 2 occurred at the bottom of the lake on 6-Oct-05 and measured approximately 110 ppb. The peak concentration at Site 3 occurred at the bottom of the lake on 19-Sep-05 and measured approximately 200 ppb (Figure 25).Historically, mean surface concentrations of total phosphorus have been measured as part of a monitoring program of China Lake (MDEP 2005c). Phosphorus concentration has been measured twice yearly since 1979 with the exception of 1980 and 1981 when it was measured once, and 1986 when it was not measured. Due to seasonal algal blooms, there is a cyclical nature to the concentration of total phosphorus.

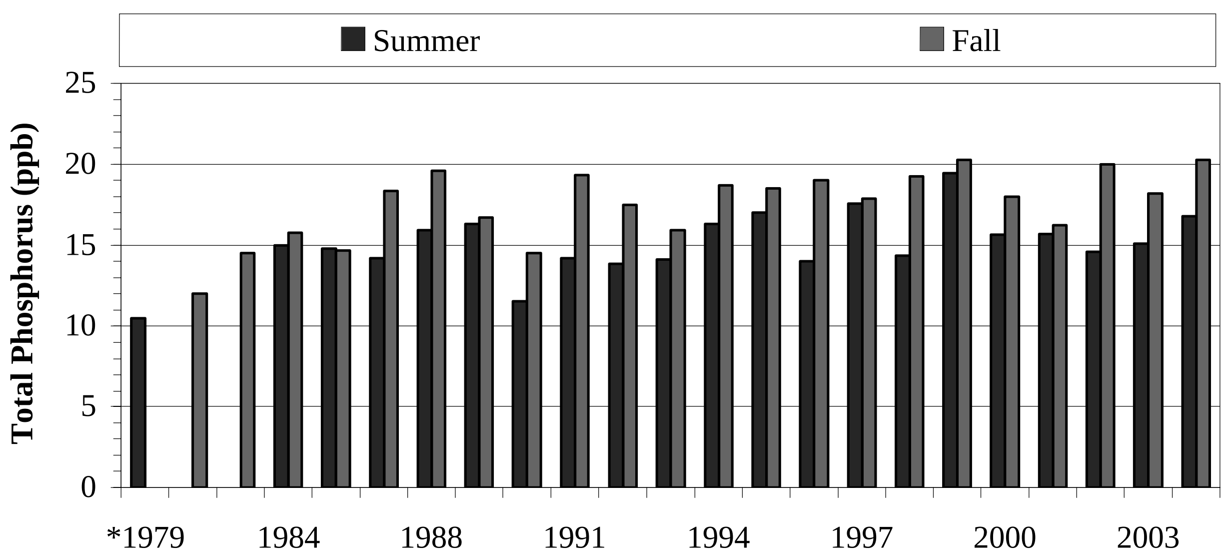

Figure 26. Historic phosphorus data for Site 1 of China Lake (MDEP 2005C). Summer (June-August) and Fall (September-October) 2005 data were collected from 1-8 m deep.

The concentration peaks during the summer and fall blooms, corresponding to spring and fall turnover and remixing of phosphorus from the bottom. For the last 26 years, total phosphorus has ranged in concentration from 10.5 to 20.3 ppb. The fall of 1984 was the first recorded phosphorus level exceeding 15.0 ppb. Since then, fall levels have decreased below 15 ppb only twice (Figure 26). Historically, summer phosphorus levels have been lower than fall levels, but have been slowly increasing over approximately the last ten years (Figure 26).

<u>BIOTIC PARAMETER</u>

Chlorophyll-*a*

Introduction

Chlorophyll-*a* is present in photosynthesizing organisms and is used to transform light energy into organic matter. Measuring chlorophyll-*a* is an indirect determination of the trophic status of freshwater lakes (Chapman 1996) and it is the most widely used aggregate measure of phytoplankton biomass (Effler et al. 1996). The growth of algae is affected by changes in temperature, light, and nutrient levels. Chlorophyll-*a* can fluctuate daily, seasonally, and with depth and weather conditions (Chapman 1996).

Methods

Chlorophyll-*a* was measured by fluorescence using the YSI 650 MDS Sonde, at each of the three comprehensive sites (Sites 1, 2, 3). Fluorescence does not directly measure chlorophyll-*a*, rather it is a relative measure that determines the chlorophyll-*a* at different locations by comparing them with a calibrated 0 standard (E-pure or deionized water was used for this purpose; see Appendix B).

Results and Discussion

In 2005, CEAT measured chlorophyll-*a* concentration profiles on 22-Jun-05, 3-Aug-05, 16-Aug-05, and 19-Sep-05 (Figure 27). In general, concentrations were relatively high at shallow depths, staying high until approximately 7 m. Chlorophyll-*a* is the indirect measurement of algae content. The inability of light to penetrate depths greater than 7 m precludes the existence of photosynthetically active algae at these depths, making the drop in chlorophyll-*a* concentrations directly correlated with the drop in dissolved oxygen (a byproduct of photosynthesis). There was a trend in chlorophyll-*a* concentration toward high values in the late summer. These data and the

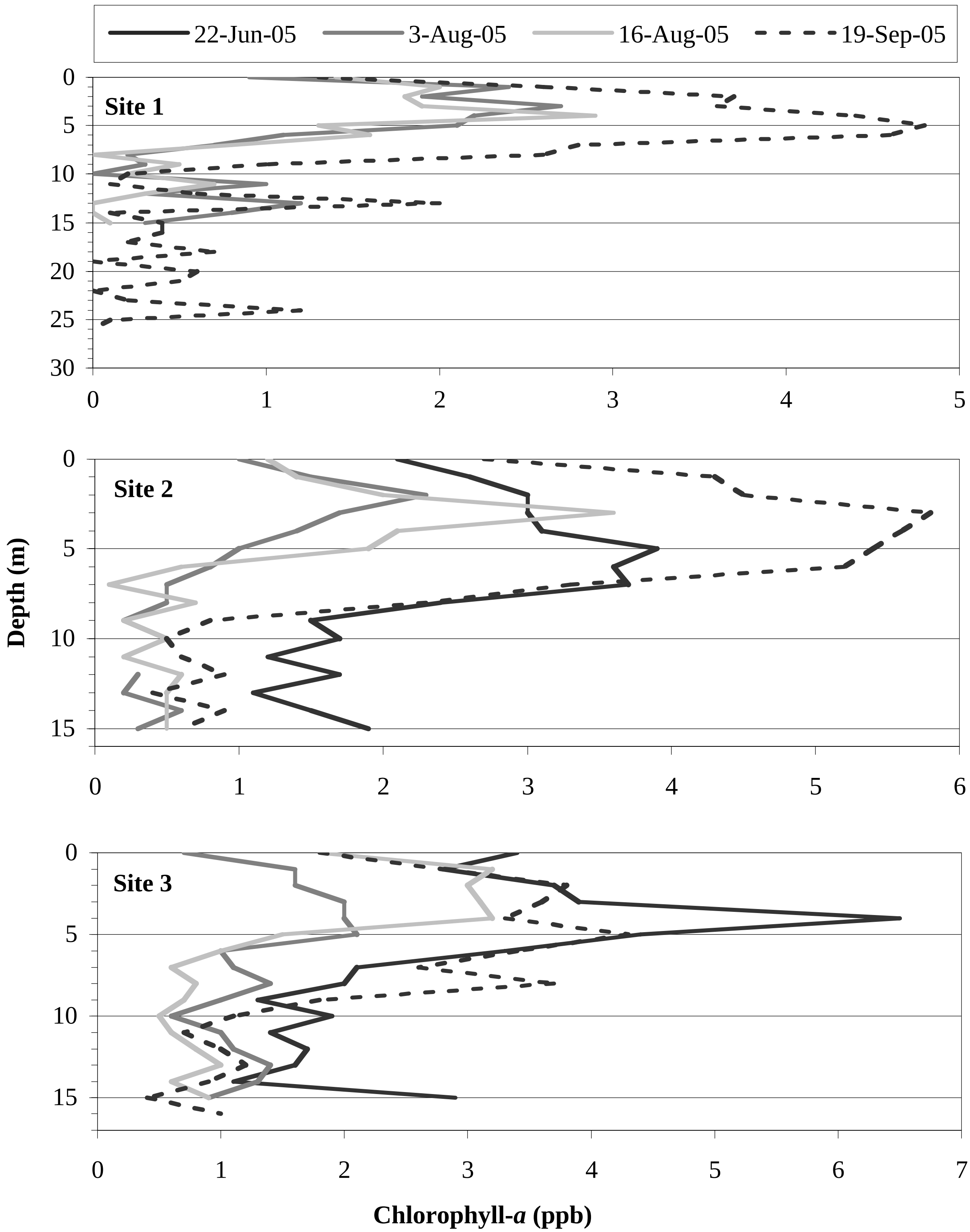

Figure 27. Chlorophyll-*a* profiles at Site 1, 2, and 3 of China Lake during the summer 2005. See Figure 12 for site location.

trends of DO and Secchi disk readings correlate well with the late summer algal bloom in China Lake, confirming the propensity of China Lake to advancing stages of eutrophication. In China Lake, chlorophyll-a concentrations have been measured during the summer in selected years since 1978 (MDEP 2005c). Mean chlorophyll-a concentration was consistently greater than 5 ppb between 1984 and 2003. The highest level was recorded in 1999 and measured 20.4 ppb (Figure 28).

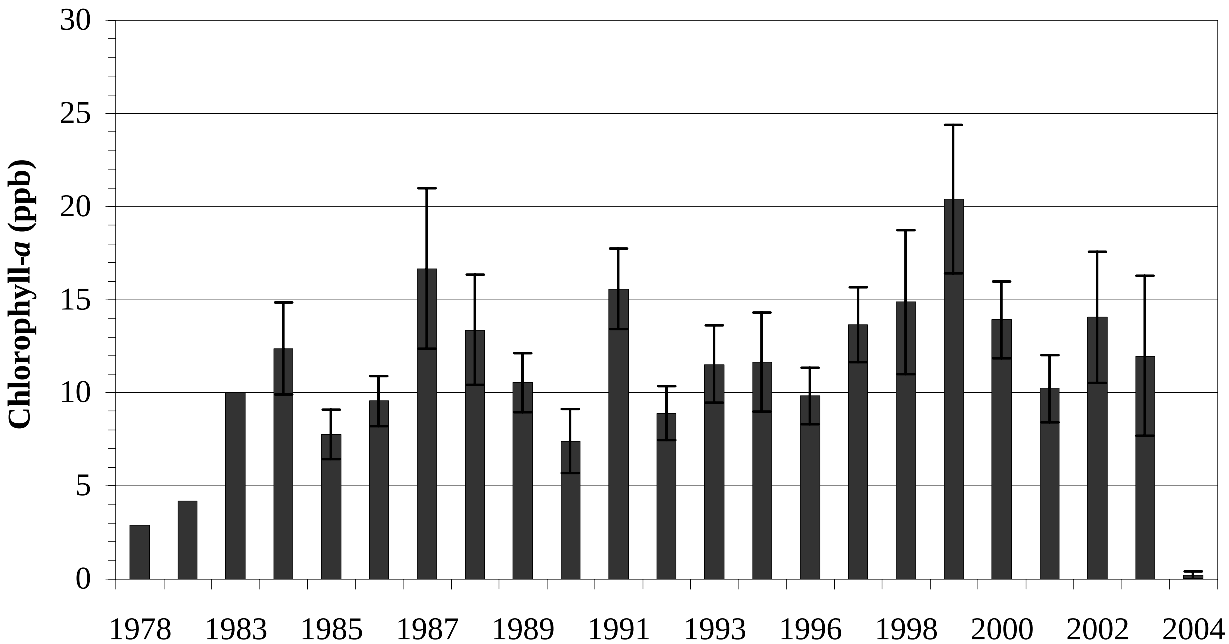

Figure 28. Historic mean (±SE) chlorophyll-*a* levels at Site 1 of China Lake (MDEP 2005c). See Figure 12 for site location.

INTRODUCTION TO GIS TECHNIQUES

A Geographic Information System (GIS) is a computer application designed to work with data referenced by spatial or geographic coordinates. It is both a database system with specific capabilities for spatially-referenced data as well as a set of operations for working with that data (Star and Estes 1990). By linking data to locations, this technology can be used to view and analyze data from a geographic perspective. GIS data can be found at various spatial data clearinghouses on the internet. Information from aerial photographs, Digital Orthophoto Quadrangles, and Global Positioning System (GPS) points obtained in field sampling can also be used in GIS analysis.

GIS data are organized into datasets, or thematic layers. For example, streams, land use, topography, buildings, and soil type represent five different thematic layers. As layers are assigned geographic positions, they can easily be compiled and overlaid on the same map (Figure 29). Each data feature (object on a map) is associated with attributes or information about the feature, such as the name and length of a stream.

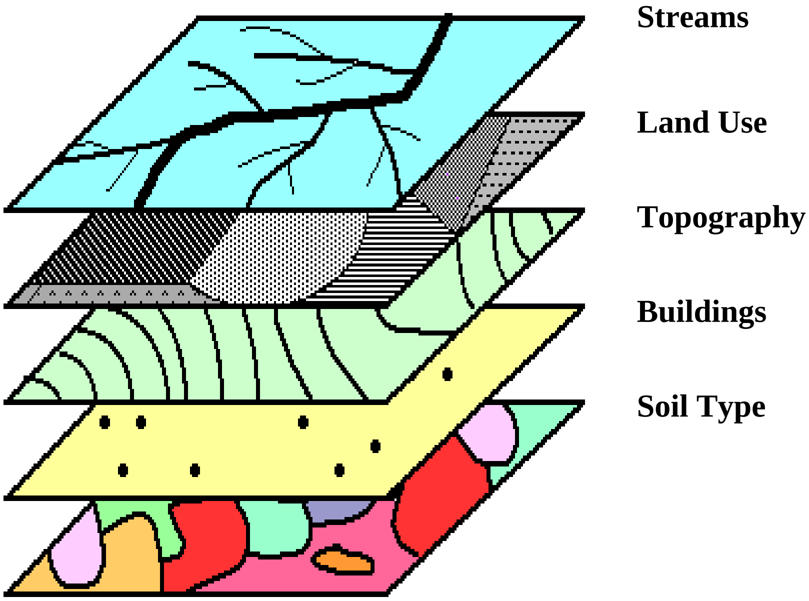

Figure 29. Datasets, or thematic layers, can be overlaid on the same map using GIS. The relationships among layers, such as streams, land use, topography, buildings, and soil type can be represented on a map.

Data overlays produce interactive maps, in which relevant layers may be chosen for display at any one time, expediting data analysis. Interactive maps are a visual representation of the relationships between layers, enabling spatial analyses, such as locating all of the streams within a watershed. Additionally, symbols can be applied to features based on their attributes. For example,

shoreline residential lots can be assigned different colors depending on buffer strip effectiveness. Also, feature patterns and densities can be detected based on their distribution.

Data can be represented on a map by vector data, where each feature has a discrete geographic coordinate. Vector data include points (discrete locations), lines (shape and length of directional features), and polygons (shape enclosing areas with a particular attribute). Raster data, another data type, breaks maps into equally sized cells and assigns each cell spatial and attribute values. Cells with the same value represent the same geographic feature. For example, in a slope map cells with the same color have the same slope.

GIS can also be used to derive new datasets from existing datasets. Various functions can be used to produce models, which take information from datasets, apply analytic functions, and write results into new derived datasets (ESRI 2005). In this way, models represent the interactions of various layers, and enable the analysis of multiple factors in a system. For example, slope, soil type, and land use type interact to influence the erosion potential in a particular area. Models can be used to determine the erosion potential at each geographic location for each combination of factors. Models can also be manipulated to simulate phenomenon and project change.

GIS has many applications to water resources and watershed studies due to the variability of the resources over time and space, and the number of variables that must be evaluated (Lyon 2003). Watershed health can be assessed by overlaying ecosystem components. For example, GIS models have been used to target watershed restoration locations by integrating data on stream channels, watershed characteristics, road density, and vegetation types.

CEAT used ArcGIS® 9 to create maps and models for the analysis of China Lake. Most data were downloaded from the Maine Office of GIS website or obtained through field sampling (MEGIS 2005). CEAT used bathymetry data compiled by the University of Maine at Farmington to produce a bathymetry map. Road quality, buffer strip effectiveness, projected anoxic area, and study site maps, and erosion potential, potential erosion impact, and septic suitability models were made (see GIS Modeling). CEAT also used GIS to identify the locations and total areas of land use types within the watershed.

WATERSHED LAND USE PATTERNS

INTRODUCTION

To complement water quality and development analyses, CEAT surveyed the land use patterns in the China Lake watershed. The survey was undertaken utilizing aerial photographs from 1965 and Digital Orthophoto-Quadrangles (DOQs) from 2003. The land use survey is crucial to develop a complete analysis of watershed health because each land use type has distinct effects of water quality within the lake. Different land use types have unique erosional characteristics and contribute distinctively to the nutrient loading of the receiving body of water (EPA 1990). Land use types characterized by high persistent vegetation (e.g., coniferous, mixed, or deciduous forest) absorb rainfall reducing its erosion potential. Additionally, the roots of persistent vegetation lend structure to underlying soil strata. As a result, areas of these land types have a low erosion potential, adding few nutrients to the receiving body of water. In contrast, areas of low vegetative coverage (e.g., commercial and municipal land) absorb less water and provide less structure to soil strata. Erosion is higher in these land use types, and nutrient additions to the receiving body of water are higher as a result (Dennis 1986).

A survey of land use patterns is beneficial to understanding the historical trends and helpful in predicting for future land use in the China Lake watershed. The greater China Lake area has undergone significant land use changes in the past three centuries, particularly in the twentieth century (see China Lake Characteristics: Historical Perspective: Regional Land Use Trends). Many of these changes are reflected in the China Lake watershed for the 38 year period between 1965 and 2003. Land use changes between 1965 and 2003 clarify the historical context for the current land use and water quality within the China Lake watershed. Additionally, land use changes between 1965 and 2003 may facilitate predictions of future land use patterns.

METHODOLOGY

To conduct a survey of the land use in the China Lake watershed, black and white aerial photographs and color Digital Orthophoto-Quadrangles (DOQs) were imported into GIS. GIS analysis was undertaken utilizing ArcGIS® 9.0 software. ArcGIS® facilitated the digital manipulation of land use types to determine total areas of each land use type within the China Lake watershed for both 1965 and 2003. For both the 1965 and 2003 surveys, ArcGIS®

displayed the aerial photographs or DOQs and facilitated the creation of a layer of digital polygons to represent each land use type. CEAT created digital polygons representing each land use area for both surveys so that the polygons filled the entirety of the watershed. The direct watershed boundary of China Lake and two subsidiary watershed boundaries (Evans Pond and Hunter Brook watersheds) were downloaded from MEGIS and compiled ulitizing ArcGIS® to form the complete China Lake watershed (See GIS : Introduction and Methods).

The land use types used in our survey were based on previous CEAT studies, specifically the Threemile Pond and Togus Pond studies (CEAT 2004, 2005). Modifications were made to previous land use types employed because of seasonal vegetative characteristics within the images surveyed. The majority of the DOQs were digitally photographed in spring 2003, before deciduous trees had developed foliage (MEGIS 2005). Under these constraints, the definitions of the forest types in our surveys focused on foliage patterns and differences as opposed to successional differences as employed in previous CEAT studies. The land use types employed in our surveys were lake, pond, stream, wetlands, coniferous forest, mixed forest, deciduous forest, tree farm, reverting land, cropland, pasture, grassland, commercial/municipal land, cemetery, gravel pit, residential land, power corridor, and roads. A brief description of each land use type is presented below:

Wetlands: Transitional land between terrestrial and aquatic land. Wetlands are characterized by proximity to water, darkened saturated soils, and topological patterns of water drainage.

Coniferous forest: Forest composed of primarily coniferous trees signified by a verdant green closed canopy in the color DOQs.

Deciduous forest: Forest composed of deciduous trees, demarcated by visible defoliated branches that would otherwise form a closed canopy.

Mixed forest: Forest composed of both coniferous and deciduous trees, distinguished by a mix of verdant and defoliated canopy cover.

Tree Farm: Forest, typically coniferous, characterized by highly ordered rows originating from planting techniques.

Reverting land: Land of forest-like characteristics, without a closed canopy, generally the product of early succession and reversion of fallow fields. Reverting land generally maintains the basic shape of previous human use.

Cropland: Agricultural land exhibiting ordered rows characteristic of planting techniques for corn and similar crops.

Pasture: Agricultural land otherwise cleared except for grasses, but without ordered rows. Characterized by typical quadrilateral shape and often associated with residential and road land types.

Grassland: Similar to pasture, but with fewer characteristics of agricultural use and greater homogeneity of vegetative cover. Characteristically associated with residential and road land types, often abutting residential developments as a lawn.

Commercial/Municipal land: 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 was designated to include the smallest land area that encompassed all of the buildings, parking areas and other areas of identifiable impervious surfaces. Municipal land was characterized by a large central structure, parking areas and recreational areas. Schools were demarcated to include only the impervious land; recreational fields were marked as grassland.

Cemetery: Land characterized by ordered headstones and park-like landscaping.

Gravel pit: Land characterized by peaks and valleys of sand and gravel. Often the sand and gravel from these areas is used on the roadways in the winter.

Residential land: Land characterized by presence of a residence. Residential land was demarcated as the smallest area containing the central residence and any outbuildings. Typically this area would include a portion of lawn and driveway around the residence.

Power corridor: Land east of China Lake running nearly the length of the watershed previously cleared, but now covered by shrubs and other low lying vegetation.

The roads of China Lake were not surveyed using GIS analysis due to the inability of DOQs to display the full road area. The canopy of the coniferous and mixed forest obscured the area of smaller camp roads. GIS analysis in these circumstances was not the most accurate method to measure the area of the roads. Unable to determine road area from the 2003 DOQs, current road area was used in the study, assuming that the area of roads has changed very little since 2003. Substituting current road area for the 2003 road area, the possibility of road

construction presented a source of error. However, the DOQs were produced recently (approximately 2½ years earlier), reducing the likelihood of error due to road construction. The current road area within the watershed was measured in a comprehensive field survey, measuring length and average width of every road to calculate area (see Watershed: Road Survey). Current road area was then added to the 2003 survey. To allow for the addition of the current road within the watershed, an area of the same size was subtracted proportionately from each land use type. Subtracting the representative area proportionately from each land use type ameliorated the effects of adding the current road area, maintaining a constant watershed area. For the 1965 land use survey, road area was not included. Similar to the 2003 survey, road area could not be measured using ArcGIS®. A field survey to estimate road area for 1965 was impossible because present roads are different (construction, size) from roads in 1965.

In the land use survey of 1965, 16 aerial photographs were obtained from the Colby Environmental Assessment Center (CEAC) and two additional photographs of the northwest and eastern extremities of the watershed were obtained from the Kennebec County Farm Service Agency Service Center Office. The aerial photographs were originally taken on 6-May-65 by the United States Department of Agriculture (USDA). The photographs were taken at a scale of 1:20,000 and printed in large format (approximately 60 cm x 60 cm). Each photograph was scanned, arranged, and combined in Adobe Photoshop CS® to form a single composite digital image. The resulting image was then imported into ArcGIS®. Once imported into ArcGIS®, it was necessary to assign coordinate values to the composite image. In contrast to DOQs, neither the aerial photographs nor the composite image were pre-referenced by the easting and northing coordinate system of ArcGIS®. The coordinate system was applied to the 1965 composite image through a system of georeferencing, whereby physical features within the image were matched to corresponding features in a pre-existing layer. In our survey, the composite image was matched to the georeferenced roads layer of the China Lake watershed downloaded from MEGIS. To exclude error of road construction and development between 1965 and 2005, only prominent intersections of well established roads were utilized to georeference to the composite image. The watershed boundary was then overlaid in ArcGIS®, land use areas were identified, polygons drawn around each land use area (filling the watershed) and total areas for each land use type calculated.

Some of the land use types could not be identified in the 1965 aerial photographs. This inability was either due to lack of resolution or color, inconsistent contrast, or inadequacy of historical information. Such was the case for the forest land use types (coniferous forest, mixed forest and deciduous forest) where poor resolution and contrast in addition to lack of color obscured differences between the forest land use types in the 1965 black and white aerial photographs. Indistinguishable in the 1965 photographs, all three forest land use types were grouped together and designated as forest for the 1965 land use analysis.

In the 2003 land use survey, 14 DOQs were downloaded from MEGIS (six of 1 ft resolution, six of 2 ft resolution and two of 1 m resolution). Unlike the aerial photographs, the GIS coordinate system is already integrated into DOQs and could be imported directly into ArcGIS® without georeferencing. Once imported, the watershed boundary was overlaid, land use areas identified, polygons drawn around each land use area (filling the watershed) and total areas for each land use type calculated. Of note, identifications of land use types within the 2003 survey were aided by physical surveys, known as groundtruthing. Groundtruthing consisted of traveling to an area of uncertain land use type and visually confirming the land use type for the area. The possibility of change between the date of DOQ and groundtruthing presents a potential source of error. However, the proximity of the DOQs and groundtruthing dates indicates that the only land use changes within the brief period would have been dramatic anthropocentric changes, and not succession. The effects of succession, which is likely occurring in selected land use types, would be slight given the time scale. In all of our groundtruthing surveys, we found no land types that could not be determined because of recent human development.

Conducting a land use survey presents many possible sources of error. Identifying land use types correctly from aerial photographs and DOQs can be difficult due to poor resolution, contrast, objects obscuring the view, breaks in photographs, or seasonal vegetative changes. Many identification problems were specific to the 1965 survey where resolution of the aerial photographs was inferior to the DOQs, and also where the process of compilation and georeferencing created artifacts in the compiled image. To minimize these errors, members of CEAT employed several techniques. To combat the issues of resolution and artifacts in the 1965 survey photographs, thorough care was taken in the compilation and georeferencing process to minimize artifacts and errors and produce the most accurate possible image to survey. Secondly, members of CEAT worked cooperatively in both surveys, cross-referencing the identification of

other members to insure consistency and accuracy. Additionally for the 2003 survey, groundtruthing methods were employed to obtain greater accuracy. For the 1965 survey, where groundtruthing was impossible, members of CEAT had to rely entirely on cross-referencing strategies for correct land use identification. However, through the experience of groundtruthing for the 2003 survey, the members of CEAT gained competence in land use identification and felt confident in the land use identifications of the 1965 survey.

Finalizing both land use surveys, many of the land use types were complied into general land use groups. Combining land use types into broader groups simplifies the final watershed maps making them easier to interpret and understand. Combining land use types also facilitates comparison between the surveys, creating similar land use groupings for both surveys. Land use types were grouped together based on similarity of vegetative and erosional characteristics so that the larger groups maintained characteristics of the constituent specific land use types. In the 2003 survey, coniferous forest, mixed forest, deciduous forest, and tree farm were joined to create a forest land type to match the forest land type of the 1965 survey. Similarly, other land use types were combined for both surveys: cropland, pasture, grassland, and cemetery were grouped together as agriculture; reverting land and power corridor were grouped together as reverting; school and commercial were grouped together as commercial/municipal.

After grouping into broad and comparable land types, individual polygons were merged to create several large polygons for each land type for both the 1965 and 2003 land use maps. Merging polygons reinforces the grouping of specific land use types to general land types and also eliminates artifacts of digitizing and superfluous borders between polygons of the same land use type. Similarly, land use area totals for each new group were recalculated for both the 1965 and 2003 surveys.

Additionally, CEAT created a land use change map employing the maps from both surveys. Rather than mapping all the possible changes between land use types, the types were grouped into two broad classes for both surveys, based upon similarity of erosion and phosphorus loading potential. The two land use classes were developed and undeveloped land. Developed land, which includes residential, commercial/municipal, and agricultural land, has a high erosion and phosphorus loading potential. Undeveloped land, which includes forest, wetlands and reverting land, has a low erosion and phosphorus loading potential. Maps from 1965 and 2003 surveys were overlaid in ArcGIS®, and changes in land use classes were generated as a separate layer

using the raster generator and spatial analyst functions of ArcGIS®. Using the new layer, changes in land use classes were designated positive, neutral, or negative their effect on phosphorus loading potential. A positive land use change was consisted of a change from developed to undeveloped land. A neutral land use change consisted of a land use type change within the developed and undeveloped land use classes. A negative land use change consisted of a change from undeveloped to developed land.

COMPARISON OF 1965 AND 2003 LAND USE PATTERNS

Watershed Description

Land use maps were created for the 1965 (Figure 30) and 2003 (Figure 31) surveys. A map was also generated to represent the changes that took place from 1965 to 2003 (Figure 32). Pie charts showing the percents of each land use type were made as well (Figure 33).

China Lake is very important in Kennebec County (see China Lake Characteristics: Watershed Description). The lake itself is 1,604.2 ha (3,964.0 acres) and the total area of the streams and ponds in the watershed is 51.7 ha (127.7 acres). All the water bodies together make up 19.4% of the total watershed area.

Wetlands

Introduction

Wetlands are areas that serve as a transition between terrestrial and aquatic ecosystems. They are usually characterized as wet areas that are rich in minerals and organic materials, inhabited by plants that are adapted to living in a damp environment (see Background: Wetlands). Some examples of wetlands include bogs, marshes, and swamps. Wetlands can either be sources or sinks for nutrients, acting as an access point or absorbing nutrients before they enter the lake depending on timing. Wetland areas can act as buffers, and are extremely important in keeping unwanted nutrients out of lakes and streams. Wetland plants take up many of the nutrients that would otherwise run into the lake (see Background: Wetlands).

When examining the DOQs from 2003 and the aerial photographs from 1965, wetlands were identified by finding areas of water, and looking at the regions surrounding them. If the land running along the streams appeared to be a different shade when compared to the forested areas, it usually indicated that there were more grasses and shrubs than trees, and so they were

identified as wetlands. Very often there would be a row of large, coniferous trees lining the edge of the wetland areas.

Results and Discussion

In 1965, the wetlands covered an area of 494.4 ha (1221.7 acres), which made up 7.2% of the land area in the watershed. In 2003, the wetlands covered an area of 655.2 ha (1,619.0 acres), which made up 9.5% of the land area (Table 6). Flooding, which occurred when the dams were put in, was probably the reason for the increase in wetland area. This increase in total wetland area may be beneficial for the water quality in China Lake, because there is more land buffering nutrients from entering into the water through runoff, which helps decrease the occurrence of algal blooms. On the other hand, the Friends of China Lake argue that the rise in water level may be the cause of the algal blooms (see China Lake Characteristics: Historical Perspective).

Table 6. Total percents of each land use category (bold) and the breakdown within each category (all other data) as described in the text (see Watershed Land Use Patterns: Comparison of 1965 and 2003).

Land Use Type	Percent in 1965 (%)	Percent in 2003 (%)
Open Land	**21.3**	**14.1**
Cemetery	N/A	0.05
Cropland	3.0	2.0
Grassland	1.0	1.9
Pasture	17.4	10.1
Commercial/Municipal	**0.4**	**1.9**
Commercial	0.3	1.5
Gravel Pit	0.07	0.2
School	0.02	0.3
Forest	**59.5**	**61.9**
Coniferous Forest	N/A	14.4
Deciduous Forest	N/A	6.3
Mixed Forest	N/A	41.1
Tree Farm	N/A	0.05
Residential	**2.3**	**8.1**
Reverting	**9.3**	**3.3**
Power Corridor	0.7	0.6
Reverting	8.6	2.7
Roads	**N/A**	**1.1**
Wetlands	**7.2**	**9.5**

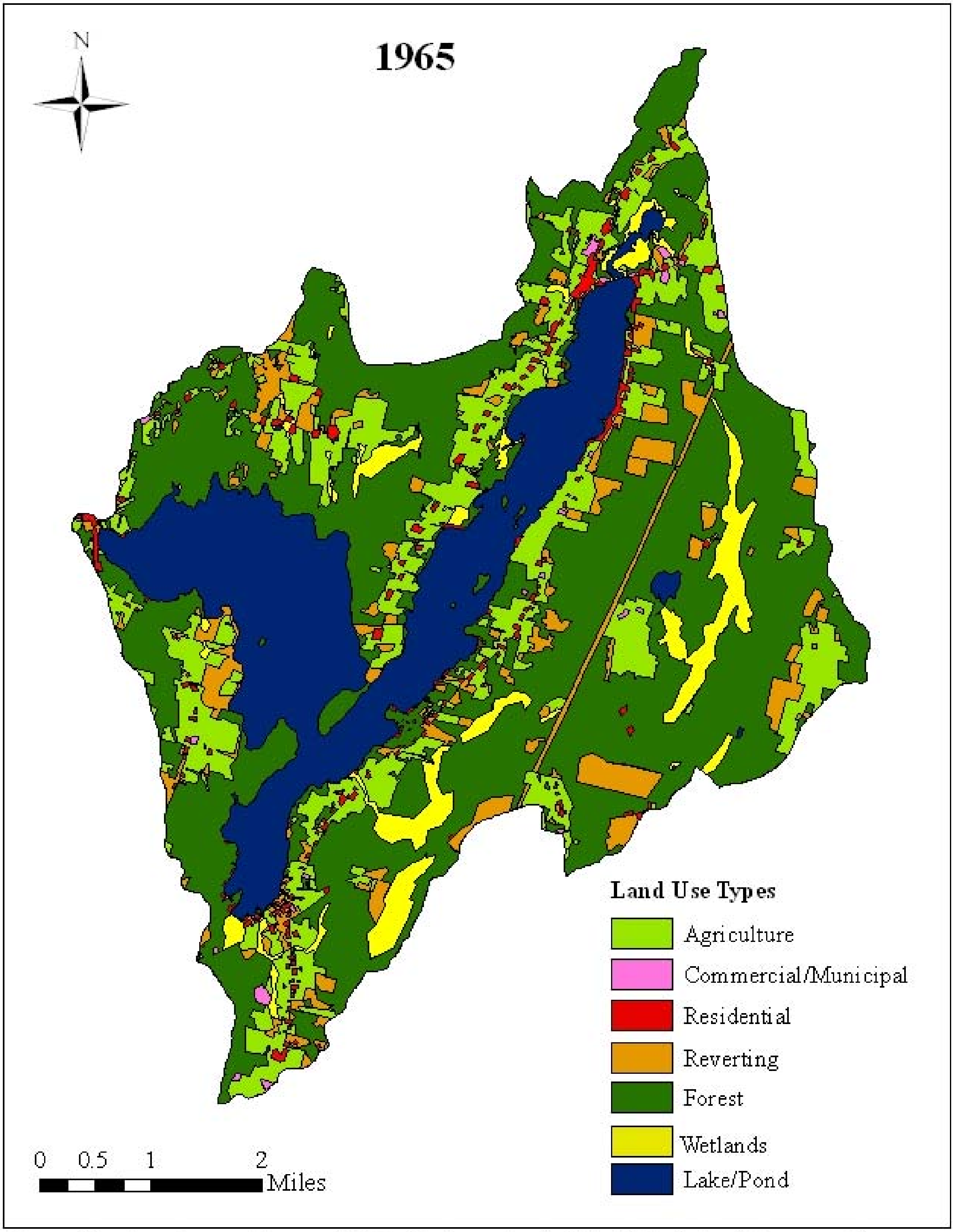

Figure 30. Land use patterns of China Lake watershed in 1965 derived from aerial photographs from the Colby Environmental Assessment Center and the United States Department of Agriculture.

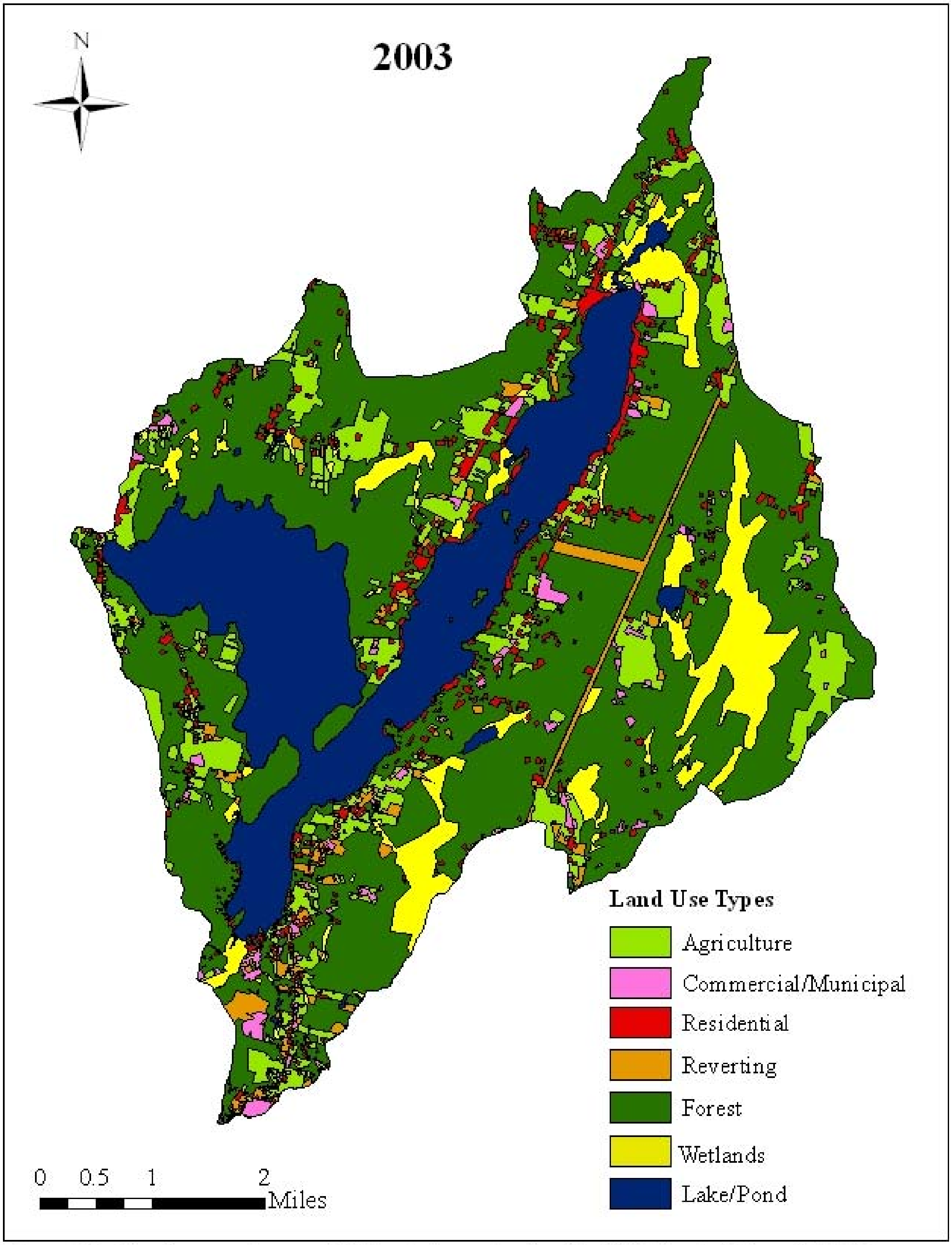

Figure 31. Land use patterns of China Lake watershed in 2003 derived from Digital Orthophoto-Quadrangles downloaded from the Maine Office of Geographical Information Systems.

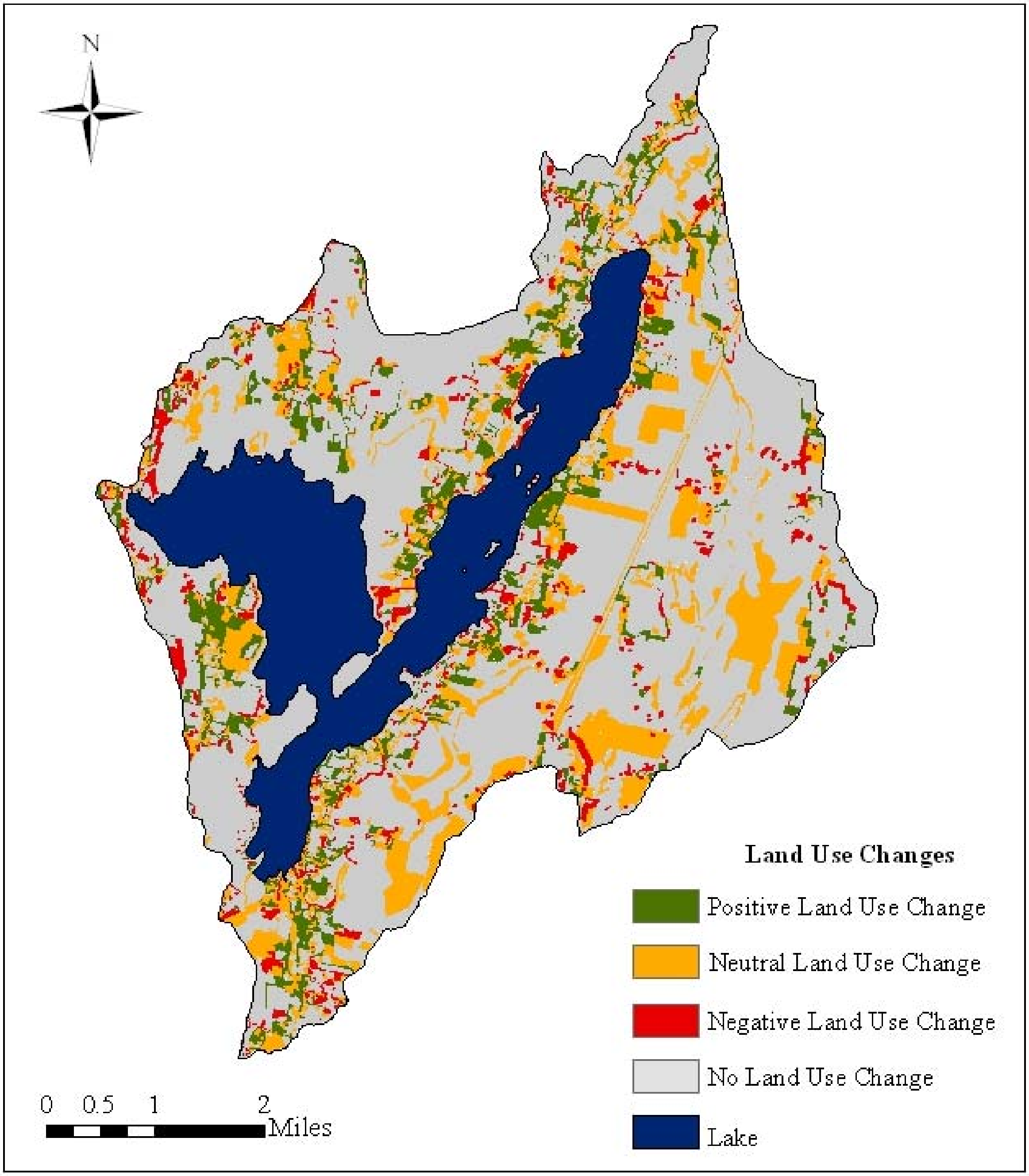

Figure 32. Areas of land use change in the China Lake watershed from 1965 to 2003. Positive land use change, which may decrease phoshorus loading, is defined as the change from developed land including residential, commericial/municipal, and agricultural to undeveloped land, including forest, wetlands, and reverting land. Negative land use change, which may increase phosphorus loading, is defined as undeveloped land changing to developed land. Neutral land use change, which causes little if any change in phosphorus loading is defined as a change of land use type within either the broader developed or undeveloped category.

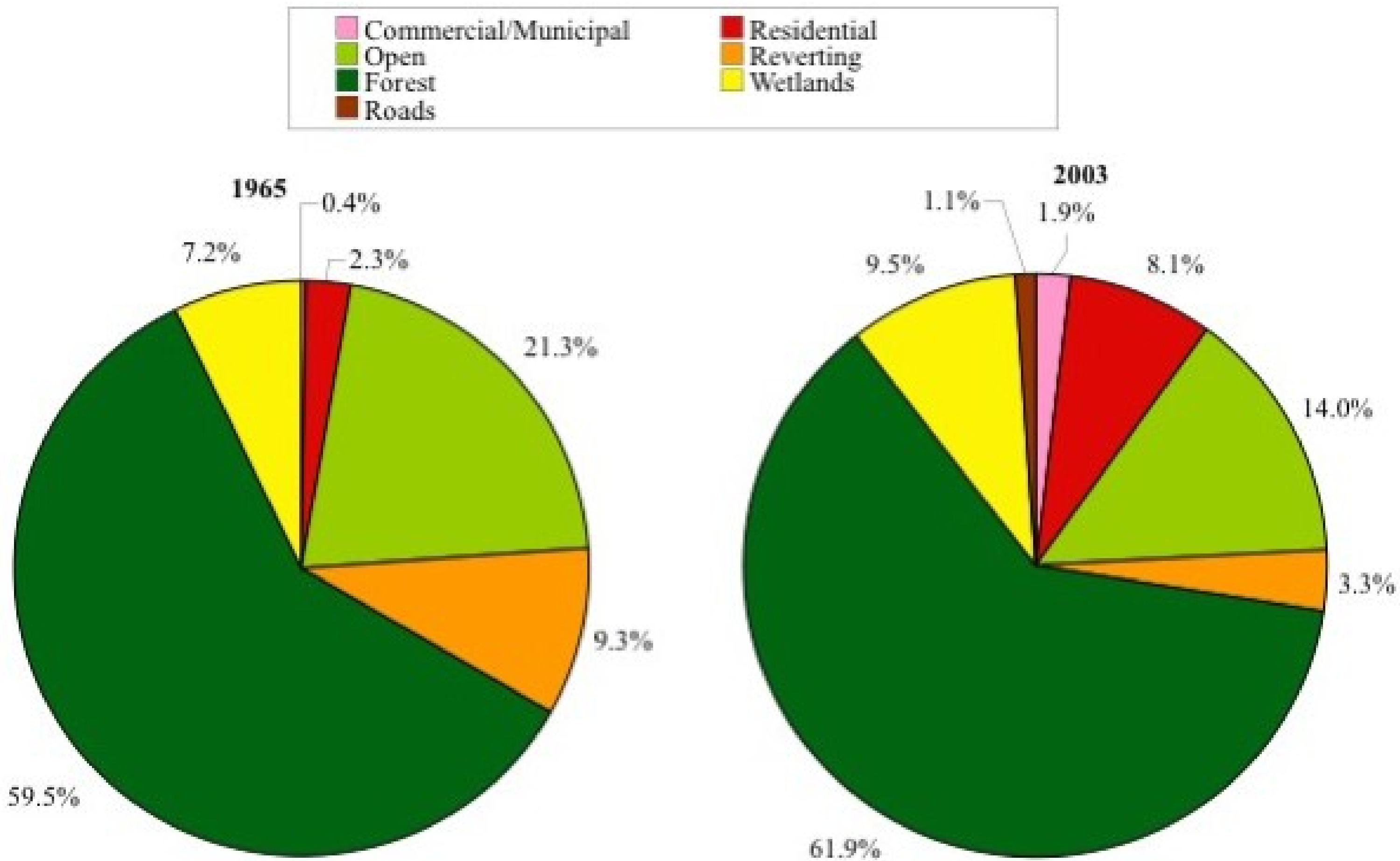

Figure 33. Percent land cover of China Lake watershed for 1965 and 2003 as determined using aerial photographs obtained from the Colby Environmental Assessment Center and the United States Department of Agriculture and Digital Orthophoto-Quadrangles obtained from the Maine Office of Geographic Information Systems, respectively.

Forest

Introduction

The forested areas in the watershed help to absorb nutrients into the ground water and can lessen or prevent runoff and erosion. The roots of trees and shrubs take up water and nutrients for their own use, while binding the soil in place so that excess nutrients are not carried into the lake when it rains. Forests with extensive canopies prevent some of the rainwater from reaching the ground, and diminish the amount of water that needs to be absorbed into the soil and roots. The canopy also weakens the force with which the rain strikes the soil, causing less erosion (see Background: Forestry).

The forest category is divided into coniferous forest, deciduous forest, mixed forest, and tree farms. In the 2003 DOQs, the different forest types were very easy to distinguish, because the images were taken in the spring before the leaves had grown back on the deciduous trees (see Methodology).

In the 1965 aerial photographs, the different types of forest were often much more difficult to distinguish because of the darker color and poorer resolution (see Methodology). All forested land was labeled as 'forest', since it was still possible to identify it as such. It was not, however, broken down within the different forest types.

Results and Discussion

In 1965, there were 4,097.1 ha (10,124.1 acres) of forest, which made up 59.5% of the land cover. In 2003, the total forest covered 4,256.0 ha (10,516.7 acres), which made up 61.9% of the land. Individually, coniferous forest was 990.6 ha (2,447.7 acres), which was 14.4% of the land (Table 6). Deciduous forest was 435.1 ha (1,075.1 acres), which covered 6.3% of the land. The largest category of forest was mixed forest, at 2826.7 ha (6984.8 acres), which made up 41.1% of the land. Tree farm was the smallest category, which covering only 3.7 ha (9.2 acres), making up 0.05% of the land.

There was an increase in forest cover from 1965 to 2003, which was probably because much of the reverting land had time to grow into mature forest. This increase is a favorable change because in a mature forest there are more roots to take up nutrients and to prevent runoff and erosion. Hopefully, this trend will continue, ensuring that even more nutrients are absorbed from the groundwater and the soil is held more tightly in place.

Reverting Land

Introduction

Reverting land is defined as an area that was once agricultural, but now lies fallow and trees are beginning to grow back. There are shrubs and small trees that control runoff and erosion. However, reverting land often has residual herbicides, pesticides, fertilizers, and manure that can get into the groundwater or can be carried into the lake during storms. Typically, reverting land is a sign that agriculture is diminishing, since it is unlikely that an area will be cleared again once the owner has decided to stop farming that land.

On the 1965 and 2003 maps, reverting land is characterized by a plot of land, usually near agricultural areas, that still shows some agricultural characteristics (see Agriculture), but also has some shrubs and trees growing on it. Often, the sections of reverting land will be located between agricultural land and forest. The power corridor on the east side of the watershed was also included in the reverting land grouping, because it was cleared in order to put in power lines, but has now begun to grow back. This area will most likely be reverting forever, as it is maintained to minimize vegetative growth so as not to interfere with the power lines.

Results and Discussion

In 1965, the total of reverting land was 638.4 ha (1,577.4 acres), which made up 9.3% of the total land cover. The reverting subcategory covered 593.0 ha (1,465.2 acres), which made up 8.6% of the land cover. The power corridor was 45.4 ha (112.2 acres), which made up 0.7% of land. In the 2003 map, the total amount of reverting land covered only 228.5 ha (564.6 acres), which made up 3.3% of the land. The reverting subcategory was 187.5 ha (463.2 acres), which made up 2.7% of the land cover. The power corridor was 41.0 ha (101.4 acres), which made up 0.6% land cover (Table 6).

When the land was left fallow in 1965, it was probably allowed to grow into forest, but more recently, some of the reverting land may have been converted into commercial or residential areas. The decrease in reverting land is advantageous to the lake. It means that the most of the land that was once identified as reverting has now become forested over the 38 years. The higher density of trees helps control erosion and runoff while absorbing many of the nutrients that were left in the ground from the fertilizers and manure, keeping many harmful substances out of the lake.

Open Land

Introduction

Open land is defined as pasture, cropland, or grassland. These three major land use types are grouped together because of similar impact on nutrient loading into the lake.

Agricultural land exhibiting ordered crop rows was identified as cropland. Owners normally till and fertilize cropland on a regular basis, increasing the probability that available nutrients could wash into adjacent lakes or streams. Cropland may also be treated with pesticides, contributing toxic chemicals into the groundwater.

Cleared land covered with grasses, but without shrubs, trees, or crop rows, characterizes pasture land. Often, pasture land abuts cropland or trees line either side. Farmers do not normally fertilize pasture land, but feces of large grazing animals, such as cows and horses, contribute to the nutrient levels in the soil. Nutrients from improperly maintained pastures close to the shoreline can contribute negatively to lake quality via runoff flowing into the lake.

Similar in makeup to pasture, grassland has fewer agricultural uses and is primarily found adjacent to residential, commercial, and farming areas. Grassland may be mowed regularly, as in the case of a residential lawn; or annually, in the case of a meadow. Regular mowing will reduce its ability to slow down precipitation leading to runoff and erosion. It may or may not be fertilized regularly. Owners who fertilize their pastures, grassland, or cropland must take caution to not over fertilize or fertilize too late in the season. Either of these practices can result in excess nutrients washing into streams or the lake.

Several cemeteries were located while digitizing the 2003 watershed map. While this land area is not of a significant size, it was defined and grouped with agricultural land because it is a plot of open land with a similar inability to slow down precipitation and prevent runoff and erosion. It may be assumed that the same cemeteries existed in 1965, however poor photo resolution prevented identification of cemeteries on the 1965 map.

The above characteristics made distinguishing among cropland, pasture, grassland, and cemeteries easy with the 2003 map. Shading differences and an overall lower resolution per square foot made the characteristics less clear in the 1965 aerial photos.

Results and Discussion

In 1965, open land represented 1,466.0 ha (3,622.5 acres), which made up 21.3% of the total land area of the China Lake watershed. In 2003, agricultural land represented 965.7 ha (2,386.3 acres), which made up 14.1% of the land area (Table 6). Cropland comprised 204.3 ha (504.8 acres), which made up 3.0% of the land area in 1965, and 138.8 ha (343.1 acres), which made up 2.0% of the land area in 2003. Grassland comprised 66.9 ha (165.3 acres), which made up 1.0% of the land area in 1965, and 130.8 ha (323.2 acres), which made up 1.9% of the total land area in 2003. Grassland is the only open land subcategory to increase over the 38 years. An increase in the cost of farming, land previously used for crops or grazing may have been converted to meadows and lawns. An increase in the amount of development also correlates with the increase of grassland as commercial and residential land correlates closely with maintained lawns. Pasture comprised 1,194.8 ha (2,952.4 acres), which made up 17.4% of the land area in 1965 and decreased to 692.7 ha (1,711.8 acres), which made up 10.1% of land cover in 2003. Due to resolution differences, cemeteries were only found in the 2003 map and comprised 3.4 ha (8.3 acres), which made up 0.1% of land cover.

The 7.3% decline in open land is a small change within the entire watershed, but is over one third of the total agricultural area in 1965. This change over the 38 years has the ability to have both positive and negative effects on lake quality depending on relative location within the watershed. While there was a significant mix of positive and negative land use changes throughout the watershed, land use change along the shoreline of the lake was slightly more beneficial than detrimental to lake quality. These changes were primarily in areas along the shoreline where much of the land use change was from open land to reverting and forested land. Land use change further from the shoreline but within the watershed boundaries appears to be more neutral to detrimental than beneficial to lake water quality from the perspective of both erosion potential and nutrient loading. Many plots of open land along the perimeter of the watershed were converted into residential or commercial area and will result in increased runoff and erosion potentials (Figure 32).

Commercial and Municipal

Introduction

Commercial/Municipal land areas, characterized by buildings with large areas of impervious surfaces, generally have little or no ability to buffer rain hitting the ground, creating potentially destructive runoff and erosion. Commercial areas include businesses, municipal buildings, schools, churches, and gravel pits. All of these areas may potentially increase the amount of toxic chemicals, nutrients, and wastewater running into the surrounding soils and water. Gravel pits allow excess penetration into the water table due to the high porosity of gravel, which can lead to high levels of pollution and nutrients entering the groundwater. CEAT identified commercial areas by the presence of large impervious surfaces, such as parking areas and sizable buildings, and their proximity to roads and highly developed areas. Light brown color of land and an inconsistent, somewhat circular, pattern of land indicated a gravel pit, frequently located in somewhat isolated areas. Schools were identified by the surrounding recreational areas, fields, and parking areas. Municipal buildings and churches were not able to be individually identified consistently using the DOQs or aerial photographs and were labeled commercial/municipal.

Results and Discussion

In 1965, commercial/municipal land comprised 0.3% of the total land area in the China Lake watershed. This percentage corresponds to 27.3 ha (67.5 acres), and increased by more than a factor of five by 2003 to cover 130.2 ha (321.8 acres), which made up 1.9% of the land area within the watershed (Table 6). Commercial/Municipal land is broken up into several subcategories; commercial, school, and gravel pit. In 1965, commercial land made up 21.0 ha (51.8 acres) of the land cover, schools made up 1.5 ha (3.7 acres) of land cover, and gravel pits made up 4.9 ha (12.0 acres) of the land cover. All of these subcategories of commercial land increased by 2003; at this point commercial land represented 101.8 ha (251.7 acres), schools represented 17.2 ha (42.4 acres), and gravel pits represented 11.2 ha (27.7 acres) of the total watershed land cover.

Residential

Introduction

Residential land area in 2005 was determined using housecounts from the CEAT shoreline and road surveys (see Watershed Development: Residential Survey). Each house categorized as shoreline was allotted half an acre of land. All other houses in the watershed were allotted one acre (Bouchard, pers. comm.). This method is more accurate then using the DOQs as many residences are in wooded areas and can not accurately be located. Residential land in 1965 was determined by using the aerial photographs and ArcGIS®. Due to manicured lawns and impervious driveways and rooftops, residential land exhibits a high rate of runoff. Runoff from residential land can be harmful to the lake quality, if it is relatively close to the shoreline, or along a stream that flows into the lake. CEAT distinguished residential land from commercial/municipal land by relative impervious surface area (parking lot size), building size, and groundtruthing.

Results and Discussion

In 1965, residential land accounted for 158.5 ha (391.8 acres), which made up 2.3% of the total land cover in the watershed. In 2005 this area increased to 343.2 ha (848.1 acres), which made up 5.0% of the total watershed land cover (Table 6). Many people working in Augusta and Waterville have moved to China to have affordable housing within a reasonable commute, causing the increase in residential land. The increase in residential property in China and Vassalboro is a trend that will likely continue into the future because of economic growth in both Augusta and Waterville (MSHA 1999).

Roads

Introduction

The roads within the China Lake watershed were downloaded from MEGIS and analyzed for the 2003 map; road data could not be obtained from the 1965 aerial photographs. The total area for the 2003 map was calculated by measuring the roads during a road survey (see Watershed Development: Road Survey). While this survey was conducted in 2005, it was assumed that the roads and their respective areas did not change significantly over those two

years. The original 2003 digitized map had to be modified to include the road area proportionate to the percentages of land use. Roads play an important role in lake health (Davis et al. 1978). Their impervious nature can directly affect runoff qualities and quantities, by channeling water toward or away from the lake. This allows a small land use area to contribute disproportionately to phosphorus loading in a water system.

Results and Discussion

In 2005, roads covered an area of 77.8 ha (192.2 acres), which constituted 1.1% of the watershed land cover (Table 6). While this may not be a large percentage of the watershed, roads, especially camp roads, contribute a significant amount of pollution and nutrients into the lake (see Background: Roads). This percentage is similar to percentages found in previous reports of nearby lakes (1.4% for Togus Pond and 0.8% for Great Pond) and may be due to the rural nature of the Kennebec County area (CEAT 1999, 2005). Depending on the quality of the roads, 1.1% of watershed land cover may contribute a significant amount of pollution into nearby groundwater (see Watershed Development: Road Survey).

GIS MODELING

BATHYMETRY

Introduction

A bathymetry map shows the shape and depth of a lake basin, with darker colors representing deeper areas and lighter colors showing areas of shallower water. Bathymetry maps for China Lake, used in several areas of this study, have been created from data gathered by Professor Dan Buckley of the University of Maine at Farmington (UMF) using ArcGIS® 9. During the summer, China Lake becomes stratified at approximately eight meters (26.2 ft) beneath the surface (see Water Quality); a bathymetry map was created and modified to display this region and its area was calculated. A bathymetry map was also used to measure the surface area of the lake bottom and determine the surface area of sediments that could add phosphorus to the water column. Invasive plant species, such as Variable-Leaf Milfoil, can only live in shallow areas of the lake, so a bathymetry map was created to display the parts of China Lake that were more susceptible to invasive species.

Methods

Many depth measurements were needed from various parts of the lake to create a map of the basin of China Lake. These depth measurements were associated with GPS readings, providing the precise latitude and longitude that ArcGIS® used to model the lake bottom. Two simple bathymetry maps were acquired from John Van Bourg of the Kennebec Water District. One map showed the 25,493 individual depth readings measured in hundreds of transects across China Lake, and the other showed lake depth contour lines computed from these points in ten foot intervals. Professor Buckley and his students at UMF made these depth readings, and they created the original contour map of lake depth. Contour lines for a depth of zero feet were added around the shoreline of China Lake and all the lake islands by overlaying the contours with a DOQ of the China Lake area. Once a map of China Lake was modified with contour lines showing depths at ten-foot intervals, the Spatial Analyst feature of ArcGIS® was used to create a Triangulated Irregular Network (TIN) map. A TIN map is a three dimensional model created by approximating depths between points of known depths; each individual point on the lake bottom is triangulated based on its relation to the known contours. The completed model (Figure 34) is

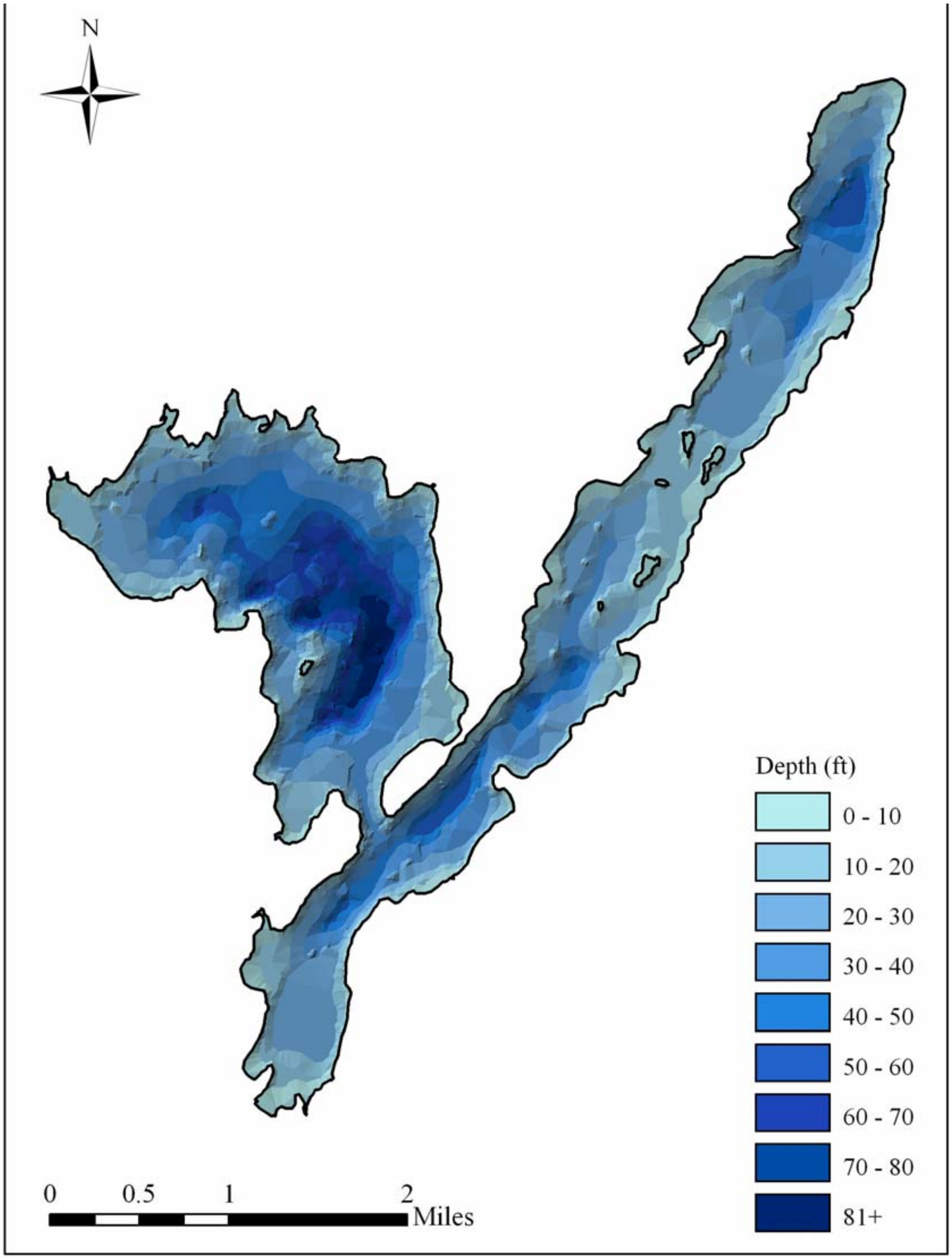

Figure 34. Bathymetric map of China Lake made with data compiled by Professor Buckley of the University of Maine at Farmington and his students.

composed of contiguous triangles that are used to estimate terrain between the known contour lines (Longley et al. 2001). Once this model was completed, it was manipulated to show various physical features of China Lake.

Results and Discussion

The average depth of China Lake is 10.0 m (33.1 ft); the deepest point is 28.2 m (92.4 ft) and is located near the center of the West Basin near Site 1 (Figure 12). Each summer a boundary forms between the cold and warm waters in China Lake at a depth of approximately seven meters (23.0 ft). There is very little mixing between water on either side of this divide and the deep, cold waters beneath eight meters (26.2 ft) can become anoxic (see Water Chemistry). Using the bathymetry maps previously created, CEAT determined that 26.9% of the lake waters, 113 million m^3 of the 420 million m^3 capacity of China Lake, are at depths that could potentially become anoxic annually (Figure 35). This figure is important in estimating the amount of phosphorus released into the water column from sediments.

Phosphorus that has been sequestered in subsurface sediments can return to the water column when the surrounding waters become anoxic. Of the approximately 16 million m^2 of sediment in China Lake, 44.80%, or approximately 7.17 million m^2, are covered by potentially anoxic waters during the summer. While the West Basin of China Lake is virtually undeveloped, Secchi disc readings from the summer of 2005 showed similar or slightly worse transparency than the highly developed East Basin (see Water Quality). The West Basin contains the outlet for China Lake; all nutrients added to any area of the lake ultimately flow through the West Basin, increasing the possibility of increased concentration of phosphorus leading to algal blooms. In addition, the West Basin is much deeper than the East Basin, leading to a larger volume of anoxic water and more phosphorus release from the lake bottom sediments.

The majority of invasive macrophyte species need to be rooted in sediments in water shallow enough to photosynthesize effectively and no invasive species can live past depths of approximately 7.5 m (24.6 ft) (see China Lake Characteristics: Biological Perspective: Invasive Plants). Based of these habitat requirements, 53.4% of the total surface area of China Lake, approximately 856 ha (2,115 acres) of 1604 ha (3,964 acres), is potential habitat for invasive macrophytes, such as Variable-Leaf Milfoil and *Hydrilla* (Figure 10).

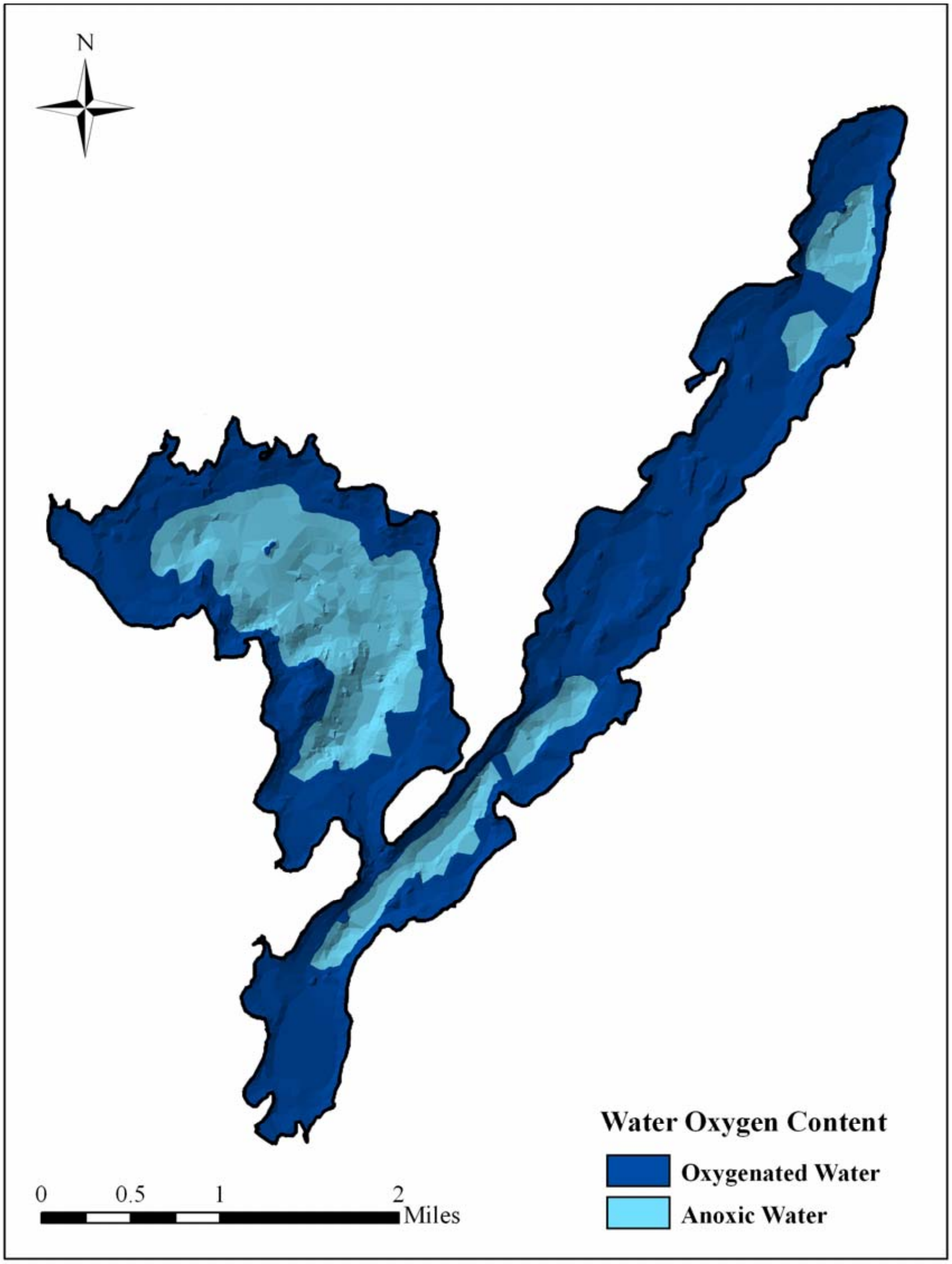

Figure 35. Projected anoxic areas in China Lake during summer stratification. Oxygenated water is above the thermocline, located at a depth of approximately 33 ft.

EROSION POTENTIAL MODEL

Introduction

Soil erosion represents a major source of potential nutrient loading, specifically phosphorus, into China Lake. As water drifts against the lake banks or flows down the adjacent slopes, it can dislodge soil and carry it into the lake. This soil contains nutrients, and potentially herbicides and pesticides.

By acknowledging the key factors that allow soil erosion, a model can be designed to show the areas at greatest risk for soil erosion in the China Lake watershed. Soil type plays an important role in erosion potential because the structure and texture of soils directly affects their erodibility. Sandy soils do not hold together well, resulting in a high risk for erosion, but clay soils pack tightly, reducing their erosion potential.

Slope acts as another important aspect that contributes to erosion. On steep surfaces, water can obtain a higher velocity, which increases its capacity to erode and transport soils. The force of gravity also assists in pulling soil particles from steep slopes. On flat surfaces, the effects of these factors are reduced, making flat surfaces less likely to erode.

Land use is the final major factor in determining erosion potential. The vegetative complexity of each land use type can dramatically affect erosion. As rain falls on a mature forest, the many layers of vegetation collect it and slow its descent. Once rain has reached the soil, small forest shrubs and groundcover slow its flow. Furthermore, roots stabilize the soil, which prevents significant erosion. Dirt roads and agriculture are major nutrient sources because the soil is exposed and is not stabilized by substantial root masses. These land uses increase the susceptibility of an area to erosion.

Methods

Soils

To determine the location of different soil types in the China Lake watershed, a soil classification layer was downloaded from the Maine Office of GIS for use in ArcGIS® 9 (MEGIS 2005; Figure 36). The erosion potential factor (k) was added to the soil type layer data table for each specific soil type (USDA 1992). Former CEAT members obtained the k-factor data from the Soil and Water Conservation District. The k-factors range from 0 to 1; 0

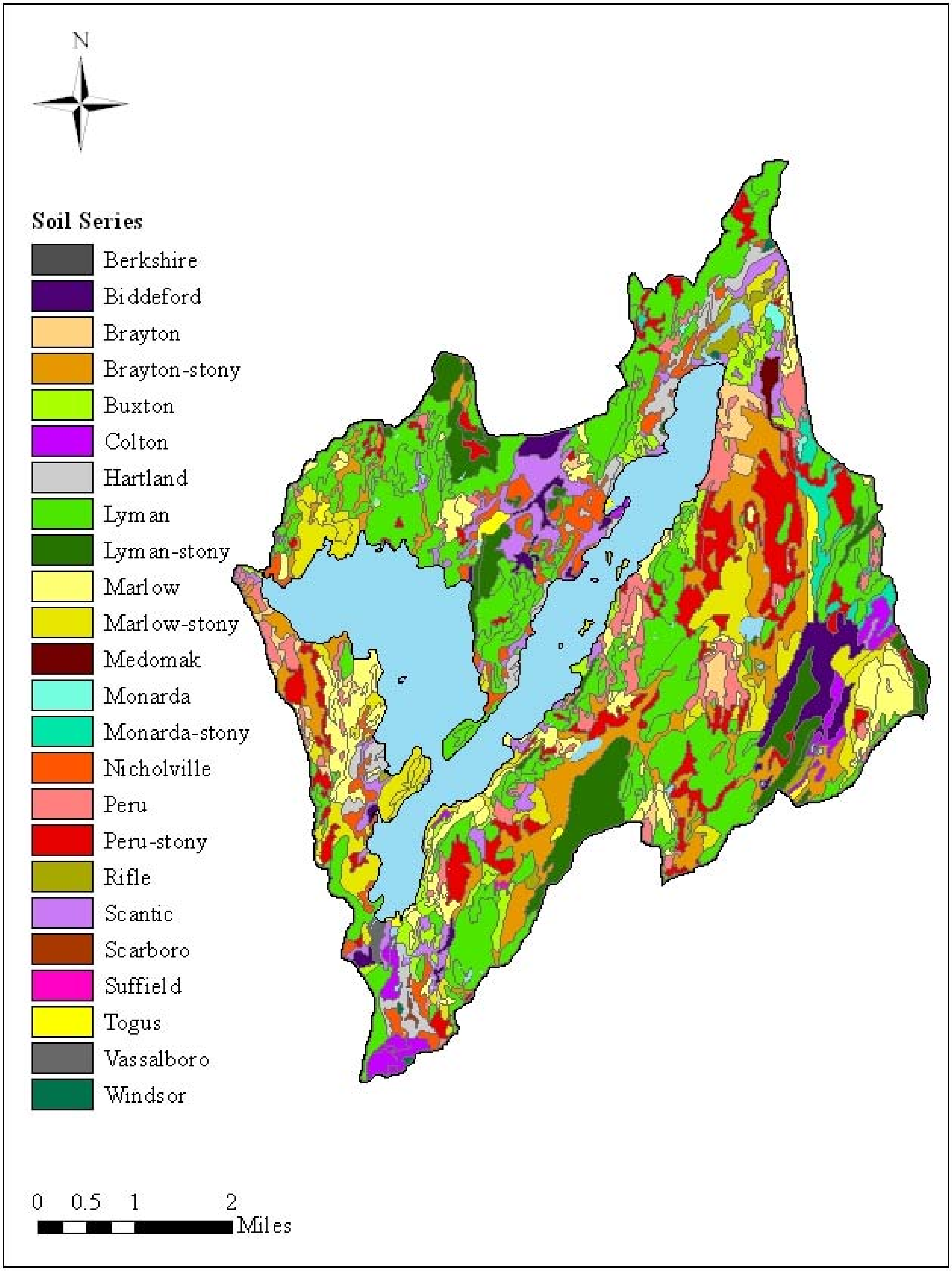

Figure 36. Soil map of the China Lake watershed (MEGIS 2005).

representing low erosion potential and 1 indicating high erosion potential. Within the China Lake watershed k-factors ranged from 0 to 0.49 (see Appendix H). The following equation was used to convert the k-factors of soil types into a scale of 1 to 9:

$$\textbf{Soil Erosion Potential Score} = 16.30 \times k + 1$$

The conversion factor 16.30 scales the k-factor values from a range of 0 to 0.49 to a range of 0 to 8. Then the "+ 1" shifts the scale to a range of 1 to 9. This calculation created a continuum of soil erosion potential scores from 1 to 9, in which 1 indicates the lowest potential and 9 indicates the highest potential to erode. The erosion potential of soils was fit to a scale of 1 to 9 to create a manageable range that is wide enough to differentiate among various erosion potential levels.

Slope

To determine the slope for each point within the watershed, CEAT downloaded a Digital Elevation Model (DEM) of the area (MEGIS 2005). The DEM is a grid of 10 m by 10 m cells, in which each cell corresponds to an elevation. Using Spatial Analyst™ software in ArcGIS® 9, the slope was derived for each 10 m by 10 m cell from the DEM. Inclines in the terrain around China Lake range from 0 to 59%. The following equation was used to convert slope values into a scale of 1 to 9:

$$\textbf{Slope Score} = \%\ \text{slope} \times 0.136 + 1$$

The coefficient 0.136 converts the 0 to 59% slope values to a 0 to 8 range. Adding one to these values shifts the range to 1 to 9. This calculation created a continuum of slope scores from 1 to 9, in which 1 indicated areas with low slopes with low erosion risk and a score of 9 indicated steep areas at high risk of erosion due to slope.

Land Use

Each land use type from the China Lake land use map was assigned a value according to its relative erosion risk as determined by CEAT (Table 7). Forests were given an erosion risk value of 1. The complex root systems of forests tightly hold phosphorus and other contaminants.

Table 7. Erosion risk values assigned for each land use in the China Lake watershed. Values of 1 indicate land uses with the lowest erosion risk, and 9 represents land uses that have the highest erosion risk. Values were incorporated as 25% of the GIS erosion potential model.

Land Use Category	Erosion Risk Value
Forest	1
Wetland	1
Reverting Forest	3
Agriculture	6
Residential	8
Commercial	9

Furthermore, rainfall does not disrupt the soil as much in forests because thick canopies of trees prevent water from hitting the soil surface directly at a high velocity. Wetlands also maintain a low erosion risk, designated with a value of 1, because the high water table in wetlands inhibits erosion. Reverting land received an erosion risk value of 3, because of the relatively open area and the lack of large tree root systems to hold the soil. Agricultural sites received an erosion risk value of 6, because there is typically only a single layer of vegetation that allows rain to reach loose soil more readily than in a forest. Furthermore, agricultural land contains a far lower root mass than forests. Residential land obtained an erosion risk value of 8. The inclusion of some lawn area in this land use type reduces its negative impact compared to completely impervious areas. However, since areas denoted as residential land contain impervious development, it has a greater erosion risk than agricultural land. Commercial and municipal areas received a maximum erosion risk value of 9 because the impervious surfaces prevent drainage, so runoff flows freely and collects debris without any hindrance from vegetation.

Weighted Overlay

The erosion potential map was calculated by combining the soil type, slope, and land use values as 25%, 50%, and 25% of the final weighted overlay, respectively. These proportions were chosen by considering some basic erosion scenarios. If an area is flat with a lot of vegetation, erosion will be minimal, even with poor soil. If an area is flat with very compact soil, erosion will be minimal, even with little vegetation. However, if an area is very steep, but has a lot of vegetation and compact soil, erosion can still be a significant problem. These scenarios show that slope is more indicative of erosion potential than the soil type and land use. Soil type and land use were weighted equally because they have a similar impact on the erosion

potential, and since they compose only 50% of the model, differences between the two weightings would not significantly affect the final model.

Results and Discussion

By combining the soil k-factors, slope data, and land use erosion risk, an erosion potential model was created (Figure 37). This model calculates erosion potential on a scale of 1 to 9.

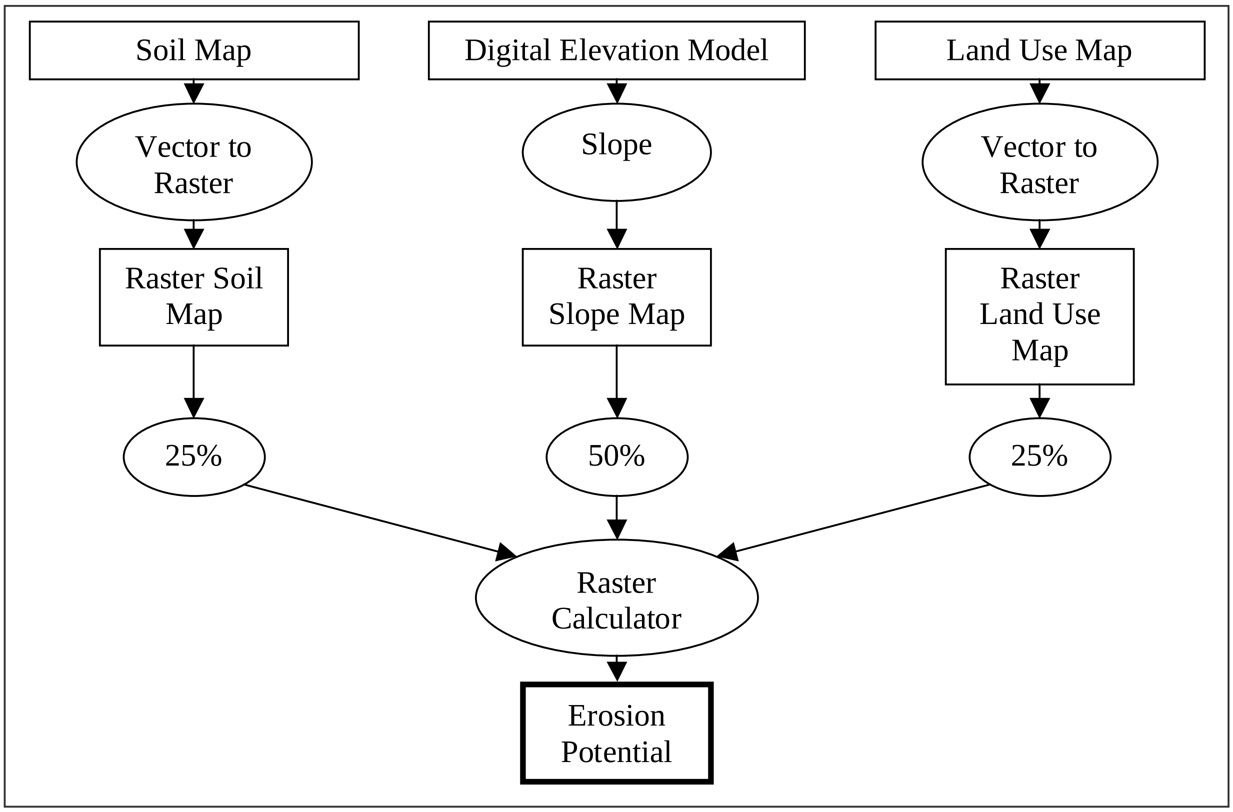

Figure 37. The inputs and weights assigned to the factors that contribute to the erosion potential model. The three input maps were converted to raster maps in which every 10 m square has an associated value. The values assigned to each point of the map for soil erosion potential, slope, and land use erosion risk were weighted and combined using the Raster Calculator in ArcGIS®9 Spatial Analyst to determine the erosion potential for the watershed of China Lake (see GIS: Erosion Potential Model).

Areas valued at 1 are at the lowest risk of erosion and are displayed as a light tan color, and areas with a value of 9 are at high risk and displayed in brown (Figure 38). The map indicates that without mitigation measures, development along the edge of China Lake creates a serious erosion threat for the lake. Outside this area of close proximity development, only a moderate

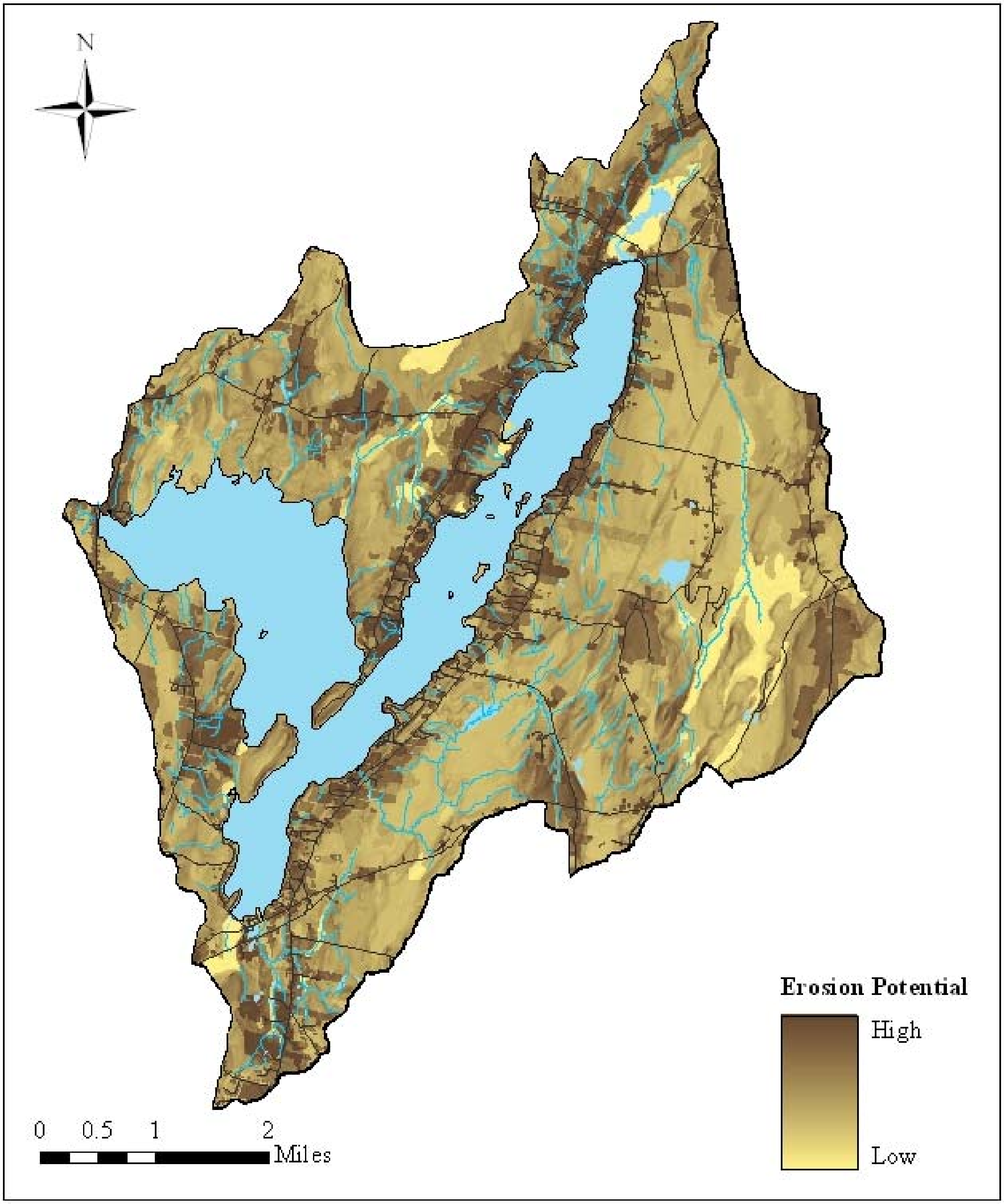

Figure 38. Erosion potential map of the China Lake watershed. Erosion potential was calculated from the erosion characteristics of slope, soil type, and land use type with a resolution of ten meters (see GIS: Erosion Potential Model). Dark brown areas indicate soil that is highly susceptible to erosion. Light tan to yellow areas indicate soil that is less likely to erode. The streams, roads, and watershed were obtained from Maine Office of GIS (MEGIS 2005).

potential for erosion exists. Distinct patches of highly erodible land ring the outer edges of the watershed, but the impact of these areas could be better interpreted in the impact of erosion model.

IMPACT OF EROSION MODEL

Introduction

The potential erosion impact model incorporates proximity to the lake and streams into the erosion potential model. This model can be used to target areas for mitigation against erosion more directly. The impact of areas at risk for erosion increases with proximity to the lake. If erosion occurs along a stream or along the lake shore, the nutrients may flow directly into the lake, but erosion distant from the lake poses a lesser threat.

Methods

A lake proximity map was created in ArcGIS® 9 by forming proximity zones around a polygon of China Lake. The first zone covered the shoreline area, which consisted of all areas within 200 ft of the lake, since this area is exceptionally sensitive to erosion. The remaining area of the watershed was divided into eight equally wide zones, which made each zone 2000 ft wide. The nine resulting zones were assigned scores from 1 to 9, with the shoreline zone having a score of 9 since erosion in this area would significantly impact the lake. Scores for each zone decreased with distance from the lake.

On a separate map, a 200 ft zone was also created around the streams in the watershed. Erosion along streams deposits nutrients into the water flowing to the lake, so erosion in this area may significantly impacts water quality. This riparian zone received a score of 8. For this input map, the rest of the watershed area received a value of 0 because its impact on the lake was already acknowledged in the lake proximity map.

For the final impact of erosion model, the erosion potential score accounted for 50% of the model, the proximity to the lake 40%, and the proximity to streams 10% (Figure 39). The proximity to streams contributes a relatively small amount to the final model because erosion along streams affects the lake indirectly since eroded materials first collect in the stream, then flow to the lake. The proximity to the lake contributes more to the model because erosion along the lake deposits soil directly into the lake, so the erosion has a direct impact on water quality.

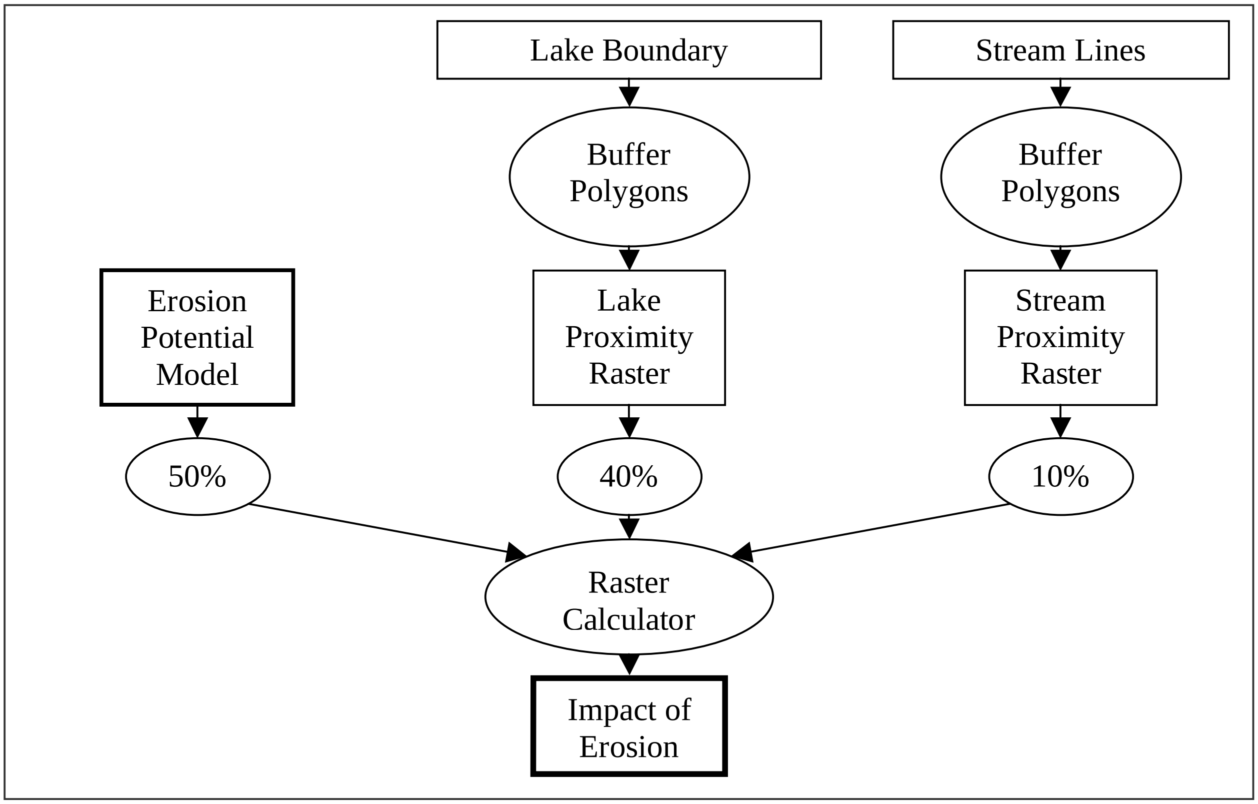

Figure 39. The inputs and weights assigned to the factors that contribute to the impact of erosion model. Proximity to China Lake and its tributaries was determined and mapped for all areas in the watershed. The erosion potential model was combined with the proximity map using the Raster Calculator in ArcGIS®9 Spatial Analyst to show the areas where erosion is most likely to impact the water quality of China Lake (see GIS: Impact of Erosion Model).

The proximity to the lake is weighted almost equally to erosion potential because erosion distant from the lake will have a negligible impact on the lake. Similarly, shoreline areas with very low erosion potential will have a minimal erosion impact on the lake, which demonstrates that the extremes of the two factors basically cancel each other. Erosion potential and lake proximity factored into the impact of erosion model in similar ways.

Results and Discussion

The potential erosion impact model is similar to the erosion potential, but it specifically identifies the more important areas within the watershed affecting the water quality of China Lake. Areas within the watershed received values on a scale of 1 to 9, represented by colors ranging between green and reddish-brown (Figure 40). Green indicates areas with a minimal

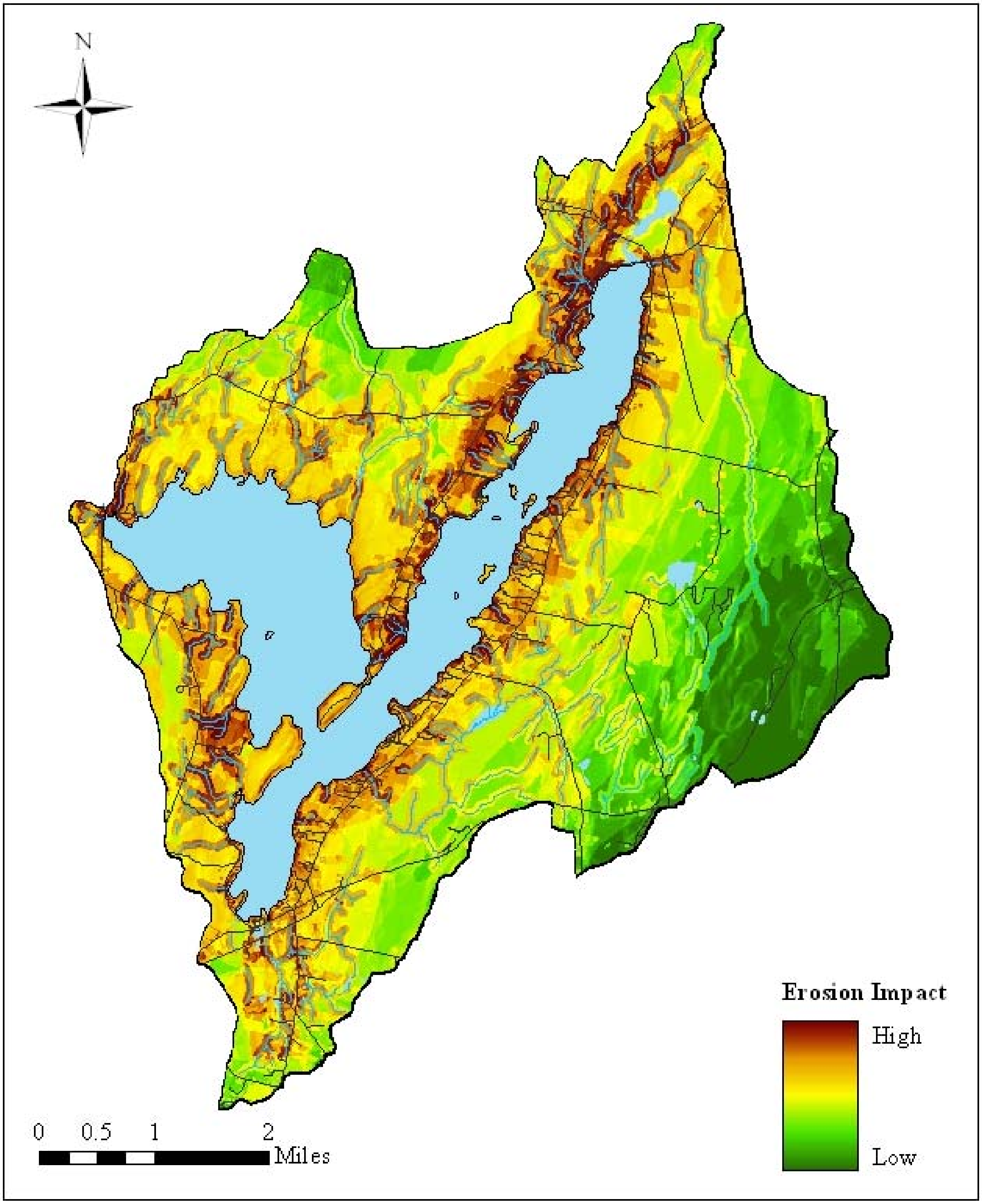

Figure 40. Impact of erosion map for the China Lake watershed. Impact of erosion was calculated from the erosion potential, proximity to China Lake, and proximity to its tributaries. The reddish brown areas indicate where erosion is likely to have a negative impact on the water quality of China Lake. Green areas indicate where erosion is not as likely to impact the lake.

impact on the lake through erosion, and reddish-brown indicates areas where erosion presents a serious threat to the lake. For example, the shore of the East Basin is displayed in reddish-brown. Erosion poses an obvious threat to the lake in this area, primarily due to the slope and the proximity to the lake. These characteristics make the area a target for erosion prevention projects. Erosion poses a relatively minor threat on the eastern edge of the watershed because erosion debris is not likely to reach the lake from this distant area. Future development in this area would have less impact on the lake through erosion than closer development. This impact rating could give the area an important role in land use planning. In conclusion, this model allows us to pinpoint areas where potential erosion should be mitigated. The model can be used to direct funding for shoreline improvement to the most sensitive areas. This map can also be used to assist in developing land use planning strategies and in minimizing the impact of future development on the lake.

SEPTIC SUITABILITY MODEL

Introduction

Septic systems are one of many factors that can contribute to lake degradation. Insufficiently treated septic system effluent can add organic particulates, nutrients, bacteria, and viruses to a lake. These additions accelerate lake eutrophication and can harm the organisms in the lake as well as humans (see Background: Watershed Land Use).

To ensure that effluent undergoes proper treatment, it must leach through soils at a slow rate. Many soil characteristics play a significant role in this leaching rate. Permeability, the rate at which water moves vertically through the soil, influences leaching rate the most. Soil texture and structure determine permeability. For example, the granular structure of sandy soils leads to high permeability, and the compactable structure of clay soils leads to low permeability. An intermediate permeability is optimal for septic systems so that the effluent drains slowly enough to allow the necessary biological processes to remove contaminants, while still draining fast enough to prevent pooling (KCSWCD 1990).

The depth to bedrock, water table depth, and likeliness of flooding are also important soil characteristics involved in effluent leaching. Soils with shallow bedrock and water table depths drain poorly (KCSWCD 1990). Soils prone to flooding also drain poorly, and flooding could flush the effluent directly into the lake.

Slope is another important factor that affects the septic suitability of an area. Steep slopes naturally accelerate the leaching of effluent from septic systems, and the absence of slopes leads to pooling. Furthermore, steep slopes have a greater erosion potential, which leads to the erosion of effluent rich soil. As a general rule, septic systems should not be developed on slopes greater than 20% (MDHS 1983).

To create a model of septic suitability for the China Lake watershed, the slope and soil type were combined into a single geographic image that weighs these factors to determine the suitability of any area for a septic system. However, the final rankings indicate suitability, which can be mitigated by changing the slope or the soil type with enough monetary investment into the land. The final ratings can best be interpreted as the relative investment required to install a septic system. The map can also be used to identify areas where septic systems present a greater threat to water quality. In this way, the resulting map can assist landowners, local planners, developers, engineers, and others with development plans.

Methods

Soils

The map of soil types from the Maine Office of GIS was used as the base map for the soil data, as it was for the soil erosion model. The soil types within the China Lake watershed were displayed at a 10 m by 10 m resolution. Using Kennebec County Soil and Water Conservation District (KCSWCD) soil septic potential ratings, soils with ratings of Very High, High, Medium, Low, and Very Low were assigned integer values of 1, 3, 5, 7, and 9, respectively (KCSWCD 1990; see Appendix H). These ratings took all of the above mentioned soil characteristics into account, including slope. Soils with optimal permeability, deep bedrock and water table, and shallow slopes received a value of 1, but soils with scores of 9 were unsuitable for septic systems according to these criteria. However, to incorporate the high resolution and precision slope information acquired through GIS, only the septic potential ratings at 0% slope were used for each soil series. This process alleviated the slope variable from the soil septic potential ratings so the slope factor could be re-evaluated at a higher resolution in the final model. The soil septic potential values composed 50% of the final septic suitability model.

Slope

The slope data used in this model were the same as those used in the erosion potential model. Once the data were converted to a scale of 1 to 9, they were calculated as 50% of the final septic suitability model. The slope and soil were weighted equally in determining septic suitability. The medium suitability soils, assigned a score of 5, are not ideal for septic systems, but they are acceptable. Similarly, moderate slopes that received a score of 5 are also not ideal for septic systems, but they are also acceptable. The extremes of each factor are also similar. The poorest soils are not suitable for septic systems regardless of slope, and the steepest slopes are not suitable for septic systems regardless of soil type.

Results and Discussion

By combining the soil septic potential and slope data, CEAT created a septic suitability map for the China Lake watershed (Figure 41). This map has calculated septic suitability scores ranging from 1 to 9 for every 10 m by 10 m area of the watershed. Scores are displayed via a color spectrum from green to red in which areas with scores of 1 are displayed in green and have conditions most suitable for septic systems (Figure 42). Areas with a score of 9 are displayed in red and could require significant mitigation before they are suitable for septic systems.

The septic suitability from the GIS model can be correlated with the KCSWCD septic potential ratings that include slope (KCSWCD 1990). The KCSWCD "Very High" septic potential is approximately equivalent to the darkest green on the GIS map. The KCSWCD "High" septic potential is approximately equivalent to the second and third shades of green on the GIS map. The "Medium" septic potential is best represented by the yellowish green coloring on the map. "Low" septic suitability is best matched to the fifth and sixth colors, yellow and yellowish orange. The KCSWCD "Very Low" septic suitability rating is covered by the lowest three colors on the GIS map, dark orange to red.

Figure 42 shows which areas could be problematic for septic systems and which areas are ideal for septic systems. For example, the most problematic areas are in the eastern end of the watershed. However, this area is distant from the lake, so even if a septic system had problems in this area, it would not impact the lake as dramatically as would a shoreline septic system. Most effluent released at this distance would probably be sufficiently leached before reaching the lake.

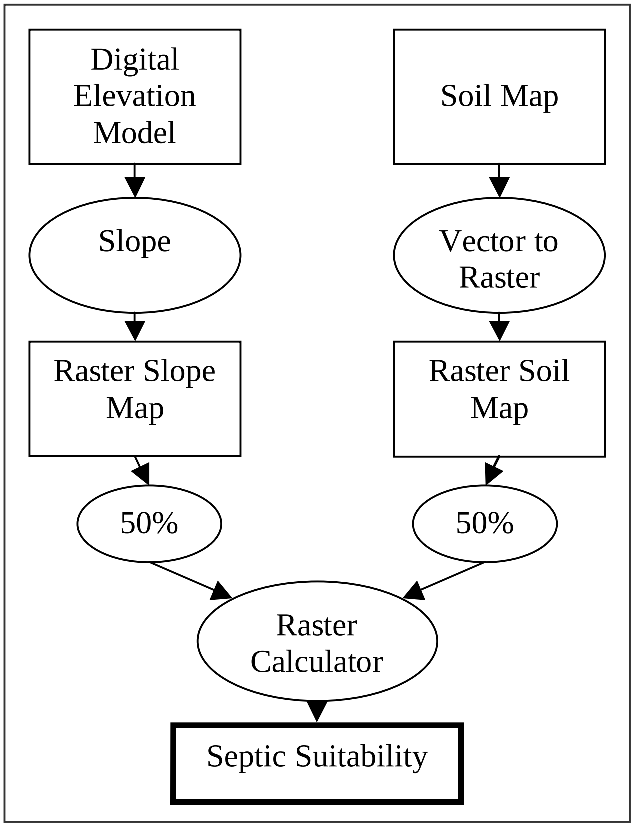

Figure 41. The inputs and relative weights assigned to the factors that contribute to the GIS septic suitability model. Slope and the septic suitability of different soil types were derived and mapped for the China Lake watershed at a 10 m resolution. These characteristics were weighted and combined to determine the suitability of areas for septic systems (see GIS: Septic Suitability Model).

A narrow swath of land, approximately 300 feet wide, with poor septic suitability ratings exists directly along the western edge and southeast edge of the East Basin. This poor rating results primarily from the slope of the shoreline. Septic systems in this general area could require significant mitigation, and installing new septic systems in this area would also be a costly endeavor.

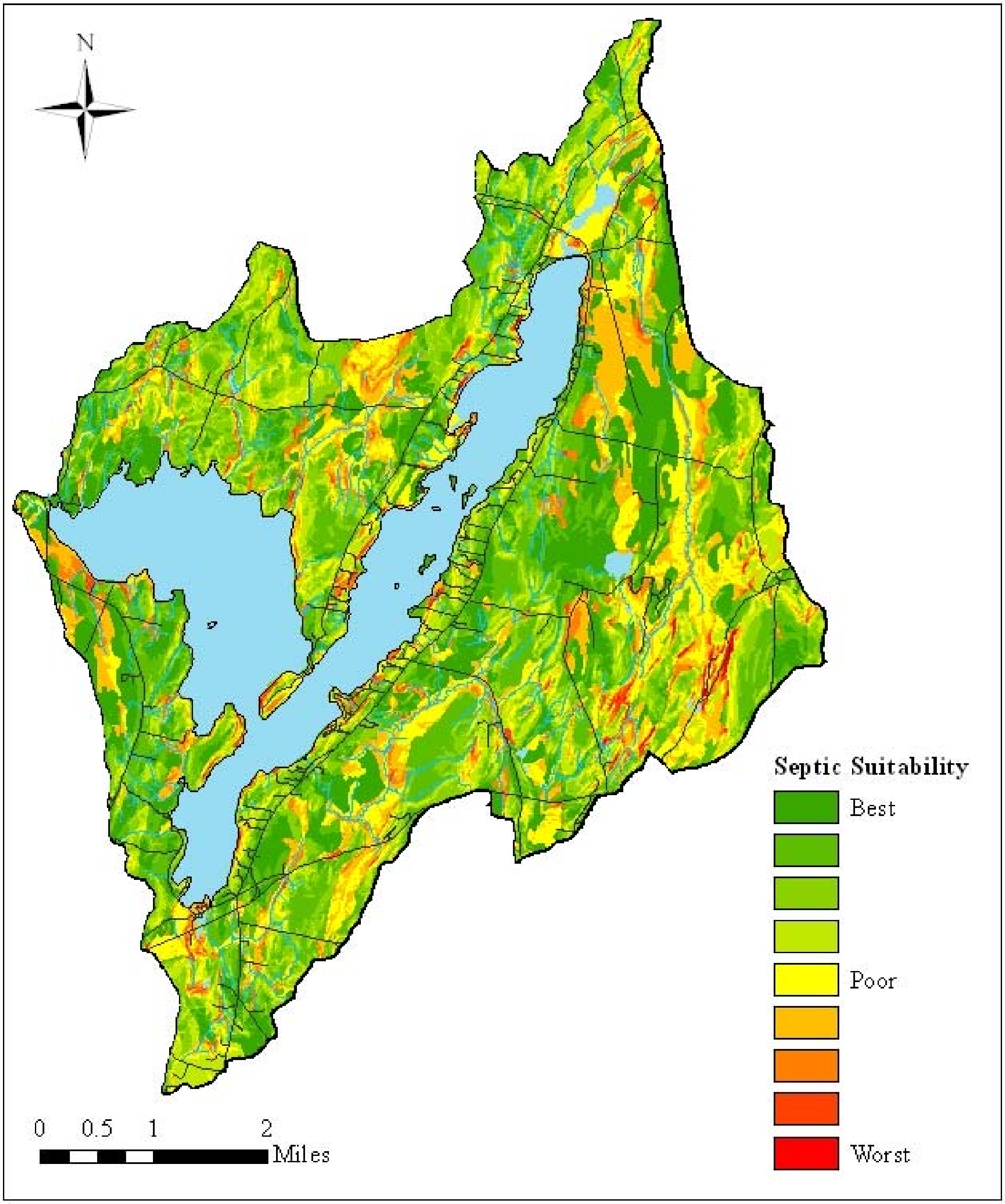

Figure 42. Septic suitability map of the China Lake watershed. This map shows the suitability of an area for septic systems based on the slope and soil type (see GIS: Septic Suitability Model). Green indicates areas where septic systems are most likely to work effectively. Areas marked with orange and red are poorly suited for septic systems and are likely to require mitigation for septic systems to function properly. Stream, road, and watershed layers were obtained from Maine Office of GIS (MEGIS 2005)

WATERSHED DEVELOPMENT

RESIDENTIAL SURVEY

Shoreline Zoning

Introduction

Development activities on land adjacent to water bodies are likely to have a negative impact on water quality. These detrimental effects often come in the form of increased inputs of nutrients and sediments from septic systems, soil erosion, and runoff from roads, driveways and other impervious surfaces. To protect the environmental, economic, and aesthetic value of the water bodies in the state, the Maine Department of Environmental Protection (MDEP) implemented the statewide Mandatory Shoreland Zoning Act in 1971 (MDEP 2003b).

Regulations

The Shoreland Zoning Act governs development and other activities occurring within the shoreland zone, which is defined as areas within 250 ft of the normal high-water line of any great pond, river, or saltwater body, and within 250 ft of the upland edge of salt or freshwater wetland. Land within 75 ft of the normal high-water mark of a stream is also included in the shoreland zone (MDEP 2003d). By 1974, municipalities in Maine were required to have implemented a shoreland zoning ordinance with requirements as strict, or stricter than those defined in the model ordinance set by the state (MDEP 1998c). The enforcement of these laws is the responsibility of the town, which is required to employ a Code Enforcement Officer (CEO) for this purpose (MDEP 2003d). The MDEP is responsible for occasional monitoring to ensure local compliance.

The shoreland zone surrounding China Lake falls under the authority of the towns of Vassalboro and China. Both towns have adopted ordinances that follow the MDEP guidelines fairly closely, with a noticeable exception for each. In China, a strict phosphorus control plan was implemented, and in Vassalboro an aggressive campaign to update outdated septic systems in the shoreland zone was enforced.

Lot Size

Under the Mandatory Shoreland Zoning Act, each residential lot must be at least 40,000 ft^2 and have at least 200 ft of shore frontage per principal structure (MDEP 1998b). Commercial lot size is required to be at least 60,000 ft^2 with 300 ft of shore frontage. These dimensions must increase proportionally for each additional principal structure erected. These minimum lot sizes serve to reduce the number of developed lots on the shoreline.

Structure Setback

To reduce phosphorus loading into water bodies and protect shoreline vegetation, all structures, roads, driveways, and parking areas must be set back at least 100 ft from the normal high water mark of great ponds (MDEP 1998b). The setback limit is 75 ft from tributary streams or the upland edge of a wetland. Structures that have a functionally water dependent use, such as a dock, are exempted from this setback requirement. To reduce the likelihood of flood damage, the first floor of all buildings is required to be located at least one foot above the 100-year flood elevation. The Shoreland Zoning Act also requires that buildings in the shoreland zone be no taller than 35 ft (MDEP 1998b).

Impervious surfaces contribute more to phosphorus loading than vegetated land. To control the increased nutrient loading from impervious surfaces, these areas are limited in the shoreland zone; the combination of all impermeable surfaces, including but not limited to structures, driveways, and decks, must not exceed 20% of the lot area (MDEP 1998b). During the development of areas that fall within the shoreland zone, a soil erosion and sediment control plan must be prepared to show how erosion will be minimized based on the slope and shape of the area affected.

Buffer Strips

Buffer strips are the areas of vegetated land that border the shore of a water body and limit the sediment and nutrient runoff into the water (see Background). Lots located in the shoreland zone of a great pond or rivers flowing into great ponds must maintain at least 100 ft of buffer between the waterline and any clear cut area (MDEP 1998a). For a wetland, a 75 ft buffer strip must be maintained. Any cutting of vegetation in this area is regulated under the Mandatory Shoreland Zoning Act. No opening larger than 250 ft^2 in the forest canopy may be made. No more than 40% of the trees on any property may be removed over a ten-year period.

Septic Systems

To account for the possible nutrient loading hazards that septic systems pose to a lake, strict guidelines are enforced in shoreland zones by town CEOs. All systems must be located at least 100 ft back from the water. All septic systems must be installed by a Maine certified site evaluator and meet guidelines in compliance with the State of Maine Subsurface Waste Disposal Rules (MDEP 1998a).

Non-conformance

Many of the structures that surround Maine's waterways, including many of the properties around China Lake, were built before the existence of the Mandatory Shoreland Zoning Act. Because these buildings were built at a time when shoreland zoning laws did not exist in the current form, many of them are not in compliance with the setback, lot size, lot coverage, or structure height regulations that have since been imposed on new development. These pre-1974 (grandfathered) buildings exist legally under the law, but any future work on the house is regulated by the act. Property owners are permitted to improve and maintain their houses and lots. A permit is required for a house to be expanded or moved (MDEP 2003e).

In 1989, an amendment was made to the Mandatory Shoreland Zoning Act that limited the expansion of non-conforming structures to a 30% increase of the floor area and volume (MDEP 2003e). This amendment also prohibited new construction to increase the non-conformance of structures by expanding toward the water further into the non-conformance zone, or making houses already taller than 35 feet any higher. These new restrictions apply only to those areas of the house that do not meet the setback requirements; meaning that if the back of the house falls more than 100 ft from the lakeshore, but the front does not, the owners are permitted to build onto the back without adhering to the 30% increase limit.

Town of China Phosphorus Control Ordinance

To supplement the state guidelines for development within shoreland zones, the Town of China drafted an ordinance to decrease the amount of phosphorus entering China Lake from new development (Town of China 2003). The limit on phosphorus export for any new land use or dwelling is 0.34 lbs of phosphorus/acre/year within the watershed of the East Basin of China Lake, and 0.57 lbs of phosphorus/acre/year in the West Basin watershed. These regulations apply to any development in the China Lake watershed under Town of China jurisdiction built after 5-Jun-93. New additions to existing structures under 1,500 ft^2 are exempted. People

seeking permits for building single-family dwellings and subdivisions must submit a plan to the code enforcement officer detailing how they plan to meet the phosphorus export standards. Buffer strip widths on these properties are specified according to the slope of the property. Those contractors seeking to build subdivisions must provide a plan showing buffer strip size and location (Town of China 2003).

Resource Protection Districts

Certain areas within a watershed are subject to more stringent guidelines, Resource Protection Districts (RPD) cover particularly vulnerable areas. Areas mandated to be RPDs are: 100 year flood plains on rivers, areas adjacent to wetlands that are rated as moderate or high value for waterfowl, areas with two or more acres of slopes over 20%, areas with two or more acres of wetlands that are not part of a water body, and areas on rivers or tidal waters subject to severe bank erosion (MDEP 2003b). Development and other land uses are more strictly regulated in these zones than in other areas, regardless of whether they are included in the shoreland zone.

The China Lake watershed has five RPD's, all located relatively close to the lake. The general location of these RPDs are:

- Area near the northernmost end of the lake, including the stream draining into the lake.
  Designation: High value habitat for waterfowl
- Area off of Wentworth Cove in the northwestern area of the lakeshore .
  Designation: Non-rated wetland, 10 acres or more
- Area off of Bickford Cove in the middle of the lake on the western shore.
  Designation: Non-rated wetland, 10 acres or more
- Area near Clarke Road.
  Designation: Moderate value habitat for waterfowl
- Area near the Route 3 corridor at the southernmost tip of the lake.
  Designation: Non-rated wetland, 10 acres or more

The specific size and location of these areas may be viewed on a map kept at the town offices of China and Vassalboro (Pierz, pers. comm).

Discussion

Many of the lots in the shoreland zone of China Lake were developed long before 1974. As a result, it is common for lakefront properties to be in legal non-conformance with the state's Mandatory Shoreland Zoning Act. Many of these houses lack a significant buffer, are less than 100 ft from the lake, and have outdated septic systems. Although the owners of these lots have no obligation to update their properties to new standards, many will eventually be upgraded when significant maintenance is required or new structures are erected. In further sections, specific problem areas concerning buffer strips and septic systems are addressed, as are suggested remediation techniques.

Residential Count

Introduction

CEAT conducted a road and shoreline survey of houses within the China Lake watershed to determine the state of residential development and potential sources of nutrient loading. Shoreline development poses a greater threat to water quality than non-shoreline development. The house lots with the highest potential for nutrient runoff did not have a proper buffer and were situated too close to the shoreline and each other.

CEAT counted all houses within the watershed because all houses potentially contribute to nutrient and sedimentation loading in the lake through runoff. Both surveys classified houses as seasonal or year-round. Year-round houses represent a higher impact on the watershed because of the amount of nutrient and sediment runoff from the roads and the use of septic systems during the year are greater than with seasonal houses. Seasonal houses, while having a lesser total impact, create a concentrated impact on the watershed during a critical period of the summertime.

Methods

In the shoreline survey, CEAT counted all houses located on the waterfront and assessed their buffers. CEAT used two different methods in the house count. Teams counted houses located on the shoreline from boats during a buffer strip shoreline survey on 22-Sep-05 (see Appendix G). During this survey, CEAT counted houses located 200 ft or closer to the shoreline because they were easily visible from a boat. Teams counted the rest of the houses within the watershed during the road survey conducted on 3-Oct-05 and 20-Oct-05 (see Appendix F).

Houses were classified as seasonal or year-round based on a number of characteristics. CEAT considered characteristics of a seasonal residence to include: an open foundation, smaller house, no chimney, dirt driveway, or a pit privy. Attributes a year-round house might display include: a closed foundation, larger house, chimney, storm windows, paved driveway, or external oil tank. Though a subjective classification, it provides a framework to help determine the contribution of each house to nutrient and sediment loading. Houses located on the shoreline were plotted using Global Positioning System (GPS), and downloaded into GIS to determine areas with higher impacts on the watershed (see Watershed Development: Discussion: Buffer Strips).

Results and Discussion

CEAT members determined that a total of 1,618 houses were located within the China Lake watershed. There were 472 shoreline houses (29% of total houses), including 296 (63%) seasonal homes and 176 (37%) year-round residences. There were 1,146 non-shoreline houses (71% of total houses), including 37 (3%) seasonal homes and 1,109 (97%) year-round residences.

The East Basin of China Lake has 30.2 houses per shoreline mile, in comparison to Three Mile Pond, which has 26.4 houses per shoreline mile and Webber Pond which as 16.6 houses per shoreline mile. This indicates that the density of houses concentrated on the shoreline in China Lake is high; consequently, the contribution to phosphorus loading of shoreline houses is potentially higher than other lakes in the area.

Many of the house lots were too close to each other and the shoreline for nutrients to be absorbed in the ground instead of running into the lake, and are often clustered together because many were grandfathered. Consequently, the potential for nutrient and sediment runoff in China Lake is much higher than one might expect from current regulations because there are legally non-compliant houses, nearly all concentrated in the East Basin. Many of the houses require buffer strip improvement to minimize their input into the lake. Only one house exists on the shoreline of the West Basin. In addition, the large percentage, 63% of the shoreline residences that are seasonal homes, creates a concentrated increase in septic system and road use during the summer.

Subsurface Wastewater Disposal Systems

Introduction

Subsurface wastewater disposal systems can be an important factor influencing water quality in Maine lakes. In rural areas where centralized sewage systems are not economically feasible, wastewater disposal must occur on individual properties. There are three types of wastewater disposal systems: pit privies, holding tanks, and septic systems (see Background: Subsurface Wastewater Disposal Systems). Septic systems are the most widely used form of on-site water treatment in the China Lake watershed. When properly constructed and maintained, septic systems can treat wastewater effectively and do not threaten water quality (Schueler and Holland 2000).

In a septic system, wastewater enters into an underground tank where solids settle to the bottom of the tank and are broken down by anaerobic bacteria (see Background: Subsurface Wastewater Disposal Systems). The liquid is directed to an absorption field, which consists of a series of pipes in shallow trenches that allow the effluent to percolate through the soil. The remaining pollutants are removed by absorption, filtration, and microbial degradation. If properly maintained, most septic systems need to be pumped every three to five years and have an average life of 15 to 25 years (MDEP 2003d). However, pumping and replacement frequencies depend on many factors, including: the size of the septic system, amount of use, and type of inputs. Even though water-tight holding tanks do not release effluent into the ground, they are not as desirable as septic systems because they require constant monitoring, pumping, and are not cost effective for year round use (MDEP 2005).

Due to widespread use and high volume discharges, septic systems could potentially pollute groundwater, streams, and lakes if they are improperly located or maintained (MDEP 2003d). Shoreline property owners face additional challenges regarding responsible wastewater disposal. Shoreline erosion can decrease the setback distance of a leach field from a water body, which increases the potential for incompletely treated wastes to drain into a lake. Contamination can occur when absorption fields become saturated because of changing groundwater and lake levels. Maintenance issues, such as clogged pipes, broken distribution lines, and infrequent pumping, can cause systems to malfunction and pollute groundwater (MDEP 2003d).

Incomplete wastewater treatment releases organic particulates, nutrients, viruses, bacteria, and pathogens which negatively impact water quality and threaten human, plant, and animal

health (Schueler and Holland 2000). Gray water from sinks and washing machines is high in phosphorus, which increases aquatic plant and algal growth if it contaminates nearby lakes. Septic systems only remove 20% of nitrogen from black water or toilet wastes (Schueler and Holland 2000). In addition, the majority of groundwater-related health complaints are associated with septic system pathogens that cause recreational and drinking supply areas to be closed. The Maine Wastewater and Plumbing Control program recommends several steps for septic system maintenance (MDHE 2005):

- Pump tank regularly.
- Do full laundry loads.
- Minimize number of laundry loads in one day.
- Use water-conserving fixtures in sinks, bathrooms, and washers.
- Minimize use of household cleaners, special additives, and disinfecting automatic toilet bowl cleaners as they can kill the natural bacteria necessary for decomposition.

In addition, the replacement of old septic systems will help to prevent household waste pollution from affecting water quality.

Methods

Houses within 200 ft of the shoreline were counted in a buffer strip survey (22-Sep-05) and all other watershed houses were counted in a road survey (3-Oct-05 and 20-Oct-05). CEAT determined whether each house was year-round or seasonal based on visible characteristics (see Watershed Development: Residential Count) to estimate septic system usage. Personal interviews were conducted with MDEP officials as well as Vassalboro and China code enforcement officers to gain a sense of wastewater disposal system practices and status. In addition, the China Lake Septic Project (2005), produced by the Town of China and Kennebec Water District, provided data such as wastewater disposal system type and date of system installation for the shoreline houses in China.

Results and Discussion

Maine regulates septic systems with the Chapter 241-7 Maine Subsurface Wastewater Disposal Rules (MDHS 2002). The regulations state that septic systems installed after 1974 within the 250 ft shoreline zone must have a 100 ft absorption field setback from the high water mark of a body of water. The absorption field must be 15 inches above the groundwater level in

the shoreline zone. Failing systems must be replaced at the expense of the homeowner. Systems installed before 1974 are grandfathered from the current regulations and only have to meet the new requirements if the system malfunctions, the home is expanded, or a seasonal property is changed to a permanent residence (MDHS 2002). People who have systems that do not comply with the current codes can apply for replacement system variances, which the MDEP grants to non-compliant systems where the 100 ft setback is impossible due to small lot sizes or unsuitable soil (Martin 2005). Code enforcement officers sometimes require the installation of additional pre-treatment systems for houses that are granted variances. Pre-treatment systems, such as hydrogen peroxide additives or extended aeration processes, increase treatment performance and reduce the area needed for a disposal field (Community Systems Advisory Group 2003).

Vassalboro and China have employed different remediation strategies to try to improve lake water quality. Vassalboro has no additional rules for the installation and construction of subsurface wastewater disposal systems beyond the state requirements (MDHS 2002). However, the town has a replacement policy for wastewater systems that do not comply with the current state requirements. In the mid 1990s, Vassalboro passed a Shoreline Zoning Ordinance requiring homeowners to prove that their septic systems were installed after July 1974 or install a new system. This policy did not affect properties on China Lake because there is only one shoreline property under Vassalboro jurisdiction and it has a holding tank (Fitzgerald, pers. comm.).

Almost all of the China Lake shoreline properties are within the jurisdiction of the Town of China. The regulations and practices for wastewater disposal systems in China are of great concern because large numbers of shoreline properties can potentially affect water quality (Town of China 2005). China has additional rules for the installation of subsurface wastewater disposal systems beyond the state minimum regulations including: a 1,000 ft^2 minimum of productive soils for leach fields, five observation holes to test the soil profile in the leach field during construction, and a septic system load capability for 90 gal/day per bedroom. The Code Enforcement Officer for China must make sure these regulations are followed, issue permits, and ensure erosion control techniques are being used during construction. Once septic systems are installed, maintenance becomes the responsibility of the homeowner and malfunctioning systems are often not brought to the inspector’s attention (Pierz, pers. comm.).

The purpose of the China Lake Septic Project was to update town records regarding the status of the wastewater disposal systems for the properties adjacent to the shoreline

(unpublished data, Town of China 2005). While CEAT counted 472 houses within the 200 ft shoreline zone, preliminary data from the China Lake Septic Project took into account 597 shoreline properties. The China Lake Septic Project includes data on all houses "adjacent to the shoreline" which is a larger survey area than the 200 ft zone used by CEAT (Van Bourg, pers. comm.). According to the preliminary project data, 481 houses use septic systems and 111 houses have holding tanks (unpublished data, Town of China 2005). The number of houses with holding tanks is inflated because when the town did not have septic system information, they assumed the property used a holding tank (also there is no data for five houses). The China Town Office has information on most septic systems and holding tank installations from 1973 to the present. Houses that do not have a septic system permit on record and were built before 1973 or do not have a construction date available are potential non-compliant systems under the current regulations (Figure 43). For these 332 houses, more information is needed to ensure that the septic systems are not contributing to groundwater pollution. In addition, some of the houses built after 1974 have replaced older houses and are still using old septic systems (Van Bourg, pers. comm.). For the 94 houses constructed between 1974 and 2004 that do not have permits on record, the problem may be more of a paperwork issue (i.e., septic systems were never inspected because local contractors were considered reputable or the code enforcement officer never got around to closing the permit) than a problem of non-compliant systems (Van Bourg, pers. comm.).

One of the goals of the most recent Town of China Comprehensive Plan (1987) is to protect the water quality of all bodies of water within the town boundaries. The plan noted a concern for older houses built on small lots before the present plumbing code was created. A town sewer line was proposed to transport sewage to disposal fields, but it is not an economically realistic solution. Though China does have stricter septic system standards than the State of Maine regulations, some people feel that the town is not adequately addressing non-compliant systems that could potentially contribute to phosphorus loading. In addition, many houses with modern septic systems have primitive gray water systems for sinks and washing machines. Gray water, which is high in phosphorus, is often allowed to leach directly into groundwater, streams, and lakes. Unfortunately, there is general public misinformation about gray water because some people think that it is good for the environment (Van Bourg, pers. comm.).

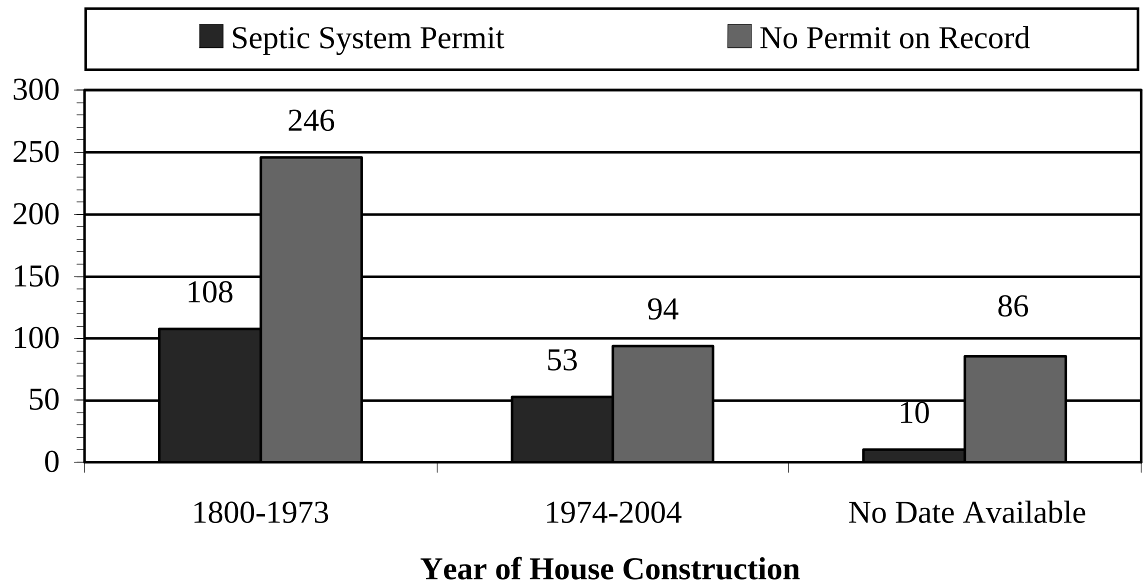

Figure 43. Records of septic system permits for the properties adjacent to the shoreline of China Lake (unpublished data, Town of China and Kennebec Water District 2005). Permits relate to the 1974 code change for installing and replacing septic systems (MDHS 2002). Septic system permits are necessary to ensure that the systems are not malfunctioning and contributing to groundwater pollution.

There are several trends with the placement and usage of the shoreline septic systems in China that indicate the systems might be possible non-point sources of phosphorus loading and are contributing to the poor water quality of China Lake. Within the shoreline zone on China Lake, 55% of properties have less than 60 ft of shoreline. The majority of houses are on small lots and are close to the shoreline, suggesting that their septic systems are as well and are non-compliant with the current setback ordinances. In addition, 63% of the shoreline houses are seasonal and contribute to concentrated septic system usage during the summer months. Even though the occupancy of many seasonal houses has increased over the years, many properties are still using a grandfathered septic system that was not designed to treat the current wastewater load effectively (Van Bourg, pers. comm.). The lack of permits on record, infrequent reporting of malfunctioning systems, and insufficient comprehensive plan for septic system remediation techniques are major problems. The Vassalboro technique of mandating the replacement of systems installed before 1974 would be met by public protest and be politically impossible in China (Pierz, pers. comm.). In conclusion, some septic systems are contributing to phosphorus

loading in China Lake and practical remediation techniques need to be employed to prevent the further degradation of water quality.

Most recently, China has begun to address grandfathered, non-compliant septic systems as a threat to water quality in China Lake. Officials in China have decided to take a different approach than Vassalboro. Before requiring the replacement of all non-compliant systems within the shoreline zone, inspectors will examine the existing leach fields and septic system designs to determine if untreated effluent is draining into China Lake. Currently, China is planning to issue a letter to shoreline residents asking for information to update the town records of septic systems. Owners of septic systems for whom the town does not have records will be asked for the following information in a letter (Pierz 2005):

- Type of septic system (i.e., leach field, stone bed, infiltrator or holding tank)
- Date of septic system installation
- Date the septic system was originally inspected by the town
- Copies of septic system plans or Subsurface Wastewater Disposal Application form (HHE-200)
- Copies of more recent inspection reports or any future septic system plans

These requirements will enable the town to group shoreline houses into three categories: compliant septic systems, grandfathered systems with a replacement plan, and malfunctioning systems or systems of people who do not respond (Pierz, pers. comm.). To address the people who have malfunctioning systems or do not respond, the town will hold a planning board meeting and may mandate the inspection of systems without permits or a replacement ordinance for non-compliant septic systems. The Town of China can take people who refuse to comply with this policy to court. CEAT recommends that China follows through with this plan of action and makes a significant effort to educate residents about how their septic systems can contribute to poor water quality.

Buffer Strips

Introduction

Vegetation along the shoreline is the last line of defense against runoff from the surrounding land. Buffer strips, vegetation between developed land and water, slow down and absorb storm water runoff, reducing the amount of nutrients and sediments entering the lake.

Depending on the depth from shore and composition of the buffer strip, as much as 70-95% of incoming sediments and 25-60% of incoming nutrients and pollution can be removed from the runoff (Dreher and Murphy 1996).

Lakes with intact buffer strips have fewer water quality problems than those with developed shorelines (MDEP 1998a). MDEP has increasingly concentrated on reducing sources of phosphorus and sediments in runoff by using Best Management Practices (BMP) as an alternative to expensive lake restoration treatments (MDEP 2003e). BMP and guidelines have been developed for landowners with recommendations to maximize buffer strip effectiveness (MDEP 1998a, 2003f).

Landowners can create buffers by allowing vegetation to regrow or by planting desired species. Native plant species should be used, as they have adapted to the local climate and require less maintenance. Buffers should be comprised of several vegetation layers to maximize effectiveness. The tree and shrub canopy layers reduce erosion by intercepting raindrops, and their root systems help absorb water and nutrients. The roots of groundcover plants also slow down and absorb runoff. The duff layer (accumulated plant matter) absorbs runoff and traps sediments (MDEP 1998a).

Buffer strip effectiveness will vary depending on the type of vegetation, the height of the vegetation, buffer depth from shore, type of soil, and slope (MDEP 2003f). Buffers on slopes >2% are usually less effective because the runoff travels relatively quickly so the vegetation cannot absorb as much (MDEP 1998a). Although any depth of natural vegetation will provide some benefits, the MDEP and Town of China mandate that buffer strips are preserved within 100 ft of a lake (MDEP 2003c, Town of China 2003; see Watershed Development: Shoreline Zoning).

Shoreline erosion is another source of nutrients and sediments. Riprap, consisting of large, loose stone, can be used to stabilize soil at the water- soil interface (MDEP 2003f). Riprap is often necessary on banks with steep slopes and little vegetation.

Methods

CEAT evaluated the buffer strip effectiveness of each China Lake shoreline residential lot on 22-Sep-05. Buffer strips were surveyed from boats, enabling a thorough assessment of each lot. GPS points were recorded for each lot and for the beginning and ending of undeveloped

shoreline using a Garmin GPS unit. These GPS points were used to map the location of each shoreline lot and undeveloped area.

Buffer strip effectiveness was evaluated based on the following parameters: percentage of the shoreline lot covered by vegetation, the depth of the buffer from the shore, the slope of the land from the shoreline to the residence, and the buffer composition (percentage of the shoreline lot covered by trees and shrubs/groundcover). Each parameter, broken into categories for the purpose of this study, was recorded on the Buffer Strip Survey Form (Appendix G). The lot shoreline distance was also recorded.

Each buffer strip parameter category was assigned a value. Each value was weighed according to its relative contribution to the overall buffer effectiveness. The percent of the shoreline lot with buffer and the buffer depth from shore were deemed to contribute the most to buffer effectiveness, and each were weighed 35% of the total score. The slope of the land was weighed 20% and the buffer composition 10%. The sum of these values was the buffer strip effectiveness score for each lot. Possible scores ranged from 5 (most effective) to 0 (least effective). Buffer effectiveness scores were broken into four classifications for data analysis: good (3.76-5.00), fair (2.51-3.75), poor (1.26-2.50), and unacceptable (scores 0-1.25).

Results and Discussion

CEAT surveyed the buffer strip effectiveness of 460 shoreline residential lots (data were not available for 12 shoreline lots). Of the lots surveyed, the buffer strips on 50 lots were rated good (11% of the total lots), 191 lots were rated fair (41%), 160 lots were rated poor (35%), and 59 lots (13%) were rated unacceptable (Figure 44). The buffer strips along China Lake seem to be more effective than those along some lakes CEAT has previously studied. Only 6% of the buffer strips on Togus Pond were rated good and 43% were rated unacceptable (CEAT 2005). Although 22% of the buffer strips on Threemile Pond on were rated good, close to a third (32%) were rated unacceptable (CEAT 2004).

Along China Lake, lots with good buffers tended to have vegetation along >75% of the shoreline and the buffer depth was usually >65 ft (Figure 45). On most lots rated as fair, >50% of the shoreline lot distance was buffered, but the buffer depth from the shore was <65 ft. Lots with poor buffers tended to have <25% of the shoreline buffered with only 1-10 ft deep buffers. Most unacceptable lots had very little or no buffer (Figure 46).

Buffer strip restoration on most lots should focus on increasing the buffer depth. The majority of lots (62%) have buffers that are only 1-10 ft deep, and increasing this depth would significantly increase the buffer effectiveness. Restoration should also focus on planting trees in buffer strips, as there was more shrub/groundcover than trees on most lots. Buffer strip restoration is critical because 56% of lots have <60 ft of shoreline, suggesting that lots are close together and development is highly concentrated.

Mapping the location of each shoreline lot with its corresponding buffer strip effectiveness score enables the identification of problem areas and may facilitate buffer restoration in these

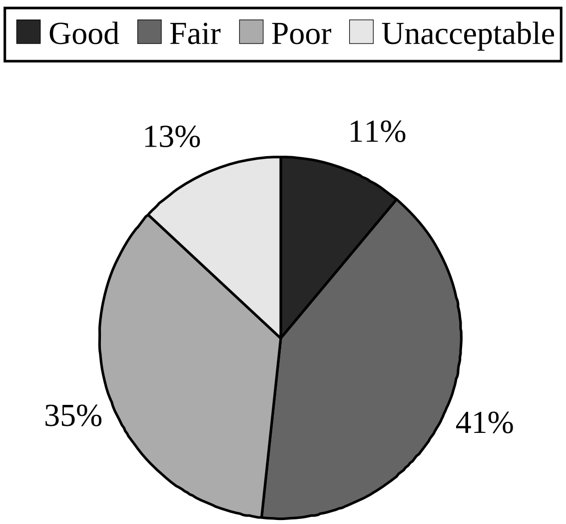

Figure 44. The percent of China Lake shoreline residential lots in each buffer effectiveness category. Buffer effectiveness was assessed by CEAT in the 22-Sep-05 shoreline survey.

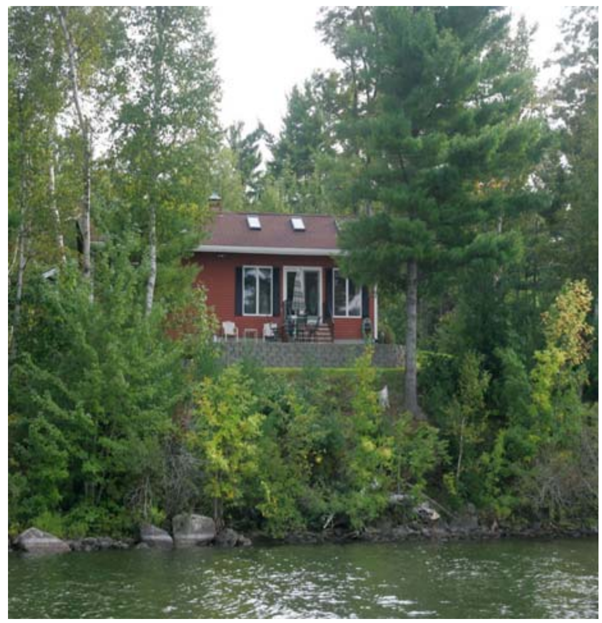

Figure 45. An example of a buffer strip that was rated as "good". Although the house is not set back an ideal distance, the buffer covers the entire shoreline and width of the lot and is comprised of multiple vegetation layers.

locations (Figure 47). Clusters of lots with unacceptable and poor buffer strips are potentially major sources of nutrients and should be prioritized for restoration. Poor buffer strips are clustered at the southern tip of the lake and on the northwestern shore. The cluster of unacceptable and poor buffers on the northeastern shore is of special concern because the shoreline lots are <60 ft. This area is highly developed and may be a concentrated source of

nutrients. Clusters of ineffective buffers are not unique to China Lake, and were also found on Togus and Threemile Ponds (CEAT 2004, 2005).

Figure 46. An example of a buffer strip on China Lake that was rated "unacceptable". The buffer strip is narrow, does not cover much shoreline distance, and is not comprised of multiple vegetation layers.

Lots with poor buffers probably exist in clusters because these areas were developed before the Mandatory Shoreline Zoning Act (see Watershed Development: Shoreline Zoning). These lots do not have the same buffer strip preservation and structure setback requirements as more recently developed lots. Because landowners in these areas are not legally required to improve their buffer strips, buffer strip restoration may rely on education about their benefits and the good will of the residents.

COMMERCIAL LAND USE

Introduction

Commercial and municipal properties within the China Lake watershed have the potential to increase phosphorus loading because of their high proportion of impervious surfaces. Rooftops, parking lots, and roads are impervious surfaces that do not absorb any sediment and when water passes over them they contribute nutrient runoff. Municipal buildings, especially schools, have potential for high nutrient loading through road, rooftop, parking lots, and septic system runoff. Septic systems connected to schools, especially those close to the lake, have a high potential to contribute nutrient runoff because schools are highly populated. Some commercial buildings also have the danger of leaking petroleum products, chemical, and toxic materials into the lake and surrounding watershed.

Methods

CEAT conducted surveys of the China Lake watershed, plotting all commercial and municipal land uses in the watershed with Geographic Information System (GIS) mapping.

Members of CEAT also spoke with the Code Enforcement Officers of China and Vassalboro (Scott Pierz and Betsy Fitzgerald, respectively) and school officials to determine past impacts of commercial and municipal land use on the watershed. Two commercial land uses that can potentially harm lake water quality are gas stations and sand and gravel pits.

Results and Discussion

Commercial land uses are numerous along state roads within the watershed. There are five gas stations which have the potential to leak petroleum products into the watershed: Lakeside Country Store, S&M Market, Emery's Meat and Produce, Frontier Village, and the Corner Market and Deli. The Lakeside Country Store is located in a Resource Protection District. Currently, a secure above ground tank for oil storage exists. When the old underground storage tank was removed 5-10 years ago, they exhumed a large amount of contaminated soil (Pierz, pers. comm.). S&M Market now has a new subsurface tank. In the late 1980s, the below ground gas tank was installed improperly and a gas plume infiltrated bedrock, seeping into the stream. The DEP tried to fix the problem by distributing water filters to houses located downstream from the contamination and extracting the contaminated soil. Emery's Meat and Produce and Frontier Village both have underground gas tanks and an above ground diesel tank that are located away from the shoreline. Corner Market and Deli had grandfathered subsurface tanks. Although they were not required to change old underground tanks, the tanks were recently upgraded.

The salt and sand storage is located on high ground, within a Resource Protection District on Route 3. In the past, salt was stored uncovered, but it now is in an enclosed structure. On Alder Park Road there is a transfer station with a capped landfill. Both sites must be maintained properly to prevent potential leaks of nutrients, chemicals, and other pollutants. The China landfill was ordered to be closed in the late 1980s and closed in the early 1990s by the DEP (Pierz, pers. comm.). There are monitoring wells around the site, but the DEP has ultimate responsibility for monitoring the site. There is no record that the town has periodically monitored the site, nor have there been any reports of leaks about the perimeter of the landfill (Pierz, pers. comm.).

A number of other commercial land uses make potential runoff contributions to the lake and potentially leak petroleum products into the watershed, including auto repair shops, fire stations, car sales lots, and other machine related businesses. The constant traffic caused by restaurants and other small businesses also contributes to runoff into the watershed.

Schools are predicted to be the largest contributor to phosphorus loading in the municipal sector. In total, there are 600 students and teachers in public schools within the China Lake watershed (Pierz, pers. comm.). School is in session for 180 days, limiting stress to certain parts of the year. China Primary (grades K-4) has 270 students. China Middle School (grades 5-8) has 280 students and is located next to the lake on Lakeview Drive. The septic system for the Middle School is older and only known to consist of some type of leach field, and a "custom-built" poured-in-place septic tank of very large capacity (Pierz, pers. comm.). The Primary School septic system was built in the early 1990s and is thought to comply with Maine Septic System regulations (Pierz, pers. comm.).

Moisture and air quality problems exist at China Middle School. There is talk of building a new school or adding a new addition onto the existing elementary school (Pierz, pers. comm.). A new addition to the elementary school would increase use of the septic system by about 300 people, creating an extra stress.

Erskine Academy is a private school located within the watershed, approximately 1.5 mi from the lake. The school has 745 students attending for 175 days of the year. This school maintains a leach field and a tank that is pumped every year (Pierz, pers. comm.).

The necessity to monitor business practices and enforce laws and regulations relating to development has been demonstrated by past commercial land uses, such as leaking petroleum products into the watershed. Municipal land uses, like school septic tanks, must also be monitored to ensure nutrient loading is minimized.

ROAD SURVEY

Introduction

Roads within the China Lake watershed have the potential to be one of the largest contributors of phosphorus to the lake. Typically, poor road construction and maintenance account for 85% of all erosion and sedimentation problems in lake watersheds, leading to large amounts of pollution in surface waters (KCSWCD 2000). Although erosion and sedimentation from roads can result in unfavorable water quality, the majority of road problems can be

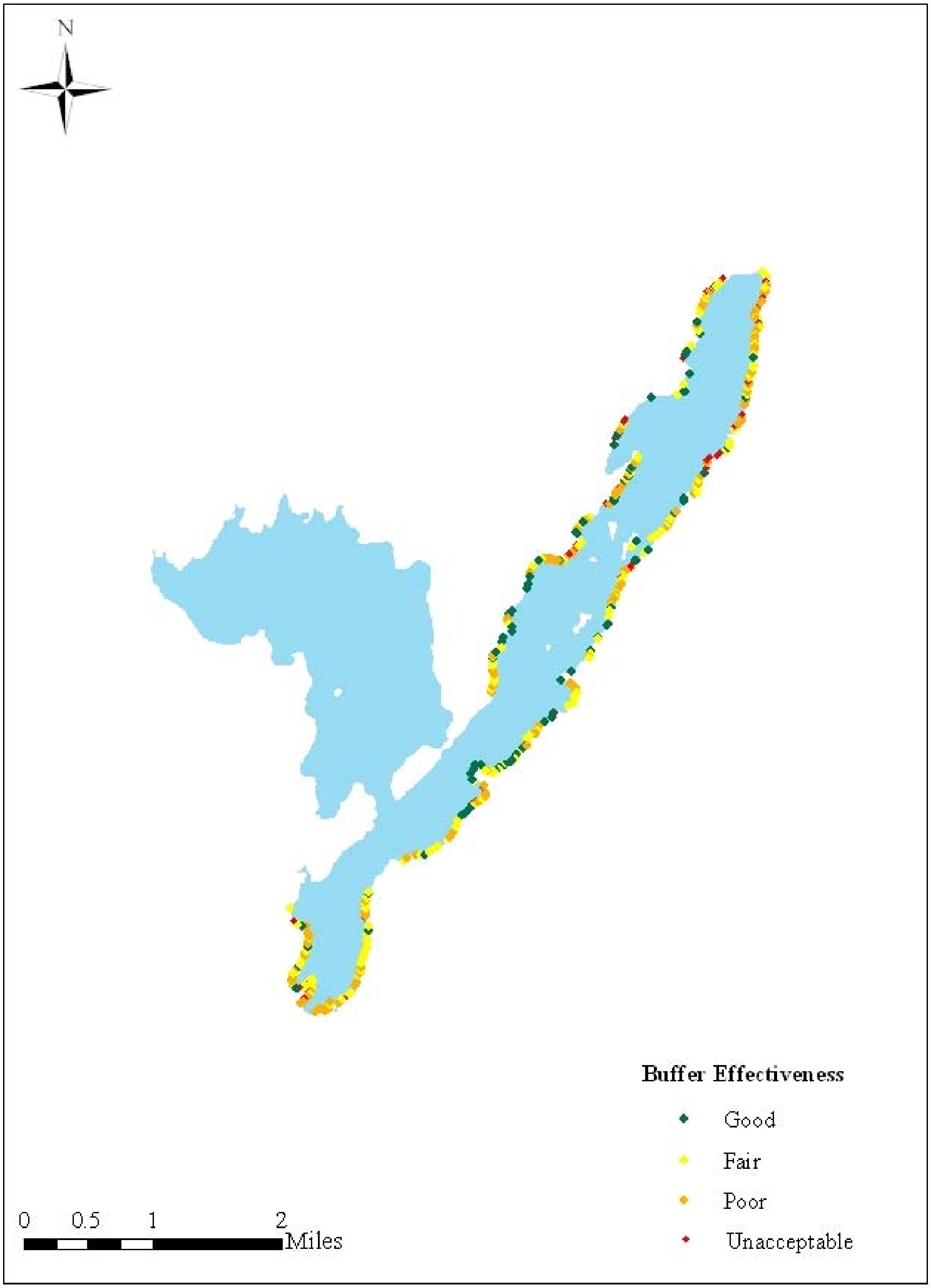

Figure 47. The buffer strip effectiveness along the China Lake shoreline. Buffer effectiveness was determined by CEAT based on the 22-Sep-05 shoreline survey (see Watershed Development: Buffer Strips, Appendix G). Points correspond to individual residential lots.

prevented with proper care. The MDEP found that the cost of preventing water pollution is less than the cost of trying to restore an already damaged waterbody, and more feasible (MDEP 2004a).

A large number of camp, state, and municipal roads exist within the China Lake watershed. Road construction materials can greatly affect the amount of soil erosion a road adds to a lake (see Background: Roads). Because of their proximity to the shoreline, camp roads represent the greatest source of potential sediment loading and runoff into the lake. Alternatively, many camp roads may be maintained at a lower level if they belong to seasonal residents and are primarily used in the summer. Driveways that extend from camp roads can be problematic because they may be even closer to the water. When the sediment is able to run directly into a lake or stream it negatively affects turbidity, phosphorus levels, and lake biota (see China Lake Characteristics: Biological Perspective).

In the State of Maine, three laws exist pertaining to camp road maintenance and construction. The Erosion and Sedimentation Control Law states that before any activity that may disrupt the soil occurs, erosion-preventing devices must be installed until the site is permanently stabilized (KCSWCD 2000). The Natural Resources Protection Act (NRPA) requires a permit from the Department of Environmental Protection (DEP) before beginning any activity in, on, over, or within 100 ft of lakes, streams, and other bodies of water. Examples of activity include dredging, draining, removing or displacing vegetation, disturbing the soil, filling, and building permanent structures. The Mandatory Shoreland Zoning Act regulates development along shorelines and requires towns to zone all areas within 250 ft of lakes, rivers, tidal areas, wetlands, and certain streams to protect the water (KCSWCD 2000).

Methods

To determine which roads have a significant impact on water quality of China Lake and may need repair, CEAT collected relevant data for every road within the watershed. To assess all roads within the China Lake watershed, the watershed was divided into ten sectors, each of which was evaluated by two surveyors on 3-Oct-05 and 20-Oct-05. The data collected varied depending on the road type and location. Camp roads and roads that ran next to the lake were measured for length, width, crown, and slope. Data were collected on any culverts, ditches, or diversions seen on a road. A GPS point was taken at the start and end of each road and wherever

a problem existed. State and municipal roads located away from the lake were not surveyed as extensively. Instead, the data collected included road length and width, GPS at the start and end, and a house count.

Camp roads and roads next to the lake were given an overall condition rating of good, fair, poor, and unacceptable. The qualitative nature of this study was taken into consideration during analysis of road quality. Two members of the CEAT team reviewed the rating of every road that was evaluated to minimize discrepancies. A good road had no problems, a fair road had minor problems, a poor road had a few significant problems, and an unacceptable road had several significant problems. Based on the data collected, CEAT was able to identify the problematic roads and estimate the total contribution roads make to the phosphorus budget for the watershed (see Phosphorus Budget).

Results and Discussion

After surveying all of the roads within the China Lake watershed, the roads were divided into three categories used for analysis: camp roads, state/municipal roads, and other roads, which included driveways, inaccessible roads, and some farm roads. Camp roads cover 24.5 mi, state/municipal cover 43.8 mi, and other roads cover 1.6 mi for a total of 69.9 mi. Of the total mileage, 59.5 mi of road are considered shorefront, with part of the road coming within 200 ft of the lake.

It is important to determine the area of watershed covered by roads to understand their relative importance to phosphorus loading. Camp roads covered 18.0 ha (44.5 acres), state/municipal roads covered 58.6 ha (144.7 acres), and other roads covered 1.2 ha (3.0 acres) for a total of 77.8 ha (192.2 acres).

CEAT used GIS to locate specific problems found on the roads (Figure 48, 49, and 50). Not all state/municipal roads received a condition rating because they are hard surfaced, regularly maintained, and many of them were not located close enough to the lake to have a significant impact on lake water quality. All of the state/municipal roads that were rated fell into the categories of good or fair, but the system used by CEAT did not focus on detailed evaluation of these roads. Although the majority of camp roads were rated fair, the remaining camp roads accounted for almost all of the poor and unacceptable roads within the watershed. CEAT determined the percent of shoreline camp roads that fell into each overall rating category and found that over one third of the shoreline road acreage fell into the poor or unacceptable category

(Figure 51 and 52). Most of the acreage covered by shoreline camp roads is in relatively good condition.

The most frequent problem recorded was erosion, which in most cases can be alleviated by the addition of diversions, ditches, and crowning. Culverts also seemed to be clogged in some areas, which can be easily remedied by clearing out the debris (Figure 53). All of these problems were located on camp roads since they were the primary focus of the road survey.

One of the explanations for more problems existing on camp roads is that they are privately owned and maintained, whereas the State of Maine and municipalities are responsible for state and municipal roads, respectively. Road maintenance can potentially be very costly when it entails constructing culverts, ditches, resurfacing, or any other tasks that require the work of someone with proper experience and equipment. It is important to check existing culverts, ditches, and diversions regularly to assure that they are clear of debris and water is flowing appropriately. The best time to check a road for problems is on, or shortly following, a rainy day. When there is water flowing down the road it is easier to assess quality and effectiveness of roads, culverts, diversions, and ditches. Continually having to repair roads that wash out is a waste of time and money, and does not solve the problem. Beneficial maintenance should minimize or eradicate recurring problems (MDEP 2004b).

All of the problems located within the watershed were found in the Town of China. These roads have been listed alphabetically and are accompanied by suggested remediation techniques. Alleviation of camp road problems could have a great impact on reducing nutrient loading into China Lake.

Camp Road Problems:

Austin Lane

Problem(s): Erosion on slope of road.

Remediation: Add water diversion and ditch.

Fire Road 1

Problem(s): Water flows towards lake where road curves and next to stream.

Remediation: Add water diversion at curve and enhance water barrier next to stream.

Fire Road 12

Problem(s): Severe erosion and ruts on the steep section of the road.

Remediation: Add water diversion and ditch. Re-crown road and fill in ruts.

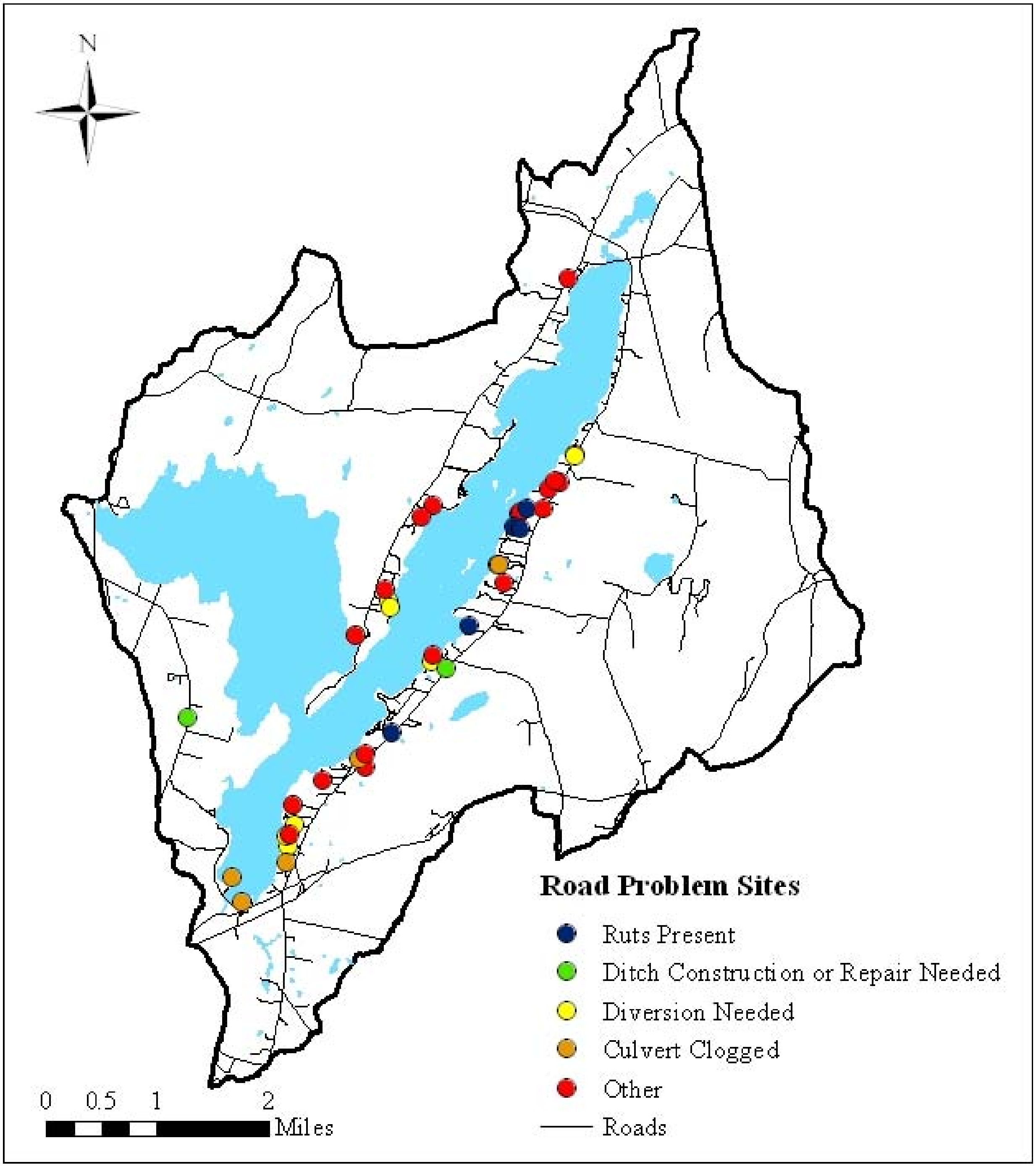

Figure 48: Problem sites identified by CEAT during 3-Oct-05 and 20-Oct-05 road surveys added to a MEGIS map of roads in the China Lake watershed (MEGIS 2005).

Figure 49. A highly eroded road, rated as "unacceptable" (left). A clogged culvert that is not allowing water to flow properly (right).

Figure 50. Example of a well constructed and vegetated ditch used to help water drain away from road.

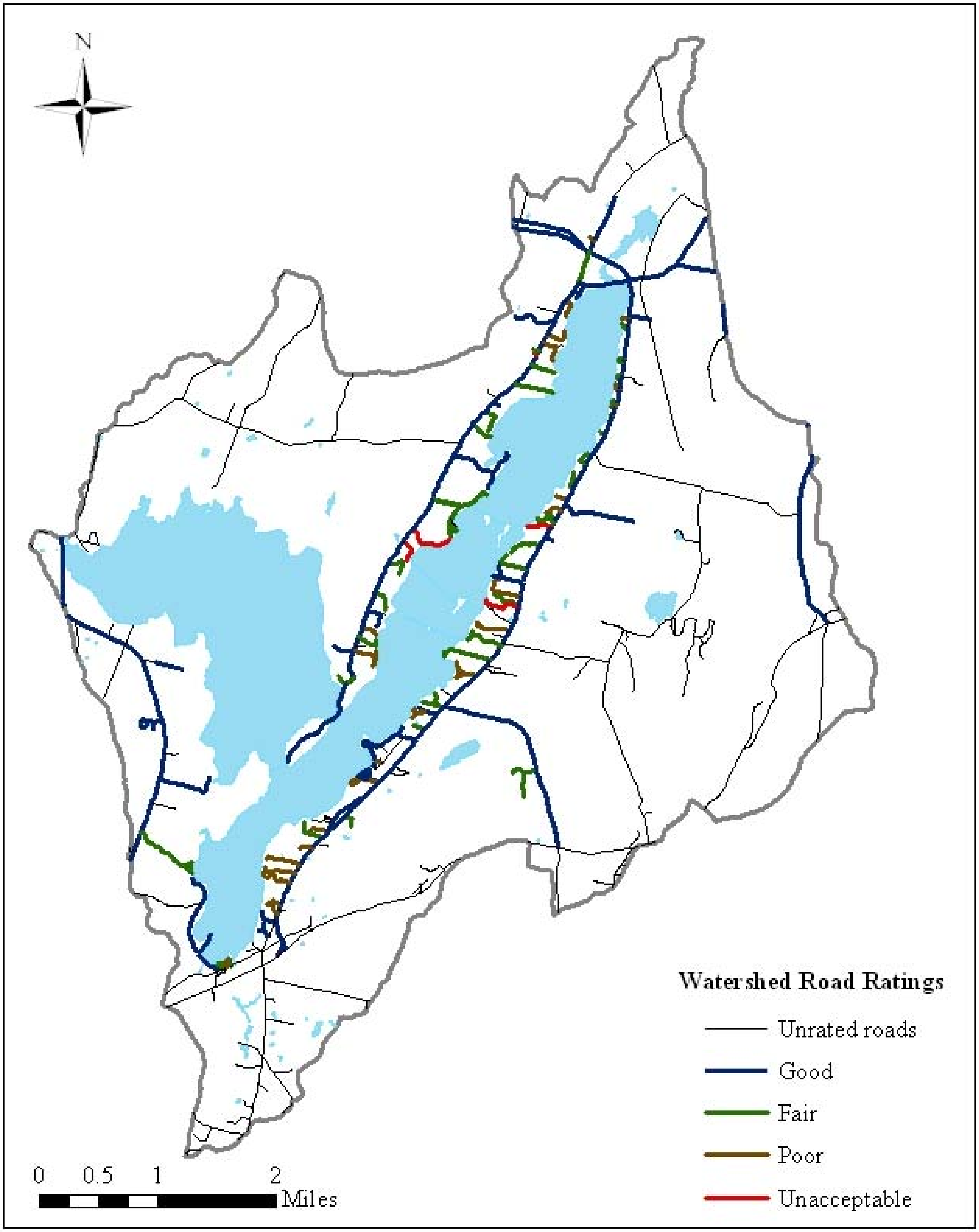

Figure 51: China Lake watershed roads (MEGIS 2005) and the ratings assigned to these roads by CEAT based on 3-Oct-05 and 20-Oct-05 road surveys. Watershed roads far from China Lake were not rated due to their low contribution to potential nutrient loading.

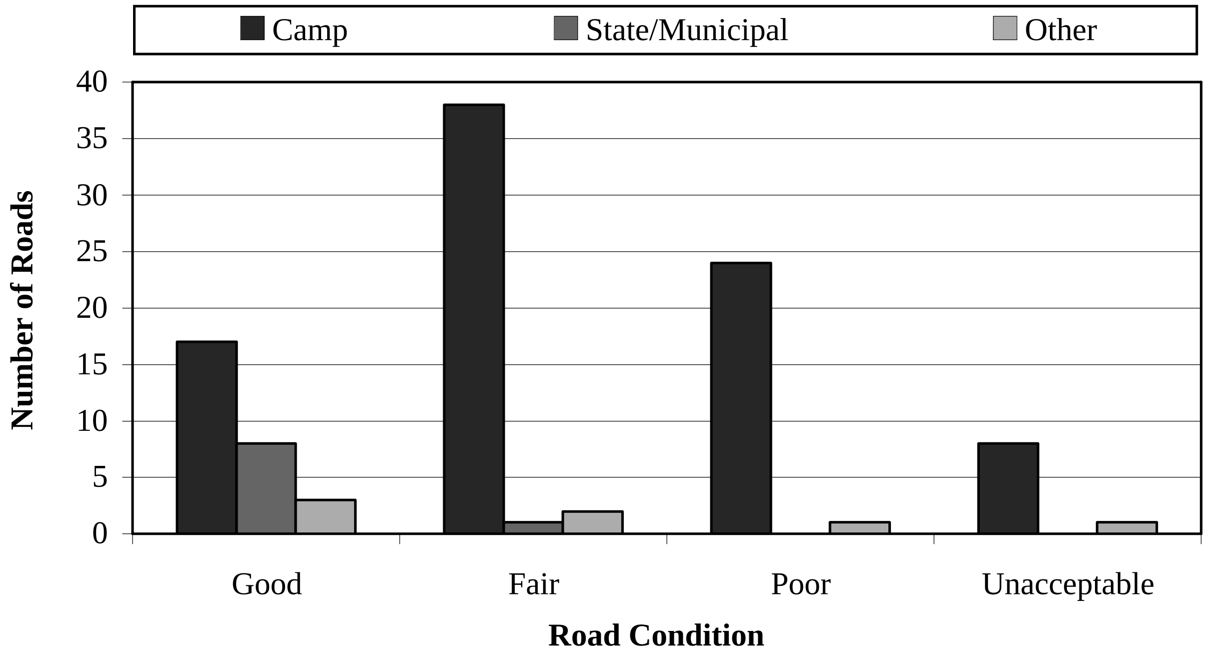

Figure 52. Road types and condition ratings for roads within the China Lake watershed. Roads were surveyed by CEAT on 3-Oct-05 and 20-Oct-05.

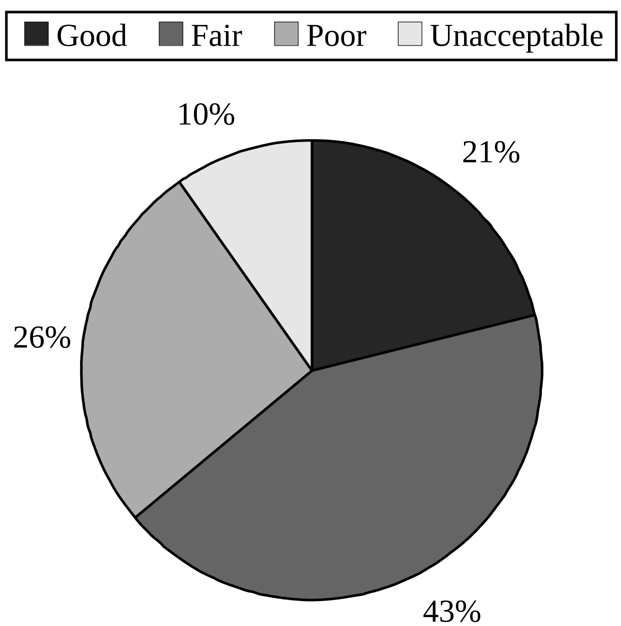

Figure 53. Percents of shoreline camp road area (acres) categorized by condition. Roads were surveyed by CEAT on 3-Oct-05 and 20-Oct-05.

Fire Road 13

Problem(s): Top of road is fine but there is erosion on the hill.

Remediation: Add water diversion.

Fire Road 16

Problem(s): Road is severely eroded and has huge rut down left side. The crown is really high and grassy.

Remediation: Add water diversion and ditch to divert water into woods.

Fire Road 18

Problem(s): Boat launch allows gravel to wash directly into lake. Road has lots of potholes and erosion.

Remediation: Add water diversion that

directs runoff into vegetated area. Fill in potholes and re-crown road.

Fire Road 29

Problem(s): Berm exists on side of road away from the lake. Little buffer preventing runoff into lake.

Remediation: Eliminate road berm and add water diversion or ditch to prevent water from reaching lake.

Fire Road 32

Problem(s): High, grassy crown and some erosion along road.

Remediation: Re-crown road and maintain already existing water diversion.

Fire Road 33

Problem(s): Road lined with berms causing large erosion ruts, loose rocks, and dirt.

Remediation: Eliminate berms and re-crown road.

Fire Road 34

Problem(s): Very minor ruts going down road and erosion at top of road.

Remediation: Add diversion at top of road to direct and slow water flow.

Fire Road 35

Problem(s): Very minor ruts going down road on right side, causing berm to form.

Remediation: Eliminate berm and add diversion at bottom of road.

Fire Road 38

Problem(s): Steep section of road is highly eroded and has ruts. Culvert is slightly clogged.

Remediation: Repair road crown and clear culvert.

Fire Road 44 and driveway located off road

Problem(s): Minor erosion at top of road and high crown. Driveway is eroding and runs towards lake.

Remediation: Repair crown of road. Add diversion near driveway.

Fire Road 45

Problem(s): Road is eroded, has ruts at the top, and a high crown. When road splits to the right, there is a high crown and erosion.

Remediation: Add water diversion where road is eroding and repair crown.

Fire Road 49

Problem(s): Road is fairly eroded, has ruts, and grass crown is very high.

Remediation: Repair road crown

Fire Road 51

Problem(s): Berm is preventing water from entering already existing ditch and preventing water diversion from working properly. Crown is very high and grassy.

Remediation: Eliminate road berm and re-crown road.

Fire Road 53

Problem(s): Culvert is clogged with debris and road is eroding down the sides.

Remediation: Remove debris from culvert, add water diversion, and re-crown road.

Fire Road 54

Problem(s): Erosion of road down slope.

Remediation: Add water diversion.

Fire Road 55

Problem(s): Water does not flow properly at steep turn.

Remediation: Add water diversion near steep turn.

Fire Road 58

Problem(s): Culvert empties directly into lake and is partially clogged.

Remediation: Clear debris from culvert and redirect waterflow.

Fire Road 61A

Problem(s): High density of houses directly on shoreline with steep slope towards lake.

Remediation: Add water diversions to direct water away from shoreline or add buffer at end of driveways.

Land’s End- Driveway A

Problem(s): Culvert empties into large gully that eventually flows into lake.

Remediation: Add retaining structure to prevent water from directly ending up in lake.

Notapine Road

Problem(s): Side of road is highly eroded.

Remediation: Add water diversion for water collected in ditch.

Pond Road

Problem(s): Culvert is crushed and partially clogged.

Remediation: Rebuild culvert and clear debris.

WATER BUDGET

INTRODUCTION

A water budget is used to calculate the flushing rate of a lake, which is a measure of how often the total volume of water in the lake is replaced, and is inversely proportional to residence time. By measuring the inputs and outputs of the lake, it is possible to track the movement of nutrients into and out of the lake. A lake with a flushing rate equal to one will fully replace its total volume in one year. The flushing rate can provide some indication of the recovery or self-purification rate of lakes (Chapman 1992).

A water budget is important in assessing the physical and chemical features of a lake. Lakes that have large watersheds or many inputs from other ponds, rivers or streams will have more water volume flowing in, and more out-flow volume. Flushing rate is directly tied to nutrient loading capacity. Lakes have low flushing rates compared to rivers and streams, which are constantly replenishing their water volume. A lake is more vulnerable to the accumulation of pollutants and nutrients both in its water column and in its organisms than a river or stream (Chapman 1992). Low flushing rates exacerbate nutrient loading problems and accelerate eutrophication because the water is not replenished often enough to prevent accumulation of nutrient-rich runoff from the watershed, leading to increased amounts of nutrients in the sediments.

METHODS

In calculating a water budget the following formulas were used:

$$I_{net} = (\text{runoff}^* \text{ land area}) + (\text{precip.}^* \text{ lake area}) - (\text{evaporation}^* \text{ lake area})$$

$$\text{Flushing rate} = I_{net} / (\text{mean depth}^* \text{ lake area})$$

The water level in China Lake is not static throughout the year. In fact, it is adjusted seasonally and controlled at the dam in Vassalboro (see Historical Trends). Rainfall and runoff are not consistent throughout the year, but over the course of many years, a mean approximates what is typical during a given year. I_{net} is the net increase in water in the lake each year contributed from direct precipitation into the lake as well as the watershed runoff. It is based on

rainfall average that was taken as a 10-year mean calculated using NOAA rainfall data collected at the Augusta airport from June 1995 through May 2005 (NOAA 2005). The other factors used in calculating I_{net}, runoff and evaporation rates, were obtained from the North Kennebec Regional Planning Commission (NKRPC unpublished data) and a U.S.G.S. study of the Lower Kennebec River Basin, respectively (Prescott 1969). Runoff is the mean rate of water flow off land, and the evaporation is a mean of water evaporating from the surface of the water.

Using ArcGIS®9.0 GIS maps obtained from MEGIS, CEAT calculated the boundary of the watershed and its land area, as well as lake area. A mean depth was also calculated using our ArcGIS®9.0-created bathymetry map (CEAT 2005).

RESULTS AND DISCUSSION

The first step in calculating a water budget is to determine I_{net}, the rate at which water flows into the lake, taking into account rainfall and runoff from the land in the watershed, and precipitation and evaporation from the lake surface. The figures used to calculate I_{net} are listed in Appendix D. Using these data, the I_{net} was calculated to be 59,356,148 m^3 per year. This represents the volume of water contributed by the runoff over the watershed area plus the precipitation over the lake area minus the evaporation that comes off the lake area over the course of one year. Using this I_{net}, it was possible to then calculate the flushing rate for China Lake, which is 0.35 flushes per year. This means that in 12 months, China Lake only replaces 35% of its water volume. In relation to other lakes in the Kennebec River Basin, this flushing rate is very low (Figure 54). Lakes with low flushing rates are less able to wash away nutrients flowing in from the watershed, and are particularly vulnerable to even slight amounts of external nutrient loading. Furthermore, nutrients in the water column, along with decaying organic matter, and any pollutants sink to the bottom, rather than be swept away, to become part of the sediment. This fact increases contributions of phosphorus from the sediments in China Lake.

The problems that China Lake faces are not solely caused by its low flushing rate. There is no concrete relationship between water quality and flushing rate, because there are so many other factors involved. However, a low flushing rate can exacerbate some of these problem factors, especially by accelerating the accumulation rate of organic sediment and because the lake will not be able to flush out nutrients released from the sediment into the lake water.

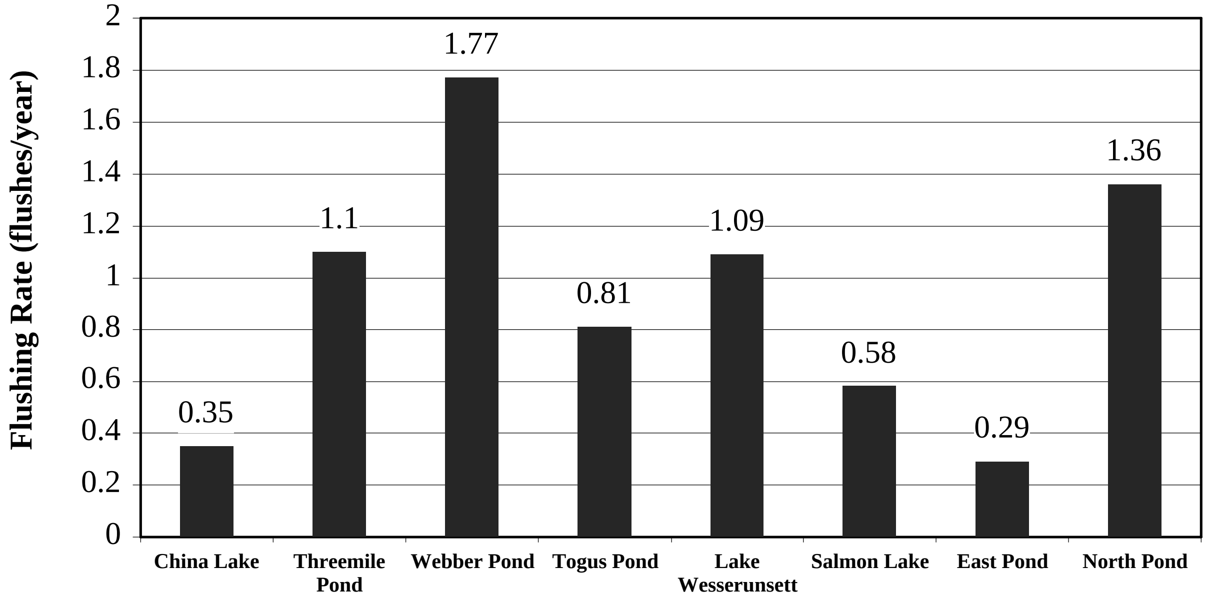

Figure 54. Flushing rate of China Lake and seven other lakes in the Kennebec Valley. All but China Lake were taken from previous Colby Environmental Assessment Team studies (CEAT 1997, 2000, 2001, 2003, 2004).

PHOSPHORUS BUDGET

INTRODUCTION

A phosphorus loading model was used to estimate the total amount of phosphorus entering China Lake from specific sources in the China Lake watershed. This model helped to identify problem sources of phosphorus loading in the watershed, and was a critical tool in assessing overall water quality as well as developing strategies to address water quality problems. The model was also used to project changes in phosphorus input to the lake as a result of potential future land use change and population growth.

METHODS

The model used for China Lake was adapted from Reckhow and Chapra (1983), as well as from past studies on similar regional lakes (CEAT 2000, 2003, 2004, and 2005). The amount of phosphorus entering the lake from various sources within the watershed was determined using the following equation:

$$\mathbf{W = (Ec_a \times A_s) + (Ec_{mf} \times Area_{mf}) + (Ec_{cp} \times Area_{cp}) + (Ec_p \times Area_p) + (Ec_g \times Area_g) + (Ec_w \times Area_w) + (Ec_{rl} \times Area_{rl}) + (Ec_{cm} \times Area_{cm}) + (Ec_{cr} \times Area_{cr}) + (Ec_{sr} \times Area_{sr}) + (Ec_s \times Area_s) + (Ec_n \times Area_n) + [Ec_{ss} \times \#capita\ years \times (1\text{-}SR_1)] + [Ec_{ns} \times \#capita\ years \times (1\text{-}SR_2)] + [I_A \times (1\text{-}SR_{3A})] + [I_B \times (1\text{-}SR_{3B})] + [I_C \times (1\text{-}SR_{3C})] + (Sd \times A_b)}$$

W represents the total mass of phosphorus entering China Lake in kg/year. The Ec terms represent the export coefficients for the various land use types, measured in kg/ha/year. The export coefficient indicates the degree to which that land use type typically contributes phosphorus to the lake through runoff (see Appendix E). Phosphorus inputs included in this model are: atmosphere (a), mature forest (mf), cropland (cp), pasture (p), grassland (g), wetland (w), reverting land (rl), commercial and municipal land (cm), camp roads (cr), state and municipal roads (sr), shoreline development (s), non-shoreline development (n), shoreline septic system (ss), and non-shoreline septic system (ns). I_A, I_B, and I_C represent the amount of phosphorus released by institutions within the watershed (see Appendix E). I_A corresponds to China Primary and Middle Schools collectively, I_B corresponds to Erskine Academy, and I_C corresponds to Friends Camp, a residential summer camp. SR_1 and SR_2 indicate the soil retention capacity for phosphorus of shoreline and non-shoreline soils, respectively. SR_{3A}, SR_{3B},

and SR_{3B} indicate the soil retention capacity at the location of the three institutions. A_s represents the surface area of China Lake. This area, as well as areas for the various land use types, was obtained using DOQs of the China Lake watershed and ArcGIS® 9 (see Watershed Land Use Patterns: Methodology). Sd represents the amount of phosphorus released from sediments at the bottom of China Lake, and A_b represents the surface area of the lake bottom.

To calculate the input of phosphorus from septic systems, the export coefficients for shoreline and non-shoreline septic systems were multiplied by the number of capita years and by one minus the coefficient values for soil retention. The capita year variable reflects the number of people per household and the amount of time the household is occupied each year. The average number of people per household was obtained from the 2000 U.S. Census for the Town of China. Capita year values for seasonal residences are lower, as seasonal homes are occupied for fewer days per year than year-round homes, and contribute lower amounts of phosphorus per year. It was estimated that seasonal residences are occupied 95 days per year (Pierz and Van Bourg, pers. comm.), and year-round residences are estimated to be occupied 355 days per year (CEAT 2005).

High, low, and best estimate export coefficients were assigned to each source of phosphorus. The coefficients were based on the phosphorus loading model by Reckhow and Chapra (1983), past studies from similar watersheds in the region (CEAT 2001, 2003, 2004, 2005), and the 2001 Total Maximum Daily Load Report for China Lake (MDEP 2001). The high and low estimates are meant to accommodate uncertainty in phosphorus loading estimates. The best estimate is the value that CEAT believes is the most accurate depiction of phosphorus inputs within the established range.

RESULTS AND DISCUSSION

The phosphorus loading model predicted a range of 1210 kg/yr to 5716 kg/yr of phosphorus entering the lake from external sources, with our best estimate being 2597 kg/yr. When sediment release (an internal source of phosphorus) was accounted for, the model predicted a range of 2814 kg/yr to 8283 kg/yr of phosphorus entering the lake from both external and internal sources, with our best estimate being 4843 kg/yr. The best estimate for total phosphorus concentration was calculated to be 18.8 ppb, with a range of 10.9 ppb to 32.2 ppb. These calculated phosphorus concentrations include phosphorus released from the sediments,

which contributed greatly to the total phosphorus concentration of China Lake. Our best estimate of the phosphorus concentration from the model corresponds with the mean phosphorus concentration determined for surface, middle, and epicore samples for summer and fall 2005 (mean ± SE; 18.8 ± 1.0 ppb, n = 62). Our high estimate corresponds with the mean phosphorus concentration for surface, middle, epicore, and bottom samples for the summer and fall (30.0 ± 3.8 ppb, n = 84). Since the phosphorus concentration on the bottom of the lake (summer and fall 2005 mean ± SE; 61.8 ± 11.8 ppb, n = 22) was much higher than the concentration at all other levels, we felt that the lower estimate (our best estimate) most accurately represented the total phosphorus concentration of the majority of the water in China Lake.

The release of phosphorus from the bottom sediments was by far the largest contributor of total phosphorus to China Lake. Our best estimate predicts that 46% (2,246 kg/yr) of the total kg/yr of phosphorus in China Lake is due to sediment release. This estimate is consistent with previous estimates of internal lake sediment phosphorus loading for years in which algal blooms were experienced (mean = 2,553 kg/yr) (MDEP 2001).

Phosphorus loading from external sources accounted for 54% (2,597 kg/yr) of total phosphorus within China Lake. Of all external sources of phosphorus, agricultural uses, mature forest, shoreline development and septic systems, and atmospheric deposition contributed the greatest amounts of phosphorus (Table 8).

The largest source of external phosphorus contribution to China Lake was open land (cropland, pasture, and grassland collectively). According to our best estimate, cropland and pasture accounted for 23% (601 kg/yr) of the total phosphorus from external sources within China Lake. Although cropland represents a small area (0.02%) of the China Lake watershed, relatively high amounts of phosphorus can flow into the lake from fertilizers applied to the land. Pasture has a much lower phosphorus export coefficient than cropland (see Appendix E). However, since pasture accounts for roughly 10% of the land within the watershed, the estimated total amount of phosphorus exported into China Lake is relatively high (Table 8).

Mature forest is the largest land use type within the watershed, accounting for 62% of the total land area. Mature forest exports very little phosphorus per area because the full canopy slows the velocity of rain, reducing the impact of rain on the underlying soil, and the roots help to hold soil in place and take up nutrients (see Appendix E). Although the phosphorus export coefficient for mature forest is very low, its large area makes mature forest the second largest

contributor of phosphorus from an external source, contributing 431 kg/yr, or 16.6%, according to our best estimate (Table 8).

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

Input Categories	Low Estimate (%)	Best Estimate (%)	High Estimate (%)
Atmospheric	13.3	9.3	7.0
Agricultural			
Cropland	1.2	8.3	7.7
Pasture	20.3	14.8	16.6
Camp roads	1.6	2.5	2.4
Commercial	5.6	6.8	7.1
Grassland	2.7	2.6	2.1
Institutional			
China Schools[a]	5.9	6.5	5.8
Erskine Academy	1.9	2.6	2.5
Friends Camp	0.2	0.2	0.2
Mature forest	17.8	16.6	11.3
Non-shoreline development	7.7	5.4	12.2
Non-shoreline septic	2.1	3.3	3.4
Reverting land	3.8	2.7	3.2
Shoreline development	4.0	6.6	5.0
Shoreline septic systems	7.6	6.8	6.7
State and municipal roads	3.4	4.1	6.1
Wetlands	1.1	1.0	0.9

[a] Includes China Primary School and China Middle School

Together, shoreline development and shoreline septic systems accounted for 350 kg/yr of phosphorus or 13.5% of the total phosphorus in China Lake from external sources, according to our best estimate (Table 8). Although shoreline lots account for only about 0.01% of the total land within the watershed, this small amount of land can have a large impact on water quality. Water running off lawns, roofs, and other surfaces can carry phosphorus directly into the lake if buffer strips are not adequate (see Background: Watershed Land Use: Buffer Strips). Septic systems built close to the waters edge or in unsuitable soil types can lead to the movement of nutrients from septic systems into the lake (see Appendix E).

Atmospheric deposition of phosphorus into the lake accounted for 9.2% (241 kg/yr) of the total phosphorus entering China Lake from external sources (Table 8). Phosphorus is a by-

product of industrial production and wood-burning stoves among other things. Once released into the atmosphere, the phosphorus can be deposited into the lake through precipitation (Reckhow and Chapra 1983). The high contribution of phosphorus from atmospheric deposition reflects the large surface area of the lake, as well as the ability of phosphorus particles in the atmosphere to travel long distances before deposition (Reckhow and Chapra 1983).

Our best estimate of the total phosphorus entering China Lake from sediments and external sources is 4,843 kg/yr, resulting in a concentration of 18.8 ppb. In order to reduce the concentration of phosphorus to 15 ppb, the threshold for algal blooms (see Background), the total amount of phosphorus entering the lake would need to be reduced to approximately 3,850 kg/yr, a reduction of nearly 1,000 kg/yr. Part of this reduction could be made by improving the quality of buffer strips and septic systems around the lake to reduce the external load. However, without addressing internal phosphorus loading, it would be extremely difficult to meet this goal. For example, even if phosphorus input from roads, septic systems, and residential development could be reduced by 50%, the total phosphorus loading would only be reduced by 373 kg/yr of phosphorus, roughly one third of the amount necessary to lower the concentration of phosphorus within the lake to 15 ppb. In addition to external phosphorus loading, internal phosphorus loading from the sediments must be addressed if this goal is to be met, since internal phosphorus loading accounts nearly half of the total phosphorus within China Lake (46%).

LAKE REMEDIATION TECHNIQUES

INTRODUCTION

Remediation is required to help lakes recover from accelerated eutrophication. Lake remediation is the process of improving degraded lake ecosystems through in-lake treatment (Fast 1979). Lakes that have been subjected to heavy development often require remediation to preserve the residential and recreational value of a lake, and return water quality to an acceptable level.

The remediation techniques that are discussed in this section offer varied options to mitigate lake quality, and can be separated into three major groups. Physical manipulation techniques include water drawdown, hypolimnetic withdrawal, dilution, hypolimnetic aeration, dredging and aquatic plant harvesting. Chemical manipulation techniques include alum treatment, ferrous treatment, calcium additions, algicides and herbicides. Biological manipulation techniques consist of the manipulation of fish stocks, wetland maintenance and manipulation, and the addition of exotic plants. The final method of lake remediation is biological manipulation. A summary of the options most suitable for China Lake that have become apparent through the examination of these manipulation techniques can be found in Appendix I.

COMMONLY USED REMEDIATION TECHNIQUES

Physical Treatments

Water Removal Techniques

Hypolimnetic Withdrawal

The water in the hypolimnion of stratified lakes has the least amount of dissolved oxygen, and as a result, is the most susceptible to the release of phosphorus, toxic metals, and hydrogen sulfide from the sediment (Cooke et al. 1993). To combat this tendency, it is possible in some lakes to draw water out of the hypolimnion to let some of the most nutrient-rich water to escape from the lake. A 1994 analysis of China Lake claimed that three times as much phosphorus was contributed by the sediments than from external loading (Walker 1994). This does not agree with our findings (see Phosphorus Budget), however, it is clear that to stop algal blooms,

reducing external phosphorus loading will not be sufficient. Reducing the amount of phosphorus in the hypolimnion will usually lead to a reduction in the amount of phosphorus in the epilimnion as well. Hypolimnetic withdrawal can be an effective long-term remediation technique for slowing the eutrophication process of a lake, and may retard or possibly eliminate algal blooms.

Hypolimnetic withdrawal systems do not work in all lakes. A pipe must be installed to run from the hypolimnion out into the outlet of the lake. Lakes with dams have successfully utilized this method because the dam allows the maintenance of the proper pressure differential to keep the flow constant (Cooke et al. 1993). The level of the lake can be manipulated to selectively draw water from the hypolimnion when appropriate, especially in times of anoxia. An alternate method of hypolimnetic manipulation involves channeling the inflows to the lake directly into the hypolimnion, rather than allowing them to flow into the epilimnion. The idea behind this method is that by bringing oxygenated stream water into the hypolimnion, the amount of dissolved oxygen would increase, and internal phosphorus loading would decrease (Cooke et al. 1993). By running a pipe from the inlet directly into the hypolimnion, preferably into the deepest part of the lake, the length of anoxia and total hypolimnetic phosphorus levels can be greatly reduced.

In Lake Wononsopomuc in Connecticut, hypolimnetic withdrawal was successful in eliminating algal blooms (Nürnberg et al. 1987). A pipe was installed into the hypolimnion at a depth of 15 m, carrying 0.9 m^3 of oxygenated stream water per minute. With such a high volume of inflow, the hypolimnion volume was totally replaced in just 5.6 months. After five years, the hypolimnetic phosphorus had decreased from 400 μg/L to under 50 μg/L, and surface phosphorus had decreased from a range of 24-30 μg/L to 10-14 μg/L. This decrease was sufficient to stop blooms of *Oscillatoria rubescens.* The dissolved oxygen levels increased, dropping the number of anoxic days from a range of 50 to 65 days to less than 30 days (Nürnberg et al. 1987).

Hypolimnetic withdrawal is not feasible in all lakes. If there are eutrophication-prone lakes downstream, the increased amount of phosphorus rich and oxygen-poor water flowing in will only pass the problem on downstream. However, if the outflow is directed into a large water body or a swift moving river, the nutrient-rich water will be diluted, and there would be no detrimental downstream effects.

Dilution and Flushing

Dilution is a way of increasing the flushing rate. If a sufficient volume of clean water can be diverted into the lake, the result would be an increased flushing rate and a decrease in total phosphorus, both by washing away phosphorus rich water and by limiting internal phosphorus loading by increasing the dissolved oxygen levels in the hypolimnion (Cooke et al. 1993). For this method to be effective, the lake must be in close proximity to an upstream source of low-nutrient water. Water would be diverted from the clean source and channeled into the eutrophic lake using canals, tunnels or pumps. By increasing the levels of dissolved oxygen at the deepest parts of the lake, it may be possible to re-create a suitable habitat for the deep-water fish species that have been extirpated from China Lake. As in all of these in-lake treatment methods, the external phosphorus loading must first be controlled to achieve a significant decrease in total phosphorus.

In Green Lake, in Seattle, dilution was achieved by directing the flows of two mountain streams into the lake using the existing metropolitan water system. Because the lake is located in a highly developed region, there was a system of pipes already installed, so it was relatively easy to transport clean water into the lake (Cooke et al. 1993). The flushing rate was increased from 0.88 flushes per year to 2.40 flushes per year, resulting in a four-fold increase in Secchi disk depth reading, a three-fold decrease in phosphorus levels and a 90% decrease in Chlorophyll *a* (Cooke et al. 1993).

Drawdown

Dropping the water level is a technique used primarily in small lakes and shallow reservoirs, and can achieve a number of improvements to water quality. It can be effective in managing fish populations, controlling macrophyte populations, and also can facilitate other remediation methods such as dredging or installing a physical liner to the bottom of the lake. Drawdown can actually contribute to algal blooms if done at the wrong time, or in the wrong place. Exposed and dying aquatic matter can deposit phosphorus into the lake, and sometimes there is a dangerous decrease in dissolved oxygen as decomposer populations expand in response to the increase in food resources.

Dredging

This remediation technique requires the physical removal of lake sediment, which in China Lake is the largest source of phosphorus loading. Since the majority of the particulate phosphorus is in the first meter of sediment, removing that first meter of sediment removes the vast majority of sedimentary phosphorus, greatly slowing internal loading (Sasseville and Norton 1975; Peterson 1979). Dredging can also be successful if enough sediment is removed so as to alter the bathymetry of the lake, changing the thermal profile (Peterson 1979).

Dredging has been successful in some lakes, but due to the high costs associated both with extraction of the sediment and storage of the sediment after its removal, it is usually used in small ponds and lakes that can be drawn down substantially (Peterson 1979). In fact, it is the placement of the nutrient-rich sediment once removed that causes the biggest issue with this type of remediation. Furthermore, the extraction stirs up so much sediment that there is often a period in which the water column is overloaded with not only phosphorus, but also mud and foul-smelling sediment gases (Peterson, 1979). It is unclear whether dredging can maintain its effectiveness in the long-run. Several studies have shown that the phosphorus concentration returns to its pre-dredging levels shortly after dredging (Kleeberg and Kohl 1999).

Hypolimnetic Aeration

Hypolimnetic aeration attempts to decrease the anoxic areas of the lake by actively pumping oxygen into the hypolimnion using an aeration system not unlike those used in fish tanks, but on a much larger scale. In the presence of oxygen, iron (Fe (III)) can form complexes with phosphate, greatly reducing internal phosphorus loading (Theis 1979). One method of hypolimnetic aeration completely destratifies the lake to bring the oxygenated water from the surface down to the sediment. Destratification can be effective, but sometimes internal phosphorus loading is not decreased, because the increased flow of water at the sediment level actually stirs up the sediment, allowing more phosphorus to be released. The second method involves pumping oxygen into the hypolimnion. The key to a successful application of this particular technique is that the aeration must be achieved without destratifying the water column, which can be disastrous for cold-water or benthic organisms (Cooke et al. 1993).

There are several types of aeration systems, including mechanical agitation, injection of pure oxygen, and injection of air using an air-lift design (Cooke et al. 1993). Air-lift carries the oxygen deficient hypolimnetic water to the surface, where it is aerated and then pumped back to

the hypolimnion. In 1971, an aeration system was installed in Togus Pond (Anderson 1972). The results did not indicate any significant improvement to water quality except increased volume of the aerobic zone. Togus Pond continues to have algal blooms, and because of the costs associated with this type of aeration, it has not been done in any of the lakes in the Kennebec Valley since (CEAT 2005).

Chemical Treatments

Alum Treatment

Aluminum sulfate (alum) is a chemical treatment intended to inactivate phosphorus in the water column and slow phosphorus release from the sediments (Cooke et al. 1993). When alum is added to a lake, it dissociates and becomes hydrated to form aluminum hydroxide, creating a solid precipitate known as floc that absorbs phosphorus at pH between 6 and 8 (see Water Chemistry pH), effectively inactivating phosphorus suspended in the water column. As this floc forms a concentrate, it sinks, creating a layer of aluminum sulfate on the lake bottom that will slow phosphorus release from the sediments by binding phosphorus as it escapes. However, if the lake water is too acidic (pH less than 4), aluminum becomes soluble and releases phosphorus back into the water column and the floc layer on the surface of the sediments is no longer effective. Unlike similar ferrous treatments, there is no disruption of the phosphorus inactivation in anoxic conditions (Cooke et al. 1993). This fact is of particular note in China Lake because of the vast volume of anoxic water in the lake during the summer.

The best time to treat a lake with alum is directly after ice-out in the spring because it catches the suspended phosphorus before the spring algal bloom (Cooke et al. 1993). However, there are certain conditions in the early spring which may not be ideal for the treatment. For instance, there are often strong winds that mix the water and can disrupt the distribution of the floc blanket, leading to thin spots, where the phosphorus-absorbing layer will not persist. It is important to time the alum treatment carefully taking into account weather patterns and the turnover schedule of the lake. To determine the ideal dosage of alum, laboratory tests are conducted in which lake samples are treated with increasing doses of alum until the desired amount of phosphorus is removed. The dose for the entire lake is then calculated based on mean depth, mean annual period of anoxia, and the results of the laboratory tests. Only those parts of the lake which are more than three meters (ten feet) deep are treated, because shallower water

leaves the floc layer on the sediment vulnerable to disruption from winds, waves, and human activity (Walker 1994).

Application of the aluminum sulfate creates toxic and acidic water until the floc settles, so it is injected into the hypolimnion, so that the littoral and some pelagic biota are not subjected to this stress. To offset the acidity created as a byproduct of alum treatment, a neutralizing agent is added along with the aluminum sulfate to maintain the lake pH at a stable level (Cooke et al. 1993). Large barges with storage tanks are used to inject the alum into the hypolimnion. To most efficiently and effectively apply the alum, these barges must be equipped with detailed bathymetry maps and GPS coordinates so that all areas of the lake are treated with the appropriate dose (Figure 34).

Alum treatment has been used effectively in many lakes in the United States, and is the most common, applicable, and successful of the chemical treatment methods. Since this treatment has been performed many times, there is a wealth of data regarding its usefulness, longevity, and shortcomings (Cooke et al. 1993, Welch 2005). The longevity of an aluminum sulfate treatment can vary significantly from lake to lake. In some cases, including Threemile Pond in 1989, the treatment is a failure, lasting four years or less, but in other cases, it can maintain effective control of phosphorus levels, stopping algal blooms for up to 18 years (Walker 1994, Welch and Cooke 1999). The reasons for these variations in effectiveness include differences in internal and external loading rates, length of stratification and anoxia, pH levels near the sediment, weather patterns and flushing rate of the lake, and control of stormwater runoff entering the lake. Since the alum floc sinks to the bottom, it can stop or seriously slow phosphorus release from the sediments, but after it sinks, it no longer binds to dissolved phosphorus in the water column. For this reason, it is imperative that external loading be reduced to an absolute minimum to increase the longevity of the aluminum sulfate treatment.

Even within Maine, the success of this type of treatment can vary widely. Annabessacook Lake, in Winthrop, ME had experienced algal blooms since the 1940's, largely due to non point-source agricultural nutrient loading, primarily from sewage effluent (Welch and Cooke 1999). After massive efforts, 80% of the municipal and agricultural wastewater was being diverted elsewhere by 1972, but the lake still experienced algal blooms despite the fact that external loading was greatly reduced. An alum treatment was carried out in 1978 and the lake had no blooms until 1991 (Welch and Cooke 1999). The alum treatment of Annabessacook was able to

stop algal blooms for 13 years, but the treatment is not always as successful; the treatment of Threemile Pond failed after just three summers.

The Threemile Pond treatment was done in July 1989 using high-speed barges that can hold up to 11,250 kg of alum and are equipped with precise navigation systems. Using the high-speed treatment is more cost-effective than traditional slow barges, but even so, it is rather expensive, costing between $1000 and $3000/hectare (Welch 2005). It is important to keep in mind that the treatment is only done over areas of the lake that are deep enough to hold stratified hypolimnetic water. The treatment cost of Threemile Pond was $170,240 (Cooke et al. 1993). In an analysis done by an independent contractor in 1994, the failure of the Threemile Pond alum treatment was blamed on poor timing of the treatment, as well as misapplication of an insufficient amount of alum over the lake. The deeper parts of the lake should have received more of the dose, while the shallowest parts of the lake should not have been treated (Walker 1994).

Calcium Additives

Addition of calcium-based compounds can bring about inactivation of phosphorus in certain conditions. Calcium carbonate salt or calcium hydroxide will dissociate in water and if the pH is high enough, the free Ca^{3+} ions can bind with available phosphorus to form hydroxypatite, ($Ca_{10}(PO_4)_6(OH)_2$) (Cooke et al. 1993). However, at pH less than 9, or in water with elevated levels of CO_2, this compound becomes soluble, and will release its bound phosphorus. Most lakes in Maine have pH less than 9 (Cole, pers. comm.). The limitations of this treatment are therefore quite strict. The lake water must be very hard and anoxic waters are not conducive to this type of treatment because carbon dioxide levels are too high.

There are no dosage limits as there are with aluminum treatment because there are no immediate consequences of overdosing with these calcium-based compounds (Cooke et al. 1993). The only concern could be that if calcium hydroxide was used, the pH of the lake could rise, but since this treatment is really only feasible in high pH lakes, this is of minimal concern. Application techniques are not as specific as those used in applying alum treatment because the calcium additives present no threat to littoral and pelagic biota in the epilimnion (Cooke et al. 1993).

The effectiveness of this treatment is limited by its requirements, it has not been done on a large number of lakes, and cost estimates are widely variable. One example of this treatment

comes from the hard, eutrophic Frisken Lake in British Columbia (Cooke et al. 1993). In the summer of 1983 and spring of 1984, the lake was treated with slaked lime, $Ca(OH)_2$. This treatment greatly increased Secchi disk transparency and phosphorus precipitation was significant. Prior treatments of the lake used the algicide copper sulfate, which caused damage to the epilimnotic biota and caused concerns over toxic buildup of copper (Welch and Cooke 1999). In these respects, the calcium treatment was more effective, as it achieved the same results as the copper sulfate had, without the toxicity. However, the precipitate that formed to bind the phosphorus dissolved the next season, meaning that the treatment would have to be done annually.

This treatment can be a serviceable alternative to toxic algicide treatment, but only if it is done in an oxygen-rich, hard-water lake over a number of years. For this treatment to be effective, the hypolimnetic pH must be above nine, which is not the case in China Lake, or most other Maine lakes (see Water Quality). Furthermore, the massive volume of anoxic water in China Lake means that there is too much CO_2 for the hydroxypartite to form, rendering the addition of calcium useless.

Ferrous

In the presence of oxygen, ferrous (iron) compounds can bind with free phosphorus to form an iron (III) hydroxide precipitate. This precipitate is far from stable, so water low in oxygen will force the complex to break up, releasing the bound phosphorus. Because this treatment method adds so much iron to the water and sediment, care must be taken to ensure that iron levels do not reach toxic levels. To maximize the phosphorus-absorbing potential, a 3:1 ratio of iron to free phosphorus should be used (Cooke et al. 1993). Unlike the calcium treatment, this method is rendered ineffective by high pH because phosphorus is released when the iron (III) hydroxide-phosphorus complex dissociates.

Like the calcium treatment, the narrow range of variables that enable this treatment to work make it a relatively uncommon treatment method. It was used with some success in the Netherlands, but phosphorus levels returned to normal after three months as the precipitate was disrupted (Cooke et al. 1993). In anoxic water, the precipitate fails to keep phosphorus bound; it is the weakness of the bonds that hold phosphorus that essentially render this treatment unfeasible.

Algicides

As opposed to all of the above chemical treatments, which act to limit algal growth by taking away the supply of phosphorus, algicides target actual algal cell growth (Moore and Thornton 1988). This method of treatment is wrought with problems. Copper sulfate, the most commonly used algicide, is extremely toxic and expensive. This compound works to effectively inhibit the ability of the algae to photosynthesize, and in turn, reproduce (Moore and Thornton 1988). This may seem like a quick fix for a lake in full bloom, but this treatment really creates more problems than it solves.

The copper sulfate may kill the algae for a number of weeks, but since it does nothing to decrease phosphorus levels, the eventual outcome will be a stronger algal bloom sometime in the immediate future, or a bloom of a different species of algae (Cooke et al. 1993). The copper quickly sinks to the bottom, where it serves no function because photosynthesis occurs in the epilimnion, but contributes to the toxicity of the sediment. Heavy metals, including iron and copper can bioaccumulate and become toxic to fish, leading to Do-Not-Eat orders or closing of fisheries. Because of its toxicity and inability to provide a long-term remediation, the treatment of lakes and ponds with copper algicides is illegal in Maine (Bouchard, pers. comm.). Even if it were non-toxic and legal, the costs associated with continued copper sulfate addition over just one summer would be astronomical. In 1993, the cost of a one-time treatment of one hectare using granular copper sulfate ranged from $346-$1,432 (Cooke et al. 1993).

Biological Treatments

Aquatic Plant Harvesting

Growing large amounts of vegetation is a way to absorb phosphorus from the water. Instead of algae acting as a phosphorus sink, this vegetation will utilize the nutrient. The key to successfully implementing this practice is that the vegetation must be removed before it can die and begin to decay, leaving its phosphorus in the lake. If a significant mass of macrophytic biota can be removed from the watershed, and properly composted, a significant decrease in phosphorus levels can be achieved.

The choice of which species to use for this is critical. In some lakes, exotic plant species including water hyacinth are brought in, with the hope that the plant will die during the harsh winter away from its natural tropical habitat (Cooke et al. 1993). Death during the winter is

crucial, because it is impossible to harvest all of the vegetation and the introduction of an exotic species can have dire consequences (see Exotic Species).

Biological Control

Biological control is the use of natural predators to control pests or to reduce pest populations and densities (Integrated Pest Management Florida 2005). There is a large potential for algal blooms to be managed by biological control. Two natural predators have been found for *Microcystis* algae, *Hordeum vulgare* and the aquatic bacteria *Streptomyces neyagawaensis* (Choi et al. 2005, Ferrier et al. 2005). Both controls were proven to inhibit growth in controlled settings, yet neither was totally effective in the field. Fungal parasitism has experimentally limited the population of diatoms, particularly *Asterionella*, but *Asterionella* control has not been accomplished in the field (Kudoh and Takahashi 1992). As *Microcystis* populations decreased in lake settings due to biological control, they were replaced by other phytoplankton species. Despite lowering the *Microcystis* population, there was no reduction in total phytoplankton biomass (Choi et al. 2005, Ferrier et al. 2005). Very few viable biological controls for algal species have been identified, and biological controls for all phytoplankton species do not exist.

Fish Stock Manipulations

Manipulating the balance between resident fish species is called biomanipulation and the stocking of sport fish is a common example (MDEP 2005e). Fish stock manipulation is the practice of introducing or removing certain species of fish from a water body to influence the structure of the ecosystem (Van-Riper, pers. comm.). Recovery efforts to restore native species to their historical range or introducing a threatened but non-native species into viable habitat employ fish stock manipulation (Wilderness Watch 2005). Although the literature suggests that restoring native fishes to a lake can help to maintain and promote the biological integrity of that lake (Harig and Bain 1998), this solution has not been proposed for China Lake.

In East Pond, MDEP is currently conducting a pilot study using biomanipulation under the assumption that the algae blooms are exacerbated by White Perch, which eat the plankton that normally eat the algae (Van-Riper, pers. comm.). Reducing the biomass of the dominant fish species that consume zooplankton may result in improved water clarity in impaired lakes (MDEP 2005e). It has been suggested that removal of the whole trophic level of the White Perch would result in less severe algal blooms. However, manipulating the trophic levels will not change the

actual phosphorus levels in the water column or in the sediments, it only increases herbivory of the algae creating the blooms. No such manipulations have been suggested for China Lake.

APPLICATIONS OF REMEDIATION TECHNIQUES TO CHINA LAKE

Though all the chemical manipulation methods fail to actually remove phosphorus from the lake, they do have promise for use in China Lake. Binding phosphorus in the lake can reduce phosphorus levels to below the 15.0 ppb threshold and cease or slow algal blooms, but only if the total external phosphorus load is reduced first. The physical methods can provide a reduction in the actual amount of phosphorus in the lake by changing the physical profile of the water column. Not all are applicable to China Lake, and some can only be truly effective if coupled with chemical methods as well (Table 9). It is important to remember that none of these methods alone will save China Lake from its algal bloom problem. Without reducing external phosphorus loading, investing in any chemical or physical manipulation would be a waste of time and money.

Physical Treatments

Hypolimnetic withdrawal could be a good way to reduce the amount of phosphorus in the water column. The risk with this method is that the outflow will be so rich in nutrients that downstream lakes and streams would be at risk. In China Lake, the outflow drains into the Sebasticook River, and then into the Kennebec River, which would be a suitable sink for such a large amount of nutrient-laden water. However, for such a system to work well, there needs to be a sufficiently large volume of clean water inflow which is not the case in China Lake, with its low rate of just 0.35 flushes per year (see Water Budget). In addition, it would be impossible to remove hypolimnetic water from the East Basin, where most of the lakeside population resides.

One way to increase the flushing rate is by diverting a clean water source into the lake, known as the flushing or dilution method. This type of treatment is only effective in areas where there is an accessible supply of clean water that can be diverted, which is not the case for China Lake. There is not a close-by source of water low in phosphorus that could be diverted into China Lake. The lakes and ponds in the surrounding watersheds have nutrient-loading problems of their own (CEAT 1989-2004). Furthermore, the costs of piping water from any of these water bodies to China Lake would be astronomical.

Table 9. Remediation techniques applicable and not applicable to China Lake.

Remediation Technique	Type of Treatment	Focus of Technique	Viable in China Lake?
Alum Treatment	Chemical Manipulation	Inactivates phosphorus (P) in water column and sediments	Yes, but expensive
Ferrous Treatment	Chemical Manipulation	Inactivates P in water column and sediments	Maybe if there is aeration too
Calcium Treatment	Chemical Manipulation	Inactivates P in water column and sediments	No- hypolimnetic pH is too low
Algicides	Chemical/Biological Manipulation	Prohibits algal cell growth	No- prohibitively expensive short-term fix
Drawdown	Water Removal Technique	Removal of nutrient-rich hypolimnetic water	Yes, but politically risky
Hypolimnetic Withdrawal	Water Removal Technique	Removal of nutrient-rich hypolimnetic water	No, flushing rate is too low
Dilution	Water Removal Technique	Displacement of nutrient-rich hypolimnetic water	No upstream source to be diverted
Hypolimnetic Aeration	Physical Manipulation	Increasing D.O. levels in hypolimnion	Could work in tandem with ferrous
Dredging	Physical Manipulation	Removing nutrient-rich sediment	No, too much sediment
Aquatic Plant Harvesting	Physical/ Biological Manipulation	Removal of P in the form of macrophyte biomass	Maybe, would be risky and unpopular

Drawdown is a promising idea for China Lake. The drawdown remediation method is very inexpensive, and in China Lake, it can be achieved by simply lowering the water level at the dam in Vassalboro. The control of the China Lake dam is discussed in detail in the Historical Perspective section of this report. If the lake level is drawn down during the fall turnover, when the lake phosphorus profile is uniform, it is possible to drain out a tremendous volume of phosphorus rich water because of the vast area of China Lake.

Dredging is a great way to actually eliminate the problem of internal phosphorus loading, but it works best in small and/or shallow lakes. It is not feasible to dredge China Lake due to the vast costs associated with dredging such a large and deep area and storing so much phosphorus-

rich sediment (Peterson 1979). In 1989, costs for dredging half a meter of China Lake's sediment were estimated by MDEP and found to be far too expensive to even entertain the idea.

The costs associated with hypolimnetic aeration are fairly high. The cost of the first year of treatment would be $2.50 per kg oxygen, or roughly $6,500 per hectare in 1993 (Cooke et al. 1993). Advances in this technology have decreased the cost per kilogram oxygen, but in a lake as large as China Lake, the costs would still be unattainably high. After the initial installation, which can cost up to $500,000, the costs are drastically reduced, and vary by lake size, volume of anoxic water, and the type of system.

Chemical Treatments

Alum treatment is the most promising way to slow internal phosphorus loading in China Lake. Like all the in-lake remediation techniques, it would fail without maximizing the reduction in external loading first. The failure of the Threemile Pond alum treatment should not be seen as evidence that this method cannot work in Maine, because it has been successful in other lakes such as Annabessacook Lake (Welch and Cooke 1999). Walker (1994) suggests that part of the reason the treatment of Threemile Pond failed was that there was not enough alum added. He suggests that by distributing the alum more over the deeper parts of the lake and less over the shallow parts that the same amount of alum (and therefore money) could have achieved much greater success. There are reasons to believe that a more precise and better-timed alum treatment could arrest internal phosphorus loading problems in China Lake for a number of years. However, this can only be achieved if external loading is brought to a minimum first.

Ferrous treatment is not a good long-term solution to the internal phosphorus loading plaguing China Lake. The water in China Lake is stratified and the hypolimnion is anoxic for much of the summer, so unless this treatment was coupled with a large-scale physical manipulation to either de-stratify or aerate the hypolimnion, this treatment would fail. It is unfeasible to destratify China Lake, but aeration of the hypolimnion could be attempted at great cost. Furthermore, the treatment is not a long-term solution, and continuous addition of iron to the lake would eventually bring about toxic iron levels and endanger sport-fishing recreation.

Algicides fail to remove or bind up phosphorus in the lake, and so can only be considered as a short-term stopgap solution to algal blooms. Based on the estimates of cost per hectare of a copper sulfate treatment (Cooke et al. 1993), China Lake is 1,604 hectares, so one copper treatment would cost between $550,000 and $2.3 million, it would only last a few weeks, and

would likely only result in a more severe algal bloom later in the summer. This is a completely unreasonable treatment method.

Biological Treatments

Aquatic Plant Harvesting

Aquatic plant harvesting is not feasible in China Lake. The labor associated with this technique coupled with the dangers of introduced species render aquatic plant harvesting unfeasible. Also, in a lake with as many shoreline homes, it is unlikely that homeowners will agree to have parts of the surface of their lake taken up by floating vegetation during the summer months because it can impede recreational activities. Such a method also would require vast amounts of human-hours devoted to the harvesting of the vegetative mats, because they grow so rapidly. In a lake as large as China Lake, the number of these mats would have to be high, and the labor associated with maintaining them would be prohibitively high.

Biological Control

The algal blooms in China Lake are a complex phenomenon consisting of four types of phytoplankton; *Anabaena, Aphanizomenon, Microcystis, Melosira* and three types of diatoms: *Asterionella, Fragelaria,* and *Tabellaria*. This compilation of algal species causes biological control, a species-specific method of control, to be exceedingly difficult. Natural predators have been identified for some of these algae, but their effectiveness in the field has not yet been proven. The two natural predators for *Microcystis* algae, *Hordeum vulgare* and the aquatic bacteria *Streptomyces neyagawaensis* have not been proven effective in natural settings (Choi et al. 2005, Ferrier et al. 2005). Biological control can be an effective natural solution to infestation problems. However, the uncertainty and lack of field success coupled with cost and introduction risks would make biological control an ineffective remediation method for the algal blooms in China Lake.

Fish Stock Manipulations

Currently, CEAT does not recommend fish stock manipulation as a method of remediation for China Lake. Once the MDEP pilot study on East Pond is completed, more information will

be available regarding the success of fish stock manipulations, and perhaps this option can be explored further at that time.

FUTURE PROJECTIONS

POPULATION TRENDS

HISTORIC

China and Vassalboro occupy the majority of the China Lake watershed. Albion occupies a small portion of the watershed that has no houses. In 1774, pioneer families moved into the area to farm (Town of China 2005). From 1820 to 1830 the population of China more than doubled, and Vassalboro grew by approximately 20% (Figure 55). As expansion toward the west of the United States increased, the population declined in the China Lake region until the 1930s. Population growth has increased slowly for both China and Vassalboro from 1930 to the present (Figure 55).

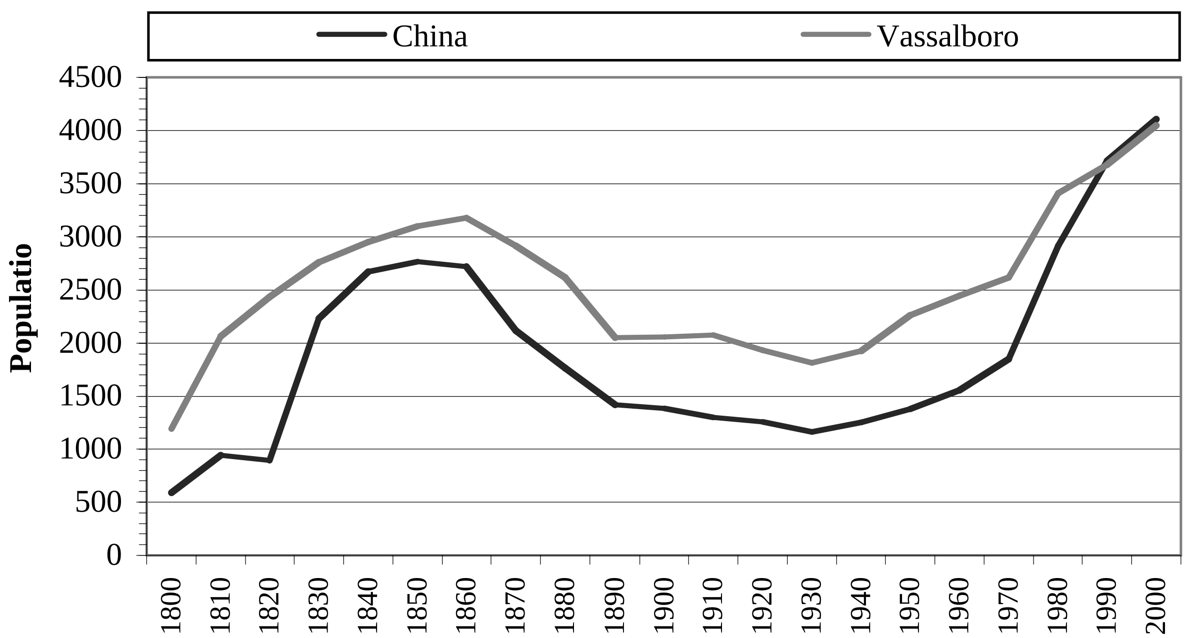

Figure 55. Population trend for the towns of China and Vassalboro from 1810 to 2000. Data obtained from Maine census data- population totals (Fogler Library 2002).

Between 1980 and 2000, the population of China increased at an annual rate of 1.7% per year (China Comprehensive Plan Committee 2005). A similar rate of population growth has occurred in Vassalboro. The period of growth between 1980 and 2000 has been the fastest long-

term growth rate either town has experienced since the 1830s (Figure 55). In the 2000 US Census, 4,047 people lived in Vassalboro and 4,106 people lived in China (Fogler Library 2002). The populations of Vassalboro and China increased by 10% over the ten-year period of 1990 to 2000 (China Comprehensive Plan Committee 2005).

FUTURE

Both China and Vassalboro expect a steady but slow increase in population to continue in the future. The annual population growth rate of 1.8% in China is expected to continue. Between 2000 and 2003, the annual growth rate was 1.6% in China. Based on current and historical growth rates, China has projected that by 2010 the population will reach 4,900 people. In 2020, the population is projected to be 5,730 people and by 2030 the population will potentially be 6,530 people (China Comprehensive Plan Committee 2005). Vassalboro projected population growth as well, but more slowly than in China. In 2020, the population is projected to be 4,800 people (Vassalboro Plan Committee 2005). This increase in population growth in both towns will pose a continuous threat to lake quality, but if residential buildings are well maintained, the population growth will be manageable.

GENERAL DEVELOPMENT

Residential, commercial, and municipal development of the China Lake watershed is expected to continue at a slow and steady rate. Both China and Vassalboro expect about 30 residential houses to be built per year for the next decade (Vassalboro Plan Committee 2005). Development is also predicted to slow down in the next ten years; it is predicted that 250 residential houses will be built in the next decade in both China and Vassalboro (Najpauer, pers. comm.). Our estimate of residential development in the watershed is expected to be 25 houses per year (Pierz, pers. comm.). Over a ten-year period as vacant land decreases, residential growth is anticipated to slow down, consequently our estimate for the ten-year period is 220 houses within the watershed.

Along with a rising population, there are an increasing number of people living alone in their homes, meaning that there may be more homes in proportion to population in the future (China Comprehensive Plan Committee 2005). Additions are built onto existing houses at an

annual rate of 20 or more per year. The increase in size of individual houses increases the amount of nutrients each house contributes to the watershed. Residential growth can have negative effects on the watershed by increasing the number of septic systems and subsurface wastewater disposal systems, expanding impervious surfaces such as rooftops and driveways, and increasing the number and use of roads that can result in higher nutrient loading in the lake.

Commercial development is predicted to grow at a rate of approximately one building per year in both China and Vassalboro, however this does not mean the development will occur within the watershed (Najpauer, pers. comm.). Development that occurs within the watershed will slowly increase impervious surfaces and nutrient runoff into the lake. Some of the commercial development may be home-based businesses, which would not pose a large threat to the watershed.

Both towns provide housing for many federal, state, and commercial employees who work in Augusta and Waterville. The new bridge linking Interstate 95 through Augusta to Route 3 is expected to increase traffic flow and runoff into the watershed (China Comprehensive Plan Committee 2005). The China Comprehensive Plan Committee also predicts that increased traffic flow will accelerate the development of roadside businesses. Commercial development in China will be directed toward the Route 3 corridor, in areas not designated resource protection, shoreland, or flood prone (Pierz, pers. comm.). Two predicted areas for substantial commercial development are the intersection of Route 3 and Route 32 (Windsor Road) and just east of Windsor Road (Pierz, pers. comm.). There was a controversial proposal to build a Bio-Diesel manufacturing plant along Dirigo Road, which could potentially contribute chemical and nutrient runoff into the watershed if improperly constructed or monitored. The Planning Board recently rejected the proposal based on neighbors' objection to the plant (Pierz, pers. comm.).

China officials are discussing the creation of commercial development clusters to concentrate business activity (China Comprehensive Plan Committee 2005), but these clusters of business could also concentrate impervious surfaces increasing potential runoff into the lake. China plans to develop a Commercial Site Review Ordinance to regulate development (China Comprehensive Plan Committee 2005). One of the criteria of the proposed ordinance would ensure that development does not occur within a shoreline zone. The proposed ordinance would also help prevent development on steep slopes, erodible soils, and wetlands (China Comprehensive Plan Committee 2005).

The Kennebec Water District owns most of the lakefront property in Vassalboro, eliminating the threat of lakeside development in that town. In a survey of Vassalboro citizens, over 70% were content with the rate of development over the past 10 years (Vassalboro Plan Committee 2005). Citizens also recognized the importance of preserving water resources, forestry resources, and farmland.

Most new development occurs along preexisting roads, lowering the amount of impervious surface that would result from development if new roads were constructed. Most residential projects consist of individual buildings, not large subdivisions, which could greatly increase phosphorus loading by creating more densely populated housing. Along the shoreline, the GIS mapping by CEAT (derived from the Town of China Land Use District Map, 1992, 1999 Town of China Property Map Index, and 22-Sep-05 CEAT shoreline survey) indicates that there are approximately 36 (7% of total lots) of 512 total lots that remain to be developed. China Code Enforcement Officer Scott Pierz confirmed this estimation of development lot availability. According to the CEAT land use map, these lots are currently forested areas, so although the percentage of lots that remains to be developed is low, the impact of converting forest to houses could have a negative impact on the watershed. Also, these lots are not located on steep slopes, so development is likely. GIS maps indicate that access roads to the forested lots exist, so development in these lots will increase impervious surface through driveways, parking lots, and roofs.

The Town of China created a Phosphorus Control Ordinance that applies to any development in the China Lake watershed built after 5-Jun-93 (Town of China 2003). Vassalboro does not currently have a Phosphorus Control Ordinance. The limit on phosphorus export differs for each basin: 0.03 pounds of phosphorus/acre/year are allowed per building in the watershed of the East Basin of China Lake, and 0.06 pounds of phosphorus/acre/year are permitted in the West Basin. People seeking permits for building single family dwellings and subdivisions must show in writing how they plan to meet the phosphorus export standards (Town of China 2003). Although these regulations limit the contribution of each building to nutrient loading and growth is not large now, every new residential, commercial and municipal building affects water quality.

PHOSPHORUS BUDGET PREDICTIONS

METHODS

Projected land use and development changes were calculated by applying predicted changes for the Towns of China and Vassalboro (see Future Projections: Population Trends and General Development) to the areas of each town within the watershed specifically. The current areas of commercial and residential development (per building) were used to approximate the total area that will be impacted by future development.

The 2020 and 2030 projections of the phosphorus budget were calculated by using the projected land use and development changes in the 2005 phosphorus loading model for China Lake. All phosphorus export coefficients used in the phosphorus loading models for the 2020 and 2030 predictions are consistent with current estimates (see Appendix E), unless otherwise specified.

RESULTS AND DISCUSSION

Land Use and Development Projections

Using the estimate that 25 additional houses will be built within the China Lake watershed each year (see Future Projections: General Development), and the current proportions of seasonal and year-round houses in shoreline and non-shoreline areas, CEAT projects that shoreline residential development will increase by 7.3 ha (18.0 acres). No additional shoreline development is predicted to occur after 2020, as all 36 currently undeveloped lots will have been developed (Table 10).

One additional commercial building is expected to be built in China and Vassalboro each year, however, only a portion of this development will occur within the watershed (see Future Projections: General Development). By multiplying the projected amount of new commercial development in each town by the proportions of China and Vassalboro within the watershed, we calculated that commercial and municipal land is expected to increase by 9 ha (22.2 acres) by 2020, and by 15 ha (37.1 acres) by 2030 (Table 10).

As long as reverting land remains undisturbed, it will slowly grow and develop into a mature forest. We predict that roughly 11 ha (27.2 acres) of reverting land in 2005 will have grown to mature forest by 2020, and 16 ha (39.5 acres) to have grown to mature forest by 2030.

Table 10. Summary of projected land use and development changes for 2020 and 2030. These projections were used to make phosphorus budget projections for the future.

Input Category	2005	Projected Changes from 2005: 2020	2030
Land Use Area (ha):			
Commercial	135.10	9.00 increase	15.00 increase
Mature Forest	4307.35	142.36 decrease	244.53 decrease
Non-shoreline Development	463.79	137.19 increase	238.36 increase
Shoreline Development	95.51	7.28 increase	7.28 increase
Reverting Land	231.11	11.11 decrease	16.11 decrease
Mean no. of persons per household	2.65	0.65 decrease	0.65 decrease
No. of students and faculty at:			
China Primary and Middle Schools	650	278 increase	408 increase
Erskine Academy	745	317 increase	470 increase
State and Municipal Roads Export Coefficient Best Estimate (kg/ha/yr)	1.80	0.20 increase	0.40 increase

Despite this growth, the total amount of mature forest is expected to decrease by 142.4 ha (351.8 acres) by 2020, and by 244.5 ha (604.2 acres) by 2030, due to the development of forested areas (Table 10).

Based on future population growth and residential development predictions (see Future Projections: Population Trends and General Development), CEAT predicts that the average number of persons per household will decrease from 2.65 people currently to 2.00 people in 2020 and 2030. CEAT also predicts that the number of students and faculty at schools within the watershed will increase proportionally to the total population of the school district (Table 10).

Finally, increased traffic on state and municipal roads due to the construction of a bridge linking Interstate 95 to Route 3, in conjunction with increased population, will increase runoff from roads into China Lake (see Future Projections: General Development). To account for this change, the best estimate phosphorus export coefficient for state and municipal roads was raised to 2.00 kg/ha/yr of phosphorus for the 2020 model, and 2.20 kg/ha/yr for the 2030 model (Table 10).

Phosphorus Budget Projections

The phosphorus loading model predicted a total phosphorus concentration range of 11.1 ppb to 33.5 ppb, with a best estimate of 19.3 ppb for 2020. For 2030, the model predicted a total phosphorus concentration range if 11.3 ppb to 34.6 ppb, with a best estimate of 19.7 ppb. These values include phosphorus released from the sediments, which remains the largest contributor of phosphorus. Our models predict that sediments will contribute 45% of total phosphorus in 2020, and 44% in 2030. The slight decrease in the proportion of phosphorus released by the sediments is due to a greater contribution of phosphorus by external sources (Table 11). The 2020 and 2030 phosphorus loading models predict that agricultural use and mature forest will remain the highest contributors of external phosphorus, although the percent of phosphorus contributed by these sources will decrease slightly over time (Table 11). The amount of phosphorus contributed

Table 11. Projected 2020 and 2030 percent contribution of phosphorus for all land use types. Percentages were determined by the different export coefficients used for low, best, and high estimates. Values reflect the amount of phosphorus input for each land use under different estimates, relative to the total phosphorus load. See text for assumptions used to make future projections.

	2020 Estimates (%)			2030 Estimates (%)		
Input Categories	**Low**	**Best**	**High**	**Low**	**Best**	**High**
Atmospheric	12.8	8.8	6.6	12.4	8.5	6.3
Agricultural						
Cropland	1.1	7.9	7.1	1.1	7.7	6.8
Pasture	19.5	14.2	15.6	18.9	13.7	14.9
Camp roads	1.5	2.4	2.2	1.5	2.3	2.1
Commercial	5.7	6.9	7.1	5.8	6.9	7.1
Grassland	2.6	2.4	2.0	2.5	2.3	1.9
Institutional						
China Schools[a]	8.1	8.8	7.8	8.9	9.7	8.5
Erskine Academy	2.6	3.6	3.3	2.9	3.9	3.7
Friends Camp	0.1	0.2	0.1	0.1	0.2	0.1
Mature forest	16.6	15.3	10.3	15.7	14.4	9.6
Non-shoreline development	9.6	6.6	14.9	10.8	7.5	16.6
Non-shoreline septic	2.0	3.0	3.1	2.2	3.4	3.4
Reverting land	3.5	2.4	2.9	3.3	2.3	2.7
Shoreline development	4.1	6.8	5.1	4.0	6.6	4.9
Shoreline septic systems	5.9	5.3	5.2	5.8	5.1	4.9
State and municipal roads	3.3	4.3	5.8	3.2	4.6	5.5
Wetlands	1.1	1.0	0.9	1.0	0.9	0.8

[a] Includes China Primary School and China Middle School

by non-shoreline development and local schools will increase the most over the next 25 years. According to our best estimates, the percent of total phosphorus from external sources contributed by non-shoreline development will increase from 5.4% in 2005, to 6.6% in 2020, and to 7.5% in 2030 (Table 11). This increase is due to the fact that CEAT predicts that non-shoreline residential development will increase by about 238 ha (588 acres) over the next 25 years.

The amount of phosphorus contributed to China Lake from schools within the watershed is predicted to significantly increase as well. The proportion of total phosphorus from external sources contributed by China Primary and Middle Schools collectively is predicted to increase from 6.5% in 2005, to 8.8% in 2020, and 9.7% in 2030. The contribution of Erskine Academy is expected to increase from 2.6% in 2005, to 3.6% in 2020, and 3.9% in 2030 (Table 11). These predictions assume that the number of students and faculty at each school will increase proportionally to the population of the school district, and that new buildings will not be constructed to accommodate the increased enrollment.

The predicted changes in phosphorus loading from 2005 to 2030 highlight the importance of regulations and ordinances designed to reduce the impact of future development on lake water quality (see Future Projections: General Development). Additionally, they highlight the importance of addressing internal phosphorus cycling if phosphorus concentrations lower than 15 ppb are to be achieved and maintained in the future.

RECOMMENDATIONS

WATERSHED LAND USE MANAGEMENT

The water quality of China Lake is largely impacted by development within the watershed and along its shoreline. Changes in each of the following areas: development, impervious surfaces, roads, agriculture, septic systems, and buffer strips could improve the water quality of China Lake. The Colby Environmental Assessment Team (CEAT) suggests the following actions be considered to address the failing water quality of China Lake.

<u>REDUCING EXTERNAL LOAD</u>

Development and Roads

- Monitor commercial and residential development, especially on the remaining shoreline lots, with strict enforcement of all shoreline-zoning regulations.
- Maintain roads with proper crowns, clear debris from culverts and ditches, eliminate berms, and install diversions where appropriate.
- Keep impervious surfaces to a minimum. Do not add unnecessary parking lots, driveways, or roads within the watershed, especially near the lake.
- To help defray maintenance costs of camp roads, form road associations (non-profit organizations composed of all the owners living on a camp road).
- Perform regular maintenance of camp roads, especially those near the streams and shoreline.
- Undertake remediation of problem sites identified in this study.
- Educate homeowners on driveway improvement.

Subsurface Waste Water Disposal Systems

- The Town of China needs to update septic system records for all shoreline properties. This initiative is in its early stages, and the next step could be to develop an ordinance requiring that failing septic systems be replaced.
- Town code enforcement officers must continue to ensure that septic systems are installed and replaced in compliance with state and town regulations.

- The Town of China should facilitate low income assistance, such as low interest loans, to help residents replace their non-compliant or malfunctioning septic systems. Options for assistance can be found at: www.maine.gov/dhhs/eng/plumb/faq.htm.

Buffer Strips

- All shoreline landowners should maintain a vegetated buffer strip across the entire frontage of their lot and the buffer should be as deep as possible. The buffer strip should be comprised of several layers, including trees, shrubs, groundcover, and duff.
- Encourage residents living in the shoreline zone to grow natural gardens as opposed to manicured lawns to help reduce nutrient loading from runoff.
- Erosion prone soil at the water-soil interface should be stabilized with riprap.

Pasture and Agricultural Land

- Allow unused agricultural land to revert to forest.
- Do not fertilize agricultural land or private property right before frosts.
- Minimize pastureland for grazing near the lake.

IN-LAKE MANAGEMENT

In-lake management is especially important, despite the high cost and labor intensity of the techniques. Internal phosphorus loading from the sediment must be addressed if total phosphorus concentration is to be reduced to 15 ppb or lower in the future, since sediment release accounts for roughly 46% of the total phosphorus in China Lake. To do this, the total phosphorus load would have to be reduced by almost 1,000 kg/yr. Reducing external phosphorus loading by 50% would only account for a 373 kg/yr reduction in total phosphorus load. Still, it is important to remember that without controlling the external phosphorus loading as well, any in-lake management will ultimately be ineffective.

- Alum treatment is recommended as the most effective means for phosphorus reduction, even though it would be expensive.
- Water drawdown would be possible but would be very difficult given the size and physical layout of the lake.

MONITORING AND REGULATIONS

Monitoring practices and regulations are an important step in maintaining and improving the water quality of China Lake. Monitoring by community members, the China Region Lakes Alliance, the China Lakes Association, the Kennebec Water District, the Maine Department of Environmental Protection, and the Maine Volunteer Lake Monitoring Program is essential to assess and improve lake quality.

COMMUNITY AWARENESS AND EDUCATION

Community awareness and education are two of the best ways to impact the water quality of China Lake. Informing residents living in the watershed about the effects of their daily activities will help to improve water quality and decrease nutrient loading. Many residents may not be fully aware of the relationship among land use, development, and water quality, and they may not realize the effects of their daily actions.

- Community residents should be educated on the importance of maintaining camp road integrity through workshops and pamphlets.
- Pamphlets should be distributed explaining the ways residents can improve water quality including: problems with malfunctioning septic systems, risks posed by invasive species, and ways to improve camp roads and buffer strips.
- The Vassalboro and China school systems could incorporate lake education into their curricula and involve children in the monitoring of the lake and its watershed.
- The China Region Lakes Alliance should continue to produce informational pamphlets on lake water quality, land use changes, and community actions for the residents of China and Vassalboro.
- Homeowners should be informed about the potential problems associated with fertilizing lawns adjacent to the shoreline and using detergents containing phosphorus.

GRANTS AND FUNDING

Grants and loans are available from state and federal agencies to help fund lake remediation projects. The Maine Department of Environmental Protection, Maine Department of Transportation, Maine State Housing Authority, and the Environmental Protection Agency are possible funding sources. See www.maine.gov/dep/blwq/grants.htm

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APPENDIX A. WATER QUALITY MEASUREMENTS AND TESTS

Physical, Chemical, and Biological tests performed between Jun-05 and Sep-05 at various sample sites on China Lake (Figure 12).

Measurement or Test	Sample Date	Sample Site
Physical Measurements		
DO/Temperature	7-Jun-05, 22- Jun-05, 3-Aug-05, and 16-Aug-05	1, 2, 3
	19-Sep-05	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Transparency	7-Jun-05, 22- Jun-05, 3-Aug-05, and 16-Aug-05	1, 2, 3
	19-Sep-05	1, 2, 3, 9, 10, 11
Turbidity	7-Jun-05, 22- Jun-05, 3-Aug-05, and 16-Aug-05	1, 2, 3
	19-Sep-05	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Color	19-Sep-05	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Conductivity	3-Aug-05 and 16-Aug-05	1, 2, 3
	19-Sep-05	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Chemical Analyses		
pH	7-Jun-05, 22- Jun-05, 3-Aug-05, and 16-Aug-05	1, 2, 3
	19-Sep-05	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Alkalinity	19-Sept-05	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Nitrates	7-Jun-05, 22- Jun-05, 3-Aug-05, and 16-Aug-05	1, 2, 3
	19-Sep-05	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Total Phosphorus	7-Jun-05, 22- Jun-05, 3-Aug-05, and 16-Aug-05	1, 2, 3
	19-Sep-05	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Biological Analyses		
Chlorophyll-a	7-Jun-05, 22- Jun-05, 3-Aug-05, 16-Aug-05, and 19-Sep-05	1, 2, 3

APPENDIX B. QUALITY ASSURANCE

The China Lake study followed a quality assurance plan developed by CEAT to standardize the procedures used. The following document was modified from CEAT (2004).

Bottle Preparation:

Using 1:1 HCl : E-pure water, triple-acid rinse all phosphorus-sample bottles before use to avoid contamination of the sample.

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. If an epicore sample is taken, triple-acid rinse the mixing bottle before sampling and E-pure rinsed after sampling was completed.

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 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.

Conductivity:

1. Use YSI Sonde or take water sample.
2. Follow surface sampling procedure.
3. Place the water sample in the cooler on ice.
4. Bring sample to 25^{o} C before test.
5. Use a YSI Model 31S Conductance Bridge to measure conductivity.

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. Place the water sample in the cooler on ice.

Acidification of Hardness Samples:

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

Using the pH Meter:

A. Calibration: Before any test is performed, the pH meter 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. Apply the pH 7 solution by opening the sensor guard and wetting the entire probe.
    3. Press the CAL button once. The sensor guard will display 7.0 and a CAL symbol will appear at the bottom right hand corner followed by a smiley face (☺) indicating that it is finished calibrating.
    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. Lift the lid of the probe fully, and immerse the pH meter 0.5 m to 1.0 m below the surface.
    2. Close the lid. Bring the meter to the surface and record the reading after the smiley face has appeared in the bottom right hand corner.

C. Quality Assurance.

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

Dissolved Oxygen:

1. Calibrate the meter in the saturated air chamber after the proper warm-up time.
2. Lower the Dissolved Oxygen/Temperature meter into the water, shaking it gently to make sure there are not bubbles around the probe.
3. Immerse the probe until covered. Record DO and Temperature readings every meter as the probe is lowered.

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 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.

Flo-Mate:

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

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 autoclaved at 15 psi for 30 mintues.
6. Conduct analysis within 28 days of sampling date.

Tributary Stormwater Sampling:

1. Use Global Water Stormwater Sampler SS201.
2. Set to start collecting after 0.5 inches of rain.
3. Place sampler in tributary in an upright position.
4. Left hose collects continuous sample, right hose collects staggered sample.

Alkalinity:

1. Take one duplicate sample for every ten samples.

2. Use the Potentiometric Method to analyze the samples.
3. Conduct analysis within 14 days of sampling date.

Color:

1. Take one duplicate sample for every ten samples.
2. Color should not vary more than ± 5 SPU per duplicate.
3. Keep color standards in the dark and protected from evaporation.
4. Use the HACH Platinum-Cobalt Standard Method and HACH DR/4000U Spectrophotometer for the color test (HACH 1997).
5. The limit of detection for the test is 2 units Pt-Co. The range of the test is 0 units to 500 units.
6. Conduct analysis within 48 hours of sampling date.

Nitrates:

1. Collect and make splits and duplicates for every ten samples.
2. Analyze nitrates by using the HACH UV Direct Reading and the HACH DR/4000U Spectrophotometer (HACH 1997).
3. The limit of detection for the test is 0.2 ppm NO_3^-N. The range for the tests is 0.0 ppm to 10.2 ppm NO_3^-N.
4. Conduct analysis within 48 hours of the sampling date.

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.

Physical tests: temperature (°C), dissolved oxygen (ppm), and conductivity (μmhos) at sites 1 – 3. Data were collected using a YSI Sonde. (See Figure 12)

	7-Jun-05		22-Jun-05		3-Aug-05			16-Aug-05			19-Sep-05		
Depth (m)	**Temp.**	**D. O.**	**Temp.**	**D. O.**	**Temp.**	**D. O.**	**Cond.**	**Temp.**	**D. O.**	**Cond.**	**Temp.**	**D. O.**	**Cond.**
Site 1													
0	16.0	10.9	19.9	9.6	24.8	9.8	89	24.6	9.3	90	21.2	9.6	84
1	15.7	10.3	19.8	9.5	24.8	9.8	89	24.6	9.4	90	21.2	9.5	84
2	15.6	10.5	19.7	9.5	24.7	9.8	89	24.6	9.5	89	21.1	9.6	84
3	15.6	10.4	19.4	9.6	24.7	9.8	89	24.5	9.4	89	21.0	9.6	83
4	15.4	10.5	18.9	9.6	24.1	9.7	87	24.5	9.2	89	21.0	9.6	83
5	14.0	10.5	18.8	9.4	23.8	8.8	86	23.3	7.1	86	21.0	9.6	83
6	12.9	10.3	14.9	9.8	21.2	6.6	81	21.9	6.2	83	20.7	9.4	82
7	11.9	10.0	13.7	8.9	15.9	5.8	71	18.6	5.2	77	20.5	8.9	82
8	11.5	9.7	11.7	8.8	14.0	4.2	68	14.2	2.9	69	20.4	8.7	82
9	11.1	9.6	10.9	8.1	12.3	3.8	65	12.9	2.2	67	15.7	2.8	76
10	10.9	9.7	10.6	8.1	11.7	4.0	64	11.6	2.5	64	13.0	1.1	71
11	10.8	9.8	10.5	8.2	11.3	4.3	63	11.1	3.3	63	11.8	0.5	67
12	10.6	9.6	10.4	8.1	11.1	4.4	62	10.9	3.8	62	11.4	0.8	66
13	10.4	9.5	10.4	8.0	10.9	4.6	62	10.7	3.7	62	11.2	0.8	66
14	10.4	9.5	10.3	8.1	10.7	4.8	61	10.5	3.6	62	10.7	0.8	65
15	10.3	9.3	10.3	8.1	10.5	4.8	61	10.3	3.4	61	10.7	0.8	65
16	10.3	9.4	10.2	8.0	10.8	4.0	-	10.5	2.6	-	10.6	0.7	65
17	10.2	9.2	10.2	7.9	10.6	4.1	-	10.4	2.5	-	10.5	0.7	65
18	10.2	9.1	10.2	7.9	10.4	3.8	-	10.3	2.2	-	10.4	0.6	65
19	10.1	9.1	10.2	7.7	10.3	4.0	-	10.2	1.8	-	10.3	0.5	65
20	10.1	8.9	10.2	7.5	10.2	3.6	-	10.1	1.6	-	10.3	0.4	66
21	10.0	8.8	-	-	10.1	3.2	-	10.1	1.6	-	10.2	0.2	65
22	10.0	8.9	-	-	10.1	2.8	-	10.1	1.5	-	10.2	0.2	65
23	10.0	8.9	-	-	10.0	2.6	-	10.0	1.3	-	10.2	0.1	66
24	10.0	8.7	-	-	10.0	2.5	-	10.0	1.3	-	10.2	0.1	66
25	9.9	8.6	-	-	10.0	2.4	-	10.0	1.0	-	10.2	0.1	66

APPENDIX C. (Continued)

	7-Jun-05		22-Jun-05		3-Aug-05			16-Aug-05			19-Sep-05		
Depth (m)	**Temp.**	**D. O.**	**Temp.**	**D. O.**	**Temp.**	**D. O.**	**Cond.**	**Temp.**	**D. O.**	**Cond.**	**Temp.**	**D. O.**	**Cond.**
Site 1													
26	9.9	8.4	-	-	-	-		10.0	0.8		10.1	0.1	67
27	9.8	8.0	-	-	-	-		-	-		-	-	-
Site 2													
0	16.8	9.9	19.9	9.4	25.0	9.0	89	24.6	9.3	88	21.2	8.7	82
1	16.3	10.1	19.6	9.3	24.8	9.1	88	24.6	9.4	88	21.2	8.6	82
2	16.2	10.2	19.1	9.3	24.5	9.1	88	24.5	9.5	88	21.2	8.6	82
3	15.6	10.2	19.0	9.3	24.3	9.0	87	24.4	9.6	88	21.2	8.5	82
4	13.7	9.8	18.7	9.3	24.1	8.7	86	24.4	9.5	88	21.2	8.4	82
5	12.3	9.5	17.4	9.3	23.2	7.6	84	24.4	9.3	88	21.1	8.4	82
6	11.7	9.4	15.0	9.0	21.7	6.2	81	21.6	5.4	82	20.6	8.0	81
7	11.4	9.1	14.1	8.8	16.4	5.1	72	16.7	4.1	75	20.5	7.5	81
8	11.1	8.8	12.0	8.5	13.4	3.4	68	14.3	2.0	70	20.2	6.5	80
9	11.0	8.7	11.7	7.5	12.7	2.2	67	13.0	1.3	69	16.5	2.8	82
10	10.9	8.8	11.4	7.1	12.2	1.8	67	12.6	1.1	68	14.1	0.7	79
11	10.9	9.0	11.2	6.7	12.2	1.7	66	12.5	1.0	68	13.5	0.3	79
12	10.8	8.9	11.2	6.6	12.1	1.6	66	12.4	0.8	68	13.3	0.1	79
13	10.8	8.8	11.2	6.6	12.1	1.6	66	12.4	0.7	68	13.1	0.1	80
14	10.8	8.8	11.1	6.4	12.0	1.6	66	12.3	0.6	68	13.0	0.1	79
15	10.7	8.6	11.1	6.4	11.9	1.5	67	12.2	0.6	69	12.9	0.1	81
16	10.7	8.0	-	-	-	-	-	-	-	-	-	-	-
Site 3													
0	18.6	9.6	20.4	9.8	25.3	9.1	89	25.0	9.2	89	21.2	8.9	82
1	18.5	9.5	20.3	9.3	25.3	9.1	89	25.0	9.2	89	21.2	8.9	82
2	18.2	9.6	19.9	9.3	25.1	9.2	89	25.0	9.3	89	21.2	8.9	81
3	18.0	9.5	19.5	9.3	25.0	9.2	89	25.0	9.2	89	21.1	8.9	81
4	17.9	9.4	17.1	8.9	24.7	9.0	88	24.9	9.1	89	21.1	8.9	81
5	14.2	9.3	14.9	8.6	22.8	7.1	84	24.7	8.8	88	21.1	8.9	81
6	12.5	9.1	14.1	8.1	20.3	4.9	79	22.9	5.2	85	21.1	8.9	81
7	11.8	9.1	12.2	8.1	14.7	3.7	68	17.2	2.4	75	20.7	8.5	81
8	11.4	9.2	11.4	7.4	12.6	1.6	66	14.4	1.0	71	20.3	8.0	81
9	11.3	9.1	11.1	6.9	11.9	1.4	65	12.3	0.3	68	14.8	4.9	83

APPENDIX C. (Continued)

	7-Jun-05		22-Jun-05		3-Aug-05			16-Aug-05			19-Sep-05		
Depth (m)	**Temp.**	**D. O.**	**Temp.**	**D. O.**	**Temp.**	**D. O.**	**Cond.**	**Temp.**	**D. O.**	**Cond.**	**Temp.**	**D. O.**	**Cond.**
Site 3													
10	11.0	8.6	11.0	6.5	11.4	0.9	65	11.6	0.2	68	12.3	1.4	78
11	10.9	8.5	11.0	6.1	11.3	0.7	65	11.4	0.2	68	11.7	0.4	79
12	10.9	8.5	10.9	5.9	11.2	0.7	64	11.3	0.1	67	11.3	0.2	76
13	10.8	8.4	10.8	5.7	10.9	0.6	64	11.0	0.1	66	11.1	0.1	76
14	10.8	8.2	10.8	5.3	10.9	0.4	64	10.9	0.1	66	11.0	0.1	77
15	10.8	8.1	10.8	5.1	10.8	0.3	64	10.8	0.1	66	10.9	0.1	78
16	10.8	7.8	-	-	10.9	0.1	-	10.9	0.1	-	10.8	0.1	80
Site 4													
0	-	-	-	-	-	-	-	-	-	-	23.0	8.5	77
Site 5													
0	-	-	-	-	-	-	-	-	-	-	23.2	7.9	59
Site 6													
0	-	-	-	-	-	-	-	-	-	-	21.4	9.2	56
Site 7													
0	-	-	-	-	-	-	-	-	-	-	21.3	8.1	56
Site 8													
0	-	-	-	-	-	-	-	-	-	-	21.8	7.9	59
Site 9													
0	-	-	-	-	-	-	-	-	-	-	73.1	3.7	77
Site 10													
0	-	-	-	-	-	-	-	-	-	-	67.7	8.5	111
Site 11													
0	-	-	-	-	-	-	-	-	-	-	70.1	8.4	143

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

	7-Jun-05	22-Jun-05	3-Aug-05	16-Aug-05	19-Sep-05	6-Oct-05
Air Temperature	21.1 °C	21.0 °C	21.3 °C	20.5 °C	23.3 °C	-
Cloud Cover	5%	10%	<5%	50%	5%	-
Wind Speed	-	15 mph	11 mph	8 mph	-	-
Wind Direction	S	N-NE	N	SE	-	-
Previous Weather	rainy & cold	rain	t-storms	hot & sunny	mild rain	-
Site 1						
Sample Depths (m)						
Epicore	5.0	6.5	7.0	7.0	9.0	-
Middle	13.5	10.5	13.0	13.0	14.0	-
Bottom	26.0	20.0	25.0	25.0	25.0	-
Secchi Disk (m)	6.10	4.30	1.25	1.20	2.55	-
Turbidity (NTU)						
Surface	0.68	0.83	5.09	6.42	4.27	-
Middle	0.73	0.72	1.10	1.61	1.19	-
Bottom	1.08	0.94	2.47	1.87	0.79	-
Color (SPU)	-	-	-	-	10	-
Site 2						
Sample Depths (m)						
Epicore	4.0	6.5	7.0	7.0	-	-
Middle	8.0	7.5	7.8	7.8	-	-
Bottom	16.0	14.5	15.0	15.0	-	-
Secchi Disk (m)	5.50	3.5	1.6	1.5	2.5	-
Turbidity (NTU)						
Surface	0.78	1.23	4.42	5.24	3.98	-
Middle	0.90	1.53	1.59	1.98	3.39	2.10
Bottom	1.56	1.78	5.48	3.78	2.51	0.85
Color (SPU)	-	-	-	-	11	-
Site 3						
Sample Depths (m)						
Epicore	5.0	6.0	7.0	7.0	-	-
Middle	8.5	8.5	8.0	8.3	-	-
Bottom	16.0	16.0	16.0	16.0	-	-

APPENDIX C. (Continued)

	7-Jun-05	22-Jun-05	3-Aug-05	16-Aug-05	19-Sep-05	6-Oct-05
Secchi Disk (m)	4.00	3.50	1.95	1.55	2.5	-
Turbidity (NTU)						
Surface	0.94	1.24	3.17	5.76	4.09	-
Middle	0.67	1.05	1.39	2.35	3.41	-
Bottom	2.21	4.32	-	17.50	1.06	-
Color (SPU)	-	-	-	-	10	-
Site 4						
Turbidity	-	-	-	-	3.09	-
Color	-	-	-	-	16	-
Site 5						
Turbidity	-	-	-	-	3.54	-
Color	-	-	-	-	14	-
Site 6						
Turbidity	-	-	-	-	2.82	-
Color	-	-	-	-	12	-
Site 7						
Turbidity	-	-	-	-	1.8	-
Color	-	-	-	-	12	-
Site 8						
Turbidity	-	-	-	-	1.81	-
Color	-	-	-	-	10	-
Site 9						
Secchi Tube[a] (cm)	-	-	-	-	122	-
Color	-	-	-	-	66	-
Site 10						
Secchi Tube[a] (cm)	-	-	-	-	75	-
Color	-	-	-	-	175	-
Site 11						
Secchi Tube[a] (cm)	-	-	-	-	113	-
Color	-	-	-	-	58	-

[a] Secchi tubes are tall cylinders with a Secchi disk symbol at the bottom. The transparency of shallow water is measured by filling the tube with water and draining it until the Secchi symbol is visible.

APPENDIX C. (Continued)
Chemical tests: nitrates (mg/L), pH, and alkalinity (mg/L).

	22-Jun-05	3-Aug-05		16-Aug-05		19-Sep-05		
Depth (m)	Nitrates	pH	Nitrates	pH	Nitrates	pH	Nitrates	Alkalinity
Site 1								
0	-	-	-	-	-	7.18[a]	0.02[a]	17.00[a]
0	1.19	9.30	4.16	9.13	8.87	8.23	0.43	-
1	1.20	9.38	3.40	9.24	6.30	8.20	0.46	-
2	1.17	9.39	2.98	9.26	5.38	8.20	0.47	-
3	1.23	9.38	2.68	9.24	4.89	8.20	0.49	-
4	1.21	9.26	2.26	9.21	4.37	8.21	0.49	-
5	1.25	8.83	1.44	8.61	1.05	8.20	0.52	-
6	1.00	8.25	0.61	8.36	0.81	8.13	0.49	-
7	0.97	8.05	0.51	8.12	0.65	7.97	0.42	-
8	0.95	7.83	0.51	7.79	0.63	7.89	0.44	-
9	0.96	7.72	0.53	7.52	0.66	7.57	0.30	-
10	0.99	7.60	0.54	7.47	0.73	7.45	0.40	-
11	1.06	7.35	0.64	7.38	0.84	7.23	0.59	-
12	1.10	7.30	0.66	7.29	0.90	7.07	0.76	-
13	1.11	7.25	0.72	7.22	1.02	7.04	0.81	-
14	1.13	7.20	0.79	7.15	1.11	7.00	0.93	-
15	1.19	7.16	0.89	7.13	1.23	6.98	0.98	-
16	-	-	-	-	-	6.93	1.07	-
17	-	-	-	-	-	6.91	1.13	-
18	-	-	-	-	-	6.90	1.17	-
19	-	-	-	-	-	6.88	1.23	-
20	-	-	-	-	-	6.88	1.27	-
21	-	-	-	-	-	6.87	1.30	-
22	-	-	-	-	-	6.86	1.33	-
23	-	-	-	-	-	6.85	1.31	-
24	-	-	-	-	-	6.85	1.33	-
25	-	-	-	-	-	6.85	1.32	-
26	-	-	-	-	-	6.85	1.30	-
Site 2								
0	-	-	-	-	-	7.28[a]	0.05[a]	16.00[a]
0	1.62	9.12	2.68	8.86	5.07	8.05	0.82	-

APPENDIX C. (Continued)

Depth (m)	22-Jun-05 Nitrates	3-Aug-05 pH	3-Aug-05 Nitrates	16-Aug-05 pH	16-Aug-05 Nitrates	19-Sep-05 pH	19-Sep-05 Nitrates	19-Sep-05 Alkalinity
Site 2								
1	1.63	9.17	2.56	8.96	4.11	8.07	0.81	-
2	1.59	9.18	2.43	9.04	4.08	8.08	0.81	-
3	1.60	9.16	2.27	9.08	3.90	8.10	0.79	-
4	1.63	9.00	1.68	9.03	3.33	8.10	0.78	-
5	1.40	8.52	0.76	8.94	2.85	8.11	0.79	-
6	1.15	8.16	0.63	8.30	0.71	8.00	0.64	-
7	1.13	7.93	0.47	8.10	0.55	7.87	0.58	-
8	1.06	7.73	0.46	7.85	0.57	7.72	0.50	-
9	1.08	7.57	0.48	7.68	0.64	7.43	0.38	-
10	1.09	7.44	0.51	7.54	0.69	7.30	0.41	-
11	1.07	7.36	0.55	7.43	0.73	7.23	0.45	-
12	1.11	7.26	0.57	7.33	0.77	7.15	0.53	-
13	1.13	7.22	0.60	7.26	0.78	7.11	0.59	-
14	1.17	7.16	0.61	7.22	0.82	7.09	0.64	-
15	1.18	7.12	0.63	7.19	0.85	7.06	0.72	-
Site 3								
0	-	-	-	-	-	7.31[a]	0.06[a]	17.00[a]
0	1.40	8.95	2.99	8.73	4.66	7.76	0.79	-
1	1.52	8.99	2.72	8.79	3.95	7.76	0.81	-
2	1.52	9.01	2.51	8.83	3.57	7.77	0.82	-
3	1.57	9.02	2.48	8.80	2.95	7.78	0.85	-
4	1.45	8.87	1.97	8.73	2.46	7.79	0.85	-
5	1.31	8.36	0.84	8.49	1.34	7.81	0.85	-
6	1.36	7.91	0.68	8.04	0.77	7.81	0.88	-
7	1.34	7.67	0.55	7.73	0.59	7.75	0.79	-
8	1.39	7.35	0.68	7.56	0.61	7.66	0.72	-
9	1.41	7.26	0.74	7.34	0.75	7.43	0.53	-
10	1.42	7.14	0.84	7.21	0.85	7.30	0.59	-
11	1.42	7.04	0.92	7.16	0.90	7.19	0.90	-

APPENDIX C. (Continued)

Depth (m)	22-Jun-05 Nitrates	3-Aug-05 pH	3-Aug-05 Nitrates	16-Aug-05 pH	16-Aug-05 Nitrates	19-Sep-05 pH	19-Sep-05 Nitrates	19-Sep-05 Alkalinity
Site 3								
12	1.44	6.99	0.96	7.12	0.94	7.15	1.06	-
13	1.44	6.96	1.12	7.04	0.95	7.11	1.41	-
14	1.43	6.88	1.21	7.01	0.95	7.08	1.76	-
15	1.44	6.86	1.25	6.99	0.93	7.08	2.36	-
16	-	-	-	-	-	7.07	3.16	-
Site 4								
0	-	-	-	-	-	7.50 [a]	0.02 [a]	17.00 [a]
Site 5								
0	-	-	-	-	-	7.40 [a]	0.02 [a]	17.00 [a]
Site 6								
0	-	-	-	-	-	7.07 [a]	0.05 [a]	18.00 [a]
Site 7								
0	-	-	-	-	-	7.63 [a]	0.07 [a]	19.00 [a]
Site 8								
0	-	-	-	-	-	7.22 [a]	0.08 [a]	17.00 [a]
Site 9								
0	-	-	-	-	-	6.76 [a]	0.04 [a]	27.00 [a]
Site 10								
0	-	-	-	-	-	-	0.03 [a]	-
Site 11								
0	-	-	-	-	-	7.54 [a]	0.05 [a]	31.00 [a]

[a] Measurements made in lab, using surface sample

APPENDIX C. (Continued)

Chemical tests: total phosphorus concentrations in China Lake for summer and fall 2005, at different sites and levels within the lake.

Site	Date	Sample Type [a]	Concentration (ppb)	Quality Control [b]
1	7-Jun-05	S	13.4	-
1	7-Jun-05	M	15.8	-
1	7-Jun-05	B	16.7	-
1	7-Jun-05	B	23.1	Duplicate
1	7-Jun-05	E	18.4	-
2	7-Jun-05	S	18.3	-
2	7-Jun-05	M	14.5	-
2	7-Jun-05	B	23.4	-
2	7-Jun-05	E	15.4	-
3	7-Jun-05	S	17.5	-
3	7-Jun-05	M	14.2	-
3	7-Jun-05	B	27.4	-
3	7-Jun-05	E	18.8	-
1	22-Jun-05	M	14.3	-
1	22-Jun-05	B	13.1	-
1	22-Jun-05	B	16.2	Duplicate
1	22-Jun-05	E	15.5	-
2	22-Jun-05	S	16.6	-
2	22-Jun-05	M	17.6	-
2	22-Jun-05	B	23.2	-
2	22-Jun-05	E	15.6	-
3	22-Jun-05	S	17.6	-
3	22-Jun-05	S	18.0	Split
3	22-Jun-05	M	20.6	-
3	22-Jun-05	B	46.8	-
3	22-Jun-05	E	14.1	-
4	11-Jul-05	St-C	16.5	-
4	11-Jul-05	St-S	21.3	-
1	3-Aug-05	S	16.1	-
1	3-Aug-05	M	11.4	-
1	3-Aug-05	M	11.9	Duplicate
1	3-Aug-05	B	25.3	-
1	3-Aug-05	E	19.7	-
2	3-Aug-05	S	12.9	-
2	3-Aug-05	M	13.1	-
2	3-Aug-05	B	59.2	-
2	3-Aug-05	B	58.1	Split
2	3-Aug-05	E	16.8	-
3	3-Aug-05	S	13.3	-
3	3-Aug-05	M	16.1	-
3	3-Aug-05	M	26.5	10 ppb Spike
3	3-Aug-05	B	81.7	-
3	3-Aug-05	E	14.1	-
1	16-Aug-05	S	15.4	-
1	16-Aug-05	M	12.9	-
1	16-Aug-05	M	12.6	Duplicate
1	16-Aug-05	B	34.7	-

APPENDIX C. (Continued)

Site	Date	Sample Type [a]	Concentration (ppb)	Quality Control
1	16-Aug-05	E	17.2	-
2	16-Aug-05	S	17.1	-
2	16-Aug-05	M	14.6	-
2	16-Aug-05	M	22.6	10 ppb Spike
2	16-Aug-05	B	32.9	-
2	16-Aug-05	E	15.3	-
3	16-Aug-05	S	18.2	-
3	16-Aug-05	M	14.5	-
3	16-Aug-05	B	111.1	-
3	16-Aug-05	B	105.5	Split
3	16-Aug-05	E	17.4	-
1	19-Sep-05	S	16.6	-
1	19-Sep-05	M	17.8	-
1	19-Sep-05	B	25.0	-
1	19-Sep-05	B	35.1	10 ppb Spike
1	19-Sep-05	E	20.8	-
2	19-Sep-05	S	21.5	-
2	19-Sep-05	M	21.3	-
2	19-Sep-05	B	22.5	-
2	19-Sep-05	E	22.7	-
3	19-Sep-05	S	18.8	-
3	19-Sep-05	S	18.1	Duplicate
3	19-Sep-05	M	19.9	-
3	19-Sep-05	M	20.1	Duplicate
3	19-Sep-05	B	199.3	-
3	19-Sep-05	B	197.1	Split
3	19-Sep-05	E	25.4	-
4	19-Sep-05	S	20.4	-
5	19-Sep-05	S	18.1	-
6	19-Sep-05	S	20.8	-
6	19-Sep-05	S	31.2	10 ppb Spike
7	19-Sep-05	S	21.0	-
8	19-Sep-05	S	18.0	-
9	19-Sep-05	S	32.7	-
10	19-Sep-05	S	63.3	-
11	19-Sep-05	S	44.7	-
11	19-Sep-05	S	42.5	Split
2	6-Oct-05	S	19.5	-
2	6-Oct-05	S	13.8	Duplicate
2	6-Oct-05	M	12.1	-
2	6-Oct-05	M	15.7	10 ppb Spike
2	6-Oct-05	B	115.2	-
2	6-Oct-05	B	102.9	Split
2	6-Oct-05	E	15.8	-
9	6-Oct-05	St-C	25.3	-
9	6-Oct-05	St-S	46.1	-
11	6-Oct-05	St-C	16.7	-
11	6-Oct-05	St - S	20.9	-

[a] S = Surface, M = Middle, B = Bottom, E = Epicore, St–C = Storm water - Continuous, and St–S = Storm water – Staggered
[b] See Appendix B

APPENDIX C. (Continued)
Biotic measurements: chlorophyll-*a* concentration in China Lake, for summer and fall 2005.

	Concentration (ppb)			
Depth	**22-Jun-05**	**3-Aug-05**	**16-Aug-05**	**19-Sep-05**
Site 1				
0	-	0.9	1.4	1.3
1	-	2.4	2.0	2.6
2	-	1.9	1.8	3.7
3	-	2.7	1.9	3.6
4	-	2.2	2.9	4.4
5	-	2.1	1.3	4.8
6	-	1.1	1.6	4.6
7	-	0.7	0.8	2.8
8	-	0.2	0.0	2.6
9	-	0.3	0.5	1.0
10	-	0.0	0.2	0.2
11	-	1.0	0.7	0.1
12	-	0.3	0.3	0.6
13	-	1.2	0.0	2.0
14	-	0.8	0.0	0.1
15	-	0.3	0.1	0.4
16	-	-	-	0.4
17	-	-	-	0.2
18	-	-	-	0.7
19	-	-	-	0.0
20	-	-	-	0.6
21	-	-	-	0.5
22	-	-	-	0.0
23	-	-	-	0.2
24	-	-	-	1.2
25	-	-	-	0.1
26	-	-	-	0.0
Site 2				
0	2.1	1.0	1.2	2.7
1	2.6	1.5	1.4	4.3
2	3.0	2.3	2.0	4.5
3	3.0	1.7	3.6	5.8
4	3.1	1.4	2.1	5.6
5	3.9	1.0	1.9	5.4
6	3.6	0.8	0.6	5.2
7	3.7	0.5	0.1	3.3
8	2.4	0.5	0.7	2.3
9	1.5	0.2	0.2	0.8
10	1.7	0.5	0.5	0.5
11	1.2	0.0	0.2	0.6
12	1.7	0.3	0.6	0.9
13	1.1	0.2	0.5	0.4
14	1.5	0.6	0.5	0.9
15	1.9	0.3	0.5	0.6

Appendix C. (CONTINUED)

	Concentration (ppb)			
Depth	**22-Jun-05**	**3-Aug-05**	**16-Aug-05**	**19-Sep-05**
Site 3				
0	3.4	0.7	1.8	1.8
1	2.8	1.6	3.2	2.8
2	3.7	1.6	3.0	3.8
3	3.9	2.0	3.1	3.6
4	6.5	2.0	3.2	3.3
5	4.4	2.1	1.5	4.3
6	3.3	1.0	1.0	3.4
7	2.1	1.1	0.6	2.6
8	2.0	1.4	0.8	3.7
9	1.3	1.0	0.7	1.8
10	1.9	0.6	0.5	1.1
11	1.4	1.0	0.6	0.7
12	1.7	1.1	0.8	1.0
13	1.6	1.4	1.0	1.2
14	1.1	1.3	0.6	0.9
15	2.9	0.9	0.9	0.4
16	-	-	-	1.0

APPENDIX D. WATER BUDGET FOR CHINA LAKE

1. Calculating Net Inputs (m^3/ year)

I_{net} = (runoff* land area) + (precipitation* lake area) – (evaporation* lake area)

2. Calculating Flushing Rate (flushes/year)

F.R. = (I_{net} Lake 1) + (I_{net} Input 2) +…(I_{net} Input *n*) / (mean depth* lake area)

3. Physical Parameters of China Lake Used in The Water Budget

Physical Parameter	**Value**	**Units**
Runoff	0.622	meters/yr.
Precipitation	1.003	meters/yr.
Evaporation	0.560	meters/yr.
Land Area	6.87×10^7	square meters
Lake Area	1.60×10^7	square meters
Average Depth	8.534	meters

4. Water Budget

- The net input to China Lake is 59,300,000 cubic meters per year.
- I_{net}= (0.622x 6.87*10^7) + (1.003x 1.6*10^7) –(0.560x 1.6*10^7)
- Flushing rate = (5.935x10^6/ (8.53x 1.6*10^7)
- The flushing rate of China Lake is 0.35 flushes per year.

APPENDIX E. PHOSPHORUS MODEL EQUATION AND COEFFICIENTS

The following coefficients are based on past studies of lakes in central Maine (CEAT 2001, 2003, 2004, and 2005), in addition to other sources that are specifically cited. These export coefficients were estimated using several factors that influence the movement of phosphorus into China Lake, including land use patterns, soil type and quality, land area, population size, and characteristics of residential development. All coefficients represent the mass of phosphorus exported from a particular source into the lake in kg/ha/yr unless otherwise noted.

Ec_a = export coefficient for atmospheric input

Estimated Range = 0.10 - 0.25 Best Estimate = 0.15

This coefficient was estimated based on past studies of central Maine lakes. The very low level of industry producing airborne particulates in the area would decrease potential phosphorus deposition. Additionally, China Lake is farther from cities than Togus Pond; the best estimate of the export coefficient is lower in comparison (CEAT 2005).

Ec_{mf} = export coefficient for mature forest

Estimated Range = 0.05 - 0.15 Best Estimate = 0.10

The majority of the forested area in the China Lake watershed is comprised of a mix of coniferous and deciduous species with slightly more coniferous areas than deciduous areas, so a relatively low export coefficient was estimated. Coniferous forests contribute less phosphorus than deciduous forests because they produce less leaf litter. In general, mature forests have a low phosphorus export coefficient because they reduce runoff and soil erosion as the canopy reduces velocity of rain and roots hold the soil in place.

Ec_{cp} = export coefficient for cropland

Estimated Range = 0.10 - 3.00 Best Estimate = 1.50

The estimated range for the phosphorus export coefficient for cropland was taken from Reckhow and Chappra (1983). The 2001 Total Maximum Daily Load Report (TMDL) for China Lake also used the coefficient of 1.50 as a best estimate for cropland in the China Lake watershed (MDEP 2001). These values are relatively high because there is generally little cover to reduce the velocity of rain and reduce soil erosion on cropland, and runoff

can contain high levels of nutrients from fertilizers. Additionally, crops planted in rows can form channels for water to flow through, carrying soil with it.

Ec_p = export coefficient for pasture

Estimated Range = 0.35 - 1.35 Best Estimate = 0.55

The range for pasture phosphorus export coefficient was taken from a TMDL study for Threemile Pond (MDEP 2003). Pastures and hayfields retain phosphorus better than cropland because of their thick grass cover.

Ec_g = export coefficient for grassland

Estimated Range = 0.25 - 0.90 Best Estimate = 0.50

Grasslands are open areas dominated by grass that have no association with agriculture (e.g., lawns). The export coefficient was estimated to be slightly lower than that of pasture because there is no association with grazing animals that can contribute nutrients to the land and runoff. Grass cover helps to prevent soil erosion. However, if grasslands are treated with fertilizers, nutrients can be washed into the lake during heavy precipitation.

Ec_w = export coefficient for wetland

Estimated Range = 0.02 - 0.08 Best Estimate = 0.04

The phosphorus export coefficient for wetlands is very low, since wetlands act as phosphorus sinks during the summer when there is active plant growth. Some phosphorus, however, may be released from wetlands during periods of runoff (CEAT 2005; See Watershed Land Use Patterns: Comparison of 1965 and 2003: Wetlands).

Ec_r = export coefficient for reverting land

Estimated Range = 0.20 - 0.80 Best Estimate = 0.30

The export coefficient for reverting land is higher than mature forest because the vegetation is dominated by grasses and shrubs with less than 50% canopy cover. There is well developed ground cover that helps to reduce runoff and prevent erosion.

Ec_{cm} = export coefficient for commercial and municipal land

Estimated Range = 0.50 - 3.00 Best Estimate = 1.30

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

Ec_{sr} = export coefficient for state and municipal roads

Estimated Range = 0.70 - 6.00 Best Estimate = 1.80

The impervious surface of state and municipal roads increases runoff, and as the roads wear down, phosphorus is released in the dust. The state and municipal roads were assigned a lower export coefficient than the camp roads because most of the paved roads in the China Lake watershed are well maintained and generally have better crowns than dirt roads. Our best estimate was slightly higher than for other lake watersheds in the region because of the close proximity of Lakeview Drive to the shoreline (CEAT 2004, 2005).

Ec_{cr} = export coefficient for camp roads

Estimated Range = 1.00 - 7.00 Best Estimate = 3.40

The export coefficient for camp roads is higher than that of state and municipal roads because they are unpaved and prone to erosion, generally not as well maintained, and closer in proximity to the lake (often leading directly to the lake shore).

Ec_s = export coefficient for shoreline development

Estimated Range = 0.50 - 3.00 Best Estimate = 1.80

Development within 200 ft of the shoreline impacts water quality significantly because water can run directly off lawns, roofs, and other exposed surfaces into the lake. Shoreline areas that are developed are relatively densely developed and there are areas of clustered older residences that are grandfathered. These characteristics can lead to increased phosphorus loading from residences, and are reflected in the high export coefficient.

Ec_n = export coefficient for non-shoreline development

Estimated Range = 0.20 - 1.50 Best Estimate = 0.30

Non-shoreline development (greater than 200 ft from the shore) impacts water quality far less than shoreline development because the soil absorbs more runoff over a greater distance, and a wider buffer exists between the homes and the lake.

Ec_{ss} = export coefficient for shoreline septic systems

Estimated Range = 0.40 - 0.90 Best Estimate = 0.60

Many of the septic systems along the shoreline of China Lake were built before the implementation of current standards for these systems, and there are many septic systems built close to the edge of the water or in soil that is not ideal for septic systems. The high export coefficient reflects the potential of these systems to export phosphorus into the lake

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

Estimated Range = 0.30 - 0.90 Best Estimate = 0.50

The estimated export coefficients for non-shoreline septic systems were slightly lower than the shoreline septic coefficients for the reasons discussed under non-shoreline development.

I_A = export coefficient and number capita years for China Primary and Middle Schools

Estimated Range = 203.72 - 509.30 kg/yr Best Estimate = 305.58 kg/yr

I_B = export coefficient and number capita years for Erskine Academy

Estimated Range = 227.01 - 557.52 kg/yr Best Estimate = 340.51 kg/yr

I_C = export coefficient and number capita years for Friends Camp

Estimated Range = 18.10 – 36.20 kg/yr Best Estimate = 24.13 kg/yr

The estimated export coefficients and number capita years for China Primary and Middle Schools, Erskine Academy, and the Friends Camp represent the number of kilograms of phosphorus per year released by each institution, respectively. These values were calculated using the following factors: (a) number of students and faculty at each institution; (b) the number of days of operation per year; (c) a high, low, and best estimate of the number of gallons of water used per day per person based on reported estimates in a 1980 USEPA report, current code regulations for water fixtures, and other factors specific to the institution; and (d) an average phosphorus concentration of institutional wastewater reported by the U.S. Environmental Protection Agency (USEPA 1980). China Primary

School and China Middle School were treated as one large school for the purpose of the model due to their close proximity to the lake and to each other. Erskine Academy was accounted for separately because it is located much farther from the lake and operates for a different number of days per year in comparison to the other two schools. The Friends Camp was also considered separately since it is a residential summer camp and has different characteristics from the schools.

SR_1 = soil retention coefficient for shoreline residences

Estimated Range = 0.65 - 0.35 Best Estimate = 0.55

The majority of soil types along the shoreline of China Lake are drained well or moderately well (USDA 1978). Well drained soil allows water to percolate through at a slow rate that allows the soil to capture nutrients such as phosphorus. This characteristic is reflected in the relatively high soil retention coefficient, which indicates the ability of the soil to hold nutrients.

SR_2 = soil retention coefficient for non-shoreline residences

Estimated Range = 0.90 - 0.75 Best Estimate = 0.80

There are large areas of excessively drained soil interspersed with areas of well or moderately well drained soil, and areas of poorly or very poorly drained soil within the China Lake watershed. Excessively drained soil allows water to percolate very quickly, carrying nutrients with it. Poorly drained soil does not allow water to percolate, trapping water where it can be flushed out during heavy precipitation. These retention coefficients are slightly higher than for shoreline residences because water travels a greater distance through the soil before reaching the lake, allowing for the soil to retain a greater amount of nutrients.

SR_{3A} = soil retention coefficient for China Primary and Middle Schools

Estimated Range = 0.65 - 0.35 Best Estimate = 0.55

Due to the close proximity of China Primary and Middle Schools to the lake, the shoreline soil retention coefficient estimates were used.

SR_{3B} = soil retention coefficient for Erskine Academy

Estimated Range = 0.90 - 0.75 Best Estimate = 0.80

Non-shoreline soil retention coefficient estimates were used because Erskine Academy is located at the edge of the China Lake watershed.

SR_{3C} = soil retention coefficient for the Friends Camp

Estimated Range = 0.90 - 0.75 Best Estimate = 0.80

Non-shoreline soil retention coefficient estimates were used because the Friends Camp is located greater than 200 ft from the shore of China Lake.

Sd = internal sediment release coefficient

Estimated Range = 1.00 - 1.60 Best Estimate = 1.40

The amount of phosphorus released from sediments was estimated by subtracting the export coefficient terms from the observed concentration of phosphorus in China Lake during the summer and fall (see Phosphorus Budget). Our results are supported by previous estimates of sediment release in China Lake, reported in the 2001 China Lake TMDL (MDEP 2001).

Calculations for Total Phosphorus Loading

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

$$L = W/A_s$$

W = annual phosphorus inflow in kg/yr

A_s = surface area of the lake = 16,041,650 m^2

Annual atmospheric water loading **(q_s)** was calculated by dividing the total volume of water inflow by the surface area of China Lake:

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

Q_{total} = total volume of water inflow in m^3/yr= 59,356,148 m^3/yr

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

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

L = phosphorus loading (m/yr)

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

q_s for China Lake = 3.70 m/yr

Phosphorus Budget Estimates

Low estimate:

W = 1209.9 kg/yr

L = 0.075 kg/ha/yr

P = 4.70 ppb

Low estimate with sediment release:

W = 2814.1 kg/yr

L = 0.175 kg/ha/yr

P = 10.94 ppb

Best estimate:

W = 2597.0 kg/yr

L = 0.162 kg/ha/yr

P = 10.09 ppb

Best estimate with sediment release:

W= 4842.8 kg/yr

L = 0.302 kg/ha/yr

P = 18.82 ppb

High estimate:

W = 5716.1 kg/yr

L = 0.356 kg/ha/yr

P = 22.21 ppb

High estimate with sediment release:

W = 8282.7 kg/yr

L = 0.516 kg/ha/yr

P = 32.19 ppb

APPENDIX F. ROAD SURVEY FORMS

OVERALL ROAD SURVEY DATA SHEET 2005

DATE: SURVEYORS: ROAD NAME:

ROAD TYPE: state road / camp road / other:

GPS at start of road:

GPS at end of road:

ROAD LENGTH (MILES):

AVERAGE WIDTH (FEET, include shoulders):

HOUSE COUNT (tally # of houses per road) Year-Round Not Shore #: Shoreline:

Seasonal Not Shore (camps) #: Shoreline:

NOTE COMMERCIAL LAND USE, GPS (gas stations, stores, etc.)

TALLY # INACCESSABLE LAKEFRONT DRIVEWAYS:

SLOPE: Draw road profile and label with significant slope range 0-5%, 6-10%, 11-15%, 16-20%, >20%

describe any discrepancies

TALLY # OF WATER DIVERSIONS:

TALLY # OF CULVERTS:

DESCRIBE CROWN:

measurment: 0-2 in 2-4 in 4-6 in 6-8 in

DESCRIBE DITCH CONDITION:

shape:

vegetation, stone-lined, dirt:

clear of debris?

DESCRIBE CULVERTS:

constuction (wood, pastic, metal, concrete)

diameter:

condition (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):

Is there a berm? (report on back of sheet)

WATER DIVERSIONS CONDITION:

Appropriate placement?

Clear of debris?

BASIC SUMMARY:

OVERALL CONDITION good acceptable fair poor

Appendix F. (Continued)

ROAD SURVEY DATA SHEET FOR PROBLEM AREAS 2005

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):					

NONCAMP ROAD IN WATERSHED

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):		

APPENDIX G. BUFFER STRIP AND HOUSE COUNT SURVEY FORM

BUFFER STRIP SURVEY – CHINA LAKE *DATE:* *GROUP #:*

General Description of first house:
General Description of last house:
Forest GPS Start: End:
Directions: Circle the best option for each category

House # (on island?): **GPS Coordinate:**						
% Shoreline w/Buffer	0	1 - 25	26 - 50	51 - 75	> 75	
	0	1	2	3	4	
Buffer depth from shore(ft)	0	1 -10	11 - 33	34 - 65	> 65	
	0	1	2	3	4	
Slope rating		Steep	Moderately Steep	Small Incline	Flat	
		1	2	3	4	
Seasonal	YES 2	NO 0				
Buffer Composition:	100%	75%	50%	25%	0%	
Trees	4	3	2	1	0	
Shrubs/Herbaceous	10	8	6	4	0	
Riprap needed:	YES 0	NO 2	Exists 2			
Total:						
Lot Shoreline distance (ft)	0-60’	60-120	120-180	>180		
Noticeable outdoor septic	YES	NO				

APPENDIX H. SOIL CHARACTERISTICS

Soil series, abbreviations and names of phases within each series, k-factors at 0% slope, and septic potential rankings (USDA 1992; KCSWCD 1990). K-factors indicate soil erosion potential on a scale of 0, low erosion potential, to 1, high potential.

Soil Series	Soil Phases	K-factor	Septic Potential
Berkshire	Bh - Berkshire fine sandy loam	0.20	Very High
Biddeford	Bo – Biddeford mucky peat	0.00	Very Low
Brayton	Rc - Ridgebury fine sandy loam	0.27	Very Low
Brayton-stony	Rd – Ridgebury very stony fine sandy loam	0.20	Very Low
Buxton	Bu - Buxton silt loam	0.20	Medium
Colton	Hk – Hinckley gravelly sandy loam	0.20	High
Hartland	Hf – Hartland very fine sandy loam	0.49	Medium
Lyman	Hr – Hollis fine sandy loam	0.28	Medium
Lyman-stony	Ht – Hollis-rock outcrop complex	0.20	Medium
Marlow	Pb – Paxton fine sandy loam Pd – Paxton-Charlton fine sandy loam	0.24	High
Marlow-stony	Pc – Paxton very stony fine sandy loam Pe – Paxton-Charlton very stony fine sandy loam	0.20	High
Medomak	Sa – Saco soils	0.28	Very Low
Monarda	Mo – Monarda silt loam	0.25	Very Low
Monarda-stony	Mr – Monarda very stony silt loam	0.26	Very Low
Nicholville	Sk – Scio very fine sandy loam	0.49	High
Peru	Wr – Woodbridge fine sandy loam	0.22	High
Peru-stony	Ws – Woodbridge very stony fine sandy loam	0.20	High
Rifle	Rf – Rifle mucky peat	0.00	Very Low

Appendix H. (Continued)			
Soil Series	**Soil Phases**	**K-factor**	**Septic Potential**
Scantic	Sc – Scantic silt loam	0.32	Very Low
Scarboro	Sd – Scarboro mucky peat	0.00	Very Low
Suffield	Su – Suffield silt loam	0.32	High
Togus	To – Togus fibrous peat	0.10	Very Low
Vassalboro	Va – Vassalboro fibrous peat	0.00	Very Low
Windsor	Wm – Windsor loamy sand	0.17	Low