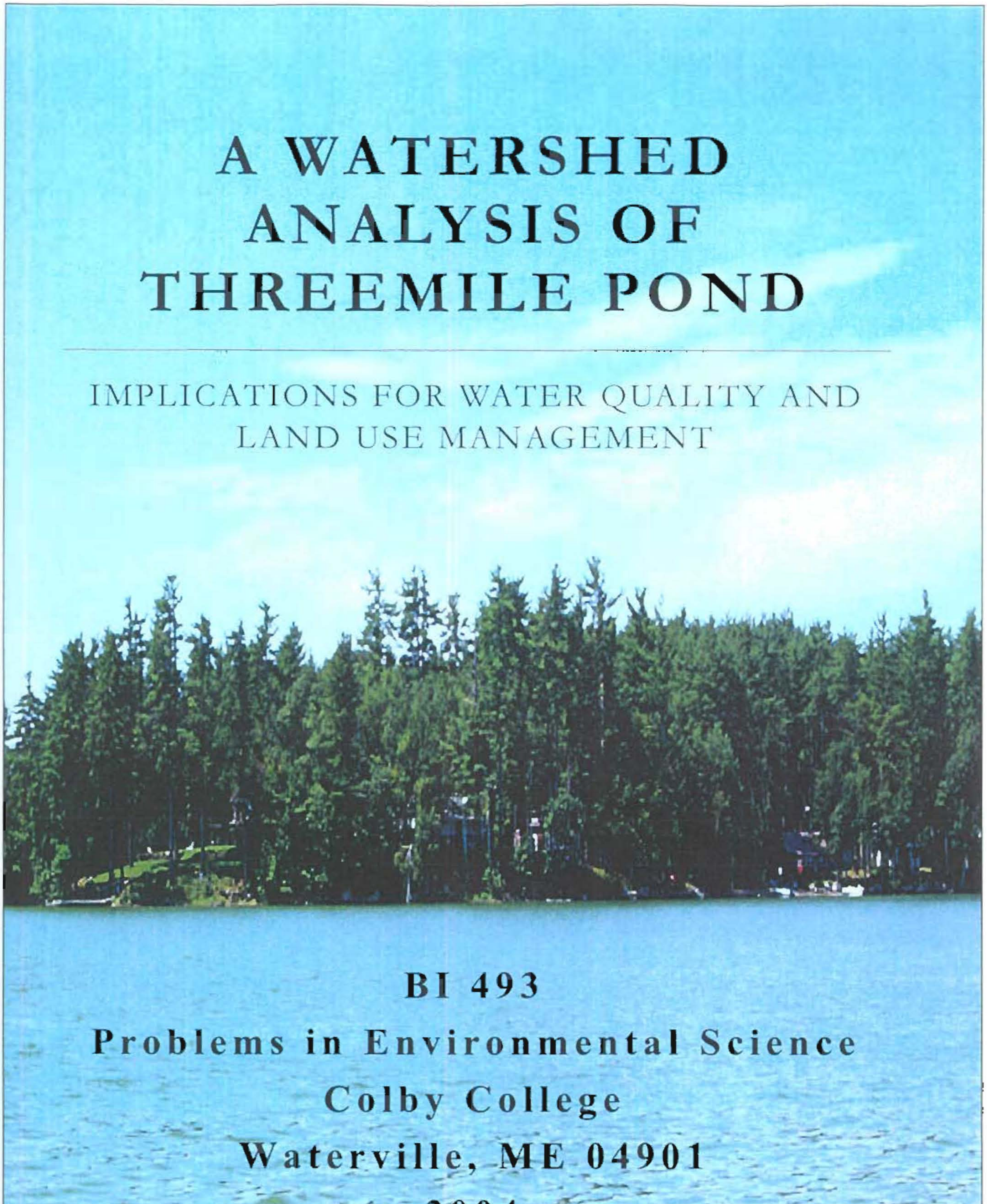
2003

A Watershed Analysis of Threemile Pond: Implications for Water Quality and Land Use Management

Colby Environmental Assessment Team, Colby College

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



A WATERSHED ANALYSIS OF THREEMILE POND

IMPLICATIONS FOR WATER QUALITY AND LAND USE MANAGEMENT

BI 493

Problems in Environmental Science

Colby College

Waterville, ME 04901

2004

DATE: April 8, 2004

TO: **Report recipients**

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

RE: **Class report on Threemile Pond**

We have very much enjoyed working with the people concerned with the water quality of Threemile Pond and hope that the work done by Colby students and herein reported will be of value to them and to other interested parties. We realize that some areas of the study could and perhaps should be expanded. We feel confident of the quality of the work done and only wish the time had been available so that the students could fulfill their desire to conduct a more comprehensive study.

This report is the work of students enrolled in the Problems in Environmental Science course (Biology 493) taught at Colby College during the fall semester of 2003. The course is taken by seniors majoring in Biology, most having a concentration in Environmental Science. The students work as though they were an environmental consulting firm. The object of the course is to teach the students how to approach a problem, how to develop a work plan, and what is necessary to implement the plan successfully. As part of this learning process, the students use methods and tools they have learned in other courses and they are also introduced to new methodology as needed. Standard methods of analysis are used as well as state of the art instrumentation for any of the original analysis done. The methods used were those approved by EPA and/or the DEP. However, there are time constraints involved in the study since all requirements for the course must be completed within the fall semester. These constraints mean that some of the new data can only be gathered during the months of September through early November and, typically, that extensive analysis can not be done. Some of the water quality data were gathered during the previous summer and made available to the class for analysis in addition to their fall sampling. In order to teach various techniques and to have the students consider a problem from a number of angles, the project is expanded to more areas than a group might normally take on for a short-term project. This means that in some areas we sacrifice some depth for more breadth.

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

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

Authors

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

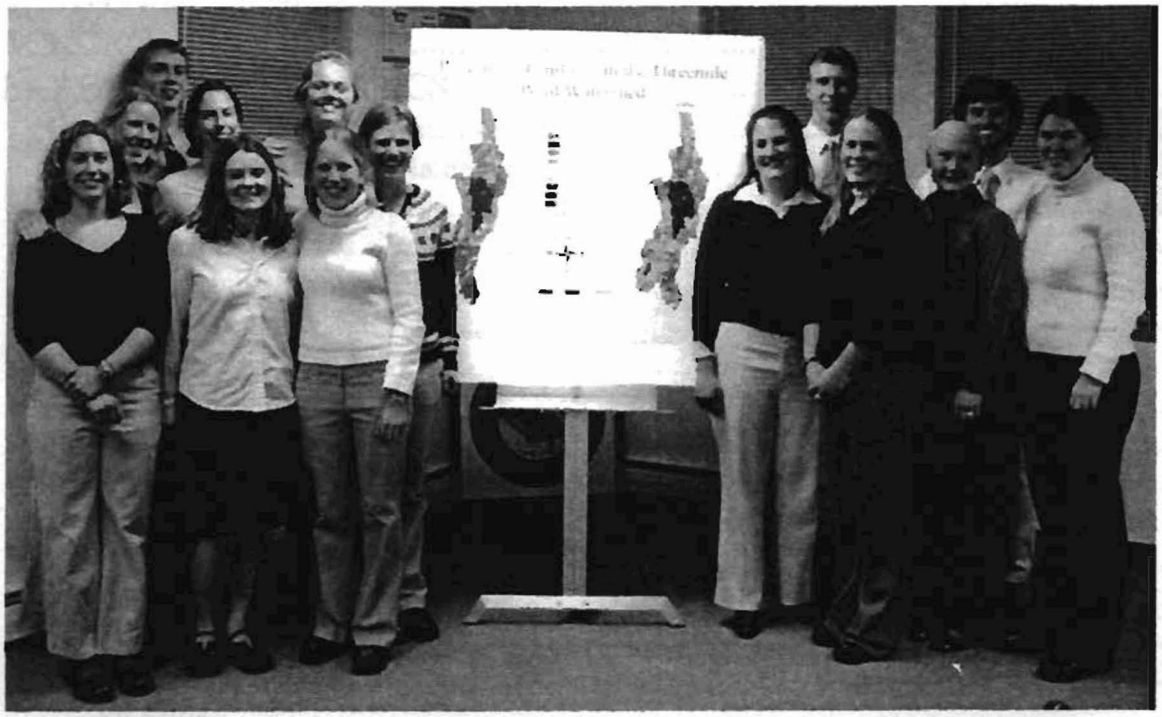


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Table of Contents

Tables

Figures

Appendices

Appendix D. Water budget values and calculations for Threemile Pond 230
Appendix E. Phosphorus model equation 231

WATERSHED ASSESSMENT INTRODUCTION

GENERAL NATURE OF STUDY

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

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

The 2003 Colby Environmental Assessment Team chose to study the Threemile Pond watershed. The Threemile Pond watershed is located in Vassalboro, China, Windsor, and Augusta, Maine. Threemile Pond is a popular site for recreation and is home to a wide range of flora and fauna. Like all other lakes in Maine, it is a young lake. However, intensive human activity in the watershed contributes a substantial amount of nutrients and the lake has algal blooms annually in the summer months.

The purpose of this study was to assess the impact of land use and development on the water quality of Threemile Pond. Physical and chemical parameters of the lake were evaluated in order to determine both the current water quality and trends in water quality over the years. The current land use patterns were also examined and categorized with respect to their effect on water quality. Development within the watershed was evaluated through the assessment of residences, septic systems and roads. The water budget and flushing rate for Threemile Pond were also calculated as well as the

septic suitability and erosion potential of the soils in the watershed. The results of the various tests and measurements were used to develop a phosphorus model, which was used to predict present and future phosphorus loading. A Geographic Information System (GIS) was used to generate models of land use and soil characteristics in the Threemile Pond watershed. These models were used to predict future impacts of human activities in the watershed on lake water quality. The findings from the lake and watershed analysis can be used to make recommendations regarding the health of Threemile Pond. Water quality and land use assessment in this study was conducted by the Colby Environmental Assessment Team during the summer and fall of 2003.

EXECUTIVE SUMMARY

The Colby Environmental Assessment Team (CEAT) investigated factors influencing the water quality of Threemile Pond in Kennebec County, Maine, from August through November 2003. CEAT analyzed physical and chemical water quality parameters, land use patterns, and the impact of residential and commercial development to study water quality trends. Data gathered during this study were used to produce models that helped identify the sources of degradation most threatening to the current and future water quality of Threemile Pond. These data were also compared to data collected in previous years by the Maine Department of Environmental Protection to gain a historical perspective. Water quality is affected by the accumulation of nutrients, particularly phosphorus, resulting from surface runoff, erosion, and internal nutrient loading. When concentrations of phosphorus reach threshold levels, a lake may experience algal blooms that decrease the aesthetic, recreational, ecological, and economic value of the lake and adjacent shoreline property. Water quality will improve with the reduction of external phosphorus loading and the reduction of sediment release of phosphorus.

A brief summary of the CEAT findings in the Threemile Pond study:

- Transparency readings and conductivity measurements for Threemile Pond were consistent with other eutrophic lakes. The mean transparency reading of 2.9 m was below the Maine average (4.8 m) and has declined over time, suggesting continued nutrient loading, which contributes to the annual algal blooms. The mean conductivity measurement was 48.2 µMHOs/cm and also above the Maine average, suggesting that runoff is contributing particulate matter to Threemile Pond.

- Tributaries can be important sources and sinks for nutrients and sediments in a watershed. Both the inlets sampled had higher turbidity, color, and conductivity readings than the mean turbidity observed for Threemile Pond. These tributaries appear to be sources of sediment and dissolved organics for Threemile Pond.

- Nitrogen levels were found to be 57 parts per billion (ppb); levels above 200 ppb will stimulate algal growth. Phosphorus levels for Threemile Pond were determined to be 30 ppb, which is well above the critical limit of 15 ppb where algal blooms will likely occur.

- The average septic suitability in Threemile Pond watershed was determined to be 2.1 on a scale of 1 to 9, where 1 is very suitable. The low slopes are the main reason for this high suitability. However, soil types found in the watershed as a whole are not ideal for septic systems. Some mitigation may be necessary when installing new septic systems.

- CEAT analyzed past and present land use patterns in the Threemile Pond watershed. ArcGIS™ 8.2 was used to create maps of land usage for 1956 and 1998, and a comparison map that shows where land use has changed over those 42 years. The acreage of mature forest has decreased since 1956, but the total amount of forested (reverting, transitional, and mature forest) area has increased. Agricultural land has decreased throughout the watershed. There has been an increase in residential and commercial development.

- CEAT found a total of 560 houses in the Threemile Pond watershed. Two hundred and three of these houses (36 percent of the total houses) are considered shoreline (within 200 feet), and 357 (64 percent) are non-shoreline. There are 142 seasonal houses (25 percent of the total) and 418 year-round houses (75 percent) in the Threemile Pond watershed.

- CEAT data show that Threemile Pond has a large number of mediocre or inadequate buffer strips. Many old homes do not meet current minimum setback standards and some may have old, overworked, or failing septic systems.

- Roads in the watershed contribute disproportionate amounts of the phosphorus load. Paved state and municipal roads contribute approximately 45.12 kg/year and camp roads contribute approximately 29.75 kg/year to the overall load. Though state roads contribute more overall, camp roads are a greater concern for lake health due to their proximity to the shoreline. Several camp roads are in need of basic improvements to limit nutrient runoff, such as grading, crowning, ditching, and diversions.

- Small commercial development exists in the watershed, and the populations of China, Windsor, and Vassalboro have steadily increased during the past century. Shoreline residences are thickly clustered in certain parts of Threemile Pond and lots remain large enough to subdivide. There is every indication that in the future, more people will be living within the Threemile Pond watershed, and that shoreline development will continue. Poor septic systems are slowly being replaced as homes are renovated and rebuilt.

- The primary problem in Threemile Pond is cultural eutrophication. Eutrophication is a natural process, but in this watershed it has been expedited by human practices. Any remediation must consider all sources of phosphorus. In-lake remediation techniques can be expensive, but the eutrophic status of Threemile Pond may require such mitigation, provided the external loading of phosphorus is controlled first. The most appropriate forms of remediation for Threemile Pond are: biological management through fish stock manipulation to control the phytoplankton population; hypolimnetic aeration to prevent phosphorus-releasing anaerobic conditions by augmenting dissolved oxygen levels; and with proper management and specific application, an alum treatment to effectively reduce the amount of phosphorus in the sediment available for release. Further study of these possibilities should be considered to determine the best plan of action.

The Colby Environmental Assessment Team presentation, "A Watershed Analysis of Threemile Pond" is available online at: http://www.colby.edu/biology/BI493/.

BACKGROUND

This section is provided so that the reader can gain background information relating to lake eutrophication. The information should help the reader better understand the findings of the study and the discussion of those findings in the Analytical Procedures and Results section of the report.

LAKE CHARACTERISTICS

Distinction Between Lakes and Ponds

Lakes and ponds are inland bodies of standing water created either naturally, through geological processes, or artificially, through human intervention (Smith and Smith 2001). Lakes and ponds differ in their size and depth profiles. Lakes most often have greater surface area and greater depth than ponds (Smith and Smith 2001). Lakes generally develop both vertical and horizontal stratification while ponds do not. Horizontal stratification in a lake divides the lake into zones based on sunlight penetration and the growth of vegetation. The littoral zone, 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 limnetic and profundal zones where sunlight cannot reach the bottom and rooted plants are not able to grow. A pond, on the other hand, does not have this zonation, as it is shallow enough that vegetation is rooted throughout (Smith and Smith 2001). The vertical zonation found in a lake depends on density and water temperature. Deep lakes will stratify with the densest water on the bottom and the least dense water toward the surface. Ponds and shallow lakes do not stratify because disturbance of wind and waves cause constant mixing and temperature distribution.

General Characteristics of Maine Lakes

Lakes are a vital natural resource in Maine (Davis et al. 1978). They provide fresh water for swimming, fishing, drinking, livestock, and agriculture. Maine's beautiful lakes draw many tourists throughout the year and also serve as important habitats for wildlife.

The majority of Maine lakes were formed during the Wisconsonian glaciation of the Pleistocene period, which occurred about 10,000 years ago (Davis et al. 1978). As a result of glacial activity in Maine, glacial till, bedrock, and glaciomarine clay-silt dominate most lake basin substrates. Generally, these deposits and the underlying granitic bedrock are infertile. As a result, most of Maine's lakes are

relatively nutrient poor. The movement of glaciers in Maine was predominantly southeasterly, carving out Maine lakes in a northwest to southeast direction (Davis et al. 1978). This unique orientation, along with lake surface area and shape, play a fundamental role in the effect of wind on the water body. Wind is an important factor in lake turnover or the mixing of thermal layers.

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

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

Annual Lake Cycles

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

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

Below the epilimnion is a layer of sharp temperature decline, known as the metalimnion (Smith and Smith 2001). Within this stratum is the greatest temperature gradient in the lake, called the thermocline (Smith and Smith 2001). This thermocline separates the epilimnion from the hypolimnion, the lowest stratum of a lake. The hypolimnion, only found in the deepest lakes, is beyond the depth

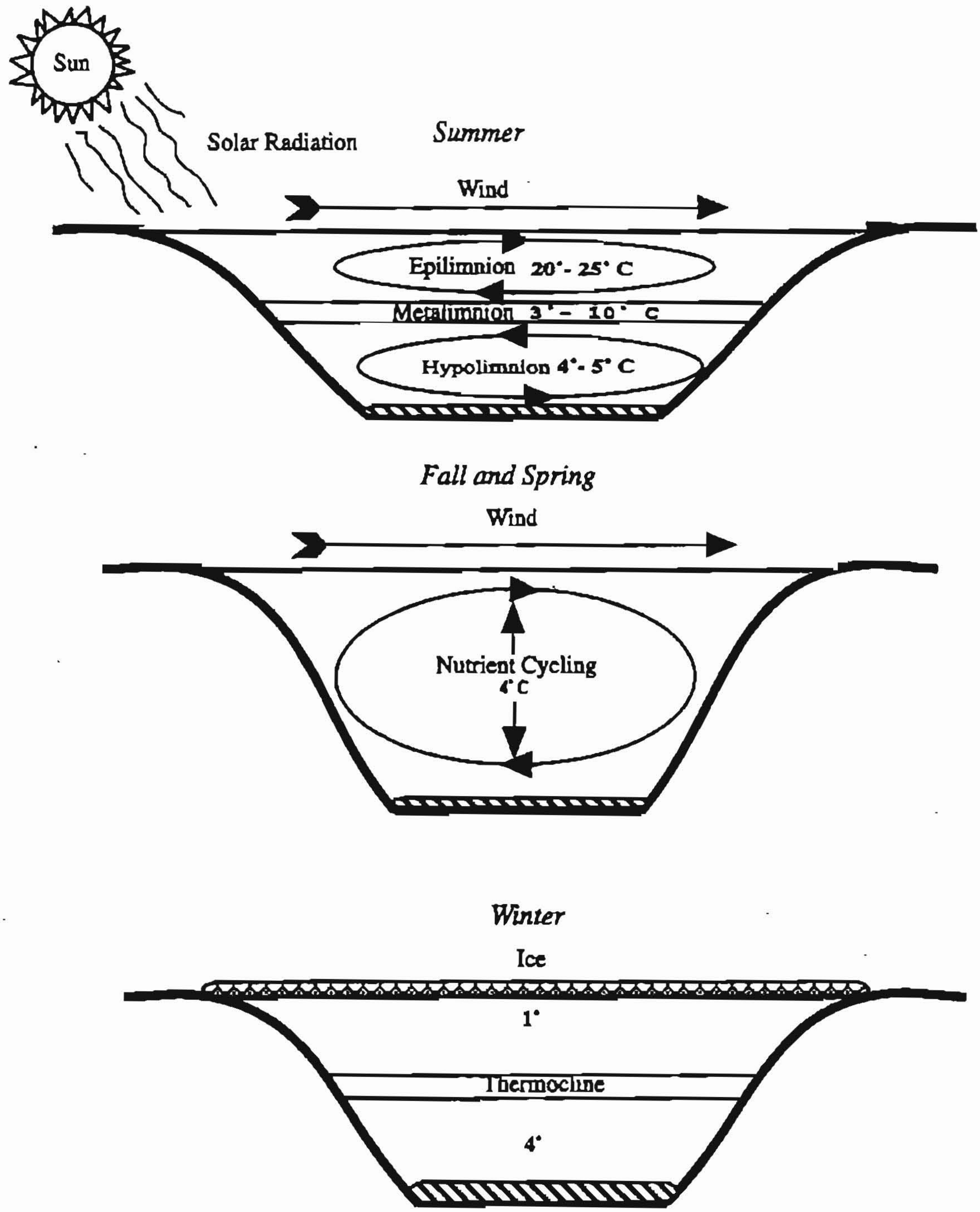


Figure 1. Mixing by means of lake turnover in dimictic lakes. During the summer, lakes are stratified into three layers (epilimnion, metalimnion, and hypolimnion). During the fall and spring, the isothermal temperature and density facilitate the lake turnover and redistribution of nutrients. In the winter,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

which sufficient light can penetrate in order to facilitate effective photosynthesis (Figure 1). It is in the substrate of the hypolimnion where most decomposition of organic material takes place through both aerobic and anaerobic biological processes. While aerobic (requiring oxygen) bacteria break down organic matter quicker than anaerobic bacteria, they also significantly deplete the oxygen at these depths (Davis et al. 1978).

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

In winter, lakes in Maine are covered with ice for 4-5 months. The stratification is reversed as the coldest water (ice) is on the surface and the warmest water (roughly 4 degrees C) is at depth. Significant snow cover on the ice may affect the photosynthetic processes during the winter months under the ice by blocking some of the incoming solar radiation. This situation can deplete oxygen levels enough to cause significant fish kills (Smith and Smith 2001).

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

Trophic Status of Lakes

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

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

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

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

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

The natural aging process of a lake begins as oligotrophic and progresses through eutrophication, eventually to become a terrestrial landscape (Niering 1985). This process can be greatly accelerated by anthropogenic activities, which increase nutrient loading. The United States Environmental Protection Agency (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)

As a lake ages, it fills with dead organic matter and sediment that settle to the bottom. Lakes may receive mineral nutrients from streams, groundwater, and runoff as well as precipitation. The increase in nutrient availability promotes primary productivity. Increased productivity leads to more dead organic material, which accumulates as sediment in lentic ecosystems (standing bodies of water such as lakes and ponds). Over time, lakes will fill in, decrease in size, and are eventually replaced by a terrestrial community (Chiras 2001).

Phosphorus and Nitrogen Cycles

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

Phosphorus is the limiting nutrient for plant growth in freshwater systems, and is considered the most important nutrient in lakes (Maitland 1990). Phosphorus naturally occurs in lakes in minute quantities measured in parts per billion (ppb). However, due to the high efficiency with which plants can assimilate phosphorus, these concentrations are sufficient for plant growth (Maitland 1990). There are multiple external sources of phosphorus (Williams 1992), but a large supply is also found in the lake sediments (Henderson-Sellers and Markland 1987). The cycle of phosphorus in a lake is complex, with some models including up to seven different forms of phosphorus (Figure 2; Frey 1963).

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

An important reaction occurs in oxygenated water, which involves DP and the oxidized form of iron, Fe (III) (Chapman 1996). This form of iron can bind with DP to form an insoluble complex, ferric phosphate, which can effectively tie up large amounts of phosphorus as it settles into the bottom sediments. Fe (III) is reduced to Fe (II) in the presence of decreased oxygen levels at the sediment water interface, resulting in the release of DP. The ferric phosphate complex, combined with the anaerobic bacterial conversion of PP to DP, can lead to a significant buildup 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 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.

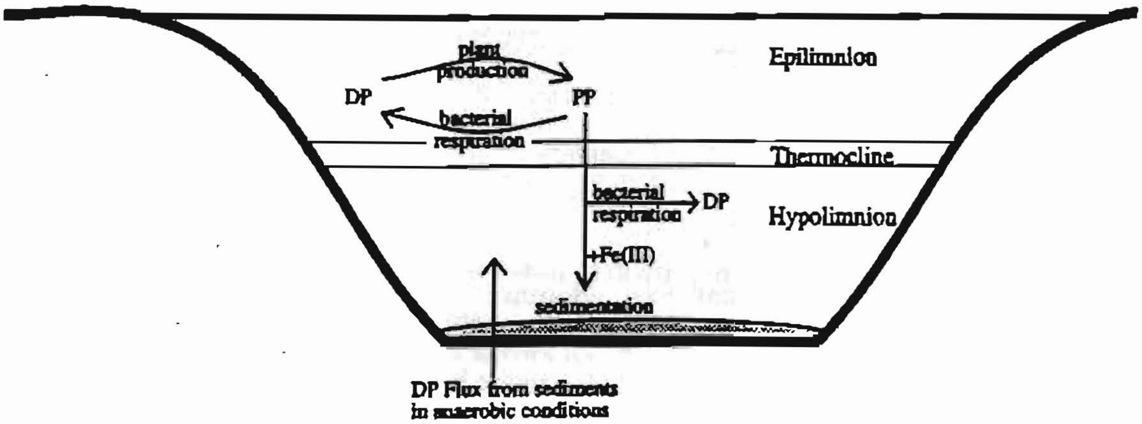


Figure 2. A model of the cycle of the major forms of phosphorus, dissolved (DP) and particulate (PP), within a lake ecosystem. The sedimentation of DP through complexation with Fe (III) contributes to the build-up of DP in the sediments. Note the production of DP in the hypolimnion due to bacterial decomposition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

During fall turnover, 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 are rise above 12.0 ppb to 15.0 ppb. If an algal bloom does occur, DP will be converted to PP in the form of algal tissues. The algae will die as winter approaches and the dead organic matter will settle to the bottom where PP will be converted back to DP and build up again, allowing for another large nutrient input to surface waters during spring overturn.(Chapman 1996).

Nitrogen, the other major plant nutrient, is not usually the limiting factor for plant growth in a lake (Chapman 1996). However, it is still important to understand its cycle because high concentrations can lead to algal blooms in the presence of phosphorus.

Available nitrogen exists in lakes in three major chemical forms: nitrates (NO_3^-), nitrites (NO_2), and ammonia (NH_3) (Figure 3). The majority of free nitrogen in a lake exists in the form of nitrates (Maitland 1990). This form of nitrogen is directly available for assimilation by algae and macrophytes. In eutrophic lakes, there may be so much algae and macrophyte growth that most of the nitrates in the lake are incorporated into plant tissues (Maitland 1990). Nitrites, however, cannot be used by plants. In aerobic conditions nitrate-forming bacteria convert nitrites to nitrates. Ammonia enters the lake ecosystem as a product of the decomposition of plant and animal tissues and their waste products, and

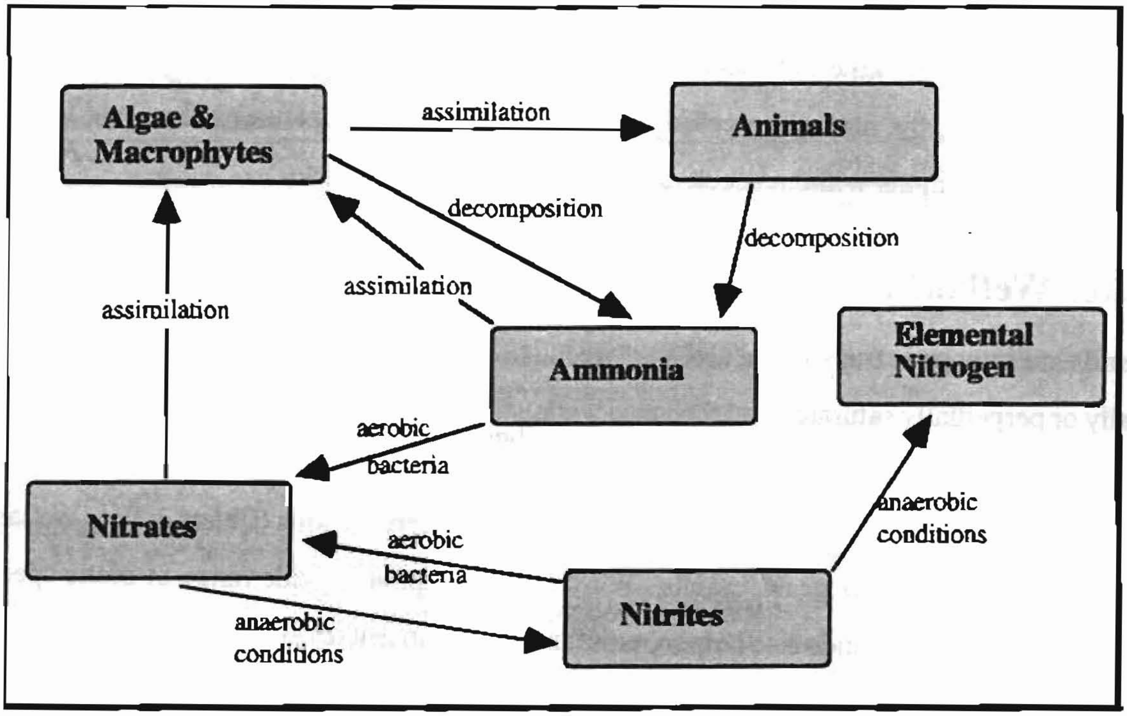


Figure 3. A diagram of the various forms of nitrogen that occur in the nitrogen cycle within a lake ecosystem. It is important to note that in aerobic conditions both ammonia and nitrites are converted to nitrates which are available for use by plants.

is processed in one of three ways. Macrophytes can assimilate ammonia directly into their tissues. Alternatively, under oxygen-rich conditions, aerobic bacteria will convert the ammonia directly to nitrates, the more usable form of nitrogen. Finally, anaerobic decomposition, a characteristic of the sediments of stratified lakes, can reduce nitrates to nitrites. If these anaerobic conditions persist, the nitrites can be broken down to elemental nitrogen (N_2). This form is not available to any plants without the aid of nitrogen-fixing bacteria. Plants depend on these bacteria to convert nitrogen to nitrates through the process of nitrogen fixation (Overcash and Davidson 1980).

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

Several in-lake mitigation techniques exist to deal with the problem of excessive nutrients once they are present in the lake (Henderson-Sellers and Markland 1987). None of these techniques are without disadvantages, but for lakes with serious algal growth problems they may be necessary (Henderson-Sellers and Markland 1987).

Once nutrients have built up in a lake, eliminating them is a challenging task. The ideal method for controlling nutrients in a lake is to regulate and monitor the input sources before they become problematic. This allows the natural processes of nutrient cycling and uptake by flora and fauna to compensate for nutrient inputs without accelerated eutrophication of the lake.

Freshwater Wetlands

Wetlands are important transitional areas between lake and terrestrial ecosystems. Wetland soil is periodically or perpetually saturated and, because wetlands usually have a water table at or above the level of the land, contains non-mineral substrates such as peat. Within this partially submerged habitat is hydrophytic vegetation that is adapted for life in saturated and anaerobic soils (Chiras 2001). Wetlands are beneficial to lakes for a number of reasons. For one, they support a wide range of biotic species (Table 2; MLURC 1976). Wetlands also help to maintain lower nutrient levels in an aquatic ecosystem because of the efficiency in nutrient uptake by their vegetation (Niering 1985, Smith and Smith 2001). Finally, wetlands have the potential to absorb heavy metals and nutrients from various sources including mine drainage, sewage, and industrial wastes (Chiras 2001).

WATERSHED LAND USE

Land Use Types

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

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

A land area cleared for agricultural, residential, or commercial use contributes more to nutrient loading than a naturally vegetated area such as forested land (Dennis 1986). The combination of vegetation removal and soil compaction involved in the clearing of land results in a significant increase

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

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

in surface runoff. This amplifies the erosion of sediments carrying nutrients and pollutants of human origin.

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

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

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

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

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

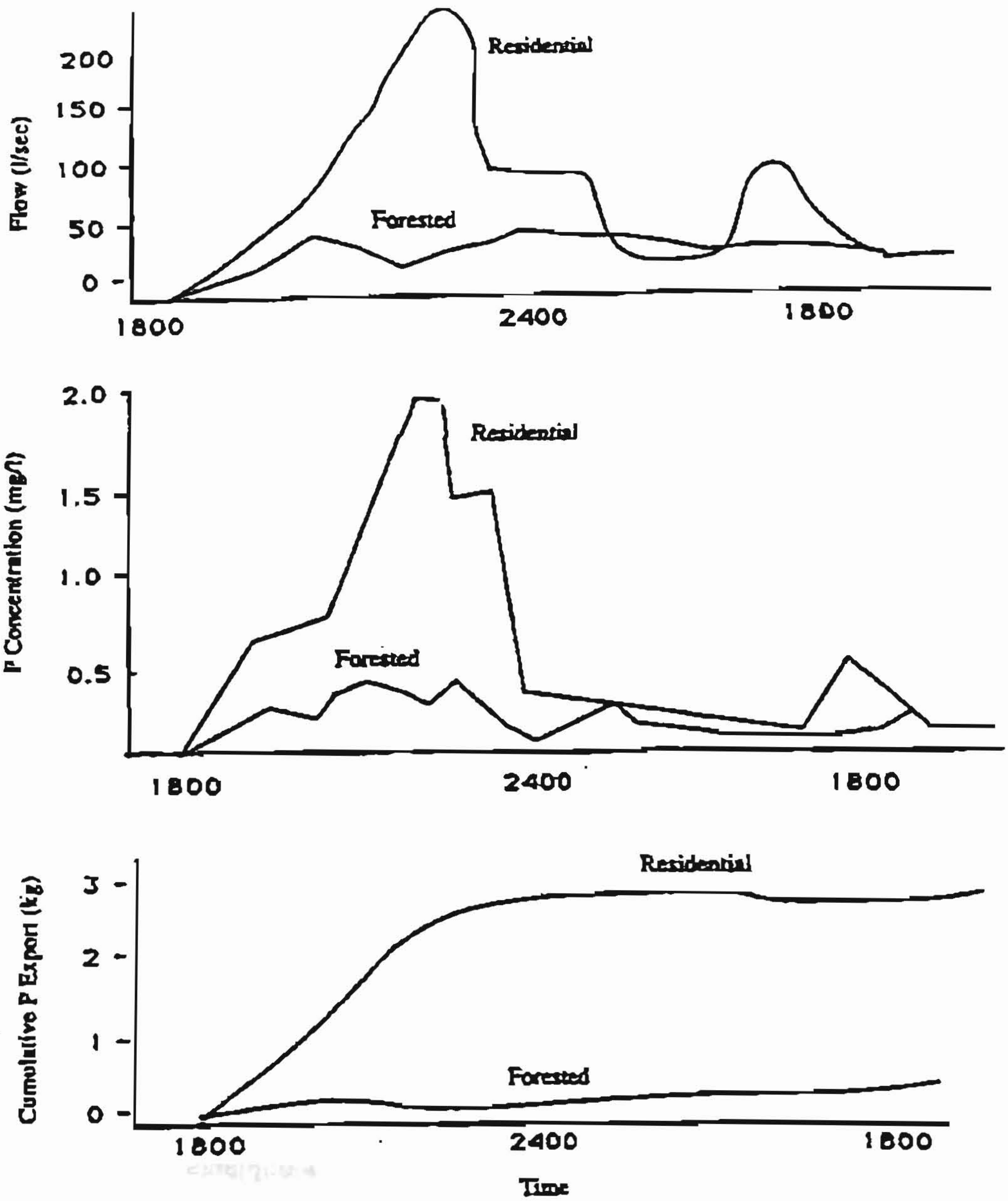


Figure 4. Comparisons of runoff after an April rain storm in two neighboring watersheds near Augusta, ME. Top: volume of immediate runoff over a 12 hour period; Middle: phosphorus concentration in the runoff; Bottom: total amount of phosphorus exported into local streams and lakes from the storm (Dennis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

Commercial uses of forested land can have detrimental effects on lake water quality. Activities that remove the cover of the canopy and expose the soil to direct rainfall increase erosion. Two studies by the Land Use Regulation Commission on tree harvesting sites noted that erosion and sedimentation

problems occurred in 50 percent of active and 20 percent of inactive logging sites selected (MDC 1983). Skidder trails may pose a problem when they run adjacent to or through streams. 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 percent of the nutrient loading problems are caused by only 20 percent of the culverts or crossings. Furthermore, roads and driveways leading to shoreline areas or tributaries can cause runoff to flow directly into a lake.

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

Buffer Strips

Buffer strips play an important role in absorbing runoff, helping to control the amount of nutrients entering a lake (MDEP 1990). Excess amounts of nutrients such as phosphorus and nitrogen can promote algal growth and increase the eutrophication rate of a lake (MDEP 1990). According to the Shoreline Zoning Ordinance for the Town of Vassalboro, a buffer strip of vegetation should be preserved or created within 75 ft of any body of water, tributary stream, or the upland edge of a wetland (NKRPC 1991).

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

sponge to absorb water and trap sediment. Duff also provides a habitat for many microorganisms that break down plant material and recycle nutrients (MDEP 1990).

An ideally buffered home should have a winding path down to the shoreline so that runoff is diverted into the woods where it can be absorbed in the forest litter (Figure 5). The house itself should be set back at least 100 ft from the shoreline and have a dense buffer strip between it and the water. The buffer is composed of a combination of canopy trees, understory shrubs and groundcover. In addition, the driveway should be curved. As opposed to a steep, straight, and paved path that leads directly into the water, a curved driveway can be a very effective deterrent to runoff. Slopes within a buffer strip that are less than two percent are most effective at slowing down the surface flow and increasing absorption of runoff (MDEP 1998). Steep slopes are susceptible to heavy erosion and will render buffer strips ineffective.

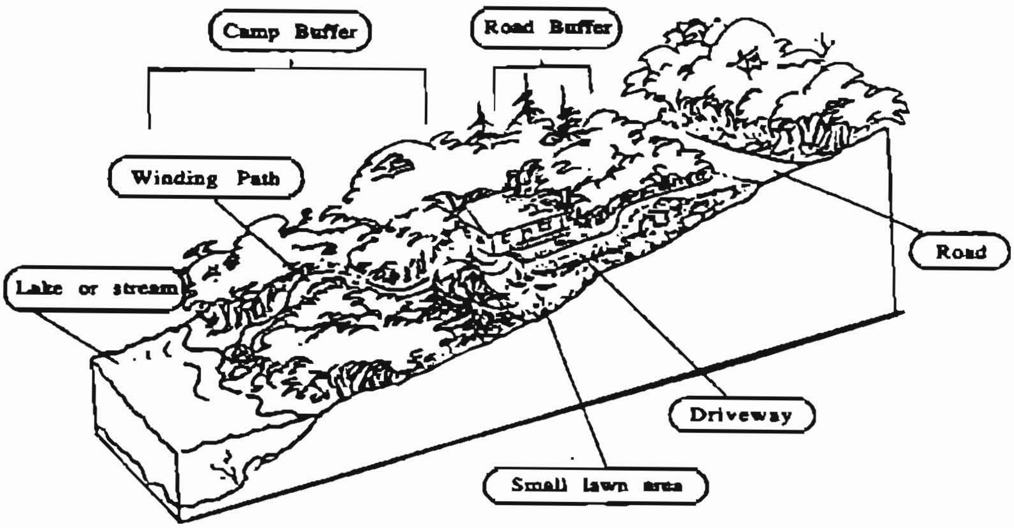


Figure 5. Diagram of an ideally buffered home.

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

Riprap depends on the soil beneath it for support, and should therefore be built only on stable shores or bank slopes (MDEP 1990).

Nutrient Loading

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

Total phosphorus loading to a lake can be determined using a phosphorus loading model. This model takes into account the various aspects upon which the phosphorus concentration in the lake basin is dependent, such as lake size, volume, flushing rate, and land use patterns within the watershed (Cooke et al. 1986). The model allows for the projection of the impact that various factors may have on phosphorus loading and generates predictions of lake responses to changes in land use. The accuracy of the predictions is determined by the accuracy of the assumptions (USEPA 1990).

Soil Types

Nutrient loading in a lake ecosystem is partially a function of the soil types and their respective characteristics. Both the physical characteristics of soil, such as permeability, depth, particle size, organic content, and the presence of an impermeable layer (fragipan), as well as the environmental features (slope, average depth to the water table, and depth to the bedrock) 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 (NKRPC 1991). Shoreline zoning ordinances regulate development along the shoreline in a manner that reduces the chances for adverse impacts on lake water quality. Uncontrolled development along the shoreline can result in a severe decline in water quality that is difficult to correct. In general, these regulations have become more stringent as increased development has caused water quality to decline in many watersheds (MDEP 1992b). If no comprehensive plan or town ordinances have been enacted, the state regulations are used by default.

Shoreline Residential Areas

Shoreline residential areas are of critical importance to water quality due to their proximity to the lake. This study considered houses less than 200 ft from the shoreline to be shoreline residences. Any nutrient additives from residences (such as fertilizers) have only a short distance to travel to reach the lake. Buffer strips along the shore are essential in acting as a sponge for the nutrients flowing from residential areas to the lake (Woodard 1989). These buffer strips consist of an area of natural vegetation growing between a building and the body of water in question.

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

Seasonal residences, especially older ones located on or near the shoreline in a cluster, can contribute disproportionately to phosphorus loading into the lake ecosystem. Such clusters of camps usually exist because they have been grandfathered, and do not follow shoreline zoning laws. Although seasonal, they may involve large numbers of people. Phosphorus export from these areas is likely to increase during periods of heavy use. The location and condition of septic systems also effects the nutrient loading from these plots (see Sewage Disposal Systems).

Non-shoreline Residential Areas

Non-shoreline residential areas (greater than 200 ft from the shoreline) can also have an impact on nutrient loading, but generally less than that of shoreline residential areas. Runoff, carrying fertilizers

and possibly phosphorus containing soaps and detergents, usually filters through buffer strips consisting of forested areas several acres wide, rather than a few feet wide (as with shoreline buffers). In these cases, phosphorus has the opportunity to be absorbed into the soils and vegetation. The majority will not reach the lake directly, but will simply enter the forest s nutrient cycle.

However, residences located up to one half mile away from the lake can potentially supply the lake with phosphorus almost directly when poorly constructed roads persist. Runoff collected on roofs and driveways may travel unhindered down roads or other runoff channels to the lake. Although 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 every bit as much of a nutrient loading hazard as a shoreline residence with a large lawn. Phosphorus washed from residential lawns without buffer strips can enter into a stream and eventually into the lake. Similar restrictions and regulations as those for shoreline residences apply to non-shoreline homes that are located along many streams.

Sewage Disposal Systems

Subsurface wastewater disposal systems are defined in the State of Maine Subsurface Wastewater Disposal Rules as devices and associated piping including treatment tanks, disposal areas, holding tanks, alternative toilets which function as a unit to dispose of wastewater in the soil (MDHS 1988). These systems are generally found in areas with no municipal disposal systems such as sewers. Examples of these subsurface disposal systems include pit privies and septic systems.

Pit Privy

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

Holding Tank

Holding tanks are watertight, airtight chambers, usually with an alarm, which hold waste for periods of time. The tanks are durable and made of either concrete or fiberglass (MDHS 1988). The

minimum capacity for a holding tank is 1,500 gallons. These must be pumped or else they could back up into the structure or leak into the ground, causing contamination. Although purchasing a holding tank is inexpensive, the owner is then required to pay to have the holding tank pumped on a regular basis.

Septic System

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

The distance between a septic system and a body of water should be sufficient to prevent contamination of the water by untreated septic waste. Unfortunately, many parcels of land are grandfathered, which means their septic systems were installed before the passage of current regulations. Those systems may be closer to the shore than is currently permitted. However, any replacement systems in these grandfathered areas must reflect the new regulations. Replacement systems can either be completely relocated, or an effluent pump installed on the outside of the existing treatment tank can be used to move the sewage uphill to an alternative disposal area further from the water body (MDHS 1983).

Human waste and gray water are transferred from a residence through the building sewer to the treatment tank. There are two kinds of treatment tanks, aerobic and septic, both of which are tight, durable, and usually made of concrete or fiberglass (MDHS 1983). The aerobic tanks rely on aerobic bacteria, which are more active than anaerobic bacteria. Unfortunately, aerobic bacteria are also more susceptible to condition changes. These tanks also require more maintenance, more energy to pump in fresh air, and are more expensive. For these reasons, septic tanks are preferable. Septic tanks rely on anaerobic bacteria. Solids are held until they are sufficiently decomposed and suitable for discharge (MDHS 1983). As the physical, chemical, and biological breakdowns occur, scum and sludge are separated from the effluent (Figure 7). Scum is the layer of grease, fats, and other particles that are lighter than water and move to the top of the treatment tank. Scum is caught by the baffles so that it

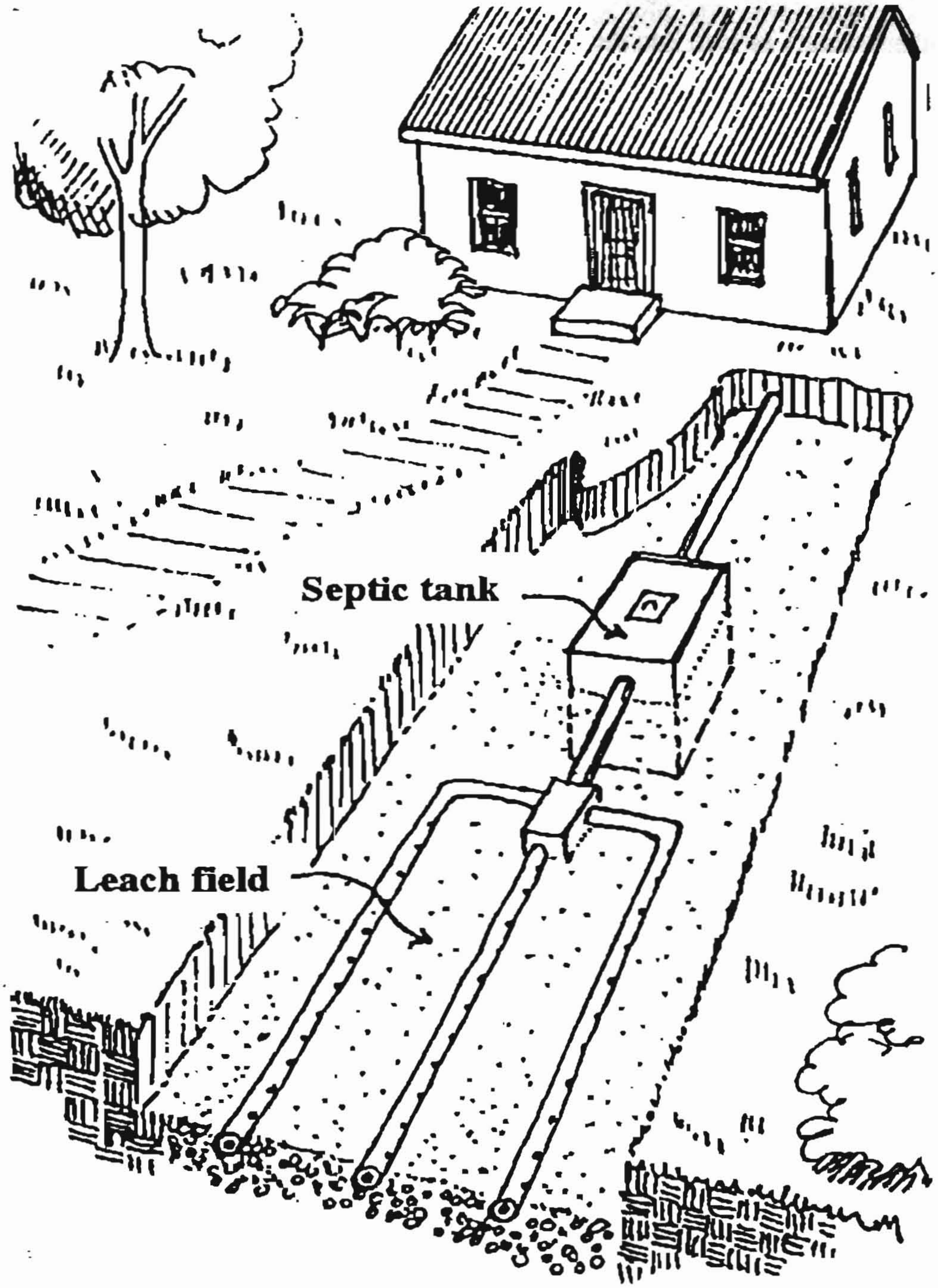


Figure 6. The layout of a typical septic system (Williams 1992).

cannot escape into the disposal area. Sludge is composed of the solids that sink to the bottom of the tank. Over time, much of the scum and sludge is broken down by anaerobic digestion. The effluent then travels through the effluent line to the disposal area.

The purpose of a disposal area is to provide additional treatment of the wastewater. The disposal area can be one of three types: bed, trench, or chamber (MDHS 1983). Beds are wider than trenches,

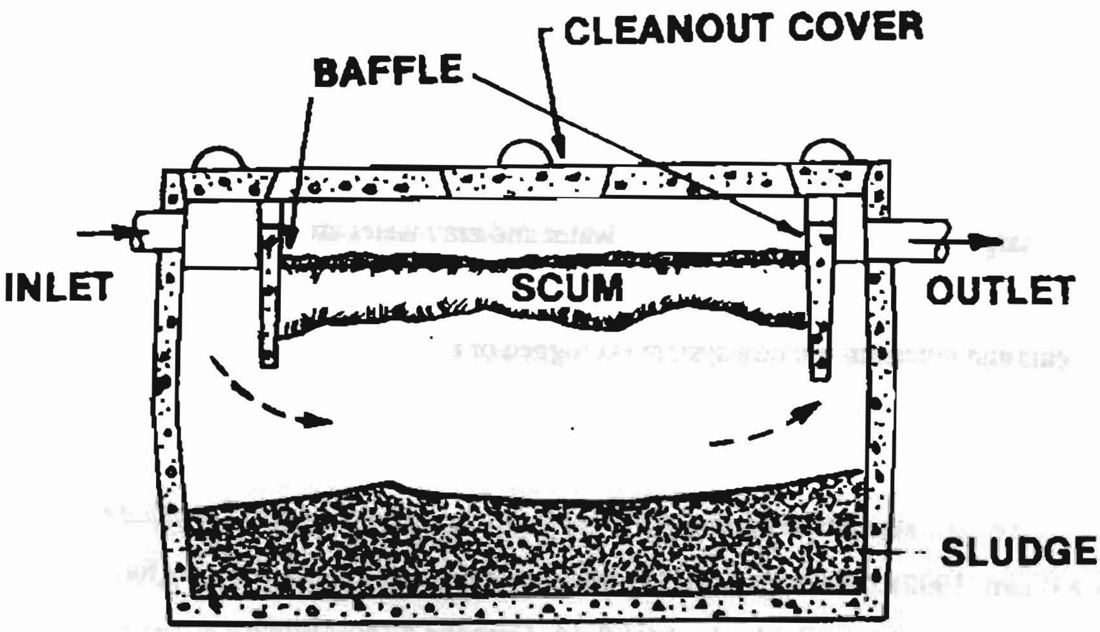


Figure 7. The cross-section of a typical treatment tank showing the movement of effluent through the tank as well as the separation of the scum and sludge (MDHS 1983).

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

BOD is the oxygen demanded by decomposers to break down organic waste in water. Organic matter will increase if there is contamination from human and animal wastes. As the amount of organic material increases, BOD increases. If the BOD depletes dissolved oxygen, species within a lake may

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

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

Reducing the chances of clogging will allow septic systems to be most efficient. Year-round residents should have their septic tanks pumped every two to three years, or when the sludge level fills half the tank (Williams 1992). Seasonal residents should pump their septic tanks every five to six years to prevent clogging from occurring in the disposal field. Garbage disposals place an extra burden on a septic system (Williams 1992). Cigarette butts, sanitary napkins, and paper towels should never be disposed of in septic systems as they are not easily broken down by the microorganisms and fill the septic tank too quickly. The disposal of chemicals, such as pouring bleach or paint down the drain, may also affect septic systems by killing microorganisms. Water conservation slows the flow through the septic system and allows more time for bacteria to treat the water. By decreasing the amount of water passing through the disposal field, the septic system can work more effectively and recover after heavy use (Williams 1992). Odors, extra green grass over the disposal field, and slow drainage are symptoms of a septic system that has been subject to heavy use and is not functioning properly.

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

Soil containing loam, sand, and gravel allows the proper amount of time for runoff and purification (MDHS 1983). Soils cannot be too porous; otherwise water runs through too quickly and is not sufficiently treated. Depth of bedrock is another important consideration. If the bedrock is too shallow, waste will remain near the soil surface. Fine soils such as clay do not allow for water penetration, again causing wastewater to run along the soil surface untreated. Adding loam and sand to clay-like soils

would help alleviate this problem. In the opposite case, if a soil drains too quickly, loam and clay can be added to slow down the filtration of wastewater.

Federal, state, and local laws are in place to protect land and water quality. The federal government sets minimum standards for subsurface waste disposal systems. States can then choose to make their rules stricter but not more lenient than federal guidelines. Maine s Comprehensive Land Use Plan sets standard regulations that each city and town must follow. Individual municipalities have the ability to establish their own comprehensive land use plan in accordance with the state regulations. However, many towns develop local ordinances that consider specific issues such as shoreline zoning. The Maine Department of Environmental Protection (MDEP), Maine Department of Conservation (MDC), and local Code Enforcement Officers are responsible for overseeing the enforcement of these laws.

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

Roads

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

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

Road construction should try to achieve the following long-term goals: minimize the surface area covered by the road, minimize runoff and erosion with proper drainage and the placement of catch basins (as well as culverts and ditches), and maximize the lifetime and durability of the road (MDEP

1990). A well-constructed road should divert road surface waters into a vegetated area to prevent excessive amounts of surface runoff, phosphorus, and other nutrients from entering the lake. Items which should be considered before 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 nonresidential uses involving one or more buildings (MDEP 1991b).

Designing a road with future use in mind is very important. For instance, a road should be constructed no longer than is absolutely necessary. A particular road should not be extended past the last structure that is to be serviced by that road. The width of a road, which is often based upon the maintenance capabilities of the area, must also be considered (Cashat 1984). Proper planning for maintenance is a more effective, practical, and economical way to develop the road area (Woodard 1989).

Road surface material is another important factor to consider in road construction. Studies have shown that phosphorus washes off paved surfaces at a higher rate than from sand and gravel surfaces (Lea 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, while sand and gravel roads are typically used for low traffic areas or seasonal use areas. Both types of roads need proper maintenance and gravel road surfaces should be periodically replaced and properly graded so that a stable base may be maintained and road surface erosion minimized.

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

The drainage of a road and the land that surrounds it must also be considered during construction or maintenance projects. Both ditches and culverts are used to help drain roads into buffer zones where nutrients added by the road can be absorbed by vegetation. These measures are also used in situations for handling runoff that may be blocked by road construction. Ditches are necessary along wide or steep stretches of road to divert water flow off the road and away from a body of water. They are ideally parabolic in shape with a rounded bottom, are of a sufficient depth, and do not exceed a depth to width ratio of 2:1. The ditch should be free of debris and covered with abundant vegetation to reduce erosion (Michaud 1992). Ditches must also be constructed of a proper soil that will not be easily eroded by the water flowing through them.

Culverts are hollow pipes that are installed beneath roads to channel water in proper drainage patterns. The most important factor to consider when installing a culvert is its size. It must be large enough to handle the expected amount of water that will pass through it during the peak flow periods of the year. If this is not the case, water will tend to flow over and around the culvert and wash out the road. This may increase the sediment load entering the lake. The culvert must be set in the ground at a 30 degrees angle down slope with a pitch of 2 percent to 4 percent (Michaud 1992). A proper crown above the culvert is necessary to avoid creating a low center point in the culvert. The standard criteria for covering a culvert is to have one inch of crown for every 10 ft of culvert length (Michaud 1992). The spacing of culverts is based upon the road grade.

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

Maintenance is very important to keep a road in good working condition as well as to prevent it from causing problems for a lake. Over time, roads deteriorate. Problems will only become worse if ignored and will cost more money in the long run to repair. Roads should be periodically graded, and ditches and culverts cleaned and regularly inspected to assess any problems that may develop. Furthermore, any buildup of sediment on the sides of the road (especially berms), which prevents water from running off into the adjacent ditches, must be removed. These practices will help to preserve the water quality of a lake and improve its aesthetic value.

Agriculture and Livestock

Agriculture within a watershed can contribute to nutrient loading in a lake. Plowed fields and livestock grazing areas are potential sources of erosion, which can carry sediments and nutrients to a lake (Williams 1992). Animal wastes are also sources of excess nutrients. To minimize these problems there are ordinances that prohibit new tilling of soil and new grazing areas within 100 ft of a lake or river. However, problems can still exist in areas that were utilized for agriculture prior to the enactment of these ordinances by the State of Maine in 1990. According to the Shoreline Zoning Act, these areas can be maintained as they presently exist and may result in relatively high levels of erosion and decreased water quality (MDEP 1990). Plowing with the contour lines (across as opposed to up and down a slope), and strip cropping both serve to reduce soil erosion and sediment deposition in the lake.

Another potential agricultural impact on water quality comes from livestock manure. Improper storage of manure may result in excess nutrient loading. Manure also becomes a problem when it is spread as a fertilizer, a common agricultural practice. Manure spreading can lead to nutrient loading, especially in winter when the ground is frozen and nutrients do not have a chance to filter into the soil. These problems become worse if areas are over-fertilized. To help prevent these problems the state has passed zoning ordinances, which prohibit the storage of manure within 100 ft of a lake or river (MDEP 1990). Another solution is to avoid spreading manure in the winter. The town may provide subsidies as an incentive if the problem is large enough. These solutions do not address the problem of livestock that defecate close to bodies of water. One solution for this 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 can also have negative impacts on water quality. Alternative methods of pest control may be appropriate, including biological controls such as integrated pest management and inter-cropping, which is planting alternating rows of different crops in the same field.

Forestry

Forestry is another type of development that can contribute to nutrient loading through erosion and runoff. The creation of logging roads and skidder trails may direct runoff into a lake. The combination of erosion, runoff, and pathways can have a large impact on the water quality of a lake (Williams 1992). Again, there are state and municipal shoreline zoning ordinances in place to tackle

these specific problems. For example, timber harvesting equipment such as skidders, cannot use streams as travel routes unless the streams are frozen and traveling on them causes no ground disturbance (MDEP 1990). Also, there is a ordinance that prohibits clear-cutting within 75 ft of the shoreline of a lake or a river running to the lake. At distances greater than 75 ft, harvest operations cannot create clear-cut openings greater than 10,000 ft2 in the forest canopy, and if they exceed 500 ft^2, they have to be at least 100 ft apart. These regulations are intended to minimize erosion (MDEP 1990). In order for these laws to be effective they have to be enforced. This may be a difficult task for most towns since they do not have the budgets necessary to regulate these areas. Illegal forestry practices may occur and negatively impact lake water quality.

Transitional Land

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

Succession is the replacement of one vegetative community by another that results in a mature and stable community referred to as a climax community (Smith and Smith 2001). An open field ecosystem moves through various successional stages before it develops into a mature forest. The earliest stages of open field succession involve the establishment of smaller trees and shrubs throughout a field (reverting land). Intermediate and later successional stages involve the growth of larger, more mature tree species. The canopy of this forest is more developed, resulting in less light reaching the forest floor. This land use type, in which a forest is nearing maturity and contains over 50 percent mature trees, is referred to as regenerating land.

Cleared Land

Cleared land also presents potential problems of erosion and nutrient runoff especially when large areas are cleared of trees and vegetation that once acted as natural filters. Sediments from these cleared areas could create a problem if they carry large amounts of nitrogen, phosphorus, other plant nutrients, and chemicals to a lake. Without vegetation acting as a buffer, problems are made even worse. Since pasture land is created by the replacement of natural vegetation with forage crops, it is

included in this category. Also included in this category are large grassy areas, such as lawns and parks.

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

Wetlands

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

The type of wetland and its location in a watershed are important factors when determining whether the wetland is a nutrient sink or source, either preventing nutrients from going into a lake or contributing nutrients to a lake. It is also important to note that one wetland may be both a source and a sink for different nutrients. This characteristic may vary with the season, depending on the amount of input to the wetland. Vegetation type within a wetland is important because different flora absorb different nutrients. For example, willow and birch assimilate more nitrogen and phosphorus than sedges and leatherleaf (Nebel 1987). This indicates that shrub swamps are better nutrient sinks than many other types of wetlands. When nutrient sink wetlands are located closer to the lake, the buffering capacity is greater than those located further back from the water body. Wetlands that filter out nutrients are important in controlling the water quality of a lake. These wetlands also help moderate the impact of erosion near the lake.

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

location, wetlands along the shoreline may be more prone to development (Nebel 1987). The decrease of wetlands caused by development will most likely have negative effects on the water quality of a lake due to runoff, erosion, and a decrease of natural buffering.

THREEMILE POND CHARACTERISTICS

WATERSHED DESCRIPTION

Threemile Pond is located in Kennebec County, Maine; and is situated in the Towns of China, Vassalboro, and Windsor (Figure 8; Maine Department of Environmental Protection 2003f). Threemile Pond is a single basin lake that spans 1,132 acres (MDEP 2003f). It has an average depth of approximately 5 m and a maximum depth of 11 m. Threemile Pond is dimictic; it experiences turnover in the spring and fall (see Background: Lake Characteristics: Annual Lake Cycles). During the summer, Threemile Pond is stratified and since the 1970s it has experienced frequent late-summer algal blooms (MDEP 2003f). Threemile Pond has a shallow depth, southeasterly orientation, and size that results in a flushing rate of about once per year (1.1 times/year). Common westerly winds create waves that churn Threemile Pond and decrease stratification, except during the summer months when stratification occurs (MDEP 2003f).

According to the Maine Department of Environmental Protection (MDEP 2003f), 30 percent of the Threemile Pond direct watershed is in the Town of China, 22 percent is in Vassalboro, 46 percent is in Windsor, and 2 percent is in Augusta. The total surface area of the Threemile Pond direct watershed is 5,965 acres. A direct watershed is the area around a lake or pond into which water drains without entering another lake or pond first (MDEP 2003f). The Threemile Pond total watershed includes the sub-watershed of Mud Pond, increasing the area to a total of 6,204 acres (MDEP 2003f). The watershed boundary used in this study was obtained from the Maine Office of GIS web page and is the same boundary that the MDEP used in their Total Maximum Daily Load (TMDL) report on Threemile Pond (MDEP 2003f). Threemile Pond is included in the chain of lakes that flows into Webber Pond, and when the corresponding watersheds are all combined, they form a watershed with a total area of 2,229,760 acres (BI493 2003a). Water in Threemile Pond flows from the south to the north (MDEP 2003f). There are three tributaries flowing into Threemile Pond and one tributary flowing out (MDEP 2003f). Barton Brook is an inlet that empties into the southwestern corner of Threemile Pond from Mud Pond and Threecornered Pond; and it is also the largest tributary into Threemile Pond (MDEP 2003f). In the north section of Threemile Pond, there are two inlets, one from the wetlands in the northern corner of the watershed and the other from the low lands in the northwestern part of the Threemile Pond watershed

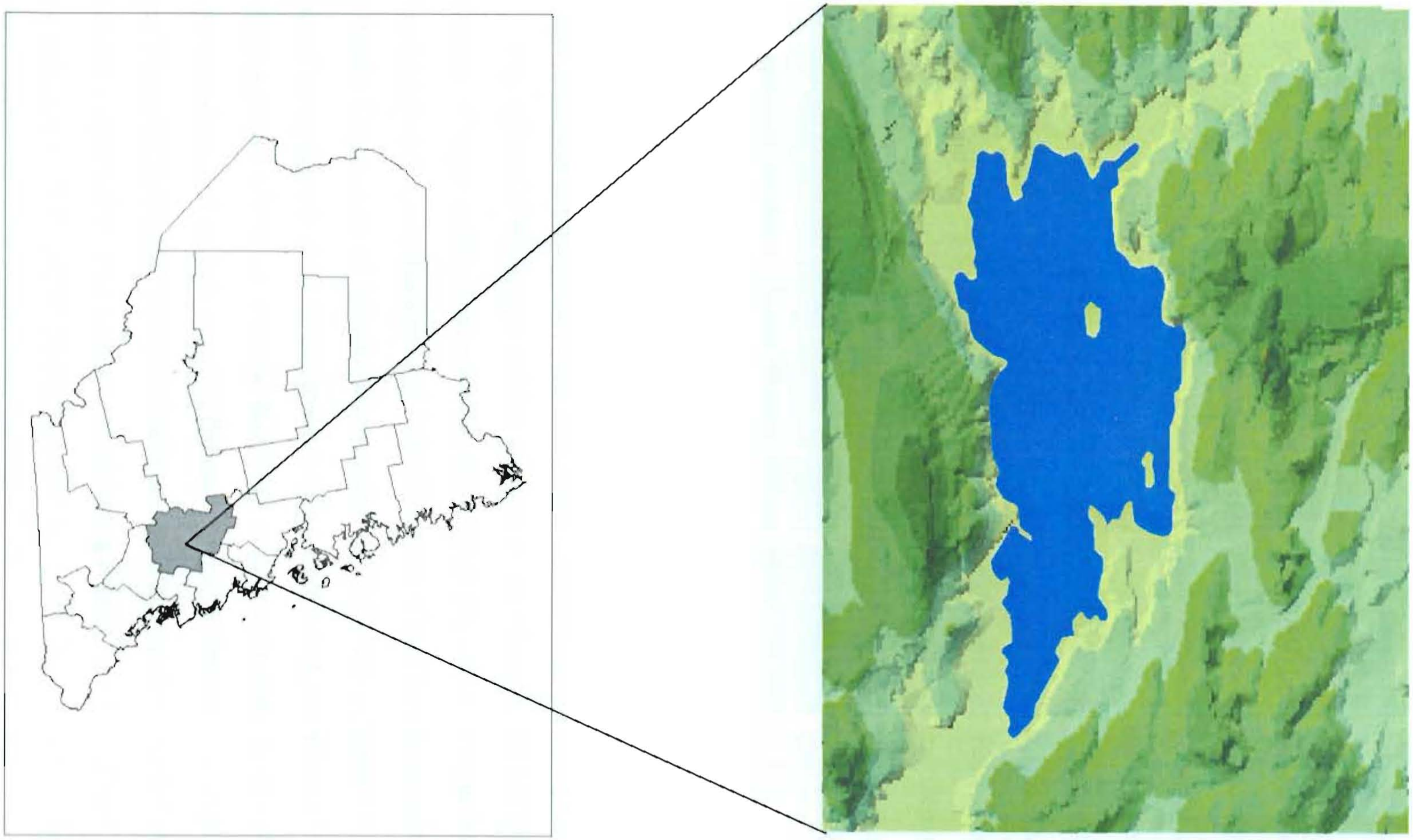
(MDEP 2003f). There is one outlet that empties into Webber Pond through the Seaward Mills Stream in the northwestern corner of Threemile Pond.

HISTORICAL PERSPECTIVE

Water Quality

Water quality is a relevant factor that visitors and homeowners consider when choosing a lake, and water quality affects the economy and population of communities living near water bodies (Bouchard 2000). Several key studies were completed in Maine between 1996 and 2000, linking water clarity to property values and recreational activity (EPA 2000). The results of these studies provided a means to quantify the economic costs of lake water quality degradation and the benefits to the state to maintain and improve water quality. Increased phosphorus in lakes often results in algal blooms turning lakes green, leaving unsightly scum, foul odors and bad tasting water (Smith and Witherill 1998). In some lakes, repeated algal blooms can result in fish kills or loss of the cold water fishery. All these factors reduce property values in lake communities and diminish Maine's appeal to visitors (Michael et al. 1996, Schuetz 1998). A one meter reduction of summertime minimum clarity (Secchi disk transparency) resulted in a reduction of three to five percent of the expected market price for lakefront property (EPA 2000). Aggregate property value loss on 164 monitored low quality lakes (minimum clarity of three meters) ranged between $200 and $400 million (EPA 2000). Schuetz (1998) illustrates that visitors also place value on the water quality of lakes and demonstrates their willingness to pay for water quality programs.

The annual economic value of Maine's lakes is about seven billion dollars (Bouchard 2000). In 2000, the cost to administer all water related programs in Maine was $11.1 million (EPA 2000). This cost included licensing, compliance, enforcement, technical assistance, pollution prevention, wastewater engineering, environmental assessment, lake restoration, non-point source (NPS) controls, and ground water protection. More than a quarter of Maine's adults (greater than 200,000 people) use Maine lakes each year, spending approximately $100 million and generating over 50,000 jobs (EPA 2000). It was estimated that the access users would be willing to pay two to six billion dollars for water quality. Consumer surplus, the economic value derived in excess of what is actually paid for the recreational experience, estimated at $7.5 billion for lakes in Maine, would decline by one to two billion dollars with measurable declines in water quality (EPA 2000). This relationship between water quality and



State of Maine **Threemile Pond and Surrounding Watershed**

Figure 8. Threemile Pond locator map. Shows the location of the Threemile Pond watershed within Kennebec County in the State of Maine. The Maine counties were supplied by ArcGIS™ software package. The Theemile Pond watershed was created from digital elevation maps from the Maine Office of GIS (MEGIS 2003).

economic well-being shows that improving the ecological health of lakes increases lake value and use. To achieve this relationship, local homeowners, commercial land owners and visitors must work together with local lake associations and government officials to systematically limit pollution to a level below an accepted threshold that maintains or improves water quality.

Algae blooms affected Threemile Pond prior to 1950, and have occurred frequently since the 1970s (BLWQ 2003, MDIFW 2003c). Threemile Pond has experienced algae blooms in 18 of the 26 years since 1977, when the Maine Department of Environmental Protection began collecting water quality monitoring data (BLWQ 2003, MDIFW 2003c). Total phosphorus and chlorophyll-a readings during this time showed increasing eutrophication (MDEP 2003F). Threemile Pond has been listed on Maine's 303 (d) list of lakes in non-attainment of water quality standards (MDEP 2003f).

In response, local watershed groups and state departments have treated Threemile Pond with chemicals to prevent late summer algae blooms. In 1981, the Maine Department of Inland Fisheries and Wildlife applied a copper sulfate treatment to the lake (MDIFW 2003c). In 1988, the department performed an aluminum sulfate (alum) treatment, including land use controls to minimize phosphorus inputs entering the lake. Algae blooms did not occur for four to five years, but returned in 1993 (Bouchard pers. comm.). After several years of extensive late summer blooms between 1993 and 1997, Threemile Pond received a five-year permit from 1997 to 2001 to perform copper sulfate treatments. This treatment was applied annually in conjunction with late summer algae blooms, with the exception of 2000 when the copper sulfate treatment was not applied (MDEP 2003F).

The effects of the copper sulfate treatments, an algicide, did not carry over to the following summers. Copper sulfate treatments do not address the cause of algae blooms, which is increased phosphorus loading (see Background: Lake Characteristics: Phosphorus and Nitrogen Cycles). Today, the Maine Department of Inland Fisheries and Wildlife only considers copper sulfate treatments in cases of severe algae blooms, due to its short-term success, cost, and adverse effects on fisheries (MDIFW 2003c). Adverse effects on flora and fauna can occur from copper sulfate accumulation and improper implementation, and include negative fishery impacts on fecundity and spawning success. The worst algae blooms in Threemile Pond historically occurred in August, the hottest month with the least rainfall. The 1981 copper sulfate treatment occurred during August as well, and this treatment coincided with a zooplankton die-off (MDIFW 2003c). Zooplankton eat algae and are an important species in limiting algal growth; a reduced zooplankton population might result in more severe algal blooms (Chapman 1992).

Aluminum sulfate immobilizes phosphorus in the bottom sediment, but it does not address phosphorus loading from stream inputs and runoff. Large quantities of aluminum sulfate lower the pH of a lake, and require a neutralizer to be applied in conjunction with the treatment. Unfortunately, a hose break during the 1988 aluminum sulfate treatment allowed a large amount of aluminum sulfate to be added to the lake without neutralization (MDEP 1991a). Smelt died from temperature and oxygen stress because of this treatment. Smelt are a cold water fish that inhabit the cool, oxygenated metalimnion during the warm summer months. The diffuser used to apply the treatment and aluminum flock from the treatment forced the smelt into either the warm epilimnion or the anoxic hypolimnion (MDIFW 2003c).

Important relationships to consider when managing water quality include the secondary effects of toxicity and the effect of weather on the success of chemical treatments. Toxins introduced into Threemile Pond may kill organisms such as zooplankton and fish. Large die-offs affect species dependent on those organisms for food or shelter. The loss of one or more species can create food or habitat space in an ecosystem for other species to grow in population and take over that niche. Prolonged, these changes can sustainably alter populations and nutrient cycling throughout an ecosystem (MEPC 1996). Toxins can also have adverse effects on populations higher in the food chain because every level in the food chain bioaccumulates higher concentrations of toxins. Toxins may also cause secondary effects by reducing available forage for species reliant on aquatic plants for food or on the predators of these species (Scott 1997). Weather, such as wind or high temperatures, can lower stress-tolerance levels among species and make them more vulnerable to chemical treatments. Threemile Pond is a shallow lake, and wind is capable of stirring up nutrient-rich bottom sediments or mixing settled treatment chemicals into the water column.

There have been no long-term successes in the chemical treatments applied to Threemile Pond. Increased sedimentation, phosphorus loading, and internal phosphorus recycling contribute to this low success rate (MDEP 2002b). At the same time, changes in human activity will be needed to maintain ideal lake quality characteristics. Improvement in water quality should benefit stocked and recreational fisheries and support late summer use in Threemile Pond.

Land Use

Before 1773, the Canibas tribe of Abnaki people lived in and around the Threemile Pond watershed (Van Strien 1975). Soon thereafter, European settlers began moving into the area. When the area

surrounding Threemile Pond was surveyed in 1773, it was heavily forested, with hardwoods on the ridges and large pines along the lakeshore (Van Strien 1975). The Town of Windsor was settled in 1790, on a site that had originally been pine forest. However, a majority of this forest had been cut down by 1867 (Boardman 1867). Europeans settled and began clearing for houses and small farms in Vassalboro around 1760 (Whitney 1887). The area that would become the Town of China was developed beginning in the late 1700s (Van Strien 1975).

Agriculture played a large role in the clearing and development of the Threemile Pond watershed. There are records of farming activity, such as mowing fields and fertile grazing grounds in China and Windsor in the late 19th century (Boardman 1867). In Vassalboro, at the end of the 19th century, there were both farms and orchards, and there were many farms near the outlet of Threemile Pond (Kingsbury and Deyo 1971, Robbins 1971). Chicken farming first appeared on the tax records of China in 1924, but most were in small flocks of fewer than 50 birds. In the late 1950s and early 1960s, chicken farming increased and in China alone there were between 150,000 and 200,000 chickens raised, most in flocks larger than 50. Many of these large chicken houses were still in operation in the mid-1970s (Van Strien 1975). Presently, no chicken farms remain in operation in the watershed. In general, land devoted to agriculture has decreased.

There was some industry in the area during the 19th century. In the 1860, Seward's Mills was powered by the stream that connects Threemile Pond to Webber Pond (Boardman 1867). Along the same stream, there were also mechanics shops, a store, and a blacksmith's shop (Kingsbury and Deyo 1971). Vassalboro also had several mills and factories to package and ship various products (Robbins 1971). Over time, the factories and mills went out of business; none are in operation today.

There have been many changes in land use over the history of the Threemile Pond watershed. Forested areas have been converted to fields and pastures, and often to industrial and residential uses. Forests in the Threemile Pond watershed are now regrowing as agriculture decreases, despite the increase in development. In the future, there will likely continue to be more changes toward increased residential development and decreased agricultural area.

REGIONAL LAND USE TRENDS

Land use in the State of Maine has changed in the last half-century to reflect a decline in agriculture that has occurred throughout New England, a predominant trend since the turn of the 20th century. Currently, 90 percent of the state is forested. The remaining land is divided between agriculture (3 percent), urban uses (2 percent) and other uses (5 percent) such as suburban housing, transportation uses, and wetlands (Plantinga et al. 1999). Much of the mature forests in the State of Maine were removed between 1900 and 1960 (Maine Forestry Service 2003). However, since the 1950s, forested land in the state has increased by almost 400,000 acres, while land used for agriculture has declined substantially. Cropland lost 713,000 acres and pasture land lost 174,000 acres. This loss occurred primarily during the 1950s and 1960s, with losses in agricultural land diminishing after the 1960s (Plantinga et al. 1999). The increase in forested land throughout the state can be attributed to the decline in agriculture. Land that was formerly used for agricultural purposes has either reverted to forests or is in the process of reverting. Residential land uses have increased in the region over the past 50 years, as has the related road network. In particular, many residences were constructed along the shores of the numerous lakes throughout the region during this time. Commercial and municipal uses have also increased in the last 50 years. State of Maine trends are indicative of general development trends for the New England states.

BIOLOGICAL PERSPECTIVE

Introduction

Threemile Pond is located in the southeastern section of the Lower Kennebec Valley, which extends from north of Skowhegan to just south of Gardiner (EPA 2003a). Broadly, the ecosystems of Threemile Pond can be characterized as lake, tributary, marshes, and riparian habitat. Each of these ecosystem groupings supports invertebrates, plants, birds, mammals, reptiles, and fish in different capacities. Migratory birds, such as the Great Blue Heron, may frequent the Threemile Pond marshes annually, while Smallmouth Bass lay their eggs and live their adult lives in the lake s shallow, rocky areas.

The interaction between natural conditions and human activities affects the biology of Threemile Pond (Bouchard 2000). Threemile Pond is a eutrophic lake with substantial shoreline development and a long history of land use (see Threemile Pond Characteristics: Historical Perspective: Land Use).

This lake is affected predominantly by non-point source pollution from these developed spaces. Nutrients can cause nuisance overgrowth of algae as well as noxious aquatic plants, which can lead to oxygen depletion through plant respiration and microbial decomposition of plant matter (see Background: Lake Characteristics: Phosphorus and Nitrogen Cycles). If not properly managed and controlled, sources such as shoreline development, agriculture, septic systems, and commercial runoff can contribute to excessive nutrients in the lake (EPA 2000).

Uncontrolled pollution from development can deter human activity and decrease biodiversity, which refers to the variety and variability of species within an ecosystem (Ellsworth 2002). All species have food and habitat needs; the more specific those needs and localized the habitat, the greater the vulnerability species have to loss of habitat from conversion to agricultural land, roads, and homes. Every ecosystem carries a different threshold for biological change. In the absence of human influence, change occurs slowly over time. Controlled development within the Threemile Pond watershed can help people to collectively minimize the adverse effects of development, habitat destruction, and pollution.

Habitat is damaged through ecosystem fragmentation, degradation, and destruction, which are important causes of known extinctions (Ellsworth 2002). Pollution is another source of stress on species and ecosystems. The 1987 Clean Water Act defines pollution as human-induced alteration of the chemical, physical, biological, or radiological integrity of water (Loeb and Spacie 1994). Pollution is the increased accumulation of naturally occurring compounds due to human activity and manufactured chemicals such as pesticides and fertilizers. When these compounds are introduced and accumulate, they have adverse effects on the health and well-being of ecosystems and humans living in them. In the long run, the only species that survive are likely to be those with highly protected habitats, or with niche requirements corresponding to the degraded state associated with human activity (Allen 2003).

Native Aquatic Flora/Fauna

Aquatic plants and wetlands in Threemile Pond play a particularly important role in regulating nutrients in the lake. High vegetation-levels in wetland areas capture phosphorus and aquatic plants stabilize the shoreline, oxygenate the water and absorb toxics (see Background: Lake Characteristics: Freshwater Wetlands). Clusters of macrophytes act as fish nurseries and create habitat for insects and crustaceans eaten by birds, fish, and small mammals. Excessive plant growth of macrophytes (large plants) can indicate pollution, as they often occur where excess sediment is carried to the lake by runoff

(Firmage pers. comm.). Plants can absorb nutrients in the short-run, but excess plant debris in the lake can increase nutrient levels as they die and decompose.

Fishing is one of the top two uses of Threemile Pond (Bouchard 2000). As a result, the Maine Department of Inland Fisheries and Wildlife (MDIFW) manages both cold water and warm water fisheries in the lake. Threemile Pond maintains a diversity of fisheries occupying a variety of habitats for spawning and food. Threemile Pond supports 17 naturally reproducing fish species, including cold water game fish, warm water game fish, baitfish, and commercial fisheries, and two stocked fish species (Table 3). There are no native andromodus (sea-run) fish in Threemile Pond because it is a landlocked water body. There is only one native cold water fish in Threemile Pond, the Rainbow Smelt. Eutrophic characteristics and shallow depth make Threemile Pond most suitable for warm water fish such as Smallmouth and Largemouth Bass, White Perch, and Chain Pickerel (Woodward pers. comm.).

Most fish in Threemile Pond inhabit the open water or shoreline, while only the Brown Bullhead is a bottom dweller (MDIFW 2002, 2003c). Bass, pickerel, and pumpkinseeds prefer shoreline habitat as adults. Trout, sunfish, smelt, suckers, and alewives spend their adulthood in open water. Stocked Alewives and the American Eel are migratory, though Alewives do not naturally migrate to and from Threemile Pond (Perry pers. comm.). Smallmouth Bass prefer shallow, rocky areas, like those around Threemile Pond's lagest island and eastern shoreline. Largemouth Bass inhabit shallow, weedy areas, including the macrophyte area around the public boat launch. Rainbow Smelt prefer cold waters, remain in the metalimnion, and use Threemile Pond's tributaries to spawn (MDIFW2003c). Sunfish, perch, pickerel, bass, and brown trout are piscivorous (fish-eating), smelts and alewives are planktivorous (zooplankton-eating), and bullheads are omnivores (animal and plant-eaters) (MDIFW 2002). While cold water fish generally spawn in the fall between October and November, warm water fish species spawn in the spring from May to late July, either along the lakeshore or in the tributaries of Threemile Pond (Woodward pers. comm.).

In general, warm water fish can be found above the metalimnion. Cold water fish live in the coolest water with sufficient oxygen, which is generally the hypolimnion between fall and spring turnover, and the metalimnion during the summer. Oxygen levels below 5 ppm stress certain cold water fish, and an extended anoxia may reduce or eliminate important habitat for sensitive cold water species (MDEP 2002b). Summer stratification is important for the survival of cold water fish in Threemile Pond because they can inhabit the cooler, oxygenated metalimnion during the warmer months (Woodward

Table 3. Threemile Pond Fisheries. Threemile Pond has 19 fish species, including two stocked species and two commercial fisheries. These fish differ in size, food, and niche requirements, and species can be found throughout most of the Threemile Pond ecosystem. Food habits were categorized into six groups: benthivore, herbivore, invertivore, omnivore, piscivore, and planktivore (NatureServe 2003). Habitat was divided into three groups: open water, shoreline, and bottom (Woodward pers. comm.). Open water fish in Threemile Pond are threatened by late-summer conditions when they are forced into the warm epilimnion or anoxic hypolimnion (MDIFW 2003b).

Fish	Food	Habitat
Coldwater Game Fish		
Rainbow Smelt*	Planktivore	Open Water
Brown Trout[1]*	Piscivore	Open Water
Warmwater Game Fish		
Largemouth Bass*	Piscivore	Shoreline
Smallmouth Bass*	Piscivore	Shoreline
White Perch*	Piscivore	Shoreline
Yellow Perch	Invertivore	Shoreline
Pumpkinseed Sunfish	Invertivore	Shoreline
Redbreast Sunfish	Invertivore	Shoreline
Chain Pickerel*	Piscivore	Shoreline
Brown Bullhead (bullhead, hornpout, catfish)	Omnivore	Bottom
Baitfish		
Minnows		
Common Shiner	Herbivore, Invertivore	Shoreline
Golden Shiner	Planktivore	Shoreline
Fallfish (chub)	Invertivore, Piscivore	Shoreline
Commercial Fisheries		
Rainbow Smelt*	Piscivore	Open Water
Alewife[1]	Planktivore	Open Water
Other		
American Eel	Piscivore	Bottom
Fourspine Stickleback	Invertivore	Shoreline
White Sucker	Benthivore	Open Water
Banded Killifish	Insectivore	Shoreline

[1] Stocked fish

* Most common fisheries

pers. comm.). Increased eutrophication can be a potential problem for cold water fish species in Threemile Pond if oxygen levels become insufficient.

The fisheries in Threemile Pond have remained mostly healthy, with only a few reported cases of disease or die-offs. In the early 1990s, several anglers reported cankers on Smallmouth Bass found dead in the southwest region of the lake (MDIFW 2003c). Abnormal fish deaths have also been associated with the secondary effects of chemical treatments added to Threemile Pond to control algae blooms. Fish deaths occurred when fish were forced or scared into deep oxygen depleted water or shallow warm water as a result of these chemical treatments (see Threemile Pond Characteristics: Historical Perspectives: Water Quality; MDIFW 2003c).

Fish Stocking

Human activity has shaped the populations of fish species found in Threemile Pond. Smallmouth Bass and Largemouth Bass are both non-natives but widely established in southern, central, and parts of eastern Maine (MDIFW 2003a). Since 1986, Maine fishery biologists have determined that illegal introductions have established new populations in 57 additional lakes. Largemouth Bass are being illegally introduced into many Downeast waters at an alarming rate with unpredictable consequences to long established, economically important Smallmouth populations (MDIFW 2003a). Largemouth bass have a wider habitat preference than Smallmouth Bass and are favored over Smallmouth populations by anglers (Woodward pers. comm.). While Threemile Pond has had long established populations of both Smallmouth and Largemouth Bass, illegal stocking of Largemouth Bass could alter the population size of Smallmouth Bass (MDIFW 2003c).

The illegal stocking of rainbow smelt to be used for commercial bait in the Maine lobster industry has also occurred in Maine lakes. Often fished in the winter for commercial bait fishing, rainbow smelt have been found in Threemile Pond since the 1970s when they established a naturally reproducing population (Woodward pers. comm.). Historically, Maine's rivers supported a large number of andromodus (sea-run) fish species, including the Rainbow Smelt. The construction of dams, loss of habitat and declining water quality depleted and in many cases destroyed populations of these species (Perry pers. comm.).

Threemile Pond has a long history of legal fish stocking. Records at the Maine Department of Inland Fisheries and Wildlife show Brook Trout, Brown Trout and Chinook Salmon stocking between 1933 and 1941 (Cooper 1942). Today, the Maine Department of Inland Fisheries and Wildlife (MDIFW)

stocks Threemile Pond with Brown Trout and the Maine Department of Marine Resources (MDMR) stocks the lake with Alewives (Perry pers. comm.; Woodward pers. comm.). Brown Trout and Alewives are both cold water fish species, and neither species can spawn in Threemile Pond, making annual stocking necessary to maintain their populations. MDMR began restoring runs in the system by trapping adult Alewives during their annual spring spawning migration, trucking them upstream in the watershed to several headwater lakes and ponds where they historically spawned before the rivers were blocked by dams (Perry pers. comm.). Brown Trout, coming from one of nine hatcheries in the state, do not have adequate habitat to spawn in Threemile Pond (Woodward pers. comm.).

Brown Trout were introduced to Maine in 1885. Today, they are one of the most important fisheries for anglers in Threemile Pond. Brown Trout stocking has continued annually since 1978, with approximately 1,100 stocked every fall for the past 20 years. The cost of this stocking is approximately $1,500 per year (Woodward pers. comm.). Although they cannot spawn, anglers have caught tagged Brown Trout years after their release (MDIFW 2003c).

The Maine Department of Marine Resources began stocking Threemile Pond with Alewives in 2001, introducing 2,258 adult Alewives. In 2002, MDMR stocked 6,237 adults, and in 2003, MDMR stocked a total of 6,487 Alewives (Perry pers. comm.). As planktivores, Alewives are low in the food chain; piscivorous fish eat Alewives. They are an important food source for both inland and marine fish species, birds including eagles, osprey, loons, mergansers, and terns, and mammals such as otters, minks and seals. Smallmouth Bass and other important fisheries also feed on Alewives (MDIFW 2003b). More Alewives mean more piscivorus fish. There is also a recreational fishery for Alewives, though it is not pronounced in Maine. Instead, Alewives are caught for bait in the spring for the Maine lobster industry, though the primary purpose of restocking Alewives in Threemile Pond is to restore alewife populations in the Lower Kennebec Valley (Perry pers. comm.)

In 1991 and 1992, the Maine Department of Inland Fisheries and Wildlife stocked Threemile Pond with 200 Smallmouth Bass from Carleton Pond in Augusta, Maine to determine the extent to which anglers control the size and structure of bass populations in Maine. Thirty percent of these fish died within days, possibly due to unseasonably high temperatures and transportation stress between the two lakes (MDIFW 2003c). The study did not have any conclusive evidence on the effect of anglers on bass populations.

Invasive Plants

The absence of natural predators and competitors coupled with high reproductive potential favors invasive species, allowing their populations to increase dramatically in a short time (Dobson and Beck 1999). Unauthorized introductions of invasive, exotic fish species are particularly destructive to Maine's native brook trout populations, but they may also cause irreversible changes to entire aquatic ecosystems by restructuring plankton and forage fish communities that have evolved since the last glacial retreat (MDIFW 2003a). Aggressive, non-native plant species are also problematic because they can spread rapidly, out-compete beneficial native plants, and can be a nuisance to lake-users when they grow in high density and congest waterways (MDIFW 2003b). Strategies to eliminate or control invasive species are difficult to design and implement, costly, and quite often entirely ineffective.

The introduction of invasive species threatens not only native flora and fauna, but also water quality. Invasive macrophytes can alter the structure and function of habitats, making them less suitable for native plants and animals. Their presence results in a degradation of Maine habitats and potential irrecoverable loss of biodiversity. People do not typically recognize non-indigenous plant species as a threat until they become so abundant that their impact on indigenous species is obvious. By this time, much damage is done, effective mitigation techniques become difficult, and control costs rise dramatically (MDC 2003). In general, Maine lakes have been spared the worst of invasive aquatic plants, but increased boating activity has increased the possibility that aggressive invasives will establish themselves in more Maine lakes.

There are 11 illegal non-native plants in Maine, meaning that one cannot sell, introduce, or propagate these plants. These are Brazilian Elodea (*Egeria densa*), Curly-leaved Pondweed (*Potamogeton crispus*), European Frogbit (*Hydrocharis morus-ranae*), European Naiad (*Najas minor*), Eurasian Milfoil *(Myriophyllum spicatum)*, Fanwort (*Cabomba caroliniana*), Hydrilla (*Hydrilla verticillata*), Parrot Feather (*Myriophyllum aquaticum*), Variable-leaf Milfoil *(Myriophyllum heterophyllum)*, Water Chestnut (*Trapa natans*) and Yellow Floating Heart (*Mynphoides peltata*) (MDEP 2003c). Two of these plants are in Maine: Variable-leaf Milfoil and Hydrilla (MDEP 2003b). While few lakes in Maine suffer from the presence of aggressive non-native plants, several lakes near Threemile Pond have had invasions in recent years. These include Variable-leaf Milfoil infestations in Messalonskee Lake in Oakland and in Cobbossee Stream bordering Horseshoe Pond in West Gardiner (MDEP 2003b, 2003e).

While Threemile Pond currently has no invasive species, similar lakes in Maine have been affected by invasive plant species. The introduction of illegal non-native plants is usually the result of fragments

transferred from recreational boats (SAM and MDIFW 2003b). Even tiny plant fragments on boats can transport populations of invasive macrophytes from a place of infestation to an uncolonized water body. Colonization is difficult to prevent, and community education programs are absolutely necessary as a first step in preventing the spread of illegal plants. One piece of Eurasian Milfoil potentially can cause the infestation of an entire lake. In a shallow lake with a muddy bottom like Threemile Pond, areas protected from wind and waves are more conducive to plant growth and possible establishment of invasive plants (Dominie 1981). The MDEP has implemented an inspection, education, and monitoring program supported through boat stickers and signs at public boat ramps (LWRC 2002). The MDEP and MDIFW uses lake associations, volunteer monitoring, and a rapid response system to quickly mitigate infestations; they also regulate surface use in plant-infested waters to help control the spread of the invasive species.

Trophic Status

In a lake ecosystem, the trophic status rates the efficiency of the nutrient use in a lake (Chapman 1992). The trophic status specifically measures the total biomass production at the primary producer level, which is photosynthesizing aquatic plants and algae. More efficient lakes have a composition of consumer species, including zooplankton and fish, capable of minimizing the biomass of primary producers. Phytoplankton and macrophyte levels grow when dissolved nutrient availability increases, resulting in consumer populations that can no longer efficiently manage the biomass of primary producers. This inefficient use of nutrients in the lake results in high levels of algae and aquatic plant death. Consumers cannot absorb the nutrients in decomposing plants, and these nutrients are instead recycled back into the lake ecosystem for primary producers to reuse (Chapman 1992).

The inefficient use of phytoplankton biomass results from high nutrient availability and can alter species composition, physical qualities, and chemical characteristics in a lake (Chapman 1992). Fish populations change as lakes become more inefficient, and herbivores such as minnows become more dominant. Oxygen depletion occurs as decomposing bacteria use up oxygen in the lower reaches of the lake, resulting in anoxia (Chapman 1992). Anoxia can kill coldwater fish species that rely on a balance of oxygenated and cold water. Making matters worse, dissolved oxygen levels below one ppm can actually release phosphorus trapped in bottom sediments, feeding the bloom (see Background: Lake Characteristics: Phosphorus and Nitrogen Cycles).

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

A trophic state index is a convenient way to quantify this relationship. One popular index was developed by Dr. Robert Carlson of Kent State University. His index uses a log transformation of Secchi disk values as a measure of algal biomass (EPA 2003b).

An oligotrophic lake is characterized by above average transparency (> 8 m Secchi disk transparency), deficient phosphorus levels (< 6 ppb total phosphorus), and low productivity (< 0.95 ppb chlorophyll *a*) (Carlson and Simpson 1996). A mesotrophic lake has average transparency (4 to 2 m SDT), moderate phosphorus levels (12 to 24 ppb TP), and moderate productivity (2.6 to 7.3 ppb Chl*a*). A eutrophic lake has below average transparency (< 2 m SDT), high phosphorus levels (> 24 ppb TP), and high productivity (> 7.3 ppb Chl*a*). The hypolimnia of shallower lakes may become anoxic at Secchi disk readings below 4 meters (Carlson and Simpson 1996). In the most severe cases, a lake can be dystrophic when the internal generation of organic matter is extremely high, water use becomes severely impaired, and anoxia occurs often in the hypolimnion during summer stratification (Chapman 1992).

The process of eutrophication is one of the most significant processes affecting lake management (Chapman 1992). There are two types of eutrophication: natural and cultural. Natural eutrophication occurs over a long period of time, sometimes thousands of years. Cultural eutrophication, caused by human activity, can accelerate this natural process (MDEP 1996). In Maine lakes, the limiting nutrient in the eutrophication process is phosphorus (see Background: Lake Characteristics: Phosphorus and Nitrogen Cycles). Phosphorus enters the lake through stormwater runoff from point or non-point sources, which is accelerated as humans remove soil-stabilizing plant root systems to construct homes, businesses, farms, lawns and roads. Fertilizers, detergents, manure, and sewage also contain concentrated phosphorus

that may enter water bodies. Phosphorus is a fertilizer; once in a lake, phosphorus nourishes algal growth and allows it to multiply into an algae bloom (MDEP 2003F).

A threatened lake classification, as determined by the Maine Department of Environmental Protection (MDEP), assesses the vulnerability of lake water quality to future impacts from changing land use. Lakes high in nutrients are eutrophic by definition, and continued degradation increases the chance that eutrophic lakes will become unsuitable for both aquatic species and human recreation (see Background: Lake Characteristics: Trophic Status of Lakes). In general, eutrophic lakes have large populations of few phytoplankton species, high oxygenation at the surface and low oxygenation at the bottom, many fish species, and high levels of suspended solids (Chapman 1992). These characteristics are typical of many lakes in Maine. A 1996 study by the MDEP showed that 602 of 1733 assessed Maine lakes were eutrophic (MDEP 1996). Seventy-five of the 456 lakes assessed in Kennebec County were considered threatened. Of these, 26 lakes were designated impaired. Impaired lakes are those at risk for future water quality degradation, including increasing algae growth, algae blooms resulting from human activity, and impairment of aquatic habitat (MDEP 1996). The study also showed Kennebec County to have four lakes with an increasing trophic trend, representing the highest number and greatest acreage (18,467 acres) of such lakes in Maine.

Threemile Pond is a threatened lake because it is a eutrophic lake with a long history of increasing human activity in the watershed (MDEP 2003f). Threemile Pond is an impaired lake because the trophic trend in the lake has been decreasing, though the lake still supports healthy fish populations and recreation (Woodward pers. comm.). Kennebec County is one to one-and-a-half hours drive from southern Maine, the state's most populated and urban region. A long history of farms, pastures, and industry in the region supported increasing populations (see Threemile Pond Characteristics: Historical Perspective: Land Use). Today, tourism and lakefront homes dominate the lakeshore uses of the Lower Kennebec Valley, including Threemile Pond. The growing human presence in the Threemile Pond watershed has not only affected biodiversity, but also the trophic level of the lake.

GEOLOGICAL AND HYDROLOGICAL PERSPECTIVE

During the Pleistocene Epoch, 25,000 to 20,000 years ago, Maine was covered completely by the Laurentide Ice Sheet (Marvinney and Thompson 2000). The majority of the ice sheet was centered over Eastern Canada, but it expanded down through New England to its southernmost point around Long Island, New York at the height of glaciation (Marvinney and Thompson 2000).

The ice sheet moved in a south-southeastern direction and spread out beyond the present coast of Maine onto the continental shelf (MDOC 1996). The ice sheet was thick enough to cover Mt. Kathadin in Maine and the weight of it carved the Earth as if the ice was a slow-moving river (MDOC 1996). The ice shaped the landscape of Maine as it slowly moved southward picking up and dropping off debris as it went (Marvinney and Thompson 2000). The previous waterways were changed and destroyed, but in their place the ice sheet left hundreds of new lakes and ponds throughout Maine (Marvinney and Thompson 2000). Most of these lakes and ponds have a southeasterly orientation since they were cut out as the glaciers moved up and down the coast.

About 21,000 years ago, the temperature started to increase and the ice sheet started to recede (Marvinney and Thompson 2000). The ice sheet receded back to Maine 13,000 years ago and was nearly gone from Maine by 10,000 years ago (MDOC 1996, Marvinney and Thompson 2000). Under the weight of the glacier, the Earth s crust was depressed about 800 feet in Maine and as the glacier receded, the sea followed it up the Kennebec Valley and the Penobscot Valley (MDOC 1996). The glacier left a substrate that consists of glacial till, bedrock, and glaciomarine clay-silt throughout Maine, which became the base of many lakes in the state (Davis et al. 1978). These lakes and ponds were formed less than 10,000 years ago, which is young in geological terms, and are naturally nutrient poor because of the substrate (Davis et al. 1978). This combination would predict that most Maine lakes would be oligotrophic, but a large number of them are eutrophic due to natural evolution and human activity (Davis et al. 1978; see Threemile Pond Characteristics: Biological Perspective: Trophic Status).

STUDY OBJECTIVES

INTRODUCTION

The purpose of this year's Colby Environmental Assessment Team (CEAT) project was to investigate the natural and human activities affecting the Threemile Pond watershed in the towns of Augusta, China, Vassalboro, and Windsor. CEAT examined the possible sources of pollution entering Threemile Pond in order to assess the overall health of the lake. Sources of pollution include both point and non-point sources; their relative effects were determined through a water quality analysis and land use assessment. Point source pollutants are connected to a single output, such as a pipe or a stream. Non-point source pollution comes from diffuse sources, which are often more difficult to address than point source pollution. Non-point sources include runoff from agricultural areas, lawns, roads, and areas of eroding soil. After completing an analysis of possible sources of pollution into Threemile Pond, especially nutrient loading, this study provides an evaluation of trends and recommends techniques for maintaining healthy water quality.

The work of CEAT compliments other water quality and land use analyses of Threemile Pond. The Maine Department of Environmental Protection (MDEP) and Maine Department of Inland Fisheries and Wildlife (MDIFW) have monitored Threemile Pond and performed lake remediation programs since 1977 (MDIFW 2003c). In particular, this CEAT analysis of Threemile Pond follows a Total Maximum Daily Load and Phosphorus remediation report on Threemile Pond completed by the MDEP in September 2003 (MDEP 2003f). CEAT has also performed watershed and lake analyses of Webber Pond (BI493 2003a) and China Lake (BI493 1989, 1990). The greater China Region Lakes Alliance monitors Threemile Pond, Webber Pond and China Lake with the goal of benefiting the local economy through Integrated Watershed Management. Threemile Pond is part of the entire Webber Pond watershed (MDEP 2003g).

WATER QUALITY ASSESSMENT

Physical, chemical, and biological tests were performed on Threemile Pond to understand water quality throughout the lake. Together these tests determine the ecological health of the lake. CEAT members began analysis of Threemile Pond in August 2003 and continued through early fall at 12 sites around the lake. During these field tests, CEAT identified sites of increased aquatic plant growth and

possible sites of non-point source pollution. CEAT members gathered data on native and stocked fisheries and invasive species from the Maine Department of Environmental Protection, Maine Department of Inland Fisheries and Wildlife, and Maine Department of Marine Resources.

Tributaries are sources of direct water flow entering the lake. Water quality tests were performed on the tributaries actively flowing into and out of Threemile Pond during fall 2003. CEAT assessed the water quality of these tributaries to determine whether the tributaries were a source of pollution or excess nutrients.

LAND USE ASSESSMENT

Land uses have direct impacts on the water quality of Threemile Pond. CEAT measured the proportion of the watershed composed of distinct land use types and modeled their relative impacts using Geographic Information Systems. Shoreline and non-shoreline residential housing, as well as year round and seasonal housing, were also quantified during fieldwork. Historical analyses of land use were conducted and future projections were made based on development trends in the watershed and in similar watersheds nearby.

Once all of the land use types were determined, a phosphorus budget was calculated to predict the annual mass of phosphorus inflow into Threemile Pond. Phosphorus loading coefficients were assigned to each land type and their relative proportion to the watershed was calculated. These values were used in the phosphorus budget to quantify how much phosphorus loading each land use type contributes annually to Threemile Pond. High, low, and best estimates for annual mass phosphorus loading were computed using this model.

FUTURE TRENDS

Ecological change is often an indicator of shifts in ecological health. The health of Threemile Pond will directly affect the economic success of the three towns bordering the Threemile Pond shoreline: China, Vassalboro, and Windsor. At the same time, because the greatest concentration of phosphorus entering Threemile Pond comes from non-point source pollution, increased development may lead to an increased rate of nutrient loading. By examining changes in lake water quality and land use and by determining potential sources of phosphorus, CEAT can recommend healthy watershed management practices to minimize the nutrient loading that accelerates the eutrophication of Threemile Pond. CEAT

also recommends appropriate planning and remediation measures to help moderate the impacts of phosphorus on Threemile Pond.

ANALYTICAL PROCEDURES AND RESULTS

WATER QUALITY STUDY SITES

SAMPLE MAP

In total, nine sites on Threemile Pond and four sites at tributaries were sampled for water quality testing (Figure 9). Sampling was completed on 11-Sep-03 by Colby Environmental Assessment Team (CEAT). Sampling locations were categorized as either characterization sites, spot sites, or tributary sites. Possible physical measurements taken at sites included depth, dissolved oxygen and temperature profiles, turbidity, transparency, color, conductivity, and flow. Possible chemical tests run on samples included pH, nitrates, alkalinity, and total phosphorus. A third category of tests was biotic testing, including only total coliform. A wide array of tests at characterization sites (Site 1 to 3) were used to create a thorough and generalized profile of the water chemistry of Threemile Pond. Spot sites were selected to assess factors specific to each location and often included many of the same tests used at characterization sites and any additional tests deemed necessary to assess that particular location or problem area. Tributary sites (Sites 9 to 13) were selected to assess the inputs and outputs of Threemile Pond and an array of physical and chemical tests were performed to do so. For a complete list of tests performed for each site, see Appendix A.

Various layers were compiled to create this map (Figure 9). The first theme included the waterbody's watershed; including Threemile Pond, Mud Pond, and various streams (MEGIS 2003). A topographic layer was then added to show the flow of streams compared to the ponds in the watershed (MEGIS 2003). Finally, a theme containing GPS points corresponding to the sample sites was added. On the day of water quality sampling, GPS points were taken at each site. Locations were taken in Universal Transverse Mercator coordinate system (UTM), the most commonly used coordinate system in a GIS. Moving on a north to south line adjusts the Easting measurement and moving on an east to west line adjusts the Northing measurement. The map marks the individual location of these sites.

THREEMILE POND

Characterization Sites

Site 1: Northing: 4912097 Easting: 0451706 Depth: 12.0 m

Site located at middle, slightly southern part of lake. In past studies, DEP has used this site for sampling, which is useful for comparisons to results from this study.

Site 2: Northing: 4910842 Easting: 0451479 Depth: 5.3 m

Site located at southern portion of lake. Samples were collected for total coliform testing at this site as a control for coliform testing from Site 5.

Site 3: Northing: 4913842 Easting: 0451181 Depth: 5.6 m

Site located at northwestern portion of lake to compare general differences in water chemistry from middle and southern portions.

Spot Sites

Site 4: Northing: 4914483 Easting: 0451676 Depth: 1.5 m

Site located at northern portion of lake. This site was selected because heavy lakefront development characterizes the area and at this site the town area is in close proximity to the lake. Both are potential sources of nutrient loading. Also, this site is closer to the shore than Site 3 and could be affected by erosion and siltation.

Site 5: Northing: 4913636 Easting: 0452459 Depth: 1.9 m

Site located at western portion of lake. Site selected for its proximity to campground and picnic area with possible sources of nutrient loading and contamination. A sample was collected here to test for total coliform, a measurement of water sanity.

Site 6: Northing: 4912006 Easting: 0452508 Depth: 2.0 m

Site located at middle to slightly southwestern portion of the lake. This site was selected for its location in a cove, a potential trap for nutrients flowing into the lake.

Site 7: Northing: 4911222 Easting: 0452048 Depth: 1.8 m

Site located at southwestern portion of the lake in a small inlet. This site was selected because the shore has heavy residential development, a possible source for nutrient loading in that area.

Site 8: Northing: 4913047 Easting: 0451176 Depth: 2.5 m

Site located on the eastern bank of the lake. This site was chosen for its proximity to a heavily developed residential area.

Site *: Northing: 4912585 Easting: 0452599

Site located near shore with heavy residential development to test total coliform.

Tributary Sites

Site 9: Northing: 4916744 Easting: 0451176

Site located on Seward Mills Brook, about 210 m from Webber Pond near a culvert for Route 3. The water in the stream was shallow and fast moving with a rocky substrate. This tributary is an input into Threemile Pond.

Site 10: Northing: 4914642 Easting: 450918

Site located on Seward Mills Brook near Threemile Pond outlet, about 290 m from the outlet on the northeastern shore. The site was relatively deep and muddy and located in a wetland area. The site was also close to an animal rehabilitation center off of Route 3.

Site 11: Northing: 4914814 Easting: 0451630

Site located on unnamed marshy inlet to Threemile Pond, about 285 m from the inlet on the northern shore. The site was located off an abandoned road running parallel to Route 3. The water was slow moving with a slight flow into Threemile Pond.

Site 12: Northing: 4909429 Easting: 0450748

Site located on Barton Brook inlet to Threemile Pond near a culvert under Weeks Mills Road, around 900 m from Threemile Pond's southern shore. A dam upstream near Mud Pond had recently been released and because of this, water at the site was deep and was running swiftly. Many beaver dams were also noted in the area.

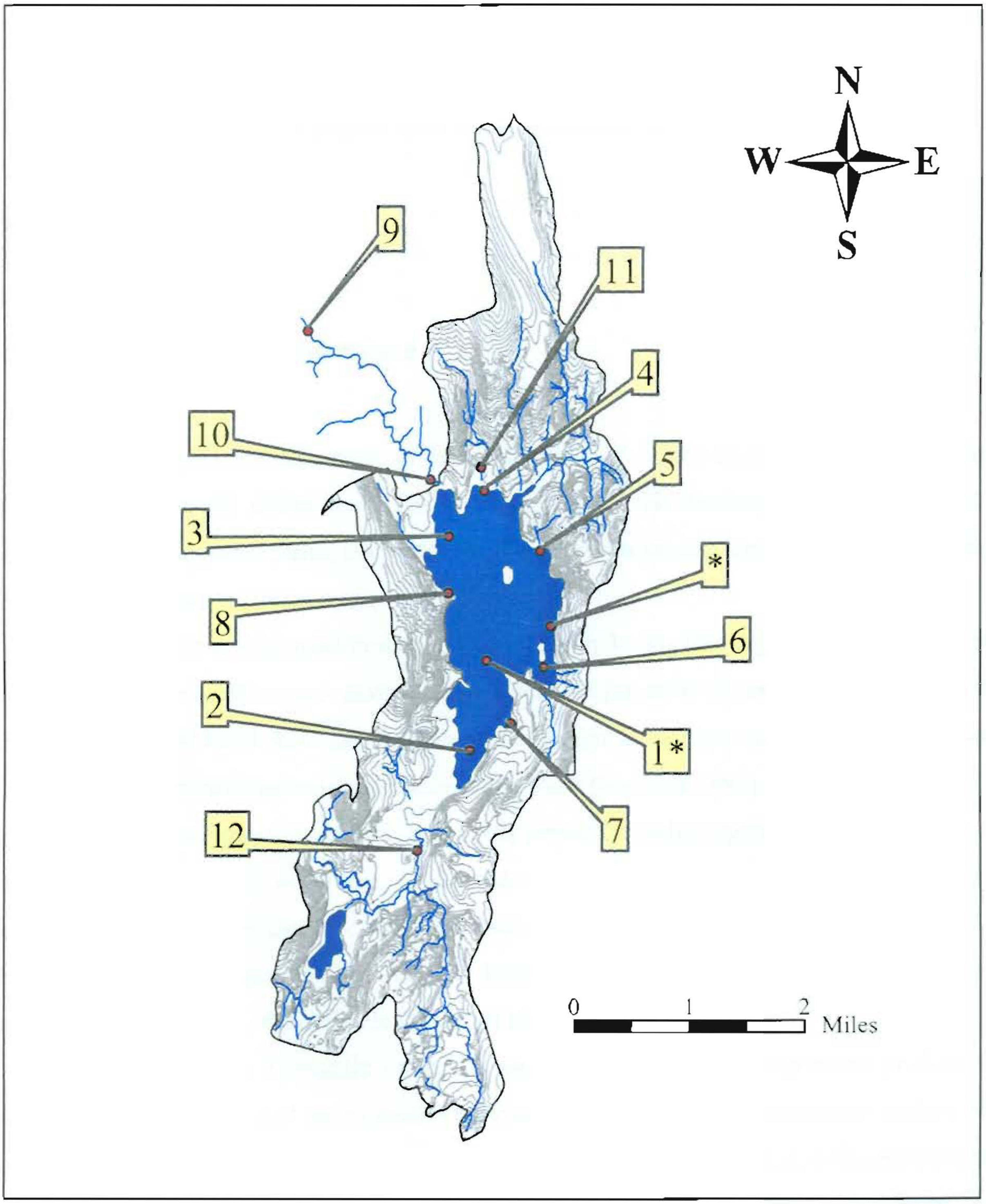


Figure 9. Sites for water samples taken on 11-Sep-03 by the Colby Environmental Assessment Team. Sites 1-3 are characterization sites, sites 4-8 are spot sites, and sites 9-12 are tributary sites. For an explanation of these sites, see Water Quality Study Sites. Sites with * are locations of total coliform testing samples.

WATER QUALITY

<u>THREEMILE POND WATER QUALITY ASSESSMENT</u>

Lake Water Quality

Physical Measurements

Dissolved Oxygen and Temperature

<u>Introduction</u>

Dissolved Oxygen is a measurement of the concentration of oxygen dissolved in the water column (MDEP 2002a). Oxygen enters the water through atmospheric exchange and is produced by photosynthetic algae and other plants, but processes such as respiration deplete the oxygen concentration in a body of water (Harper 1992, Lampert and Sommer 1997).

Dissolved oxygen is influenced by a variety of factors including lake depth, basin shape, salinity, pressure, nutrient levels, and organic matter, but is influenced primarily by temperature (Harper 1992, Stanicoff 1996, Wetzel and Likens 2000). Dissolved oxygen and temperature are inversely related. Cold water can hold more dissolved oxygen than warm water (Stednick 1991). Low levels of dissolved oxygen indicate poor water quality and can negatively impact the living organisms within the lake that depend on the oxygen supply to survive. Dissolved oxygen below 5 ppm can cause stress for some organisms. Fish, for example, can have difficulty breathing, and levels below 1 ppm, considered anoxic, can be detrimental to all organisms, including fish kills. Anoxic conditions can also cause a release of phosphorus from sediments, which can lead to algal blooms (Stanicoff 1996).

In dimictic lakes like Threemile Pond, the dissolved oxygen and temperature profiles vary dramatically throughout the year due to stratification and turnover. During the summer, surface water is heated, creating distinct layers of warm, less dense water on the top and cooler, more dense water on the bottom. Light penetrates the upper layer, the epilimnion, which contains most of the photosynthetic producers, enriching it with oxygen. Organisms that die sink to the bottom of the water column and are decomposed by bacteria in the lower layers, the hypolimnion, resulting in depleted oxygen levels (Harper 1992). Since the water column stratifies into layers of different temperatures with different densities, mixing is restricted. Oxygen depleted near the bottom of the lakes cannot be replaced until autumn

when the temperature in the upper layer drops again and the wind increase (see Background: Lake Characteristics: Annual Lake Cycles). At this time, the lake destratifies and turnover occurs (Lampert and Sommer 1997).

Methods

On 15-Aug-03 the Colby Environmental Assessment Team (CEAT) took dissolved oxygen (DO) and temperature measurements at Sites 1, 2, and 3. On 11-Sep-03 CEAT took DO and temperature measurements at Sites 1 and 3. Measurements were taken using an YSI Dissolved Oxygen meter at one-meter intervals from the surface to within one meter of the bottom. Dissolved oxygen was measured in parts per million (ppm) and temperature was measured in degrees Celsius (°C). Refer to the water quality assurance plan (see Appendix B) for all water chemistry procedural details. Past data were obtained from the Maine Department of Environmental Protection (MDEP 2003c).

Results and Discussion

Dissolved oxygen concentrations for surface to bottom profiles at Sites 1, 2, and 3 on 15-Aug-03 ranged from 9.5 ppm to 0.2 ppm and at Sites 1 and 3 on 11-Sep-03 ranged from 0.0 ppm to 8.9 ppm. Due to a faulty DO and temperature meter, Site 2 was not sampled; Site 3 was not deep enough to show any stratification. The dissolved oxygen profiles for 15-Aug-03 and 11-Sep-03 for Site 1 show stratification (Figure 10). The profiles are similar except the 15-Aug-03 profile dissolved oxygen drops below 1 ppm (anoxic) at 7.0 m, while the 11-Sep-03 profile becomes anoxic at 9.0 m. This suggests that on 11-Sep-03 some mixing of surface waters with the hypolimnion had already occurred, and oxygen had begun to be distributed throughout the water column.

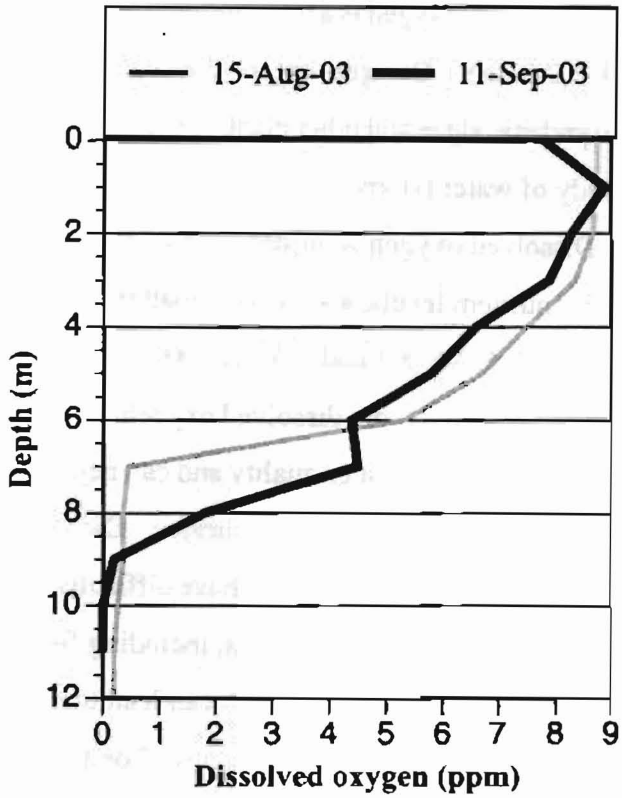


Figure 10. Dissolved oxygen (ppm) profile for Threemile Pond at Site 1 for 15-Aug-03 and 11-Sep-03. Data collected by Colby Environmental Assessment Team. See Threemile Pond sample site map for sample locations (Figure 9).

The historical profiles from the MDEP for Site 1 are all clearly stratified as well (Figure 11). On 15-Aug-03 CEAT depths greater than 7 m (the bottom 5 m) were found to be anoxic, while on 11-Sep-03 CEAT depths greater than 9 m were found to be anoxic (the bottom 2 m). The 15-Aug-03 data gives Threemile Pond a total volume of anoxic water of 634,877 m^3 (Figure 12). Although the volume of anoxic water is low, low oxygen levels are present throughout the summer months, and phosphorus is still released from the bottom, contributing to late summer algal blooms (Harper 1992). With 46.32% of the surface area of the lake above anoxic water, phosphorus is released from the sediment for 667,090 m^2 of the total 1,440,176 m^2 of Threemile Pond every summer. Although stratification did cause oxygen depletion throughout the summer for all dates, the volume of anoxic water does not appear to be increasing each summer.

Temperatures for Site 1 on 15-Aug-03 ranged from 25.9 degrees Celsius (°C) in the epilimnion to 15.5 °C in the hypolimnion and ranged from 23.4 °C in the epilimnion to 14.6 °C in the hypolimnion on 11-Sep-03. Both the profiles were stratified and show thermoclines. However, the 15-Aug-03 profile had a more rapid drop in temperature earlier (at 7.0 m) than the 11-Sep-03 profile, which exhibits more gradual temperature drops until 9.0 m, again possibly indicating that the lake was beginning to experience turnover when the 11-Sep-03 sampling took place (Figure 13). The temperature profile for Site 1 on 11-Sep-03 decreases more gradually than its corresponding dissolved oxygen profile.

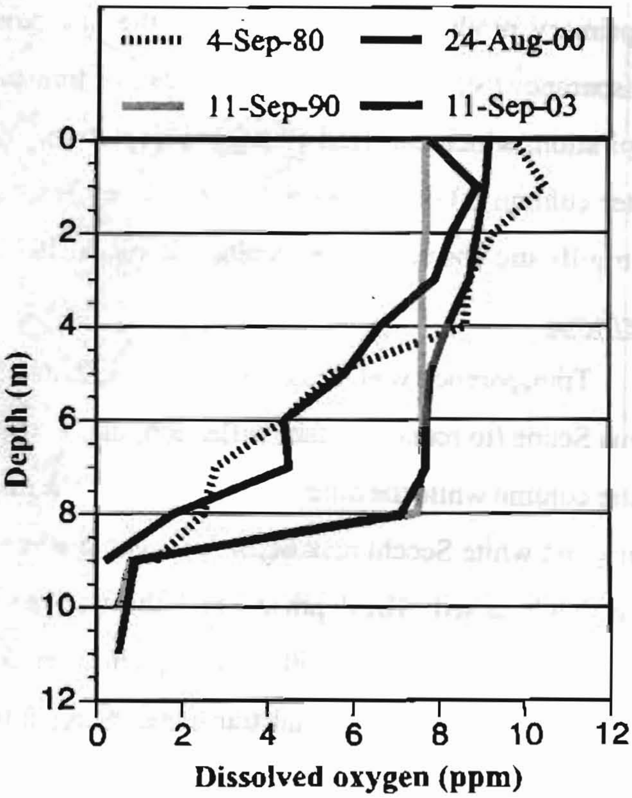


Figure 11. Dissolved oxygen (ppm) for Threemile Pond at Site 1 versus depth (m) for selected dates from 1980 to 2003. Data collected for 1980, 1990, and 2000 from Maine Department of Environmental Protection (MDEP 2003). Data from 11-Sep-03 collected by the Colby Environmental Assessment Team. See Threemile Pond sampling site map for sample locations (Figure 9).

Transparency

Introduction

Transparency is a measurement of the suspended particulate matter such as eroded soil, bottom sediment, and microscopic organisms in the water column (Stanicoff 1996, Wetzel and Likens 2000). Transparency measurements are a simple way to evaluate the water quality and trophic state of a lake. Transparency is influenced by primary productivity, which is determined by the amount of algal biomass in the water (Harper 1992). Transparency levels fluctuate seasonally due to spring runoff and resulting erosion and late summer algal blooms. Levels also fluctuate daily due to weather patterns. High levels of primary productivity, especially in the late summer during an algal bloom, lead to decreased transparency (Stanicoff 1996). Low levels of transparency can limit photosynthesis rates and increase respiration, which can lead to oxygen depletion. Higher concentrations of particulate matter in the water column often follows a decrease in transparency, and can negatively impact fish by clogging their gills and obscuring their vision (Stanicoff 1996).

Methods

Transparency was measured at Sites 1, 2, and 3 on 15-Aug-03 and 11-Sep-03 by CEAT using an Aqua Scope (to reduce surface reflection) and Secchi disk. One team member lowered the disk in the water column while the other member viewed the disk through the Aqua Scope. The depth at which the black and white Secchi disk became invisible was recorded, the disk was lowered another meter, and then slowly raised. The depth at which the black and white disk was again visible was recorded. Refer to Water Quality Assurance Plan (see Appendix B) for procedural details. These two depth values were averaged to produce the final transparency reading in meters. Historical data were obtained from MDEP (MDEP 2003c).

Results and Discussion

The mean transparency (n=3) for Threemile Pond collected by CEAT at Sites 1, 2, and 3 on 15-Aug-03 and 11-Sep-03 were 0.7 m and 2.9 m, respectively (Table 4). The readings on 15-Aug-03 ranged from 0.6 m to 0.8 m and on 11-Sep-03 ranged from 2.5 m to 3.3 m in depth. Historical data from MDEP shows that transparency has fluctuated dramatically since 1977 (0.6 m to 4.0 m) (Figure 14). In 1981, Threemile Pond was treated with copper sulfate to kill algae (Bouchard pers. comm.), which may explain the increase in transparency from 1981 to 1983 (0.6 m to 2.5 m). However, the treatment did not last long, and transparency levels plummeted to less than 1.0 m clarity in 1985. In 1988, Threemile Pond was given an alum treatment to improve the water quality for brown trout and rainbow

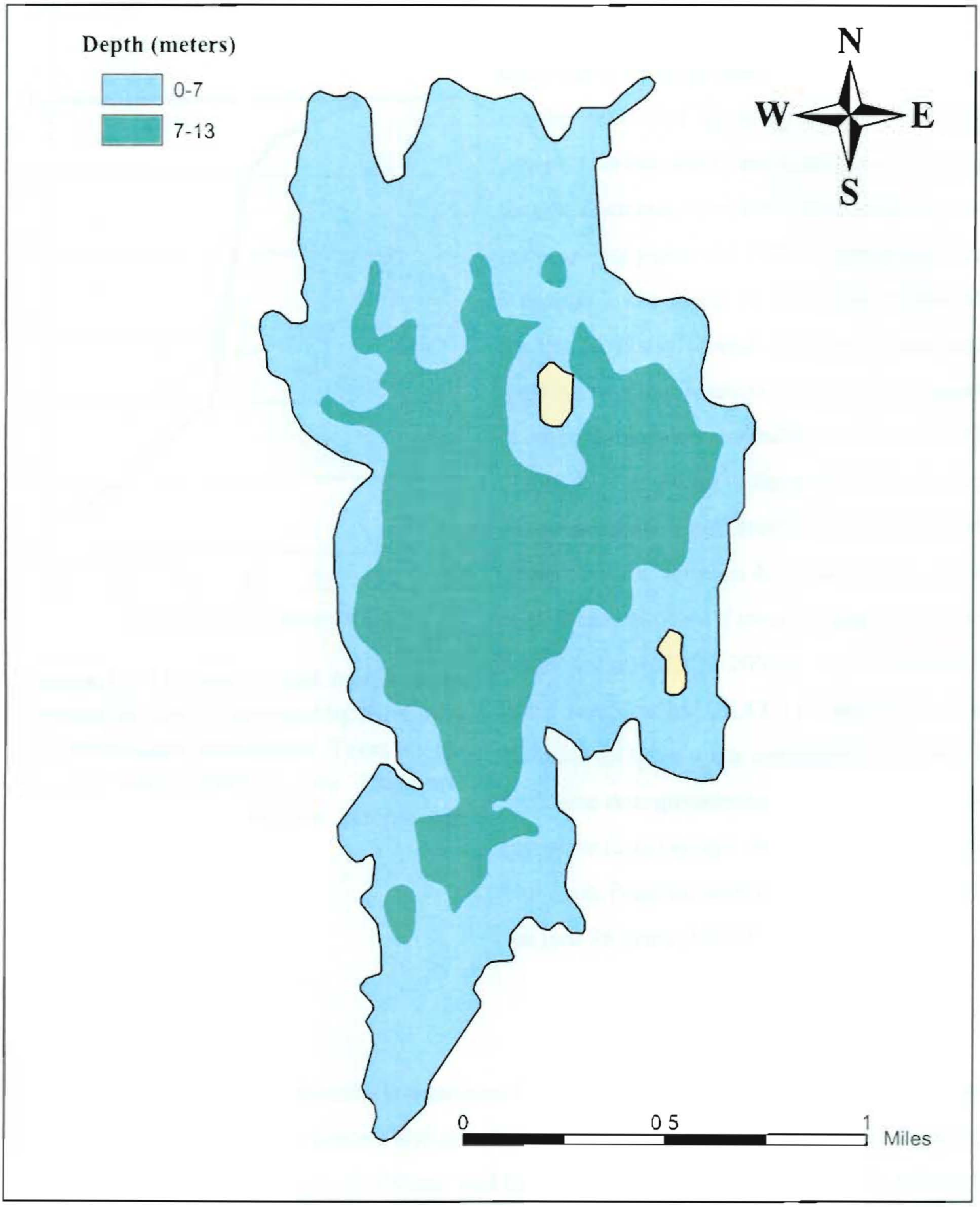


Figure 12. Anoxic areas of Threemile Pond. Green areas show depths greater than 7 meters, where water typcially becomes anoxic during summer stratification (see Water Quality Methodology: Dissolved Oxygen and Temperature Measurements).

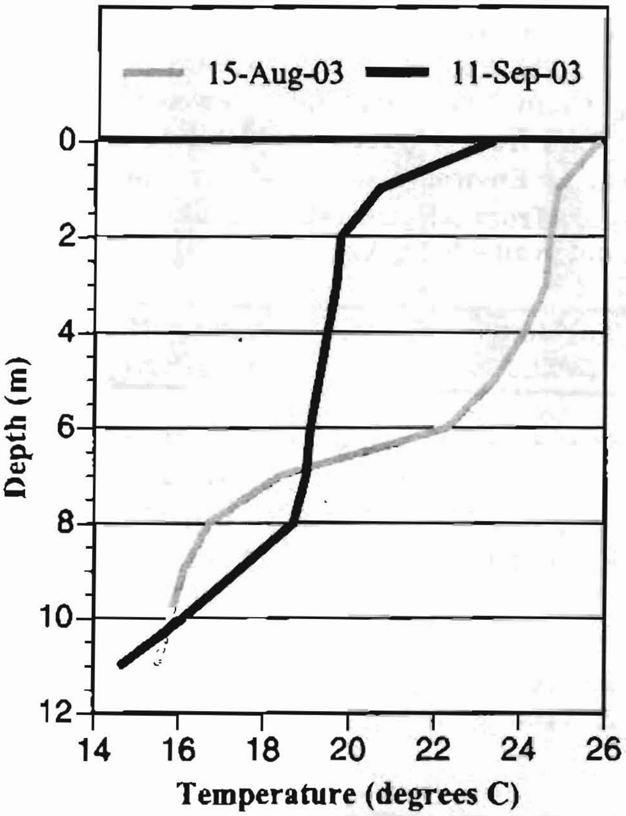


Figure 13. Threemile Pond temperature profiles for Site 1 recorded by the Colby Environmental Assessment Team on 15-Aug-03 and 11-Sep-03. See Threemile Pond sample site map for sample site locations (Figure 9).

smelt fishing (Bouchard pers. comm.). The transparency increased to 4.0 m in 1989, most likely due to the alum treatment. Other fluctuations can be explained by weather differences and proximity to the most recent algal bloom. Although the data fluctuates, there is a slight decreasing trend in transparency since the 1970 s, perhaps indicating a decline in the health of Threemile Ponds over the last 26 years. Overall, Threemile Pond has a slightly lower than average transparency compared to other Maine lakes studied by CEAT and MDEP (Table 4). According to the productivity indices, Maine lakes are considered mesotrophic if mean transparency is between 4.0 m and 7.0 m and are considered eutrophic if mean transparency is at or below 4.0 m (MDEP 2003a). All of the Maine lakes sampled by CEAT and MDEP that are recorded in Table 4 are considered eutrophic by the Maine state government's productivity indices, except for Lake George. According to MDEP data, Threemile Pond has been considered eutrophic for the past 26 years (MDEP 2003c).

Turbidity

Introduction

Turbidity measures the suspended inorganic and organic particulate matter in the water column. The suspended particulate matter scatters and absorbs light, rather than transmitting it, and negatively influences rates of primary productivity (Wetzel and Likens 2000). Turbidity is also highly influenced by daily weather patterns, and can vary dramatically due to strong winds and rainstorms, which can disturb bottom sediments and facilitate erosion into the lake.

Table 4. Comparison of mean (±SE) physical characteristics of selected Maine lakes. Data for Threemile Pond collected by Colby Environmental Assessment Team on 11-Sep-03. Other data collected by Colby Environmental Assessment Team from 1994, 1997, 2000, 2001, 2002. Data from Threecorner Pond and China Lake collected by Maine Department of Environmental Protection in 2001 (MDEP 2003). Transparency readings are from selected fall dates due to selected sampling. Some turbidity data were not available (N/A).

	Transparency (m)	Turbidity (NTU)	Color (SPU)	Conductivity (µMHOs/cm)
China Region Lakes				
China Lake	1.5±0.1	N/A	35.3±4.8	84.7±0.3
Threemile Pond	2.9±0.4	1.62±0.81	14.2±8.5	48.2±5.8
Threecornered Pond	3.4±0.1	N/A	32.8±7.9	62.5±0.7
Webber Pond[1]	1.3±0.1	5.89±2.70	18.5±3.6	39.3±1.0
Belgrade Region Lakes				
East Pond[2]	3.3	N/A	16.9	27.5
North Pond[3]	3.8±0.3	2.79±0.28	17.0±2.0	27.3±1.9
Salmon Lake[4]	2.9±0.4	2.23±0.17	13.0±2.0	69.8±11.9
Skowhegan Region Lake				
Lake George[5]	5.8±0.4	0.63±0.10	23.0±3.0	25.6±0.2

[1] BI493 2003a, [2] BI493 2000, [3] BI493 1997, [4] BI493 1994, [5] BI493 2001a

Methods

Surface, mid-depth, and bottom turbidity were measured by CEAT on 15-Aug-03 and surface turbidity only was measured by CEAT on 11-Sep-03 in the field using a HACH™ 2100 Turbidimeter for Sites 1, 2, and 3, as well as Sites 4 through 8. Turbidity was measured in Nephelometric Turbidity Units (NTU). Refer to Water Quality Assurance Plan (see Appendix B) for all procedural details.

Results and Discussion

Surface turbidity readings ranged from 22.0 NTUs to 24.4 NTUs for 15-Aug-03 with a mean turbidity of 23.6 NTUs (n=3). The mid-depth and bottom turbidity readings on 15-Aug-03 ranged from 1.7 NTUs to 13.0 NTUs. Surface turbidity readings for 11-Sep-03 for Threemile Pond ranged from 1.0 NTUs to 3.5 NTUs with a mean turbidity of 1.6±0.8 NTUs (n=12). The higher turbidity readings on 15-Aug-03 than on 11-Sep-03 indicate that there are greater amounts of suspended particulate matter in the water column, most likely due to the algal bloom. On 11-Sep-03, Threemile Pond has a much lower surface turbidity than Webber Pond, into which Threemile Pond flows, and a lower average turbidity compared to other Maine lakes sampled by CEAT and MDEP (Table 4). Turbidity can range from 1 to 1000 NTUs, but is generally less than 50 NTUs for a natural body of water (Boyd 2000).

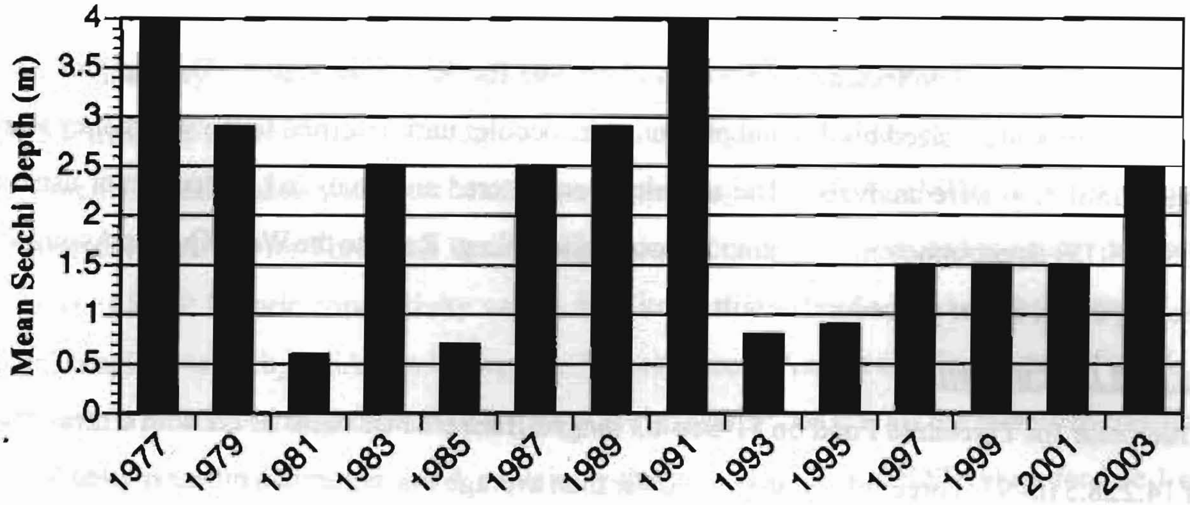


Figure 14. Historical Secchi disk transparency depths for dates in late August and early September reported by Maine Department of Environmental Protection for Threemile Pond Site 1 for selected years from 1977 to 2003 (MDEP 2003). 2003 data collected by the Colby Environmental Assessment Team. Copper sulfate treatment was administered in 1981 and alum treatment was administered in 1988. See Threemile Pond sampling site map for site location (Figure 9).

Low turbidity readings indicate that there is little sediment loading in the lake, but our turbidity readings on 11-Sep-03 could be uncharacteristically low due to clear weather prior to sampling. Due to the absence of rain, there would be few eroded particles in the water column and the bottom sediments would be undisturbed. CEAT sampling on 11-Sep-03 would have given the algae time to die off from the summer algal bloom, leaving the water relatively free of particles.

Color

Introduction

Color can be measured as apparent or true color. Apparent color results from the amount of light scattered by dissolved organic matter and suspended particulate matter (Wetzel and Linkens 2000). True color is measured by the amount of natural dissolved organic acids in the water column (MDEP 2002a). Light absorption of ultraviolet and violet wavelengths increases as the concentration of dissolved organics such as tannins and lignins increase (Wetzel and Linkens 2000). Color in a lake water sample is measured by comparing it to Standard Platinum Units (SPU). Colored lakes (greater than 30 SPUs) usually have lower transparency and higher phosphorus concentrations (MDEP 2002a).

Methods

Water samples were collected by CEAT on 11-Sep-03 for Sites 1 through 8. The samples were collected in appropriately sized bottles and put on ice in a cooler until returned to lab where they were refrigerated until they were analyzed. The samples were filtered and analyzed for true color using a HACH™ 3000 DR Spectrophotometer within 24 hours of sampling. Refer to the Water Quality Assurance Plan (see Appendix B) for procedural details.

Results and Discussion

True color for Threemile Pond on 11-Sep-03 ranged from 6 SPUs to 30 SPUs with a mean true color of 14.2±8.5 (n=9). Threemile Pond has a lower than average true color than other sampled Maine lakes and is considered uncolored (Table 4). Color, in general, ranges from 2 SPUs to 194 SPUs with an average for Maine lakes of 27 SPUs (MDEP 2002a). MDEP has little historical data on color for Threemile Pond, and so it is difficult to make any comparisons. In Sep-98, a color value of 20 SPUs for Site 1 was recorded. For Site 1 in Aug-01, a color value of 51 units was recorded. The color values collected by CEAT are much lower than either of these values. This difference could be due to an increase in development along the lakeshore, which would decrease the amount of tannins entering the watershed from forest floors. Seasonal differences in rates of decomposition could also account for these variable readings.

Conductivity

Introduction

Conductivity measures the ability of a body of water to carry an electrical current (MDEP 2002a). The strength of the electrical current through the water depends on the concentration and extent of dissociation of dissolved ions in the water column and is closely related to both true color and transparency (Wetzel and Likens 2000). Conductivity is also influenced by temperature (Lampert and Sommer 2000). Conductivity is measured in micrombs per centimeter (µMHOs/cm).

Methods

Samples were collected by CEAT on 11-Sep-03 for Sites 1 through 8. Samples were kept on ice in a cooler and returned to the lab where they were refrigerated until analyzed. Samples were analyzed within 24 hours using an YSI™ Model 31A Conductance Bridge. Refer to Water Quality Assurance Plan (see Appendix B) for procedural details.

Results and Discussion

Conductivity values from 11-Sep-03 ranged from 40 to 56 μMHOs/cm with a mean value of 48.2±5.8 μMHOs/cm for Sites 1 through 8 (n=9). Conductivity values can range from 10 to 888 μMHOs/cm in Maine lakes, with most Maine lakes in the range of 20 to 40 μMHOs/cm (MDEP 2002a). The mean conductivity for Threemile Pond is slightly above average compared to nearby Maine lakes (Table 4). MDEP historic conductivity values for Site 1 on Threemile Pond are consistently higher than the readings taken by CEAT on 11-Sep-03. Values taken in August and September of 1978, 1979, 1980, and 2001 for Site 1 range from 58 to 60 μMHOs/cm (MDEP 2003c). MDEP measured conductivity only in select years for Threemile Pond, explaining the gap in the data. CEAT values for Site 1 on 11-Sep-03 were 40 and 41 μMHOs/cm. Given the cited data, the conductivity appears to have decreased over the past 25 years. This could be due to increased development (see Watershed Land Use Patterns), as explained for color, variation in the weather patterns prior to and on the day of sampling, or different sampling methods.

Chemical Analyses

pH

Introduction

The pH is a measurement of the hydrogen ion concentration in water, or the level of dissociation of H^+ ions and OH^- ions in the water. Higher levels of pH indicate higher concentrations of H^+ ions. Because the pH scale is logarithmic, a pH decrease of 1 unit indicates an increase in acidity by a factor of ten. A reading of 7.0 indicates a neutral pH, readings of 7.1 to 14 are basic and 0.0 to 6.9 are acidic (Boyd 2000). The average range in pH for Maine lakes is 6.1 to 6.8 (Pearsall 1993). Changes in pH are caused by deposits from acidic rainwater from nitric or sulfuric acid rain, dissolved carbon dioxide reacting with water to create carbonic acid, acidic soil substrates such as iron sulfide, or organic acids produced by decomposition processes (Boyd 2000). Very low or high pH limits the diversity of species that can be sustained in a lake because it adversely affects the ability of organisms to homeoregulate.

Methods

The pH of the surface water was taken on-site for all 12 sites sampled by CEAT on 11-Sep-03. The pH was measured using standardized HORIBA Twin pH meters, calibrated before the measurement was taken (see Appendix B). The data from each site were later averaged to get the overall lake pH. Data from other lakes were gathered from past CEAT reports to compare values for Threemile Pond.

Results and Discussion

The mean (±SE) pH of Threemile Pond was found to be approximately neutral at 7.07± 0.33 (n=8) (Table 5). The readings for individual sites ranged from 6.55 to 7.75 (see Appendix C). The pH for Threemile Pond is within the range of the other lakes studied by CEAT, and does not constitute a problem for lake water quality. A possible explanation for the slightly more basic pH of Threemile Pond when compared to the average range is the high alkalinity levels found in the lake (see Alkalinity). High alkalinity increases the capacity of the lake to buffer against pH changes.

Hardness

Introduction

Hardness is a measurement of the total amount of magnesium (Mg^{2+}) and calcium (Ca^{2+}) cations in the water. Calcium and magnesium ions are deposited into the lake primarily through the dissolution of limestone, which is accelerated by the presence of carbon dioxide (Boyd 2000). Because of this, in many waters calcium and magnesium ions are proportional to carbonate and bicarbonate ions.

According to the United States Geological Survey, water ranging from 0-60 ppm $CaCO_3$ is considered soft, water from 61-120 parts per million (ppm) $CaCO_3$ is moderately soft, 121-180 ppm $CaCO_3$ is hard, and concentrations above 180 ppm $CaCO_3$ are considered very hard (USGS 2003). Because higher hardness levels can cause increased sedimentation of phosphorus by providing increased ions for bonding, hardness levels relate inversely to algal blooms, so that when hardness increases, algal blooms are less likely to occur (Pearsall 1993).

Water hardness is a regular concern for rural residents who obtain water from wells. Hard water creates difficulties in washing and bathing because the minerals precipitate in the presence of soaps and make it difficult to create a lather. Hard water is often mitigated in home water systems through the use of commercial water softeners, designed to take the minerals out of the water. In addition, hard water can cause mineral buildup in pipes and sewage systems.

Methods

Hardness was tested for Sites 1, 2, and 3 from samples collected on 11-Sep-03. The water sample was brought to a pH of less than 2 using concentrated nitric acid, and then the sample was placed immediately on ice until it could be stored in a refrigerator. The samples were tested within 28 days of sample collection using the HACH titration method (HACH 1997; see Appendix B).

Table 5. Comparison of mean (± SE) chemical characteristics of selected Maine lakes. Data for Threemile Pond collected by Colby Environmental Assessment Team on 11-Sep-03. Other data collected by Colby Environmental Assessment Team from 1994, 1997, 2000, 2001, 2002. Data from Threecorner Pond were collected by Maine Department of Environmental Protection in 2001.

Lakes	pH	Hardness (mg/L)	Nitrates (ppm)	Alkalinity (mg/L)
China Region				
Threemile Pond[1]	7.07±0.33	4.04±1.04	0.06±0.02	42.3±4.75
Threecorner Pond[2]	7.36±0.04	N/A	N/A	13.5
Webber Pond[3]	7.13±0.31	2.91±0.09	0.07±0.02	37.00±22.40
China Lake[4]	6.20	N/A	N/A	18.0
Belgrade Lakes				
Salmon Lake[5]	7.78±0.13	25.38±0.77	a	N/A
East Pond[6]	7.06	3.90	0.04	11.20±0.72
North Pond[7]	7.07±0.05	10.10±0.40	0.05±0.01	12.40±0.40
Lake George[8]	7.11±0.33	4.16±0.93	0.06±0.02	8.70±1.93

a = Below the limit of detection

[1] BI493 2003, [2] MDEP 2001, [3] BI493 2002, [4] MDEP 2002, [5] BI493 1994, [6] BI493 2000, [7] BI493 1997, [8] BI493 2001

Results and Discussion

The hardness reading for Threemile Pond was found to be extremely low at 4.04 mg/l, which is considered extremely soft water. Although it has the lowest hardness level of the lakes sampled in recent years by CEAT, it is still in the same range as the other nearby Maine lakes, all of which are quite soft (Table 5). The lack of calcium and magnesium in the lake may be a result of the substrate being low in limestone (see Watershed Land Use Patterns). This low hardness level is a possible contributing factor to the annual algal blooms in Threemile Pond, because low hardness causes low levels of phosphorus precipitation, which increases the amount of inorganic phosphorus available for algal growth.

Alkalinity

Introduction

Alkalinity is defined as an index of the total concentration of titratable bases (Boyd 2000). Alkalinity measures the level of calcium carbonate in the water and is an indicator of the ability of a lake to buffer against pH changes. A highly alkaline lake will usually have a pH close to neutral, or even slightly above neutral because of the high levels of bases in the water. The bases most typically found in freshwater lakes are carbonate and bicarbonate (Boyd 2000). A lake greatly decreases its ability to buffer against pH changes when its alkalinity levels drop below 24 ppm (Chapman 1996). Maine lakes generally have alkalinity within the range of 4 to 20 ppm (Pearsall 1993). When a lake loses this ability to buffer against pH changes, small amounts of acid deposition, such as from an acid rain event, can cause major changes in the pH.

Methods

Alkalinity was tested from surface water samples taken from Sites 1, 2, and 3. The samples were taken on 11-Sep-03 and were placed on ice until they were returned to the laboratory and refrigerated. The analysis took place within eight hours of collection time. Samples were titrated with 0.02 N sulfuric acid and $CaCO_3$ equivalents readings were taken in parts per million (ppm) (see Appendix B).

Results and Discussion

The mean (± SE) alkalinity of Threemile Pond was found to be 42.3 ± 4.7 mg/l (n= 3) (Table 5). This value is higher than for the other lakes sampled recently by CEAT except Webber Pond. There are high levels of basic free ions in Threemile Pond, which result in a strong ability to buffer against changes in pH.

If acid rain or acid water deposition were a problem in Maine lakes, as it is in other areas of the Northeast such as the Adirondack region of New York, the high alkalinity levels of these Maine lakes would be beneficial to the lake. The high alkalinity would allow the lake to remain buffered when faced with increasingly acidic water inputs. While this buffering capacity does explain the slightly basic water pH of 7.07, acid deposition is not the major water quality issue for these Maine Lakes.

Nitrates

Introduction

Along with phosphorus, nitrates are the primary limiting nutrient necessary for algal blooms and eutrophication of lakes (Chapman 1996), nitrogen is highly important in plant production. It is an

essential component of DNA, enzymes, proteins, amino acids and lipids, as well as having other structural functions in plant cells. However, because the levels of nitrogen in Maine lakes are usually sufficient for high levels of primary production, nitrogen, unlike phosphorus, is not normally the limiting nutrient for algal blooms. The deposition of nitrogen into these lakes in the absence of phosphorus deposition will not directly cause eutrophication.

Although nitrogen is 78 percent of the atmosphere by volume it is not readily available to plants in atmospheric form (N_2) (Boyd 2000). It must first be fixed by either bacteria in soil or cyanobacteria in water through one of a series of nitrogen-fixing processes that convert atmospheric nitrogen into nitrites, nitrates, and ammonia. Nitrogen is found only in trace amounts within mineral deposits. The majority of nitrogen is found stored in organic matter, biomass, and in atmospheric forms. In lakes, nitrogen is found mostly in the form of nitrates, as nitrites are the ephemeral form of nitrogen (Boyd 2000). Ammonia is the second most abundant form of nitrogen found in lakes, primarily caused by the bacterial decomposition of dead organic matter. When ammonia is not in ionized form (NH_3), it is toxic to fish and aquatic animals (Boyd 2000).

Primary sources for nitrates in the water column include homes, sewage, logging operations, industry, and agricultural runoff from fertilizers. Concentrations above 0.2 mg/l $N0_3$-N (the unit for nitrates in a lake) usually stimulate algal growth in the presence of sufficient levels of phosphorus, whereas concentrations of 5.0 $N0_3$-N or more indicate direct contamination by human or agricultural wastes (Chapman 1996).

Methods

CEAT measured the combined nitrate and nitrite levels for all lake sites from epicore samples and tributary sites from surface samples taken on 11-Sep-03. The epicore samples were used so that a general idea of the water column could be obtained. The samples were brought to a pH of less than 2 with concentrated sulfuric acid and placed on ice until they could be refrigerated. The samples were analyzed within 24 hours. The HACH DR /4000 spectrophotometer was used following the HACH (1997) methods to determine total levels of combined nitrates and nitrites for Threemile Pond.

Results and Discussion

The mean (±SE) combined nitrate/nitrite levels for Threemile Pond were found to be 0.057±0.020 ppm (n=8). This mean is higher than several of the other Maine Lakes sampled in past years, but is still lower than the 0.2 mg/l that stimulates major algal growth. Because the nitrate/nitrite levels of Threemile Pond and other nearby lakes do not differ greatly, there appears to be similar levels of nitrogen loading

in all of the lakes sampled in recent years. The levels of nitrogen, though not problematic, are still sufficiently high to help promote algal growth in the presence of sufficient phosphorus.

Potential sources of nitrogen might include the small farms within the watershed. Furthermore, the lake might be historically loaded with nitrogen due to the high levels of farming present within the watershed fifty years ago (see Watershed Land Use Patterns). Sources such as the chicken farms and agricultural sites present in 1956 could have caused an accumulation of nitrogen in the lake.

Total Phosphorus

Introduction

Total phosphorus is the most important test for assessing the trophic state of a lake, because it is the limiting nutrient for algal growth in freshwater systems (see Background: Lake Characteristics). Phosphorus is easily deposited into lakes from surfaces within the watershed because it remains on soil layer surfaces rather than leaching into deeper soil layers (Pearsall 1993). When there are sufficient levels of phosphorus in a lake, algae are able to grow at an increased rate. This condition creates algal blooms, which turn the lake green and render it unusable for recreation and inhospitable for many plants, fish, and aquatic wildlife (see Background: Lake Characteristics).

Normally there is not sufficient phosphorus in a healthy lake to cause algal blooms. Lakes above 13 ppb are considered productive, lakes between 6 and 13 ppb are moderately productive, and lakes below 6 ppb total phosphorus are considered unproductive (Pearsall 1993). Blooms caused by phosphorus deposition are nearly always due to human activities (Pearsall 1993). Even small amounts of phosphorus deposition can be a major problem in lakes. The critical limit for seasonal average levels of phosphorus in lakes is 15 parts per billion (ppb), above which algal blooms will occur with frequency.

Phosphorus is found in lakes in both the organic and inorganic form. Organic phosphorus is the form that is found in highest amounts suspended within the water column (Firmage pers. comm.). Inorganic phosphorus bonds with other molecules and precipitates to the bottom of the lake if not incorporated in plant or animal tissue, rendering it unusable to plants and algae. Total phosphorus includes both organic and inorganic forms of phosphorus collectively, and is the measurement most often used when referring to the phosphorus levels in a lake, since turnover of both forms in the water column can quickly occur.

Some phosphorus deposition in lakes is natural. Nutrients are deposited in the lake from dead leaves and other plant matter along the lakeshore that fall or are washed by rain into the lake. Stream

inlets carry phosphorus into the lake as they flow over dissolving rocks and minerals, and carry with them dead organic matter and suspended sediments (Williams 1997). It is the accelerated loading of phosphorus caused by human activity and development that results in algal blooms (Pearsall 1993).

The main source of phosphorus loading in lakes is surface runoff. When rainwater touches a surface and runs off, it carries with it small amounts of phosphorus found on these surfaces. Any surface that rainwater touches, including roofs, roads, fields, rocks, trees, gravel, and dirt contains trace amounts of phosphorus (Williams 1997). Runoff is more likely to occur on harder surfaces such as roofs, roads, and hard packed dirt and gravel, than it is to occur on soft surfaces such as meadows and forest duff. Heavily vegetated areas will hold water and allow it to soak up more than non-vegetated areas. Mature forest is the best impediment to phosphorus runoff because it is best able to hold water in the ground. It does this by holding together soil surfaces, soaking up water in root systems, and stopping the force of raindrops with leaf cover (Williams 1997).

Methods

Samples were collected by CEAT for all 12 sites on 11-Sep-03. Samples were collected by CEAT for sites 1, 2, and 3 on 15-Aug-03 as well. For Sites 1, 2, and 3, samples were taken from the surface, mid-depth, bottom, and the epicore. For all other sites, only surface samples were taken. For every tenth sample a split or duplicate was made to ensure quality testing. Splits are single samples divided into two samples in the laboratory. Duplicates are two separate samples of the same site and depth taken in the field (see Appendix B). Phosphorus was tested using methods outlined by Eaton et al. (1995) with modifications from G. Hunt and C. Elvin.

Samples were taken in triple acid rinsed 125 ml PMP flasks and were placed on ice until they could be stored in a 4 degrees C refrigerator. The samples were digested in a 15 lbs per square inch autoclave at 120 degrees C for 30 minutes after being injected with 1 ml of 1.75 N ammonium peroxysulfate, and 1.0 ml of 11 N sulfuric acid. The purpose of the digestion process was to convert all of the phosphorus into inorganic form. Standards of 0 ppb to 80 ppb were made to calibrate the spectrophotometer and create a linear equation of absorbance. The samples were brought to a pH of 6 using 11 N sodium hydroxide and 5 N sulfuric acid. Samples were then treated with a combined reagent of 5 N sulfuric acid, potassium antimonyl tartrate, ammonium molybdate, and absorbic acid. After reacting for 10 minutes, the samples were read on the Milton Roy Thermospectronic Aquamate Spectrophotometer using the programmed spectrophotometric method from HACH (1997).

Results and Discussion

Characterization Site History

From the historical data for Site 1 on Threemile Pond (Figure 15) a slight upward trend of total phosphorus levels is apparent. The phosphorus levels are generally above 20 ppb. The mid-September levels are higher than the mid-August levels for all of the years except 1993 and for the two years in which September levels were not taken. A probable cause for this is the overturning of the lake as the temperatures cool down in the fall (see Background: Lake Characteristics). During the late summer,

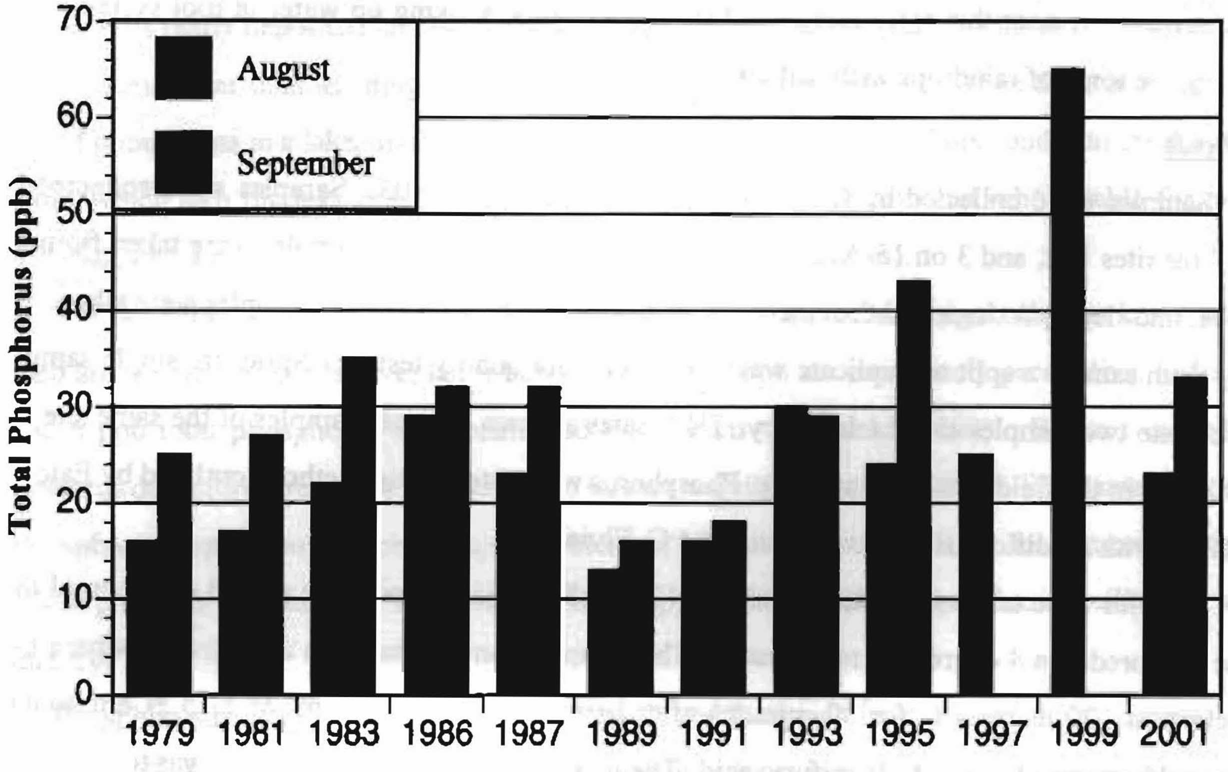


Figure 15. Historical total phosphorus for Threemile Pond from Maine Department of Environmental Protection (2002). Samples taken at a depth of 5 m in August and September.

when the lake is highly stratified, the phosphorus deposits sink to the bottom of the lake, and those already present stay in the organic matter of the lake bottom. When the lake water starts to turn over due to the onset of temperature changes and the increased winds of September, phosphorus from the bottom of the lake is brought to the epilimnion.

While the trend of overall phosphorus levels may be only slightly rising, what is of particular note is the trend in increased phosphorus spikes. Sudden extreme increases in phosphorus levels will trigger algal blooms more than the overall phosphorus levels (Chapman 1996). The phosphorus spikes shown for the 1990s, especially in 1999, (Figure 15) are a major cause of algal blooms.

Characterization Site- Summer

The overall mean total phosphorus level for Threemile Pond taken from Sites 1, 2, and 3 on 15-Aug-03 was 30 ppb (Figure 16). The surface readings were higher than those taken from the bottom, and two out of three of the surface readings were higher than the mid-depth reading. All three sites had similar readings, ranging around 30 ppb. The sites exceed the critical limit of 15 ppb by two times, which helps explain the annual algae bloom found during this time of year. At the time when this reading was taken, the lake had a general pale green color and Secchi disk readings were very poor, less than 0.5 meters.

The overall mean total phosphorus level for Threemile Pond on 11-Sep-03 was 30 ppb. Of the Maine lakes displayed in Figure 17, only Webber Pond had levels of phosphorus higher than Threemile Pond. The phosphorus levels found for Threemile Pond are well comparable to local lakes, such as China Lake and Webber Pond, but are well above those of many nearby lakes. Webber Pond and Threemile Pond are directly linked because the major outlet from Threemile Pond flows directly into Webber Pond, which may explain why Webber has such high levels of phosphorus. Webber Pond must withstand the effects of a high phosphorus input from the Threemile Pond tributary, as well as all of the inputs from its own watershed. By the middle of September the weather is usually cold enough to inhibit algae growth, which helps explain why the lake was not as green on 11-Sep-03 than on 15-Aug-03 (Figure 18b).

Characterization Site-Fall

The epicore phosphorus values for Sites 1 and 2 were the highest of all of the measurements taken, at 42 ppb and 38 ppb respectively (Figure 18). The epicore values here were higher than any of

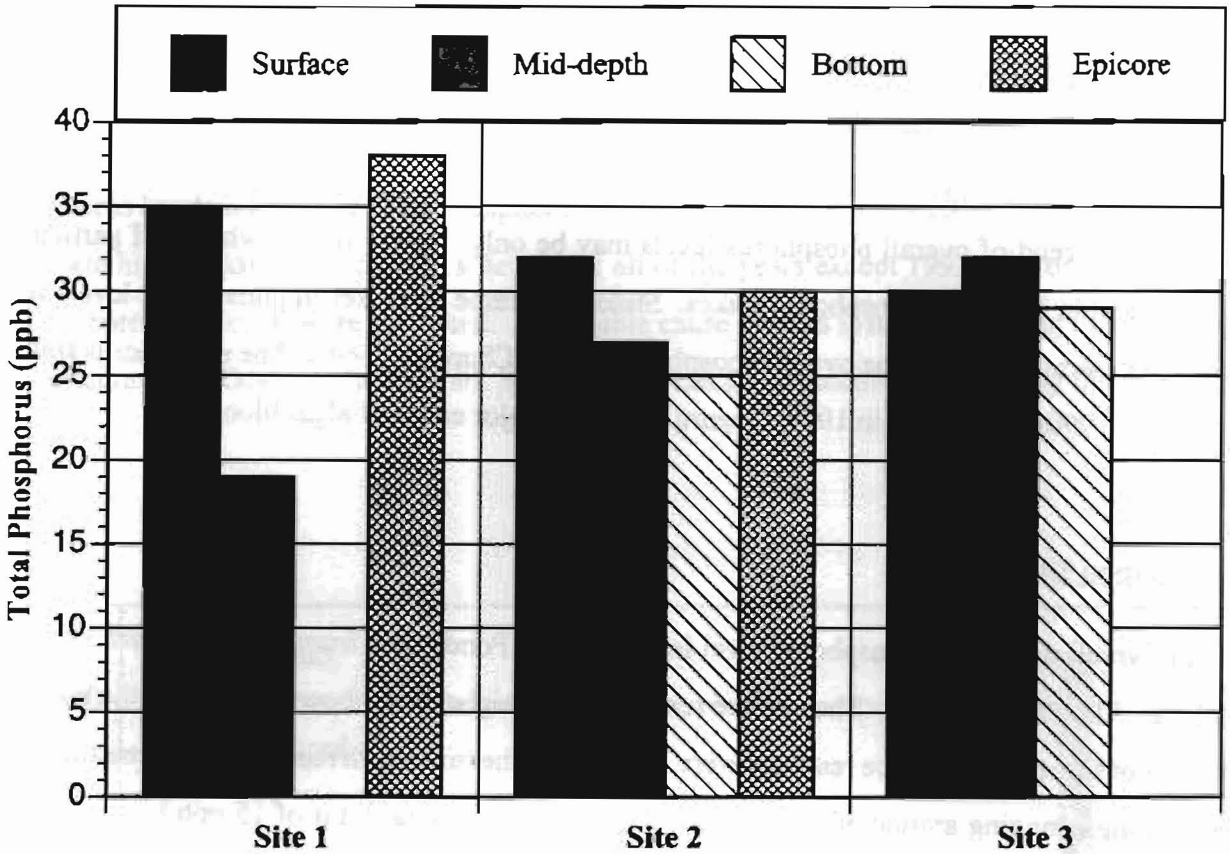


Figure 16. Total phosphorus levels for surface, mid-depth, bottom, and epicore readings for Threemile Pond Characterization Sites 1, 2, and 3 collected by Colby Environmental Assessment Team on 15-Aug-03. Total phosphorus values for the bottom from Site 1 and Site 3 were not available.

the readings for the other sites, which may be the result of water stirred up at the bottom of the lake by the epicore sampling. The levels of phosphorus measured throughout the lake do fluctuate greatly, showing that the lake is not uniform in nutrient levels and that sources along the shore may greatly influence local phosphorus levels. Runoff from the lawn of an unbuffered house or agriculture will cause temporary spikes in phosphorus levels in the area of the lake into which the water is running. This phosphorus will eventually disperse and increase phosphorus levels in the lake as a whole.

Biotic Measurements

Fecal Coliform

Introduction

Coliform bacteria are found in the fecal excrement of both humans and many mammals, including farm animals. These bacteria can be found directly in both sewage and manure in fields, and indirectly

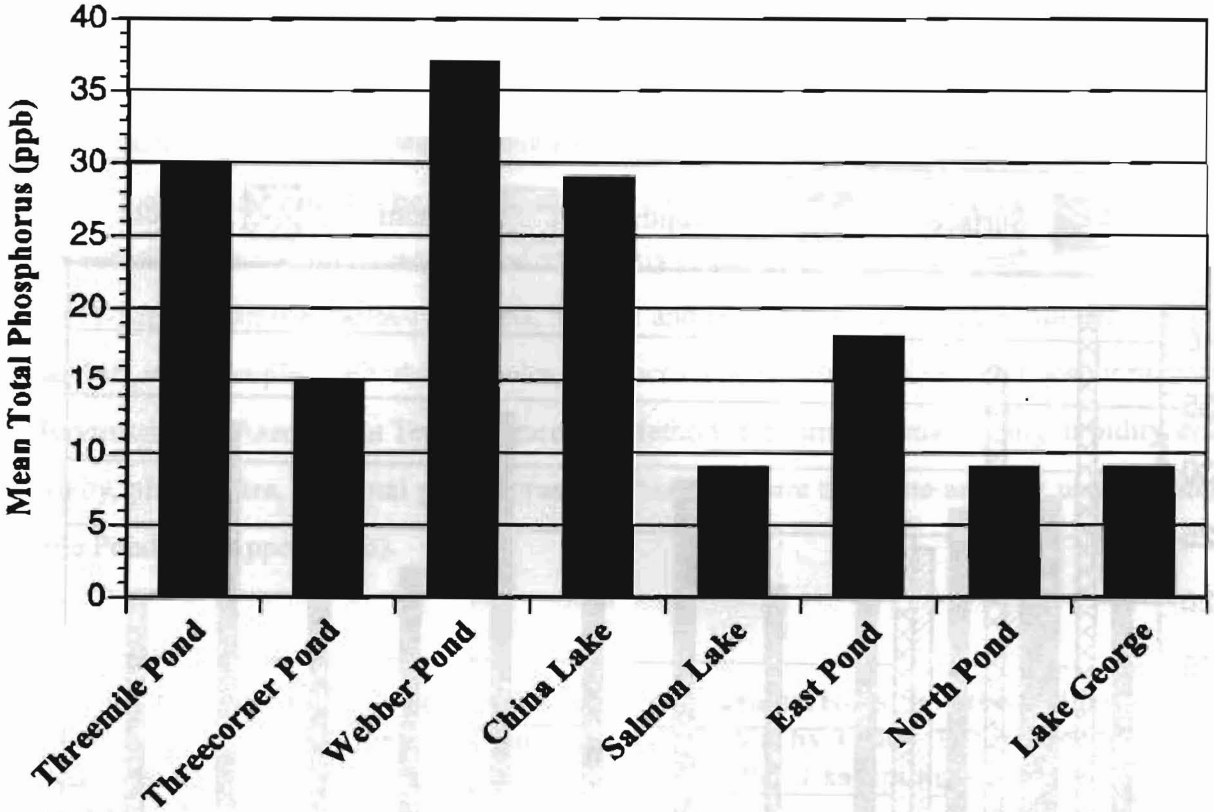


Figure 17. Mean total phosphorus (ppb) for several Maine lakes taken from past years of Colby Environmental Assessment Team data for Salmon Lake (BI 493 1995), North Pond (BI 493 1998), East Pond (BI 493 2001), Lake George (BI 493 2002), and Webber Pond (BI 493 2003), and from Maine DEP data for China Lake and Threecorner Pond (MDEP 2003).

in places contaminated by manure or sewage. Lakes can become contaminated with fecal coliform bacteria through leaky septic systems and outhouses, agricultural runoff, and defecation by humans, pets, livestock, and wild animals into or near the lake. Fecal coliform contamination can be hazardous to human health, particularly in water to be used for drinking. Ingestion of fecal coliform bacteria can lead to serious illness or death. Theoretically, no fecal coliform should be permitted in drinking water, but public health regulations often allow up 10 total coliform colonies/100 ml as long as there are no fecal coliforms present (Boyd 2000).

Methods

Total coliform kits were obtained from Northeast Laboratory Services in Winslow, Maine before the sample date. On 11-Sep-03, surface water samples were taken from Site 1 to obtain a characterization site reading and from Site 5 because of its proximity to an old campground. The latter site was tested

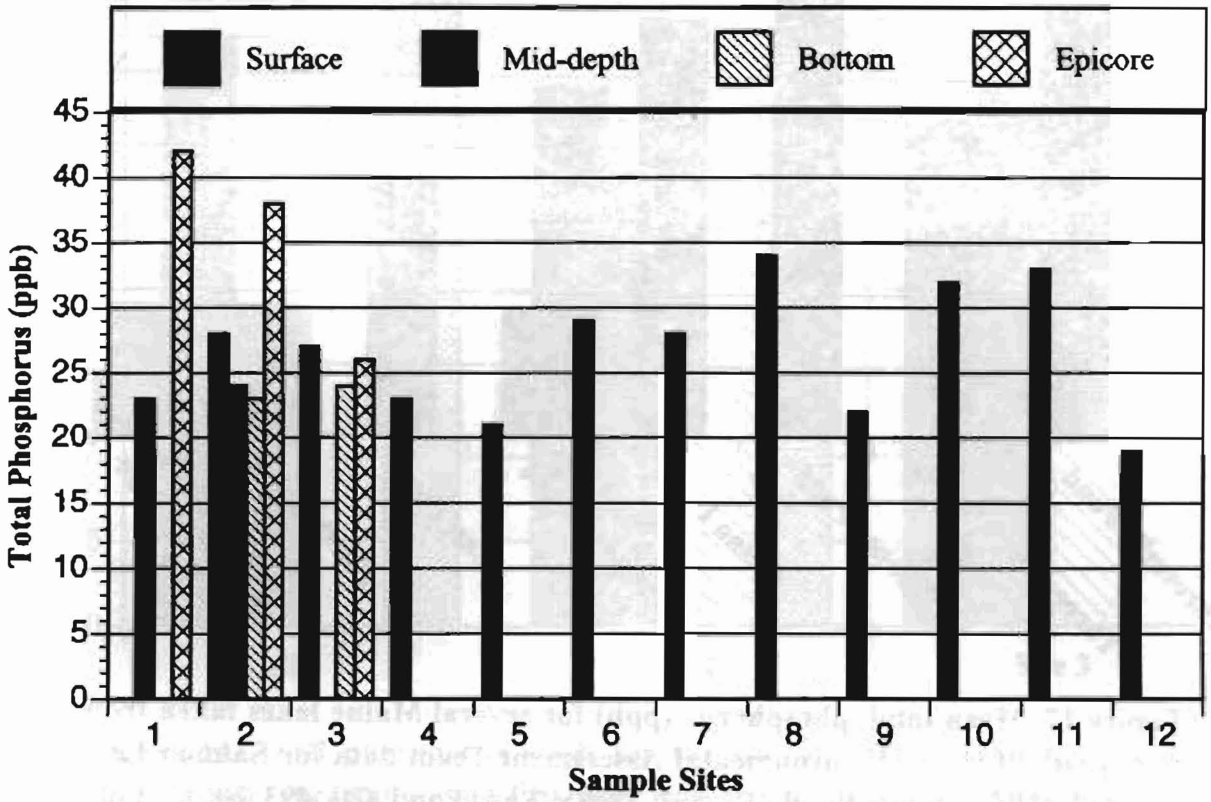


Figure 18. Total phosphorus in ppb for all sites on Threemile Pond on 11-Sep-03 collected by Colby Environmental Assessment Team. Total phosphorus values for the surface and bottom from Site 1 and for the mid-depth from Site 3 were not available.

to determine whether there was any contamination from the campground, or from pets or children defecating near the water. The samples were returned to Northeast Laboratory Services for analysis.

Results and Discussion

The Site 1 sample contained 3 Coliform Forming Units/100 ml water, and the Site 5 sample contained 12 CFU s/100 ml water. The site close to the campground did have higher total coliform levels, indicating that a small amount of leakage may have occurred. Although this water would be unsuitable for drinking directly without treatment, neither reading is considered dangerously high for recreational use of the water.

Tributary Water Quality

Tributary water quality is also important to the quality of a watershed because tributaries transport nutrients into and out of the lake. Assessing tributary water quality can help interpret sources of pollution and nutrient loading and can also be used to assess the amount of nutrients that are leaving the lake. Tributary contributions are often seasonal and are greatly affected by rainwater runoff and spring melts.

On 11-Sep-03 four tributaries-two inlets, Sites 11 and 12, and one outlet sampled at two locations, Sites 9 and 10, were sampled for turbidity, color, conductivity, pH, nitrates, and total phosphorus by the Colby Environmental Assessment Team (Figure 9). Methods for sampling and testing turbidity, color, conductivity, pH, nitrates, and total phosphorus in tributaries were the same as those used to sample Threemile Pond (see Appendix B).

Table 6. Selected physical and chemical characteristics for the primary tributaries around Threemile Pond. Data collected by Colby Environmental Assessment Team on 11-Sep-03. See Threemile Pond sampling site map for locations (Figure 9).

	Physical			Chemical	
	Turbidity (NTU)	**Color (SPU)**	**Conductivity (µMHOs/cm)**	**pH**	**Nitrates (ppm)**
Site 9-Seward Mills Brook- Webber Pond Inlet	1.48	10	59	7.09	0.24
Site 10-Seward Mills Brook- Outlet to Webber Pond	1.30	8	58	6.89	0.19
Site 11-Inlet	7.36	51	122	6.79	0.10
Site 12-Barton Brook Inlet	3.53	29	61	6.70	0.05

Physical Measurements

Turbidity

Results and Discussion

Surface turbidity readings on 11-Sep-03 for the two inlets, Site 11 and 12 were 7.36 NTUs and 3.53 NTUs, respectively (Table 6). Site 11, an unnamed inlet, had much higher turbidity reading than

Site 12. The Site 11 tributary runs nearer to a developed area than the other tributary and could have greater turbidity due to a larger amount of runoff from lawns and human activity. Site 12, Barton Brook inlet, had a greater turbidity than the mean turbidity for Threemile Pond, indicating that Barton Brook could be a source of sediment for the lake.

Surface turbidity readings for Seward Mills Brook, the outlet from Threemile Pond to Webber Pond, were taken at two locations, Site 10, at the outlet next to Threemile Pond, and Site 9 at the outlet next to Webber Pond. Site 10 had a turbidity reading of 1.30 NTUs and Site 9 had a surface turbidity of 1.48 NTUs. These values are lower than the mean turbidity reading for Threemile Pond (1.62±0.81 NTUs) and indicates that Threemile Pond is not a source of particulate matter for Webber Pond. However, the contributions of tributaries to lakes vary dramatically by season due to spring runoff, storms, and other weather patterns and CEAT values from one day of sampling are not necessarily indicative of tributary impact throughout the year.

Color

Results and Discussion

True color readings for Sites 11 and 12 on 11-Sep-03 were 51 SPUs and 29 SPUs, respectively. The high color readings for Site 11 and Site 12 are most likely due to the higher concentration of tannins and lignins in detritus that is decomposing in these tributaries. Site 12 comes through a marsh before entering Threemile Pond, which would contribute to increased tannins and lignins. Site 11, however, flows through a residential area. The higher color reading for Site 11 could be due to runoff from lawns and residences. The higher color readings correspond to higher turbidity readings. Sites 11 and 12 could also be sources of dissolved organics for Threemile Pond.

Color values for Sites 10 and 9 at Seward Mills Brook are 8 SPUs and 10 SPUS, respectively, and are much less than those for the two Threemile Pond inlets. Seward Mills Brook does run through an extensive wetland, which would explain the slightly higher color reading for Site 9. However, these values are lower than the mean color readings for Threemile Pond (14.2±8.5 SPUs).

Conductivity

Results and Discussion

Conductivity readings on 11-Sep-03 for Sites 11 and 12 were 122 μMHOs/cm and 61 μMHOs/cm, respectively. These readings are much higher than the values for Threemile Pond. Conductivity is also directly influenced by the amount of erosion, detritus, and sediment in the water. Again, this is

partially due to the fact that streams are likely to have a higher accumulation of detritus than lakes. Because the water in a stream is flowing, the bottom sediment is more easily disturbed than in a lake, which results in greater dissolved solids, and greater conductivity in streams than lakes. The high reading for Site 11 could also be influenced by runoff from lawns.

Conductivity readings on 11-Sep-03 for Sites 9 and 10 were 59 µMHOs/cm and 58 µMHOs/cm, respectively. These values are also higher than the readings for Threemile Pond, but less so than the inlets. These values could be lower due to less erosion entering Seward Mills Brook or a lower flow rate.

Chemical Analyses

pH

Results and Discussion

The pH of the four tributaries was found to be approximately neutral, ranging from 6.70 for Site 12 to 7.09 for Site 9 (Table 6). Because Threemile Pond is alkaline, a tributary with a pH of 6.70 is not going to greatly change the overall pH of the lake.

Nitrates

Results and Discussion

In total, all four tributaries had nitrate readings higher than the mean levels for Threemile Pond (Table 6). The nitrogen levels of inlets ranged from 0.05 ppm to 0.10 ppm (Table 6) indicating that the tributaries are sources of nitrogen to the lake. Site 11 flows slowly from a wetland into Threemile Pond, and although it is carrying nitrogen into the lake, it is not a major source at this time of year because the stream velocity is so low and the nitrogen levels are only slightly higher than those of the lake. At other times of year, when spring runoff increases the water flowing in the tributary, these streams may act as a source of nitrogen for the lake. Site 12, Barton Brook, has nitrogen levels equal to those of the lake, which puts negligible deposits of nitrogen into the water, although it could possibly be a larger source of nitrogen in the spring with higher water velocity and volume caused by snowmelt. Sites 9 and 10 (Figure 9) do not affect the water quality of Threemile Pond because they were both taken on the Seward Mills Brook outlet to Webber Pond from Threemile Pond at two different locations. They are indicators of the quality of the water flowing out of the lake. The outlet tributary from Threemile Pond to Webber Pond picks up nitrates along the way; the nitrate values change from 0.19 ppm leaving Threemile Pond to 0.24 ppm entering Webber Pond.

Figure 18b. Threemile Pond 15-Aug-03 in full algal bloom.

Total Phosphorus

Results and Discussion

Total phosphorus levels in the tributaries were comparable to those of the lake as a whole (Figure 18). The highest total phosphorus reading in a tributary came from Site 11, which comes into Threemile Pond from the wetlands. The value determined at this location was 33 ppb, which is slightly higher than the 30 ppb reading for Threemile Pond, but it is not considered a major source of phosphorus at this time of year because the water velocity for this stream was slow at 0.03 meters per second. During the spring, this tributary is probably a greater source of phosphorus for Threemile Pond. Sites 9 and 10 are not sources of phosphorus because they run directly out of Threemile Pond at the Seward Mills Brook outlet into Webber Pond, but they are indicators of the levels of phosphorus coming out of Threemile Pond. The stream is a sink for phosphorus because the reading goes from 32 ppb to 22 ppb

by the time the stream is near Webber Pond, which is potentially explained by the fact that the stream goes through a wetland. Site 12, which is known as Barton Brook, and drains water from Threecornered Pond and Mud Pond, does not appear to be a major source for phosphorus for Threemile Pond because the water velocity is slow at 0.05 meters per second, and the phosphorus levels of 1.9 ppb are well below the average for Threemile Pond. However, during spring runoff, the phosphorus levels in the lake, and the velocity of water flow in the stream may increase drastically, causing phosphorus deposition. These data demonstrate that most phosphorus does not enter the lake through the tributaries we tested at the time of year during which we tested them, but rather from direct runoff from the land area within the watershed. At other times of year, such as during spring runoff, these tributaries may act as a major source of phosphorus for Threemile Pond.

WATER BUDGET

INTRODUCTION

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

A water budget is an important place to start when assessing the physical and chemical features of a lake, which are often complementary because water naturally dissolves many substances (Thompson and Coldrey 1984). Higher concentrations of substances in a lake may relate to a lower flushing rate. These dissolved substances will affect the aquatic species and alter species composition in the lake. Lakes have lower flushing rates than streams and rivers, making them more vulnerable to the accumulation of pollutants in the water column and to bioaccumulation of pollutants in aquatic life (Chapman 1992). Low flushing rates can compound nutrient loading problems and accelerate eutrophication because the water is not replenished often enough to prevent the accumulation of sediments and associated nutrients on the lake bottom or in the water column.

METHODS

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

$$I_{net} \text{ (cubic meters/year)} = (\text{runoff} \times \text{land area}) + (\text{precipitation} \times \text{lake area}) - (\text{evaporation} \times \text{lake area})$$

$$\text{Flushing rate (flushes/year)} = (I_{net} \text{ Threemile Pond} + I_{net} \text{ Anderson Pond} + I_{net} \text{ Threecornered Pond} + I_{net} \text{ Mud Pond}) / (\text{mean depth} \times \text{lake area})$$

While water level in Threemile Pond does rise and fall over the course of a year, one can assume that the same amount of water is entering and leaving the lake at any given time and in aggregate over the course of a year (MDEP 2003d). I_{net} is the net increase in water in a lake each year coming from within the direct watershed. I_{net} was calculated for Threemile Pond, Mud Pond, Threecornered Pond, and Anderson Pond. The input lakes were added to the Threemile Pond input to determine the sum of the lake inputs (I_{net} Threemile Pond + I_{net} Anderson Pond + I_{net} Threecornered Pond + I_{net} Mud Pond). This sum divided by the lake volume of Threemile Pond equals the annual flushing rate of Threemile Pond.

Respectively, runoff (0.622 meters per year) and evaporation (0.56 meters per year) rates were derived from a regional study done by the North Kennebec Regional Planning Commission reported in an unpublished study (NKRPC unpublished data) and a U.S. Geological Survey study of the Lower Kennebec River Basin (Prescott 1969). Runoff is the average rate of water flow off land and evaporation is the average rate of water leaving the surface of the water. Precipitation (1.012 meters per year) is a 10-year average (1993 to 2002) taken from the Augusta State Airport meteorological station using the National Climactic Data Center (NCDC 2003). CEAT also used this 1993 to 2002 10-year precipitation average for Webber Pond in fall 2003 to recalculate the Webber Pond water budget to include Anderson Pond, though rainfall was 1.102 meters per year in both Webber Pond calculations.

Topographic maps were used and personal communications were conducted to determine the direction of water flow, the total water inputs, and the boundaries of the Threemile Pond watershed (MDEP 2003g; Halliwell pers. comm.). Watershed land area and lake surface area for Threemile Pond, Anderson Pond, Threecornered Pond, and Mud Pond were computed using ArcGIS™ with themes downloaded from the Maine Office of GIS (MEGIS 2003). ArcGIS™ was also used to calculate average depth from a 2002 boating map of Threemile Pond (Maine Lake Charts 2002). This map was selected over a 1972 MDEP map of Threemile Pond because it provided more depth points and was more recent.

RESULTS AND DISCUSSION

The majority of water inputs to Threemile Pond come from spring runoff, storm events, and inflow from other watersheds. In addition to several seasonal streams and small tributaries, Barton Brook, the major tributary found at the southern tip of the lake, brings water to Threemile Pond from

Anderson Pond, Threecornered Pond and Mud Pond (Figure 19). Threemile Pond drains from its northwest corner into Webber Pond through Seaward Mills Brook. Webber Pond drains to the north into the Kennebec River flowing south to the Gulf of Maine. Evaporation also removes water off the surface of Threemile Pond.

The I_{net} for Threemile Pond is 17,534,324 cubic meters per year. The flushing rate for Threemile Pond is 1.10 flushes per year (see Appendix D). Conceptually, this means that the water in Threemile Pond is being completely replaced 1.10 times per year.

One flush per year is a rough average flushing rate for the Lower Kennebec region (Woodward pers. comm.). Maine lakes have 1 to 1.5 flushes per year on average (MDEP 2003h). Figure 20 compares the annual flushing rates of six lakes and ponds in the China Lake region, which includes China Lake and lakes in the Webber Pond watershed. Figure 21 and Table 7 compare five lakes in Kennebec County with similar lake volumes to Threemile Pond. The flushing rate for Threemile Pond falls in the middle range both for the China Lake region and for similar lakes in Kennebec County. Typically, lakes with smaller volumes will have higher flushing rates and lakes with larger volumes will have lower flushing rates (Firmage pers. comm.). The flushing rate of 1.10 flushes per year for Threemile Pond is most similar to North Pond (1.36 flushes per year) and Lake Wesserunsett (1.09 flushes per year) (BI493 1997, 2001a).

The boating map used by CEAT to calculate average depth in Threemile Pond increased average depth from 5.18 meters (17 feet), used in the 2003 PCAP-TMDL report, to 5.41 meters (17.75 feet). Both the PCAP-TMDL and CEAT reports used ArcGIS™ to calculate lake area, but the CEAT value increased lake area by almost 65,000 squared meters (16 acres). This increased lake area and change in average depth added approximately 14,950 cubic meters (3.9 million gallons) of water to the CEAT water budget calculation for Threemile Pond.

An increase in lake volume usually decreases flushing rate when all other factors are equal (Table 7). Threecornered Pond and Anderson Pond were apparently not calculated into the flushing rate in the Threemile PCAP-TMDL. CEAT included these two lakes because the Threecornered Pond watershed drains into Threemile Pond through Barton Brook. The Maine Department of Environmental Protection (MDEP) calculated the water budget for Threemile Pond to be 0.93 flushes per year in the 2003 Threemile PCAP-TMDL Report (MDEP 2003f). The discrepancy between the CEAT calculation and the MDEP PCAP-TMDL report comes from the addition of Anderson Pond to the CEAT equation. Anderson Pond flows into Threecornered Pond and should be included in the water inputs entering Threemile

Pond. The flushing rate calculated by CEAT for Threemile Pond did not account for evaporation or infiltration of water off streams or wetlands.

Watershed land area also affects the overall flushing rate of a lake. For example, Threecornered Pond has a large direct watershed when compared to its small size, giving it a greater flushing rate potential (Figure 19). Threecornered Pond and Mud Pond have flushing rates over two times higher than Threemile Pond (Figure 20), but they also have high nutrient concentrations. Mud Pond, Threecornered Pond, and Anderson Pond have little development along their shorelines and only a small number of homes in their watersheds, but these three lakes and ponds also have small volumes. Threecornered Pond commonly has late summer algae blooms, and Mud Pond is a warm, very shallow pond with a silt and mud bottom and a high concentration of decaying organic matter (BLWQ 2003, MDEP 2003f). Greater land area and smaller lake volume can contribute to higher nutrient concentrations in a lake from runoff.

There is no obvious trend in the relationship between water quality and flushing rate. Secchi disk transparency readings show that some lakes with a greater flushing rate, such as North Pond (3.8± 0.3 m, 1.36 flushes per year), are clearer than Threemile Pond (2.9± 0.4 m, 1.10 flushes per year) (BI493 1997). Webber Pond has a higher flushing rate (1.77 flushes per year) than both North Pond and Threemile Pond, but lower clarity (1.3± 0.1 m) (BI493 2003a). This suggests that these lakes have other factors influencing nutrient loading and their overall health, such as high internal cycling of phosphorus and non-point source pollution (MDEP 2002b). Still, the average flushing rate for Threemile Pond appears to be consistent with the mid-range chemical and physical measurements recorded for this lake (see Water Quality).

Nutrients found in rainwater, surface water, and runoff will enter Threemile Pond and contribute to nutrient levels in the lake. Nutrients will also leave the lake through Seaward Mills Brook. While low-nutrient water inputs theoretically could help to cleanse lakes of point source and non-point source pollution, such as industrial waste and leaking septic systems, a higher flushing rate is not related necessarily to a clearer lake. Springtime runoff is likely to increase the lake volume of Threemile Pond with water containing higher nutrient levels (Firmage pers. comm.). Recreation, construction, agriculture, pesticide and fertilizer use, and increased summer populations also increase nutrient concentrations in the lake during summer and fall runoff. Over time, the altered quality of water entering Threemile Pond will affect the physical and chemical properties, the species composition, and the level of human activity in the lake (see Threemile Pond Characteristics: Historical Perspectives: Water Quality). While

Threemile Pond has an average flushing rate for the region, water quality remains threatened and the lake is at risk for annual algae blooms.

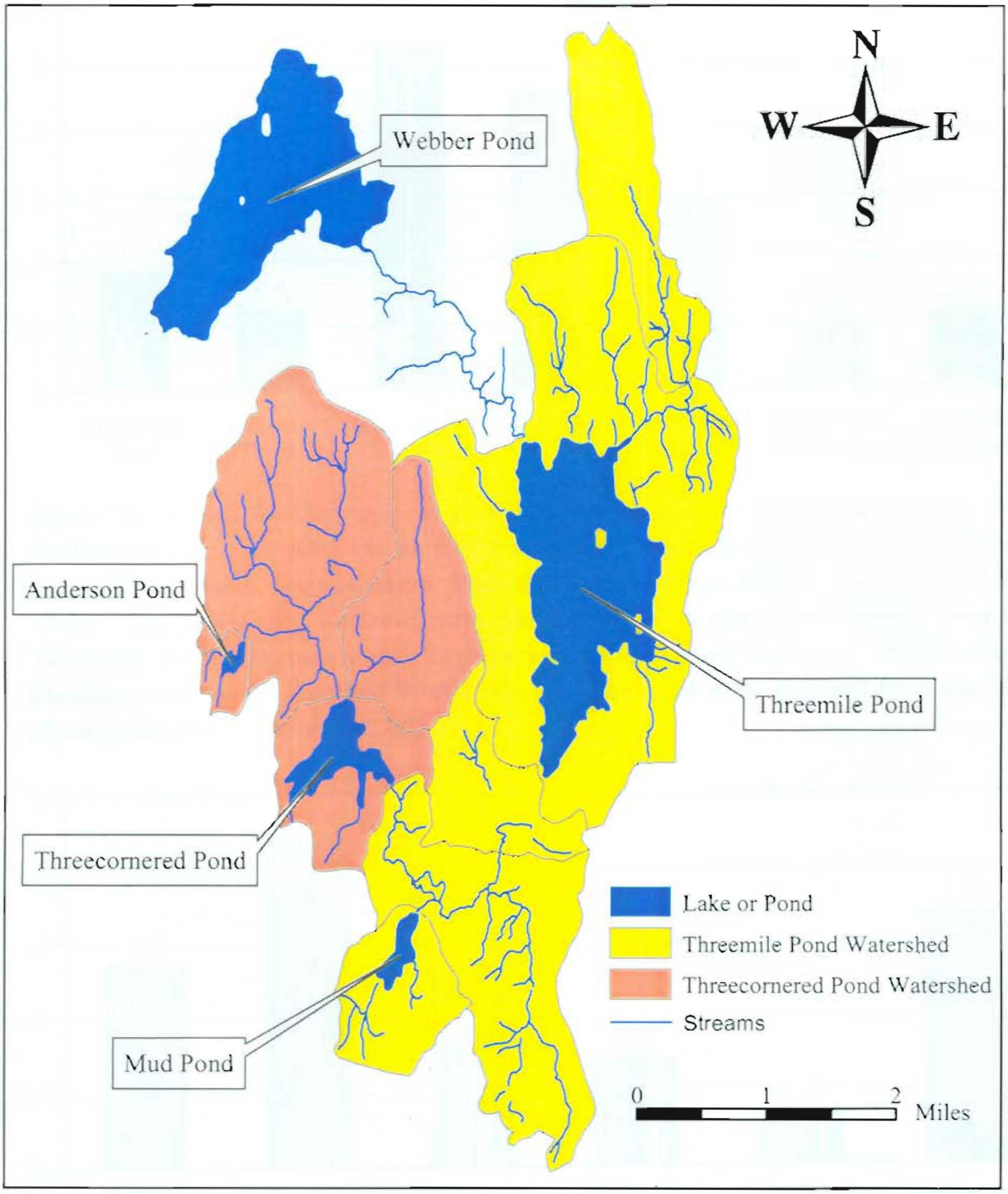


Figure 19. Watersheds included in the Threemile Pond water budget. The Threemile Pond watershed and Threecornered Pond watershed both contribute to the Threemile Pond water budget. Within the Threemile Pond watershed, water enters Threemile Pond through precipitation, runoff and tributary inputs. Threecornered Pond drains into Threemile Pond thorugh its southern and major tributary, Barton Brook. Threemile Pond drains into Webber Pond to the north. The Threemile Pond and Threecornered Pond watershed boundaries were obtained from the Maine Office of GIS (MEGIS 2003).

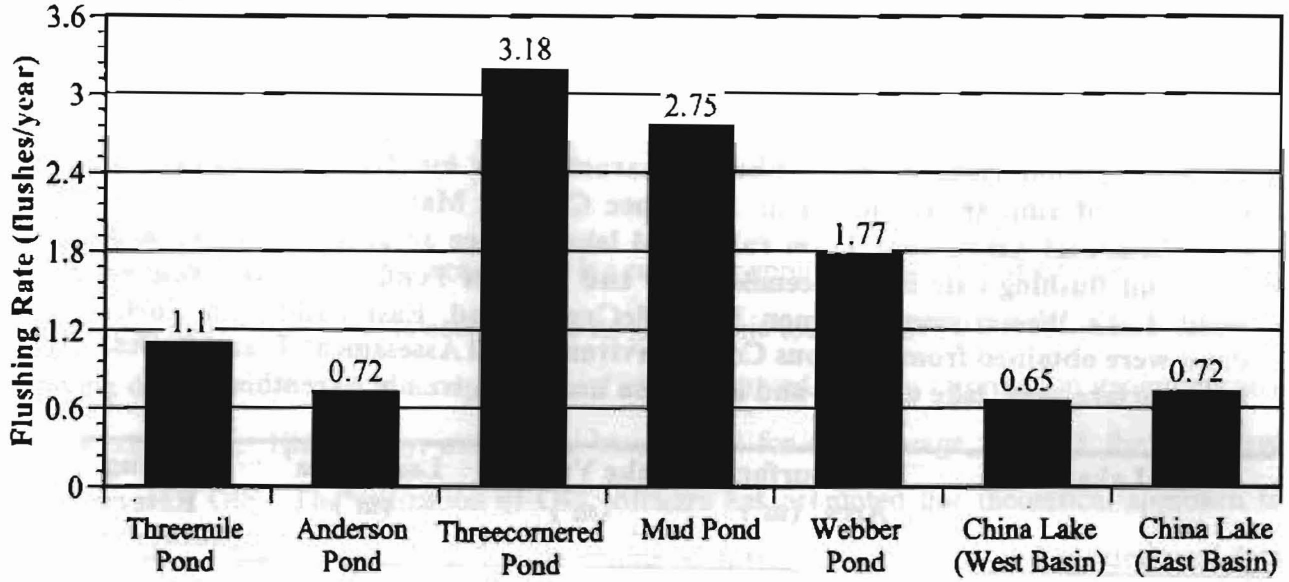


Figure 20. Annual flushing rates for six ponds and lakes in the China Lakes region. The flushing rate for each lake was derived from watershed land area, lake area, a 10-year annual precipitation average, taken from the Augusta State Airport 1993-2002 (NCDC 2003). The 2004 Colby Environmental Assessment Team quantified flushing rates for Threemile Pond, Anderson Pond, Threecornered Pond, Mud Pond, and Webber Pond. Flushing rates for the East and West Basin of China Lake were obtained from the 2001 China Lake TMDL report (MDEP 2001).

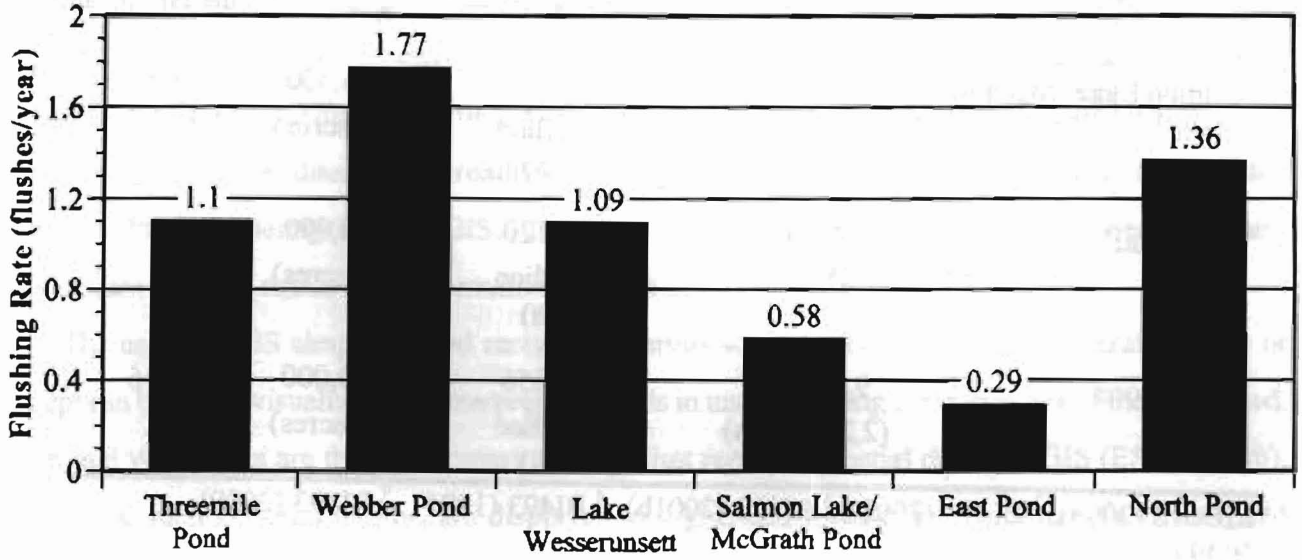


Figure 21. Annual flushing rates for Threemile Pond and five similar lakes in Kennebec County, Maine. See Table II.C.3.a. for lake volume and land area comparisons. Threemile Pond and Webber Pond flushing rates were determined by the 2004 Colby Environmental Assessment Team. Previous Colby Environmental Assessment Teams collected data for Lake Wesserunsett (BI493 2001b), Salmon Lake/McGrath Pond (BI493 1994), East Pond (BI493 2000), and North Pond (BI493 1997).

Table 7. Comparison of water budget characteristics for Threemile Pond and five lakes of similar size found in Kennebec County, Maine. The 2003 Colby Environmental Assessment Team calculated lake surface area, lake volume, land area, and flushing rate for Threemile Pond and Webber Pond. Data for Webber Pond, Lake Wesserunsett, Salmon Lake/McGrath Pond, East Pond, and North Pond were obtained from previous Colby Environmental Assessment Team studies. Lake surface area, lake volume, and land area units are given in parentheses.

Lake	Lake Surface Area[1] (m^2)	Lake Volume (m^3)	Land Area[1] (m^2)	Flushing Rate (flushes/yr)
Threemile Pond	4,645,730 (1,148 acres)	25,120,168 (6.64 billion gallons)	24,813,955 (6,132 acres)	1.10
Webber Pond[2]	5,008,914 (1,238 acres)	24,427,472 (6.65 billion gallons)	21,416,204 (5,292 acres)	1.77
Lake Wesserunsett[3]	5,851,754 (1,446 acres)	22,888,673 (6.05 billion gallons)	42,110,000 (10,406 acres)	1.09
Salmon Lake/ McGrath Pond[4]	4,657,500 (1,151 acres)	28,410,750 (7.51 billion gallons)	23,126,300 (5,715 acres)	0.58
East Pond[5]	6,769,624 (1,673 acres)	33,848,120 (8.94 billion gallons)	10,949,000 (2,706 acres)	0.29
North Pond[6]	9,123,000 (2,254 acres)	37,148,856 (9.81 billion gallons)	30,920,000 (7,640 acres)	1.36

[1] MEGIS (2003), [2] BI493 (2002), [3] BI493 (2001b), [4] BI493 (1995), [5] BI493 (2000), [6] BI493 (1997)

GIS

INTRODUCTION

A Geographic Information System (GIS) is a computer application capable of assembling, storing, manipulating, and displaying data according to its geographic location (ESRI 2000a). The concept of portraying different layers of data on a series of base maps and relating information geographically predates computers. Historically, maps have been useful for data storage, but lack the analytical capabilities of a GIS. The utilization of GIS software has promoted this theoretical approach to interpreting data. The ability of a GIS to determine adjacency, containment, and proximity of data enables in-depth analysis. Approximately 80 percent of all data have a spatial component (ESRI 2000a), creating numerous applications for the use of a GIS, including watershed analysis.

GIS data are referenced to particular points on the Earth. The data may be obtained from a number of sources, including: aerial photos, a Global Positioning System (GPS), databases, Digital Orthophoto Quadrangle (DOQ) maps, and field sampling of attributes. GPS technology was originally designed as a military application by the United States Department of Defense during the Cold War era to locate Soviet missiles, but the declassification of this information led to the proliferation of its applicability for GIS as well as increased accuracy (Trivedi 2002). Most of the data used in the GIS portion of the study of Threemile Pond were downloaded from the Maine Office of GIS (MEGIS 2003). GIS categorizes data such as roads, wetlands, lakes, or contours into themes that can be added or removed independently using a GIS. This allows the user to alter each map in order to present specific data without extraneous information (Figure 22).

The use of a GIS simplifies and merges numerous sources of data so that an overall picture or concept can be easily visualized and interpreted. It aids in understanding the intricacies of the watershed. Raster and vector data are the two primary formats that represent spatial data in a GIS (ESRI 2000b). Raster data, such as aerial photos, are displayed in a grid-cell format, each cell having an assigned value, which allows the grid cells to be referenced with other spatial data. Referencing the data sources geographically enables greater precision by zooming to the pixel level. Vector data are one-dimensional, linear points, lines, and polygons such as the Threemile Pond theme. Each data type has specific analytic capabilities for the watershed and ArcGIS™ 8.2 software allows conversion of most data between raster and vector formats.

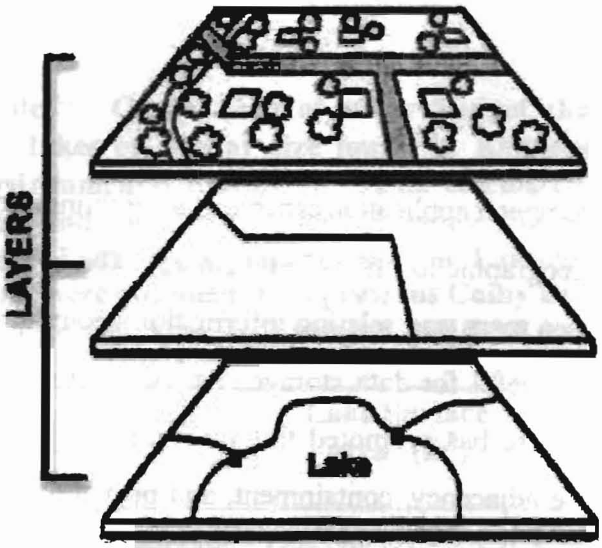


Figure 22. A Geographic Information Systems map allows users to add layers such as roads, lakes, or contour themes in order to present specific data without extraneous information (Louisiana State University 2003).

The Colby Environmental Assessment Team (CEAT) visualized many aspects of the Threemile Pond watershed using GIS technology. Environmental Systems Research Institute (ESRI) ArcGIS™ 8.2 applications were used to create a bathymetry map, soil map, septic suitability model, and erosion potential model. Recent upgrades in the CEAT software, including Spatial Analyst, Image Analyst, and 3D Analyst, allowed more advanced analysis and greater resolution than in past studies. The models presented in this study were utilized as tools to assess the factors present in the watershed that are leading to a decrease in health of Threemile Pond. GIS was also used to make informed, location-specific recommendations for remediation.

BATHYMETRY

Introduction

A bathymetry map is a contour map of the basin of a water body, where darker regions show the deeper portions of the water body and lighter areas show shallower areas. Bathymetry maps can be used to locate sub-basins and compute lake volumes for water budget calculations (Chapman 1992). Bathymetry maps are also required for sediment mapping and are used for predicting the presence of organisms (Chapman 1992). A bathymetry map can also visually display portions of a lake that become anoxic, typically the deeper areas of the hypolimnion. Since anoxic hypolimnia can be detrimental to lake dwelling organisms, typically fish and benthic organisms as well as causing excess phosphorus loading, understanding where this oxygen depleted area is can be useful for analyzing the health of a

Methods

A map of depth points was first needed to create a bathymetry map of Threemile Pond. A boating chart with more than 200 depth points was obtained for this purpose (Maine Lake Charts 2002). This map was scanned using a wide format scanner and the image was saved in ArcMap, part of the ArcGIS™ software suite. Four layers of lakes digitized from USGS 1:24,000 scale quadrangle maps by various contractors were downloaded from the Maine Office of GIS, including Vassalboro, China, Windsor, and Togus (MEGIS 2003). Threemile Pond was isolated from these four layers. The boating map was then geographically referenced (georeferenced) to the Threemile Pond layer so that the two could be seen in the same view. Georeferencing places a layer on a map relative to another layer so they can be viewed in the same space. Depth points and data from the boating chart were then digitally transferred to the lake layer. Using the spline interpolator feature of Spatial Analyst™, mathematical contours were created from point to point. Spline is a method where values are estimated using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points (ESRI 2001). Zero points were added all along the edge of Threemile Pond so the spline would continue to the edge of the lake, creating a complete bathymetry map for Threemile Pond (Figure 23).

To visually display areas of the lake that become anoxic during summer stratification, the bathymetry map was adapted to display two categories of depth; those depths greater than seven m that typically become anoxic and depths less than seven m that do not become anoxic (see Water Quality: Threemile Pond Water Quality Assessment: Lake Water Quality: Dissolved Oxygen and Temperature Measurements). This map uses the same methodology as the bathymetry map described above (Figure 12).

Results and Discussion

The average depth of Threemile Pond is 18.5 ft. This is slightly different than the average depth reported in the TMDL study on Threemile Pond (17 ft) because the boating map used to create this bathymetry map included more points than the depth map used by the MDEP. The deepest point in Threemile Pond according to the boating chart is 43.6 ft. However, only 18 percent of Threemile Pond is deeper than 28.0 ft. The majority of Threemile Pond, 82 percent, is shallower than 28.0 ft. Some studies show that approximately three meters is the deepest level at which invasive plants can grow and survive, but water quality and light penetration affects the final depth at which these plants will grow

(Strand and Wiesner 2001). Twenty-three percent of Threemile Pond's area is shallower than that three-meter cut off point, a significant area where invasive plants could potentially grow. Understanding where Threemile Pond becomes anoxic in the summer is also relevant because lack of oxygen would affect the viability of invasive plants and should be considered (see Water Quality: Threemile Pond Water Quality Assessment: Lake Water Quality: Dissolved Oxygen and Temperature Measurements).

SOIL MAP

Introduction

Understanding the various types of soils in a watershed leads to a better understanding of how to manage and protect a lake or water body. Soils carry phosphorus, which in high levels can lead to algal blooms in Maine lakes. Although solubility of phosphorus in phosphorus-carrying soils is generally low, anaerobic conditions that frequently plague the hypolimnion of eutrophic lakes tend to increase the solubility, causing greater impact in terms of phosphorus loading in those lakes that are already in trouble (Wild 1993). The anoxic conditions tend to break down complexes that hold phosphorus to iron and other compounds in the soil. Usually soil enters a water body in the form of runoff from eroding surfaces. These surfaces can be in the form of roads, farmland, or homes along the shore of a lake. Erosion can cause loss of productivity at the erosion site. Erosion can also contribute to off-site deposition particles of soil in a body of water and the accumulation can be detrimental to the lake s water quality (Hillel 1991).

Soils are broken down into various categories that are specific to certain watersheds. One characteristic that separates the various soil types is the K value. The K value quantifies how easily a type of soil will erode on a range of 0 (water body or wetland) to 1. As the K value approaches 1, it is more likely that the soil will erode. K values for the Threemile Pond watershed were found in soil literature (USDA 1978) and those not found in literature were supplied by the Kennebec County Soil and Water Conservation District (Sylvester pers. comm.). This information is of critical value to watershed studies where erosion is a major factor in determining water quality.

Methods

The soil map shapefile was supplied by the Kennebec County Soil and Water Conservation District

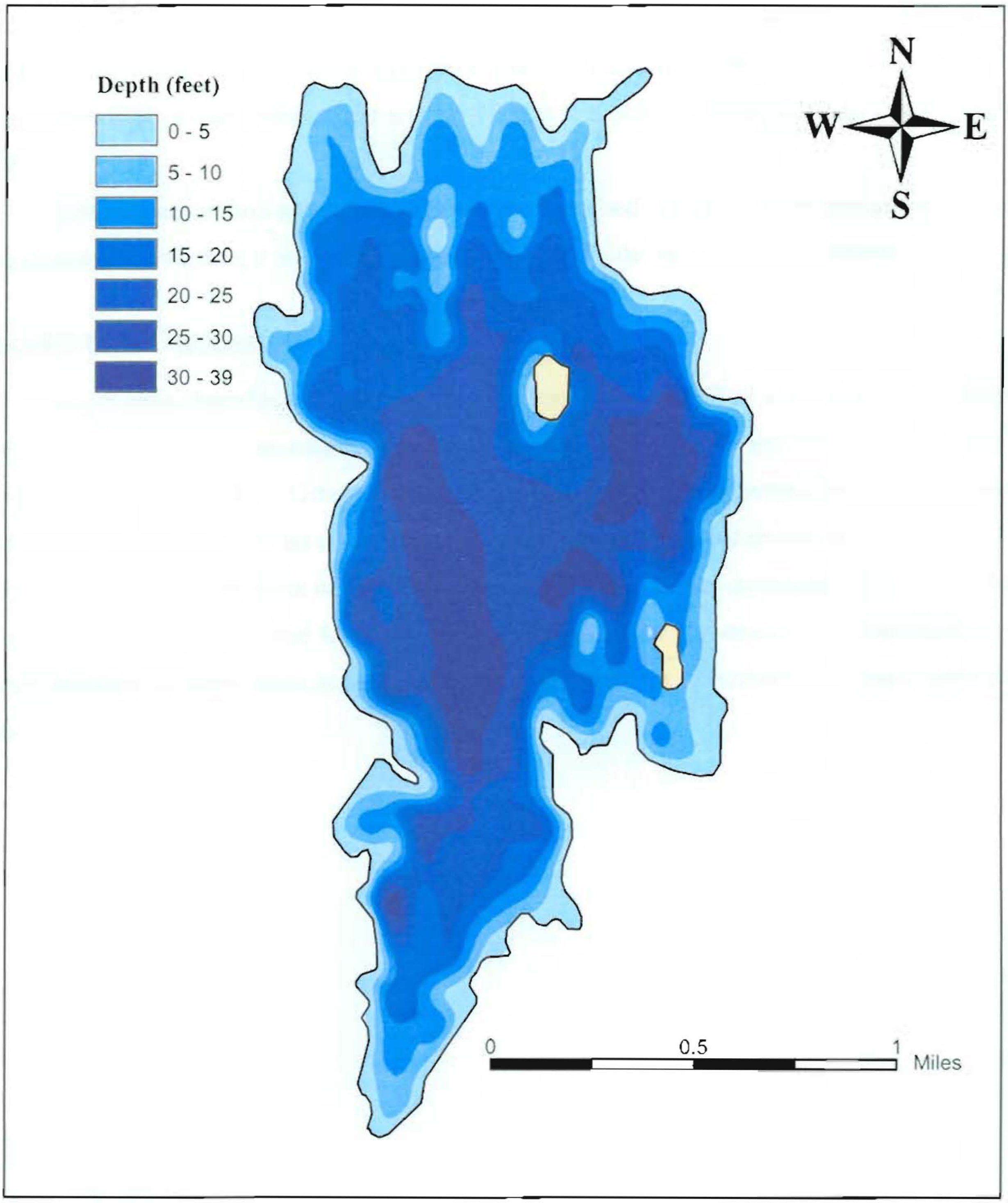


Figure 23. Bathymetry map for Threemile Pond with depth measurements in feet. Depth points were derived from a boating map of Threemile Pond (Maine Lakes Charts 2002). Depth points were interpolated using the spline interpolator method of Spatial Analyst in ArcGIS 8.2 (ESRI 2001). Brown areas indicate islands.

(KCSWD 2003). This map consisted of polygons indicating all the soil types in the Threemile Pond watershed. General descriptions of the types of soils present were also included with the shapefile. Soil types are divided into soil series, a grouping based on similar profiles (USDA 1978). Soils that differ in terms of human development use are divided into phases within each soil series (USDA 1978).

Since the fourteen soil series found in the Threemile Pond watershed show enough variation in composition and structure, it was not necessary to further divide these series into phases.

Results and Discussion

The soil map shapefile was supplied by the Kennebec County Soil and Water Conservation District (KCSWD 2003). This map consisted of polygons indicating all the soil types in the Threemile Pond watershed (Figure 24). General descriptions of the types of soils present were also included with the shapefile. Soil types are divided into soil series, a grouping based on similar profiles (USDA 1978). Soils that differ in terms of human development use are divided into phases within each soil series (USDA 1978). Since the fourteen soil series found in the Threemile Pond watershed show enough variation in composition and structure, it was not necessary to further divide these series into phases.

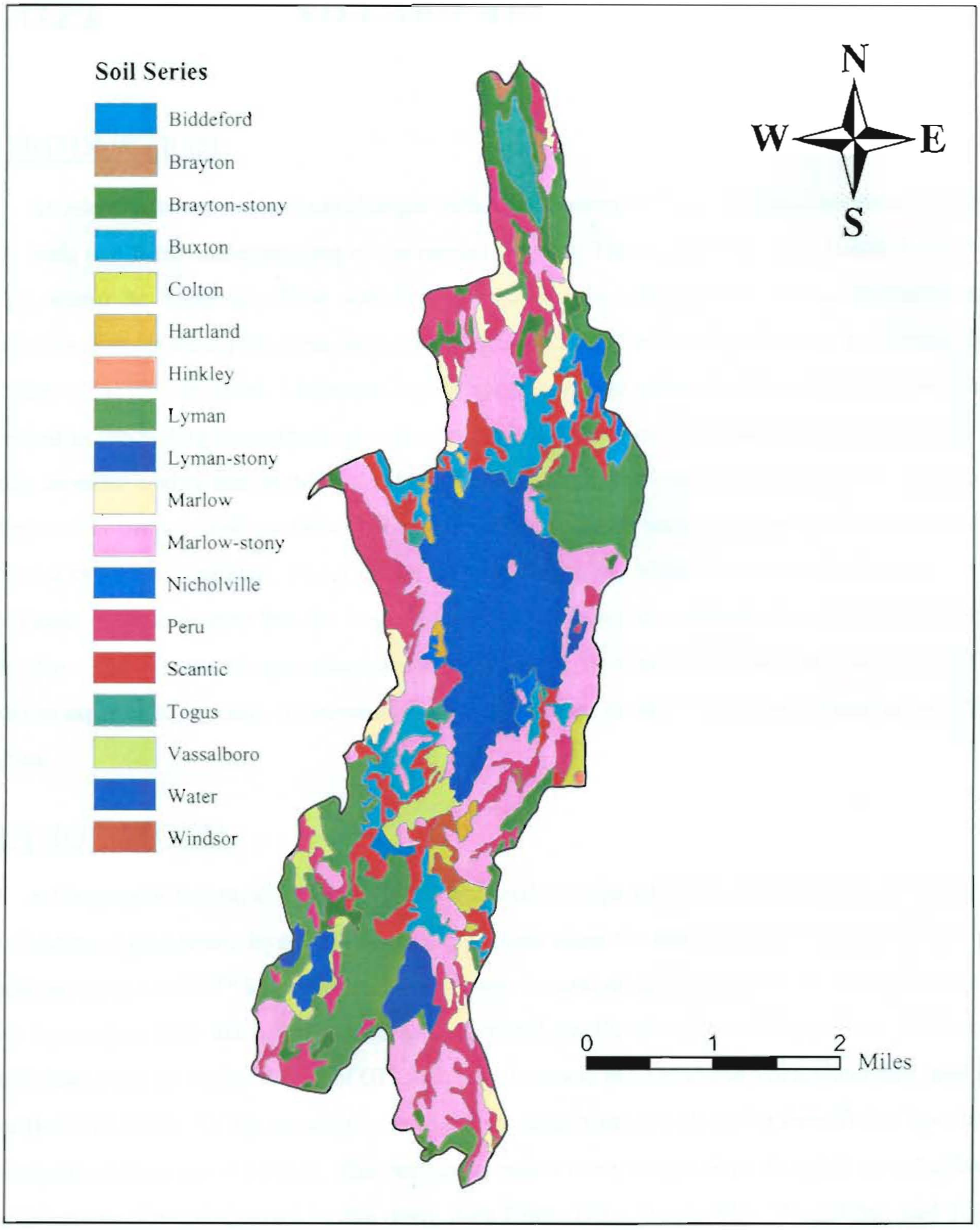


Figure 24. Soil series present in Threemile Pond watershed. The entire soil series theme was obtained from the Kennebec County Soil and Water Conservation District (KCSWD 2003). For descriptions of series present in the Threemile Pond watershed, see GIS: Soil Map.

WATERSHED LAND USE PATTERNS

INTRODUCTION

An examination of the land use changes within the Threemile Pond watershed between 1956 and 1998 leads to a better understanding of the current status of Threemile Pond. The Lower Kennebec Valley, where the Threemile Pond watershed is located, has undergone significant economic and population changes during this time period (see Regional Land Use Trends), affecting the various land use types within the watershed. Understanding the land use patterns within the Threemile Pond watershed is critical to conducting an analysis of watershed health. Each land use type has particular potential effects on water quality and on the level of pollution that reaches a body of water. It is also crucial to understand the historic land use trends because these trends can be used to interpret how the watershed arrived at its present condition. For example, if much of the forested land in a watershed was removed, it is reasonable to anticipate that the loss of forest functions would contribute to nutrient loading in a body of water. If large-scale agriculture or commercial uses have increased over time, nutrient loading would be expected to increase. Understanding the land use patterns also helps identify potential pollution sources.

METHODOLOGY

A Geographic Information System (GIS) was used to prepare land use maps because it allows the use of different geographic layers to help make decisions about the land use types. The GIS work was conducted using ArcGIS™ 8.2, which enabled the user to manipulate the layers and combine them with other layers (see GIS: Introduction). Digital Orthophoto Quadrangles (DOQs) from 1998 were downloaded from the Maine Office of GIS web page to create the Threemile Pond watershed land use maps (MEGIS 2003). DOQs are aerial photos of land taken from a high-flying aircraft that have been corrected for differences in altitude. This correction makes everything look as though it were displayed on a flat plane. The DOQs used in this study were China Lake, Weeks Mill, Vassalboro, and Togus Pond. Aerial photographs of the watershed in 1956 were obtained from the James W. Sewell Company in Old Town, Maine because there were no DOQs available from that time period. These aerial photographs are similar images to the DOQs, but their three meters resolution is not as good as the one-meter resolution of the DOQs. As a result, it was more difficult to determine land use types on the 1956

map. Satellite imagery taken on 18-Sep-99 was acquired from the United States Geological Society and used to help determine questionable land types on the DOQs. This imagery uses light waves to determine what wavelengths are reflected by the land surface. Since water, trees, crop plants, cleared land, and developed areas absorb different wavelengths, they are represented by different colors on the image, making it easier to differentiate land use patterns.

The watershed boundary was obtained from the MEGIS web page and is the same boundary that the MDEP used in the TMDL report (MEGIS 2003). The boundary image imported into ArcGIS™ 8.2 and georeferenced to the DOQs/aerial photographs of the area around Threemile Pond. A polygon of Threemile Pond was acquired from the MEGIS and was added to the project (MEGIS 2003). A new layer was formed in order to outline the different land uses with those three layers in place. A polygon setting was used to outline each area on the map; these areas were color-coded to distinguish among land use characterizations (Figure 25 and Figure 26).

The land use characterizations and descriptions follow those used by CEAT in the Webber Pond study (BI493 2003a). The nine characterizations used in the land use maps are wetlands, mature forest, transitional forest, reverting, cleared, pasture, cropland, residential, and municipal/commercial. Cropland and pasture were grouped into one category: agriculture. The definitions of these land use categories are as follows:

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

Mature forest: distinctly closed, continuous canopy of trees with no identifiable patches or breaks.

Transitional forests: at least 50 percent forest cover, consisting of a mixture of shrubs, young trees, and old trees that results in a patchy, uneven canopy.

Reverting: land that has been released from cultivation and is undergoing the process of succession from previously agricultural land towards mature forest. Characterized by canopy cover of less than 50 percent of the total area of the forest and can be identified in DOQs since this forest type often retains the shape of the agricultural field.

Cleared land: cleared patches of forest that may or may not contain trails from skidders and logging roads; this is different from agricultural land because it is typically surrounded by forest and is not found in association with houses or barns.

Cropland: exhibits even rows that indicate planting and includes hayfields.

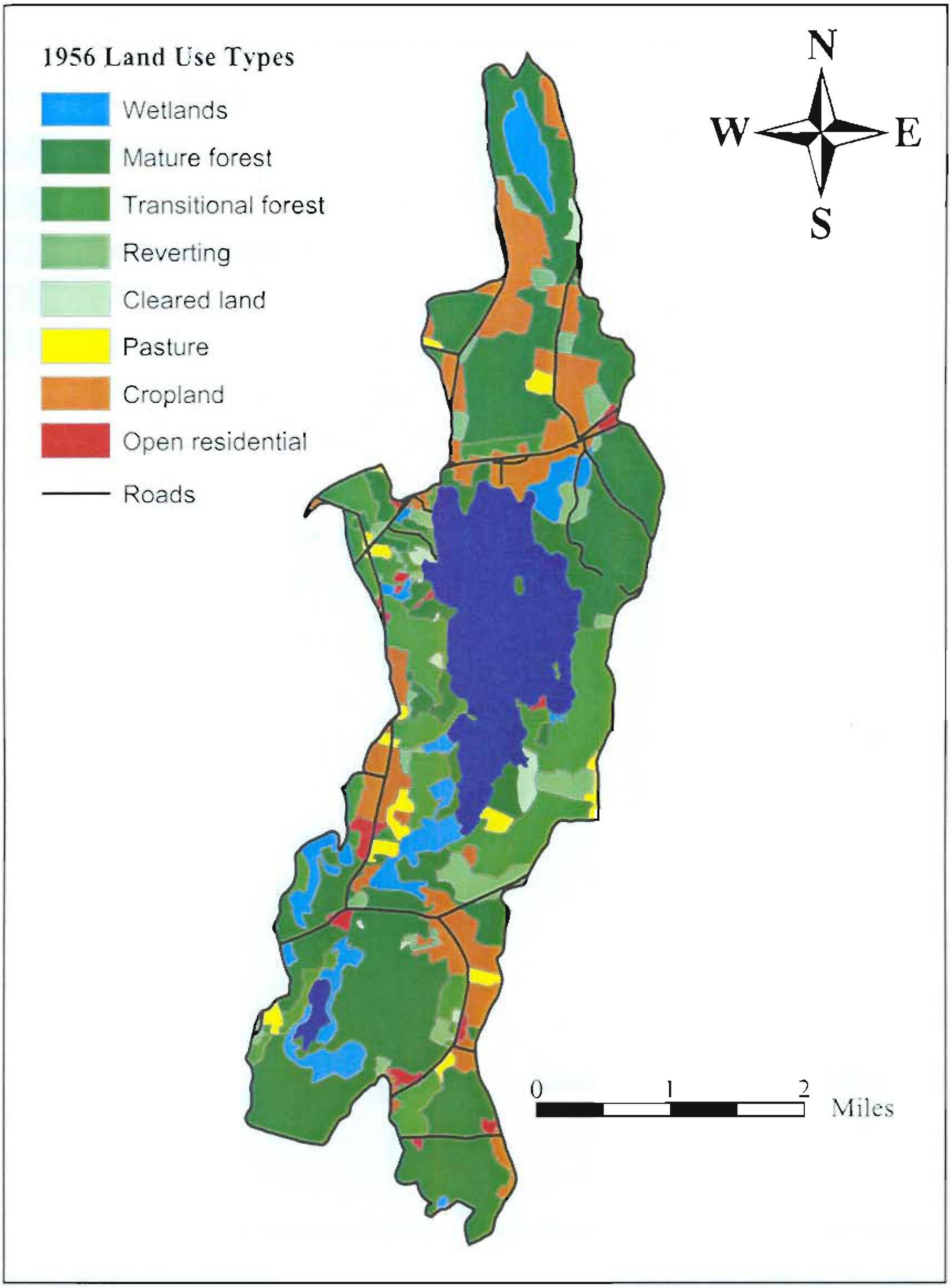


Figure 25. Land use patterns for the Threemile Pond watershed in 1956. Each color represents a distinct land use type as defined in the text (see Land Use: Methodology). Aerial photographs acquired from James W. Sewell Company were used to identify land use types.

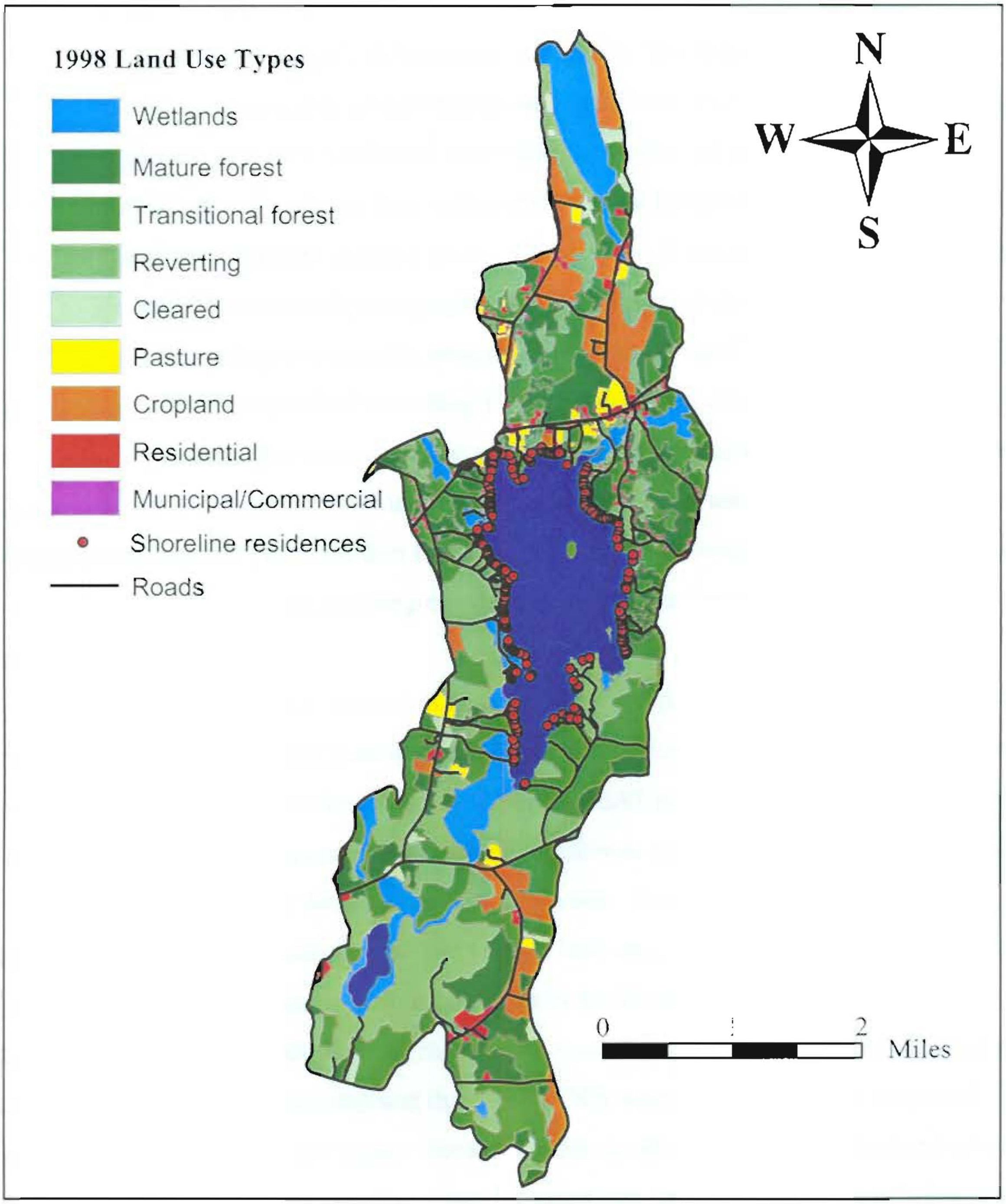


Figure 26. Land use patterns for the Threemile Pond watershed in 1998. Each color represents a distinct land use type as defined in the text (see LandUse: Methodology). Digital Orthophoto Quadrangles acquired from the Maine Office of GIS (MEGIS 2003) were used to identify land use types. The major roads were also obtained from MEGIS and the shoreline residences were obtained from the house servey performed on Threemile Pond by the Colby Environmental Assessment Team.

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

Commercial and municipal: all businesses and public facilities such as schools.

Open residential: privately owned land greater than 0.5 acres, usually comprised of a grouping of residential units or a residential unit with a large, cleared lawn.

Residential: privately owned land with one residential unit and associated buildings such as a garage or shed. Each is assigned an area of 0.5 acres. Houses and small lawns are difficult to see on DOQ and aerial photographs because of the tree canopy.

The areas of the polygons were calculated to find the total areas of those land uses in the Threemile Pond watershed after the watershed was categorized and digitized. The 1956 and 1998 land use maps were projected over each other to create a new map that shows the land use areas that have and have not changed since 1956. An intersection function in ArcGIS™ 8.2 was used to find the areas that have not changed between the two years and then those areas were deleted so that only the areas of change were shown on the map. These areas are categorized by their 1956 land use type, not the 1998 land use type (Figure 27).

There are sources of error inherent in this method of creating land use maps. It could be difficult identifying the image on the DOQ and there may have been some interpretation errors, discrepancies as to what images represent which land type, by different CEAT members working on the two maps. To minimize these errors, the team members worked together as the map was being created to make sure that there was consistency in determining land use types. Ground-truthing was performed after the images on the DOQ were all categorized into various land uses. The ground-truthing process included taking pictures and GPS points of various land uses in the Threemile Pond watershed. These pictures and points were compared to the land use map to make sure that the DOQs were characterized correctly. One difficulty with the land use map was that 1998 DOQs were used to make the maps and some land uses have changed in the past five years. The team had to decide if the land was digitized incorrectly or if the land use changed in the past five years by using our previously gained knowledge about the Threemile Pond watershed.

Digitizing residential area also had obstacles. Some of the smaller lots were covered with trees and could not be seen in the DOQs. CEAT performed house counts along the roads of the watershed and along the shore of Threemile Pond to take these unseen houses into consideration as a percent of land use type. The houses on the shore of Threemile Pond were designated as an area of 0.5 acre each

and non-shoreline houses at least 200 feet away from the shoreline were assigned an area of 1 acre (MDEP 2003f; see Residential Survey: Shoreline Zoning). These data were then used to calculate the total area of residential land use in the watershed. The area of the residential polygons on the 1998 land use map was subtracted from the total area of residential land calculated by the CEAT house count data to determine the total residential area in the watershed. The area of the shoreline houses was subtracted from the mature forest, transitional forest, and wetlands that surrounded the edge of Threemile Pond on the 1998 land use map to account for the houses that are in the watershed but not on the map. The area of houses that were 200 feet or more away from Threemile Pond was subtracted from the total areas of mature and transitional forest. GPS points were taken in front of each house on the shore of Threemile Pond and an image was created to show the location of these houses. This image was added to the 1998 land use map to show the shoreline areas of heavy development and what areas are undeveloped.

Not all of these houses may have been present in 1998, but these numbers more accurately depict the residential area in 2003 than the number of houses that are visible in the 1998 DOQs (Figure 28).

WETLANDS

Introduction

Wetlands are defined as areas where water covers the soil for the entire year or for extended periods during the year, including the growing season (EPA Office of Wetlands, Oceans, and Watersheds 2003). Wetlands are also transitional zones between terrestrial and aquatic ecosystems. They serve important functions for both people and wildlife (EPA Office of Wetlands, Oceans, and Watersheds 2003). The shallow water, high productivity, and nutrients in wetland areas provide an environment for numerous species. Wetlands also help protect lakes from harmful pollutants, sedimentation, and runoff. The wetlands act as a filter, slowing runoff and removing sediments and pollutants that would otherwise reach the lake. Plant roots and microorganisms in the soil absorb nutrients; other pollutants bind to soil particles (EPA Office of Wetlands, Oceans, and Watersheds 2003). Wetlands also act as nutrient sinks, where anthropogenic sources of phosphorus are naturally reduced before entering lakes and streams (Keenan and Lowe 2001).

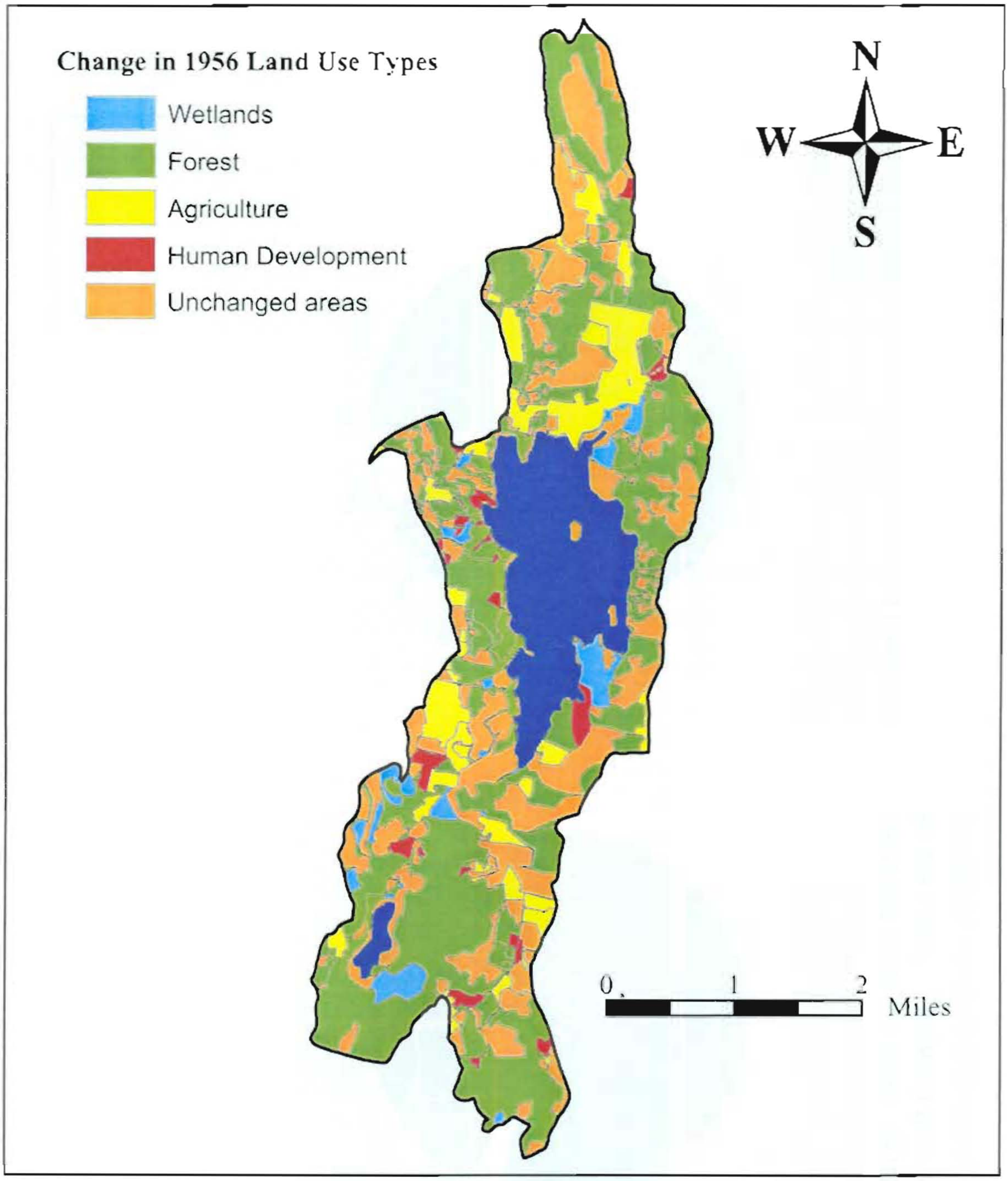


Figure 27. Areas of land use change from 1956 to 1998 in the Threemile Pond watershed. The various colored areas represent the 1956 land use types that have changed to another use in the past 42 years. The general categories used are wetlands, forest (includes mature forest, transitional forest, reverting, and cleared), agriculture (includes cropland and pasture), and human development (includes open residential). These land use types are defined in the text (see Land Use: Methodology).

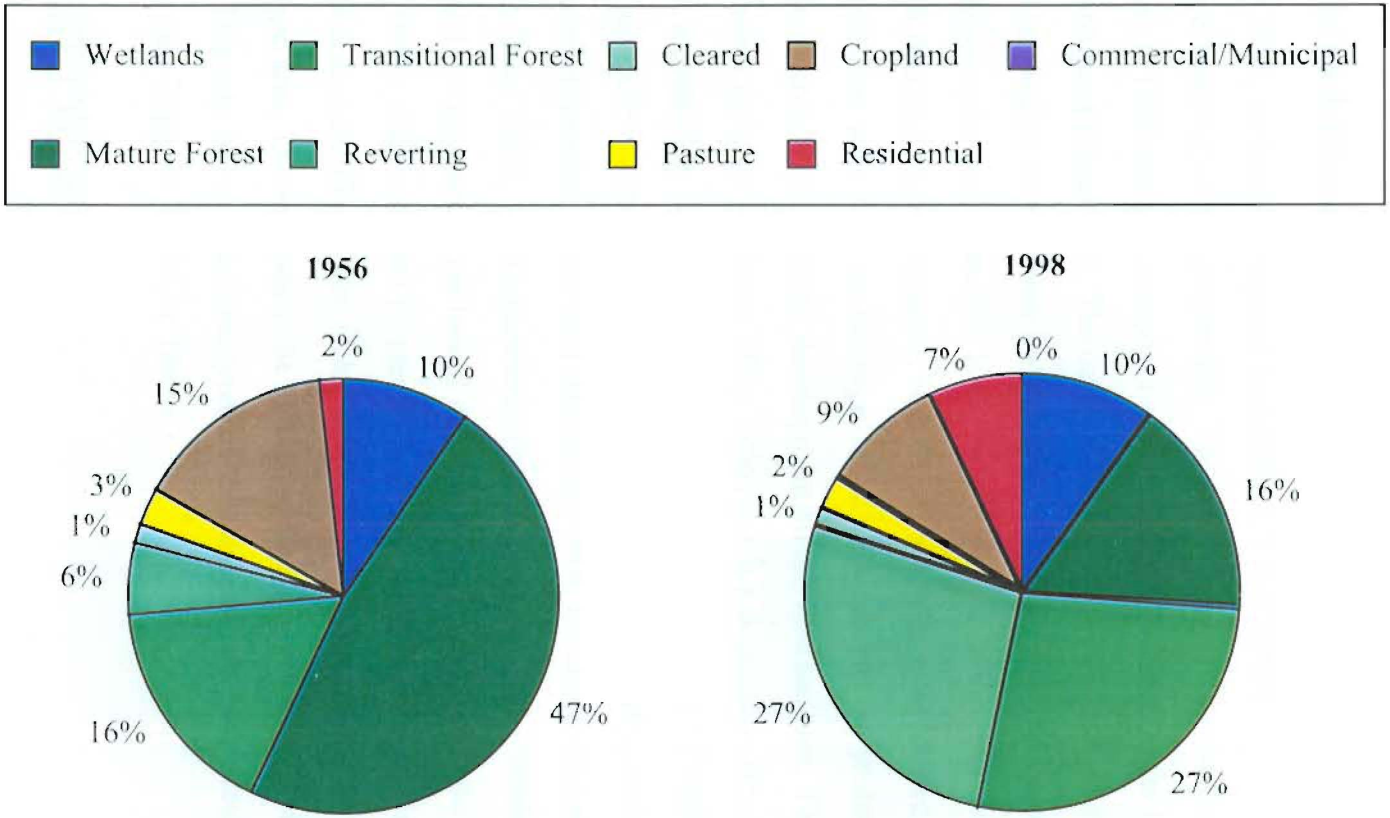


Figure 28. Percent of the watershed covered by each land use type in the Threemile Pond watershed for 1956 and 1998 (see Watershed Land Use Patterns: Methodology for definitions of each category). Land use areas for 1956 were determined using aerial photographs obtained from the J.W. Sewall Company. Land use areas for 1998 were determined using Digital Orthophoto Quadrangles obtained from the Maine Office of GIS (MEGIS 2003).

Methods

The Threemile Pond watershed contains only freshwater wetlands. The land use classification of wetlands included marshes.

Results and Discussion

In 1956, wetlands composed approximately 9.8 percent of the total watershed area in the Threemile Pond watershed (Figure 25). The total acreage of wetlands in 1956 was approximately 650 acres. In 1998 wetlands composed approximately 10 percent of the total watershed area, with an area of 665 acres (Figure 28). The data show an increase of 15 acres between 1956 and 1998. This increase in wetland acreage may be real but may also be a reflection of the poor resolution of the aerial photographs used to analyze land use in 1956 or a delineation error in drawing the polygons. The 1998 data also show residences built where wetlands were located in 1956. It is possible that these residences were built on the edge of the wetlands but not probable that they were built on wetlands due to laws that prohibit development on this land use type. The likely explanation for this trend is either the poor resolution of the 1956 map or a delineation error.

It is promising that these data do not indicate a decline in wetland acreage. National trends indicate opposite results from those found by CEAT. Historically, wetlands have decreased since the era of colonial America. From the 1780s to the 1980s, the United States lost 53 percent of its original wetlands (Dahl 1990). The Department of the Interior Fish and Wildlife Service reports that between 1986 and 1997 there was a net loss of 644,000 acres of wetlands in the nation (US Fish and Wildlife Service 1998). Data collected by previous CEAT studies (BI 493 2001a, 2001b) indicate a decline in wetlands in the Lake George and Oaks Pond watersheds and in the Lake Wesserunsett watershed in the Skowhegan area. The wetlands in the Threemile Pond watershed do not exhibit these local and national trends. This may be because of the types of development that have occurred in the region over the last 50 years (see Regional Land Use Trends.)

<u>FOREST TYPES</u>

Introduction

Forests cover nearly 90 percent of the State of Maine (Maine Forestry Service 2003). They protect bodies of water from pollutants, sedimentation, and runoff. Forests can have varying impacts

on watersheds, depending upon the amount and type of vegetative cover provided. The foliage, bark, and litter from forests protect aquatic ecosystems by reducing the rate of water runoff and by encouraging absorption of rainfall (Gottle et al. 2003). Forests also slow wind, reducing soil erosion in the watershed (Gottle et al. 2003). The erosive effects of rainfall are reduced when falling water is slowed by the canopy of the forests.

Methods

Within the Threemile Pond watershed, forests were defined as undeveloped land. This category was divided into three classifications. Forests in the watershed are at different successional stages (reverting, transition, and mature) because of the historical land use in the watershed. Reverting land was defined as land formerly used for agriculture, but has now been released from cultivation. This land use type consists of low shrubs and young trees with a canopy of less than 50 percent complete. Reverting land generally retained the shape of agricultural fields on the DOQs, making identification clear. Transitional forest was defined as land that is composed of shrubs, young trees, and old trees with an uneven, patchy canopy, comprising greater than 50 percent canopy coverage. Mature forest was defined as forested land with a continuous, closed canopy.

Results and Discussion

In 1956, 69 percent of the Threemile Pond watershed was composed of forest (the sum of reverting, transitional, mature forest). Mature forest was 47 percent of the total area of the 1956 watershed, (Figure 28) with an area of 3,154 acres. This land use type was the most prevalent in the watershed at that time. Transitional forest was the second most prevalent land use in 1956 with 1,094 acres, comprising 16 percent of the total area. Reverting land accounted for 6 percent of the total watershed land use in 1956.

In 1998, approximately 70 percent of the watershed was forest (Figure 28). However, the percentages for the various forest types are quite different from 1956. In 1998, mature forest accounted for 16 percent of the watershed area (1,056 acres), down from 47% in 1956. Transitional forest was the most prevalent land use type (27 percent, 1,083 acres). Reverting comprised 26 percent of the land use (1,778 acres) (Figure 28). This is four times greater than the 1956 value of 6%.

In 1956 and 1998, forest accounted for the majority of the watershed area. This trend is consistent with the regional trends discussed previously (see: Regional Land Use Trends). Both years displayed

approximately 69 to 70 percent of the watershed as forested. However, the difference lies within the composition of that total. In 1956, 47 percent of the watershed was comprised of mature forest, while it accounted for 16 percent in 1998 (Figure 28). Mature forests were removed to accommodate the increase in development. While the amount of mature forest declined, the amount of transitional and reverting land increased. This accounts for the total forest area staying fairly constant over the 47 years.

In 1956, the watershed was comprised of 16 percent transitional forest. This land use type grew to account for 27 percent of the land in 1998 (Figure 28). These data are consistent with trends seen in similar watersheds in Maine. A previous CEAT study of the nearby Webber Pond watershed found that transitional forests increased between 1956 and 1997. In 1956, transitional forest accounted for 34 percent of the land use in the Webber Pond watershed and accounted for 49.7 percent in 1997 (BI 493 2003b). The changes observed in the forest composition between 1956 and 1998 are reflections of regional trends. When agriculture declined in this area after the 1960s, the land underwent natural succession. This accounts for the increase in transitional land.

Similar trends were seen for reverting land. In 1956, 6 percent of the watershed was reverting. This value increased to 26 percent in 1998 (Figure 28). This trend also reflects the general land use patterns in the region. There was less reverting and transitional land in 1956 because much more of the watershed was used for agriculture than in 1998. When this agricultural land was released from cultivation, over time it became reverting and transitional land. This change in land use accounts for the increase of these two land use types in 1998. Mature forest declined as a result of the development in the region. Land was cleared for residential development, cordwood, and road construction. This also accounts for the increase in transitional and reverting land.

CLEARED LAND

Introduction

Cleared land is a serious concern for water quality within a watershed due to the resulting increased rates of erosion and nutrients in over land runoff in the area (Institute of Water Research 1997). The weight of the machinery used to clear land compresses the soil and is a major reason for lower levels of transpiration, increased loss of dissolved nutrients, and decreased soil absorbency (Institute of Water Research 1997). Decomposed material left after clearing increases acidity and sedimentation in runoff

water (Institute of Water Research 1997). Eutrophication of water bodies occurs when storm water washes away the top layer of soil and frees debris. Increased acidity in the water can negatively affect biological diversity in the ecosystem (Institute of Water Research 1997).

Methods

Cleared land was classified from DOQs and represents cleared patches of forest that may or may not contain trails from skidders and logging roads (BI493 2003a). This distinction differed from agricultural land because cleared land was typically surrounded by forest and was not found in association with houses or barns (BI493 2003a). It was more difficult to distinguish cleared land in the 1956 aerial photos than it was in the 1998 DOQs because of the image quality.

Results and Discussion

The total area of cleared land increased from 77 acres in 1956 to 96 acres in 1998. There has been an increase of about 20 acres in this land use type over 42 years, a 24 percent increase from 1956. In both years, cleared land constituted less than 1.5 percent of the total land use in the watershed (Figure 28). All areas of cleared land seem to be small sections throughout the watershed and have varied in location over time. This suggests that there have not been any large logging operations in the watershed and that the same areas are not being cleared repetitively. The cleared land could be plots of land that are going to be used for development (Figure 25 and Figure 26). One major change between 1956 and 1998 is the absence of vegetated buffer between all cleared land and Threemile Pond present in 1998. This buffer reduces the effects of cleared land on Threemile Pond, by absorbing nutrients, preventing sediments from being washed into the water, and increasing the water quality.

AGRICULTURE

Introduction

Earlier this century, the Threemile Pond watershed was made up of cropland and pasture with very little untouched forest left in the area (Manthey per. comm.). This extensive agricultural use could have contributed to the eutrophication of Threemile Pond because agricultural practices can be very harmful to surface and ground water quality (University of Maryland 1999). Nitrogen and phosphorus loading are two major impacts from agricultural practices (University of Maryland 1999). Extra nitrogen

and phosphorus are added into the natural cycle from agricultural waste, manure and chemical fertilizers through surface runoff, and by seeping into ground water (University of Maryland 1999; see Background: Lake Characteristics).

Methods

The agricultural land use was composed of two separate categories: cropland and pasture. Cropland was defined as images of land that exhibit even rows, indicating planting, including hayfields on the DOQs. Pasture lands were defined as cleared land without crop rows and were distinguished from other cleared land by its proximity to cropland, roads, and nearby houses (BI493 2003a). Once identified, these two land use areas were combined into one group for three reasons. The images of the two land types can occasionally be difficult to distinguish depending on the resolution of the images. Cropland and pastures affect water quality in similar ways, mostly through nitrogen and phosphorus loading, and there were relatively small amounts of each in the Threemile Pond watershed (University of Maryland 1999). After the land use maps were completed, the changes in land use patterns between 1956 and 1998 were compared.

Results and Discussion

In 1956, the total area of agricultural land was 1,216 acres, comprised of 1,024 acres of cropland and 192 acres of pasture. The amount of agricultural land decreased to 767 acres in 1998 with 609 acres of cropland and 158 acres pasture. There was 37 percent less agricultural land in 1998 than there was in 1956, but compared to total watershed area, agricultural land only decreased from 18 percent in 1958 to 12.9 percent in 1998 (Figure 28). Agricultural areas were mostly concentrated in the northern and southern part of the watershed in both 1956 and 1998. The areas of greatest concern to the lake are a few pastures close to the shoreline just north of Threemile Pond (Figure 25 and Figure 26). Agricultural areas along the shoreline of Threemile Pond in 1956 were no longer present in 1998 (Figure 25 and Figure 26). A buffer between agricultural land and the lake allows some nutrients to be reabsorbed before the runoff flows into the Threemile Pond, which increases lake water quality. With proper agricultural methods and sufficient buffer, cropland and pasture should not significantly increase the nutrient loading of the Threemile Pond. Methods to help prevent runoff, erosion, and nutrient loss include minimizing tillage, stubble mulching, and contour cultivation (Ministry of Agriculture and

Forestry, New Zealand 2002). These practices can help reduce soil loss by 25 to 90 percent without affecting crop production (Ministry of Agriculture and Forestry, New Zealand 2002). If these agricultural areas were to go out of business, it would create an opportunity for more development, which permits more nutrient loss and prevents re-absorption than agricultural land (University of Maryland 1999).

COMMERCIAL AND MUNICIPAL

Introduction

Commercial land is land being used for businesses, such as restaurants, gas stations and car washes. Municipal land usually consists of schools, town halls, road maintenance facilities, or other areas being used by a city or town. Generally, large parking lots or other impervious surfaces are associated with commercial and municipal property. These areas prevent the absorption of water during storms, which can increase the amount of runoff and subsequent erosion. The activities of specific businesses may also add excess nutrients, heavy metals, and other forms of toxins to a watershed (Bowen et al. 1996).

Methods

All land in the watershed that was surrounded by large paved areas was classified as commercial and municipal on the 1998 land use map. Digital photos were taken of this area during ground-truthing (see Land Use: methodology).

Results and Discussion

There was no commercial and municipal land classified on the 1956 map (Figure 25). Some commercial land might have existed at this time, but it was not discernible on the aerial photo. On the 1998 map, however, there was a small portion of land (1.4 acres) designated as commercial/municipal (Figure 26). In ground-truthing, a municipal garage was discovered that was not found on the 1998 DOQ of the Threemile Pond watershed. It was not added to the area for our calculations, because it did not exist in 1998. The existing commercial land is not located on the lakeshore and comprises less than 1 percent of the total watershed area. It is unlikely that this commercial land has had a large impact on the eutrophication and degradation of Threemile Pond, because of its small size, distance from the shoreline and the DEP permitting process. If residential and recreational development increases in the

region, commercial and municipal development is likely to grow as well. Increased commercial and municipal development could be a future concern for the water quality of Threemile Pond.

RESIDENTIAL

Introduction

Residential land is defined as land occupied by houses. Any yard that is adjacent to a house, up to one acre, is also included in the residential designation. Open residential land was delineated in aerial photographs and DOQs of the 1956 and 1998 watersheds.

Methods

Non-shoreline, open residential land was classified as a house with an acre of open land surrounding it (Bouchard pers. comm.). This land type was discernible on both the 1956 and 1998 maps.

Many houses in the watershed were obscured on the aerial maps by trees. CEAT members performed two house counts to obtain a more accurate value for the acreage of residential land in 2003. The survey of lake front houses was conducted on 18-Sep-03 and the non-shoreline house survey was conducted on three days: 22-Sep-03, 25-Sep-03, and 9-Oct-03. No house counts were available for the 1956 watershed. Given more time, it may have been possible to obtain housing information for 1956. However, this study focuses on the present land use of the watershed, and looks at general development trends over time.

To calculate residential area, each shoreline house was assumed to have 0.5 acres, and 1.0 acre was allocated to each non-shoreline house (Bouchard pers. comm.). The total area resulting from the calculation was then subtracted from other land-use types (transitional forest, reverting land and wetlands) to keep the total watershed area consistent. All residential land determined by the house count was included in area calculations for the 1998 watershed (Figure 26). The actual watershed map itself was not changed; the land use polygons were not altered.

Results and Discussion

In 1956, there were 105.5 acres of open residential land. This comprised a small portion (2 percent) of the 1956 watershed (Figure 28). In 1998, there were 205.0 acres of open residential land. The total residential area of the watershed was calculated to be 458.5 acres from the 2003 house survey

data. This number is more than three times the area from 1956 (105.5 acres) and represents a more significant portion (7 percent) of the watershed (Figure 28).

There were multiple causes that contributed to the increase in residential land area. First, a current residential survey was conducted, which allowed CEAT to identify many more houses than were visible on aerial photographs. It was also possible to obtain more accurate values for the more recent watershed map because of higher map resolution and house survey data. The resolution of the aerial photo from 1956 was poor and no past house counts were available. It can be determined that there has been an increase in residential development in the watershed since 1956. Even without including the residential area from the house counts (which was not fully evident on the 1998 map), there was almost twice as much residential area in 1998 as in 1956. This shows a trend toward increasing residential development in the Threemile Pond watershed.

This trend is supported by data from the Maine state census: the population of Kennebec County increased from 83,881 in 1950 to 117,114 in 2000 (Fogler Library 2002a). The populations of the towns in the watershed have increased as well. The population of China rose from 1,375 in 1950 to 4,106 in 2000. The population of Vassalboro increased from 2,261 to 4,047 in the same time period. The population of Windsor grew from 740 in 1950 to 2,204 in 2000 (Fogler Library 2002b). These trends illustrate a substantial increase in residential development in the Threemile Pond watershed between 1956 and 1998. (See Future Predictions: Population Trends for more information).

RESIDENTIAL SURVEY

Shoreline Zoning

Regulations

Development near the shore of water bodies can have a negative effect on water quality. Shoreland development can lead to increased soil erosion, road runoff, and septic inputs increasing the nutrients and sediments in the water body. In 1974, the MDEP enacted the Mandatory Shoreland Zoning Act to prevent water pollution and damage to the natural beauty and habitats provided by lakes, ponds, rivers, streams and freshwater wetlands (MDEP 1997). The act requires towns to adopt and enforce a shoreland zoning ordinance that is in accordance with the State of Maine Shoreland Zoning Regulations (MDEP 1997). Every town in Maine is required to enact an ordinance that is at least as strict as the state regulations, but each town has the freedom to enforce stricter regulations. The regulations apply to all

areas within 250 ft of the normal high water mark of all lakes, great ponds, rivers, and freshwater wetlands. The ordinance also includes areas within 75 ft of streams. The shoreland zoning ordinance is enforced by the town through the efforts of the code enforcement officer and the planning board (MDEP 1997). The towns of China, Vassalboro, and Windsor have adopted the State of Maine regulations with a few adjustments. Vassalboro created stricter regulations for septic systems and China implemented a Phosphorus Control Ordinance (Town of China 2003, Town of Vassalboro 2003). These regulations will be discussed later in this section. The Town of Augusta includes only a small part of the watershed distant from the shoreline of Threemile Pond and will not be considered further.

1. Residential Units

The zoning regulations for residential units in the shoreline zone are the same for all towns in the Threemile Pond watershed. Structures are required to be setback from the shoreline a minimum of 100 ft (horizontal distance) from the shoreline. The minimum shore frontage for a proposed lot is 200 ft with a minimum area of 40,000 ft^2. Structures are allowed to be a maximum height of 35 ft. In addition, all structures and non-vegetative surfaces including driveways and parking lots may not cover more than 20 percent of the lot (Town of China 2003, Town of Vassalboro 2003, Town of Windsor 2003).

2. Resource Protection Districts

Certain areas within the Threemile Pond watershed are considered Resource Protection Districts. Resource Protection Districts are areas where new development would adversely affect water quality, productive habitat, biotic systems, or scenic and natural values (Town of China 2003, Town of Vassalboro 2003, Town of Windsor 2003). Development is prohibited within 250 ft of the shoreline in Resource Protection Districts. These areas include: 1) freshwater wetlands that are rated as having moderate or high levels of significant wildlife habitat by the Department of Inland Fisheries and Wildlife, 2) 100-year flood plains along rivers, 3) areas with two or more acres of wetland vegetation not connected to a water body, and 4) areas of two or more acres with slopes of 20 percent or greater (Town of China 2003, Town of Vassalboro 2003, Town of Windsor 2003). The Resource Protection Districts in the Threemile Pond watershed can be found according to town on the Land Use District Maps located in the town offices.

3. Buffer Strips

Buffer strips along the shoreline are an important part of shoreline protection. China, Vassalboro, and Windsor require that a vegetated buffer strip of 100 ft (horizontal distance from the high water mark) be preserved for all properties adjacent to Threemile Pond (Town of China 2003, Town of

Vassalboro 2003, Town of Windsor 2003). In addition, the clearing of an opening greater than 250 ft along the shoreline in the shoreland zone is not permitted.

4. Septic Systems

Septic waste disposal regulations vary between towns. Each town requires that all subsurface sewage disposal systems must be installed in compliance with the State of Maine Subsurface Waste Disposal Rules (Town of China 2003, Town of Vassalboro 2003, Town of Windsor 2003). New septic systems must be no less than 100 ft from the normal high water mark. As of 31-Dec-95, Vassalboro required owners to provide documentation that their septic system was installed after 1-Jul-74, or install a new system (Town of Vassalboro 2003). Other regulations pertaining to campgrounds, parking areas, roads and driveways, agriculture, and clearing of vegetation that are outlined in the State of Maine Shoreland Zoning Regulations also help to regulate water quality.

5. Non-conforming uses

Non-conforming (grandfathered) structures, lots and uses that do not meet the current regulations are allowed to continue if they existed before the effective date of the Mandatory Shoreland Zoning Act in 1974, with the exception of septic systems in the Town of Vassalboro. Much non-conformity occurs because prior to 1974, there were not house setback or buffer regulations in place. Conditions of non-conforming uses that are allowed include: 1) the transferal of non-conforming structure, lots and uses, 2) the normal upkeep and maintenance of non-conforming uses and structures, 3) the expansion of non-conforming structures up to 15 percent of the current volume of the floor area of the structure (must be expanded away from the shoreline if it does not meet the 100 ft setback rule), and 4) the change of a non-conforming use to another non-conforming use if the proposed use has no greater negative impact (Town of China 2003, Town of Vassalboro 2003, Town of Windsor 2003).

6. Phosphorus Ordinance

China created a Phosphorus Control Ordinance to control the amount of phosphorus going into Threemile Pond and China Lake from all new development in the Threemile Pond and China Lake watersheds (Town of China 2003). This ordinance does not pertain to any structure or land use that was in use before the establishment of the ordinance on 5-Jun-93. The ordinance states that all structures and land uses must meet the phosphorus export standards of not more than 0.013 pounds of phosphorus/acre/year for the Threemile Pond watershed (Town of China 2003). Applicants for single-family dwellings and subdivisions must show how they will comply with the phosphorus export standards. For a new single-family dwelling the width of the buffer strip must be between 50 and 100 ft depending

on lot size (Town of China 2003). Subdivisions must provide a plan showing the location and dimensions of buffer strips and their maintenance in accordance with the Phosphorus Control Guide of the DEP (Town of China 2003).

Results

During the buffer strip survey performed on 18-Sep-03, the Colby Environmental Assessment Team (CEAT) observed a great number of houses along the Threemile Pond shoreline that did not meet the above regulations. Many of these houses did not meet the minimum shoreline setback regulations and/or they did not have suitable buffer strips. This is most likely due to the fact that these residences were built before 1974 when the Mandatory Shoreland Zoning Act was adopted. These residences are considered grandfathered and have no obligation to comply with the ordinance (Town of China 2003, Town of Vassalboro 2003, Town of Windsor 2003). However, when there is a need to replace these residences, each new residence will have to meet the new regulations. The construction of new complying residences may help cut down on runoff and nutrient loading into Threemile Pond and in turn, may improve water quality. However, expansion of the structures allowed within the guidelines may increase the adverse effects of these residences.

House Count

Introduction

CEAT conducted a road and shoreline survey of houses in the Threemile Pond watershed. The main goal of the survey was to determine the intensity of residential development in the Threemile Pond watershed and most importantly, the development along the shoreline. Due to the proximity to Threemile Pond, development along the shoreline has the biggest impact on the water quality. In assessing the impact of each house, whether the house was seasonal or year-round was recorded to determine the difference between summer and winter external phosphorus loading from septic systems and regular house use.

Methods

The number of houses in the Threemile Pond watershed was counted using two methods. The shoreline houses were counted by boat during the buffer strip survey conducted on 18-Sep-03. A shoreline house was classified as such if it was located within 200 ft of the normal high water mark of the lake. The non-shoreline houses were counted during the road survey conducted on 22-Sep-03, 25-Sep-03

and 9-Oct-03 (see Appendix J). Surveyors classified houses as seasonal or year-round based on certain features. Features suggesting seasonal residency included the presence of an open foundation, a dirt driveway, or a pit privy. Features such as the presence of a closed foundation, a chimney, storm windows, a paved driveway, or an external oil tank suggested a year-round home. Due to the subjectivity in the classification of year-round and seasonal homes, some homes may have been improperly classified. Most likely, seasonal homes were mistakenly classified as year-round. The houses were grouped according to town to show a comparison of the residential development in each town. This classification was accomplished using GIS technology, by overlaying a road map with the town lines. Other commercial and municipal buildings in the watershed were also recorded.

Results and Discussion

In the Threemile Pond watershed, CEAT found a total of 560 houses. Two hundred and three of these houses (36 percent of the total houses) are considered shoreline, and 357 (64 percent) are non-shoreline. Of the shoreline residences, 136 (67 percent) are seasonal and 67 (33 percent) are year-round. In the non-shoreline zone, 351 houses (98 percent) are considered year-round, while only six (2 percent) are seasonal. The total number of seasonal houses within the entire watershed is 142 (25 percent of the total houses). There are 418 year-round houses (75 percent of the total houses). Other buildings and land uses that were recorded include two gas stations, a car wash, a car repair garage, a motel, two sand and gravel pits, and five small farms.

CEAT found that there are more non-shoreline houses than shoreline houses in the Threemile Pond watershed. However, the concentration of shoreline houses is much greater. The perimeter of the lake is 52,400 ft; if the houses were evenly spaced, there would be one house every 258.2 ft. The shoreline of Threemile Pond has been densely developed with only a few sections of natural vegetation still left intact. The most densely developed areas are along the western, northern and northeastern boundaries of the lake. The southeastern shoreline of the lake has very little development. The majority of the houses found along the shoreline are too close to the water and have poor buffer strips, factors which have a negative effect on lake water quality. Sixty-seven percent of the houses along the shoreline are seasonal, implying that there is a concentrated increase in septic system and road use during the summer months. This increase in use leads to increased sediment and phosphorus loading into Threemile Pond in the summer. Some of the seasonal houses along the shoreline are being converted to year-round homes. Though the newly year-round houses will contribute phosphorus and sediments to Threemile Pond all year, the septic systems of these homes must be in accordance with the State of

Maine Subsurface Waste Disposal Rules (Town of China 2003, Town of Vassalboro 2003, Town of Windsor 2003).

House count data for each town is shown in (Table 8). China has 210 houses (38 percent of the total houses). Vassalboro has 155 houses (28 percent of the total houses). Windsor has 174 (31 percent of the total houses). Augusta has only 21 houses (3 percent of the total houses) located a far distance from the lake in the southwest corner of the watershed, causing minimal impact to Threemile Pond. China has the largest amount of shoreline with 26,259 ft (50 percent of the total shoreline). Vassalboro has 11,087 ft of shoreline (21 percent) and Windsor has 5,159 ft (29 percent). Vassalboro has 74 houses and China has 82 houses along the shoreline, together comprising 77 percent of the total number of shoreline houses. Although Windsor has the second largest shoreline land area, it has only 47 shoreline houses. The shoreline of Vassalboro is the most developed while Windsor has, by far, the least amount of development.

Table 8. Total House Counts for the Threemile Pond watershed. Data collected during the buffer strip survey conducted on 18-Sep-03 and during the road survey conducted on 22-Sep-03, 25-Sep-03, and 9-Oct-03 by the Colby Environmental Assessment Team.

	Shoreline		Non-Shoreline		
Town	**Seasonal**	**Year-Round**	**Seasonal**	**Year-Round**	**Total**
Augusta	0	0	0	21	21
China	44	30	4	132	210
Vassalboro	63	19	2	71	155
Windsor	29	18	0	127	174
Combined	**136**	**67**	**6**	**351**	**560**

Buffer Strips

Introduction

Homes in close proximity to the shoreline can have large impacts on lake water quality. Disturbed natural vegetation, impervious surfaces, landscaping, and increased exposed soil can lead to erosion and increased sediment and nutrient runoff into the lake.

Properly designed buffer strips are a practical and economical method of minimizing nutrient runoff. They are an essential component of lake water quality improvement programs because they prevent phosphorus-laden sediment from entering the water. Other benefits of buffer strips include: adding privacy, providing habitat for wildlife, protecting property from harsh weather, decreasing landscaping and maintenance expenses, and increasing property values (Welch MDEP; see Background: Buffer Strips).

Ideal buffers stretch across the entire length of the lot's shoreline, have a depth of greater than 65 feet, and incorporate a mix of forbs, shrubs, and trees. A buffer comprised of diverse tree and shrub species will stabilize soil and capture phosphorus-rich nutrient runoff with the combination of deep and shallow lateral root systems. Trees are important components of buffer strips because their leaves slow rainfall, protecting soil from raindrop erosion (see Background: Buffer Strips).

Homeowners can easily create their own buffers. One of the best ways to begin buffering a property is to stop mowing the lawn to the shore. A swath of vegetation will grow naturally, saving time and expensive lawn maintenance as well as fertilizer and pesticide use. Allowing depressions and irregularities to remain in lawns and landscapes absorbs excess water. Landowners should also minimize bare areas and impervious surfaces such as driveways (Welch MDEP). Information for building buffer strips and minimizing phosphorus runoff is available through the Maine Department of Environmental Protection and the town offices of China, Windsor and Vassalboro.

Methods

A survey was conducted on 18-Sep-03 by the Colby Environmental Assessment Team (CEAT) to analyze the quality of residential buffer strips around Threemile Pond. Four CEAT boats assessed buffers by navigating around the perimeter of the lake. All groups used a survey form developed by CEAT (see Appendix H). At each property, GPS coordinates were recorded using a Garmin GPS unit. Survey categories included: percent of lakeshore lot length with buffer coverage; buffer depth from shoreline; slope between the house and shore; buffer composition (relative percentage of trees and shrubs) and the need for riprap. Riprap is a layer of fabric and rock that helps protect shoreline from erosion by wave action (see Background: Buffer Strips).

Buffer strips were graded on the basis of their components on a scale of 0 to 100. The worst possible score was zero; a house with a score of 100 had a high quality buffer strip capable of significantly mitigating phosphorus and sediment loading into Threemile Pond.

To receive a grade of good a home must have earned at least 75 of the possible 100 points in the buffer survey. A good buffer would stretch across at least 75 percent of the shoreline lot, have a depth greater than 65 feet, and be composed of both trees and shrubs. A fair buffer earned 60 to 74.5 percentage points in the CEAT survey. For example, a buffer in this category might have had a deep buffer with diverse, thick species of vegetation but only stretch partway across a lot. A poor buffer earned 40.0 to 59.5 percentage points. To earn this rating, a buffer was usually deficient in two of the three categories: composition, percent shoreline length and depth from shore. Any score below 40 percent represented a buffer strip that failed to meet minimum requirements for mitigating phosphorus runoff. For example, a buffer with a score of 24 percent had less than 25 percent of the lot shore length covered, a buffer depth of less than 11 feet and was made entirely of trees.

Results and Discussion

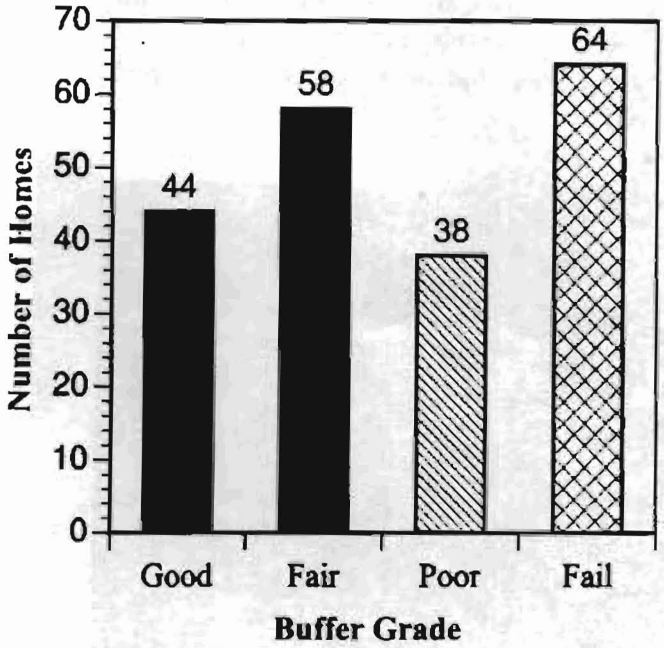


Figure 29. Buffer strip scores for shoreline properties in Threemile Pond watershed. Survey conducted 18-Sep-03 by Colby Environmental Assessment Team

A total of 203 properties were surveyed. Of these lakeshore residences, 44 buffer strips were classified as good, 58 were fair, 38 buffers were poor, and 64 failed. (Figure 29)

Figure 30 is representative of lots receiving a grade of fail from CEAT's buffer strip survey. The lawn stretches to the shore and no substantial vegetation separates the home and the water. Figure 31 illustrates a well buffered home. Riprap has been laid on the bank and the buffer is a thick mix of shrubs and trees resembling a natural forest. Ideally, this home would be set back further from the shore, but given its location, the homeowner has maintained a functional buffer strip

The information compiled from this survey provided the basis for the GIS buffer survey map (Figure 32). The map shows the location of the 203 homes on the lake and their respective score. Buffer strips with lower scores were sometimes clustered around more developed areas. The arrows on the map point to areas with a dense development and a high concentration of inadequate buffers. These areas are: in China along Park Lane; in the

northern region of the lake, south of the town center of South Vassalboro; and on Threemile Pond's steep western shore.

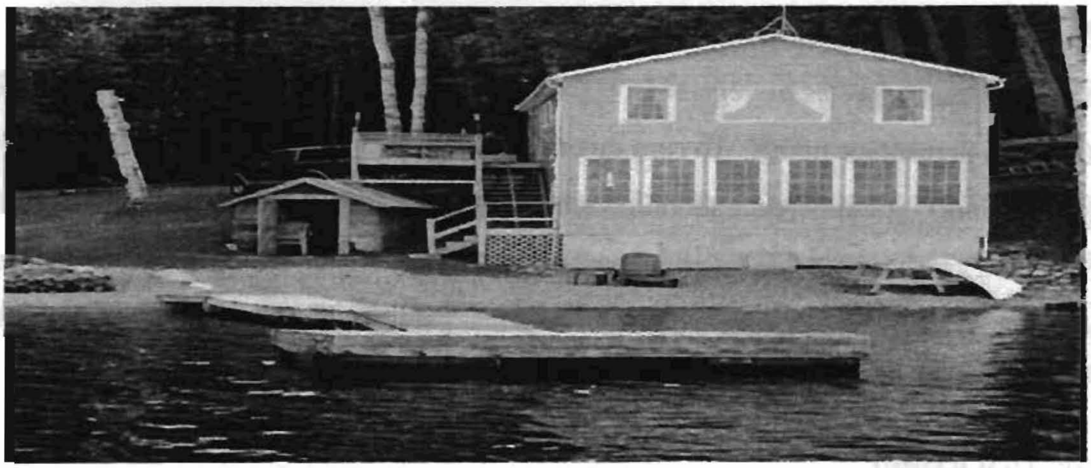


Figure 30. Photo of a poorly buffered home. The lawn is mowed to the shore and there is an artificial beach. There are no trees or shrubs between the home and the lake to take up phosphorus-laden runoff. Furthermore, the lawn is sloped and lacks natural depressions to absorb water.

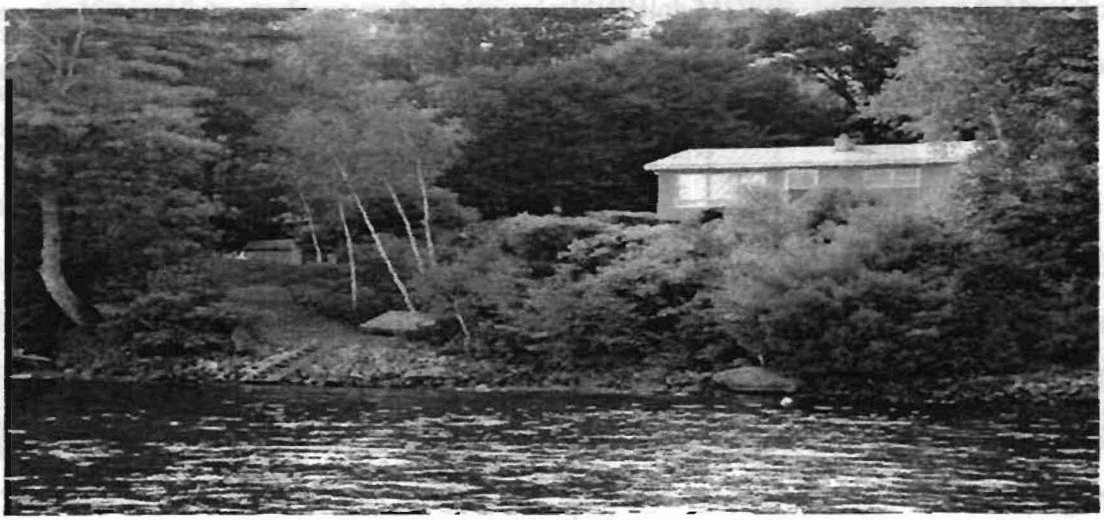


Figure 31. Photo of a well-buffered home. There is riprap and a mix of shrubs and trees. Ideally, this home would be set back 250 feet from the shore. However, the structure was built before Maine s Shoreline Zoning Ordinance took effect and is presently exempt from set back regulations (MDEP 1997).

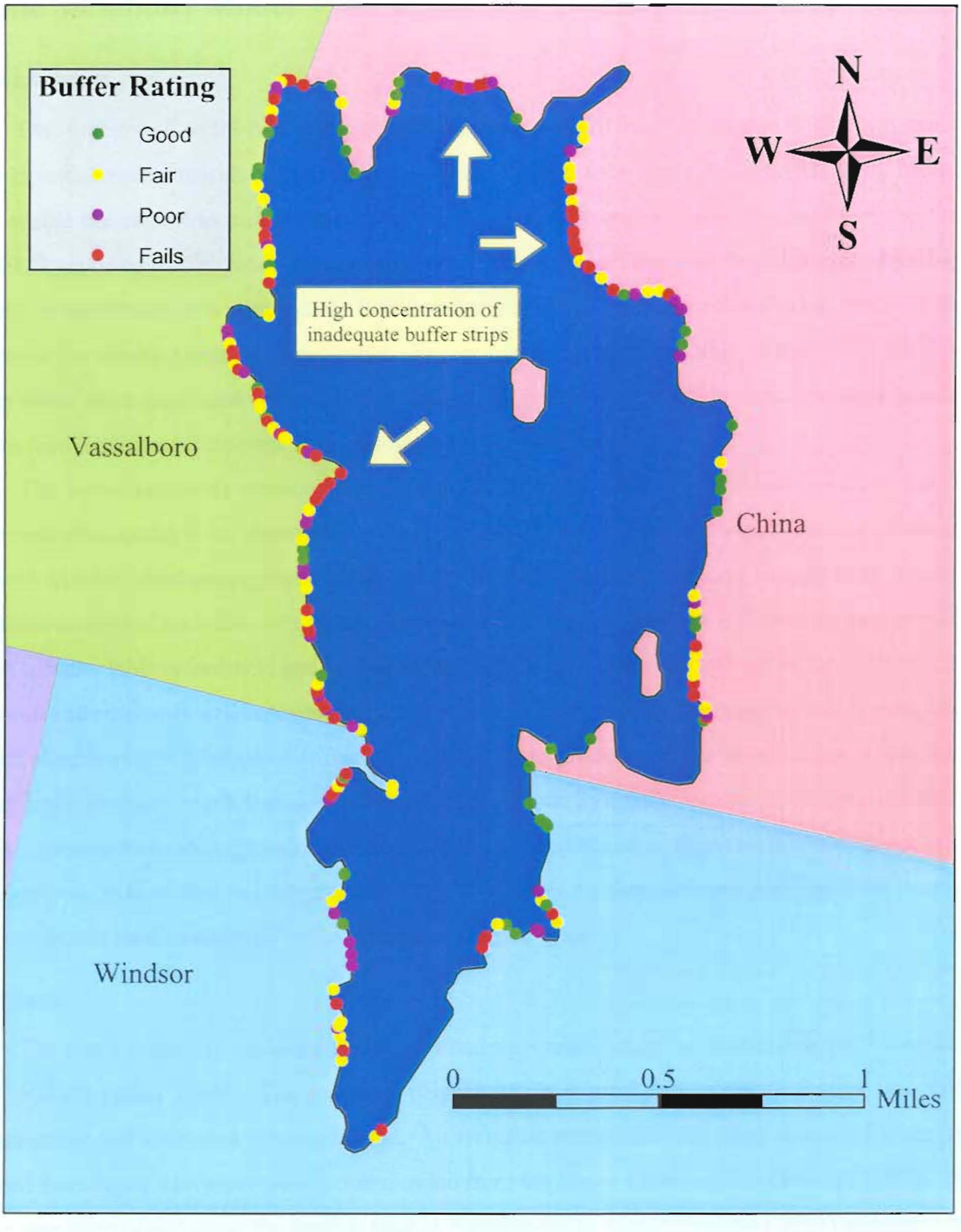


Figure 32. Buffer evaluation map for Three Mile Pond. Buffer evaluation determined by buffer survey on 15-Sep-03. Points correspond to house lots. Watershed, lake, and townline themes obtained from the Maine Office of GIS (MEGIS 2003).

Septic Suitability Model

Introduction

One function of a GIS is to interpret multi-faceted, abstract data and display this information in simple, visual models that allow particular attributes of the data to be highlighted (ESRI 2001). Models also enable the creator to utilize the various inputs in order to make predictions based on the final model. A septic suitability model was included in CEAT's study ofThreemile Pond because of the high density of residences in the watershed. Septic waste is a form of point source pollution, meaning that the pollution can be located and mitigated. Excess nutrients are more likely to leach into the pond when septic tanks are placed in soil that is unsuitable for processing the waste and are located on steep slopes (see Background: Sewage Disposal Systems: Septic System).

The septic suitability model combined the soil map (see GIS: Soil Map) with a slope map to determine which areas in the watershed are more capable of processing septic waste. The soil properties considered when determining septic suitability are its ability to absorb effluent as well as its capacity for construction and operation of a septic system (USDA 1978). Absorption is altered by permeability, depth to water table or bedrock, and susceptibility to flooding. The slope influences the potential risk of runoff and erosion as well as layout and construction feasibility. Slow permeability and uncontrolled runoff of soils may severely detract from a soil's ability to process sewage effluent from septic tanks effectively (see Background: Sewage Disposal Systems: Septic Systems). Awareness of septic suitability when planning future development and renovations can contribute to the overall health of the lake. Mitigation techniques such as adding or removing soil to alter the slope and permeability of the location can rectify unsuitable sites prior to installment of a septic system.

Methods

The septic suitability model for Threemile Pond was created using the Spatial Analyst™ extension of ArcGIS™ (ESRI 2001). The soil map (Figure 24) was produced in vector format (see GIS: Introduction) and converted to raster format. An elevation map of the watershed in raster format was created from digital elevation models downloaded from the Maine Office of GIS (MEGIS 2003). The slope was interpolated using the Spatial Analyst™ extension in ArcGIS™ (ESRI 2001) and the slope map was created with a resolution of 25 meters per pixel. Conversion to a common suitability scale of was necessary to permit the addition of the two inputs: soil map and slope map. The nine interval scale chosen for this study matches the 2002 CEAT study of Webber Pond to facilitate a comparison between

both lakes (BI493 2003a). Dividing the steepest slope of 27.6 meters by nine created nine slope intervals, which were put on a 1 to 9 scale with 1 representing the lowest slope and 9 representing the steepest slope.

The soil map (Figure 24) was classified based on the septic limitations of each soil and categorized on a 1 to 9 scale to match the slope map. Each soil has an associated septic limitation classification which reflect its ability to process septic waste. Classifications of *slight, moderate,* or *severe,* are designated for each soil type by the Kennebec County Soil Survey (Table 9; USDA 1978). To create a numerical scale from these values, soils designated as *slight* were equated to a value of 1, *moderate* were given a rank of 5, and a numerical value of 9 was assigned to *severe* soils. *Slight* indicates a desirable soil that has few or no limitations for septic system instillation (USDA 1978). In *Moderate* soils, an obstacle (such as a large rock) exists that would limit the ability of the soil to process septic waste, but remediation may improve the soil's ability to process waste (see Background: Sewage Disposal Systems: Septic System). *Severe* soils are limited by the severity of their obstacles, which are difficult or impossible to mitigate.

Table 9. Characteristics of soil types used in the septic suitability model and the erosion potential model. For the septic suitability, a severe classification was given a 9, moderate classification a 5, and slight classification a 1. The K values were used in the erosion potential model, representing the erodibility of the soil, and were classified on a one to nine scale using the Spatial Analyst extension in Arcmap.

Soil Series	Septic Suitability	K Value
Colton	Slight	0.18
Hinkley	Slight	0.20
Windsor	Slight	0.17
Hartland	Moderate	0.49
Marlow	Moderate	0.24
Brayton	Severe	0.27
Brayton-stony	Severe	0.20
Buxton	Severe	0.32
Lyman	Severe	0.28
Lyman-stony	Severe	0.20
Marlow-stony	Severe	0.20
Nicholville	Severe	0.49
Peru	Severe	0.20-0.24
Scantic	Severe	0.32
Togus	Severe	0.00
Vassalboro	Severe	0.00
Biddeford	Severe	0.00

Figure 33 illustrates the inputs, functions, and outputs of the weighted overlay that produce the septic suitability model. The intermediary maps are weighted by their varying contributions to septic suitability. Slope was given a weight of 66 percent, signifying that it is a relatively large determinant in septic suitability. Soil type, a less influential factor, was weighted 34 percent (BI493 2003a). The weighted, reclassified values were added using the Spatial Analyst™ raster calculator to produce an output grid of septic suitability that represents the most appropriate areas to install septic

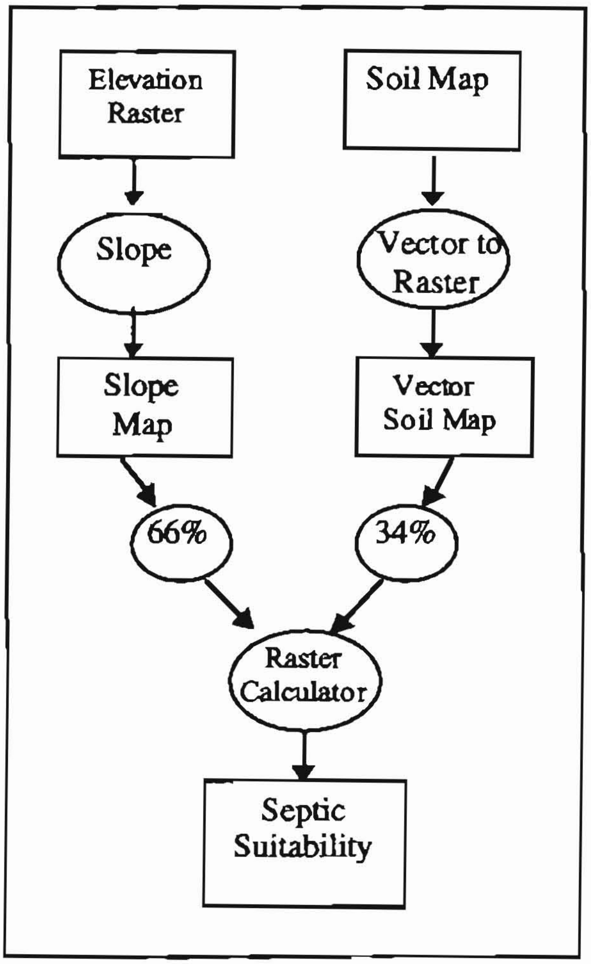


Figure 33. Flowchart visualizing the intermediary steps taken to create the septic suitability model. The weighted overlay is shown by the shaded circles representing their relative contribution. Because septic suitability is influenced more by slope than soil type, slope was given a weighting of 66%. The figure was adapted from ArcView® ModelBuilder (ESRI 2000a).

systems. Manipulating each of the input maps to their optimal resolution resulted in great detail of septic suitability to a resolution of 10 meters per pixel.

Results and Discussion

The model shows nine classes of suitability, 1 being the most suitable and 9 being the least suitable location for septic development (Figure 34).

Using the model, CEAT calculated the mean septic suitability of 2.12, making the watershed as a whole quite suitable for processing the extra demands septic systems can place on the watershed. This is most likely due to the moderate elevation and subsequently lower slopes within Threemile Pond watershed.

The three most unsuitable rankings (7 and greater) were added and divided by the total area of the watershed to determine that less than one percent of the watershed has highly unsuitable conditions for septic systems. Highly suitable values of 3 and less account for 84 percent of the watershed. In comparison, a CEAT septic suitability model of Webber Pond determined that 99 percent of Webber Pond watershed is moderately to least suitable for septic systems (ranking of 4 or above); only 16 percent of Threemile Pond watershed is classified moderately to least suitable (BI493 2003a).

Visual analysis of the Threemile Pond model shows that the degree of suitability is not distributed evenly throughout the watershed (Figure 34). The least suitable areas of the watershed are found along the shoreline. The model shows that the southern area of the watershed that lies in Windsor is very suitable to process human waste. The western shoreline of Mud Pond in the southwest corner of the

watershed is highly unsuitable to septic system installation. The slope of the southwest shoreline is very steep, and with the weighted overlay emphasizing slope, this shoreline would be unable to deter waste from entering the lake. Additionally, the soil type on the western shoreline is Bruxton-Stony, classified as having *severe* limitations for septic systems (see GIS: Soil Map).

Another area of concentrated unsuitability to septic development is the middle of the western slope of Threemile Pond in Vassalboro where the camp road, Park Lane, parallels the lake (Figure 34; see Land Use Patterns in the Watershed: Roads). Septic tanks in this problematic area should be efficiently processing the septic waste due to a 1996 regulation that required replacement of all septic systems installed in Vassalboro before 1974 (see Land Use Patterns in the Watershed: Subsurface Disposal Systems). There is a high density of homes on this section of the shoreline, concentrating the number of septic tanks and volume of waste that must be processed by the soil (Figure 32).

The most common soil types in the wetlands of Threemile Pond watershed are Biddeford, Togus and Vassalboro (see GIS: Soil Map), all of which have *severe* classifications for septic suitability (Table 9). The septic suitability model (Figure 34) shows these areas to have high septic suitability because of their very low slopes. To visualize the low suitability of wetlands for septic processing accurately, a wetland theme was added to the model.

The model may help managers consider the effects of future development and septic system installation on the overall health of the lake. Areas of unsuitable classification may be mitigated (see: Background: Sewage Disposal Systems: Septic System) before installing a septic system to make the site more suitable. Development of septic systems in unsuitable locations without appropriate mitigation will further contribute to impaired water quality and the annual algal blooms in Threemile Pond.

Subsurface Disposal Systems

Introduction

Using natural processes, subsurface wastewater disposal systems can be effective, low-impact methods of managing wastewater. Subsurface wastewater disposal system is a general term that includes pit privies, holding tanks, and septic systems. This study focused on septic systems, the predominate method of disposing domestic wastewater in the Threemile Pond watershed. In a properly functioning septic system, wastewater from the shower, washing machine, toilets, and kitchen is collected in a large holding tank. Solids fall to the bottom of the tank, while grease and suds rise to the top (Welch MDEP). Bacteria break down the solid waste. After a settling period, the liquid moves through a series of

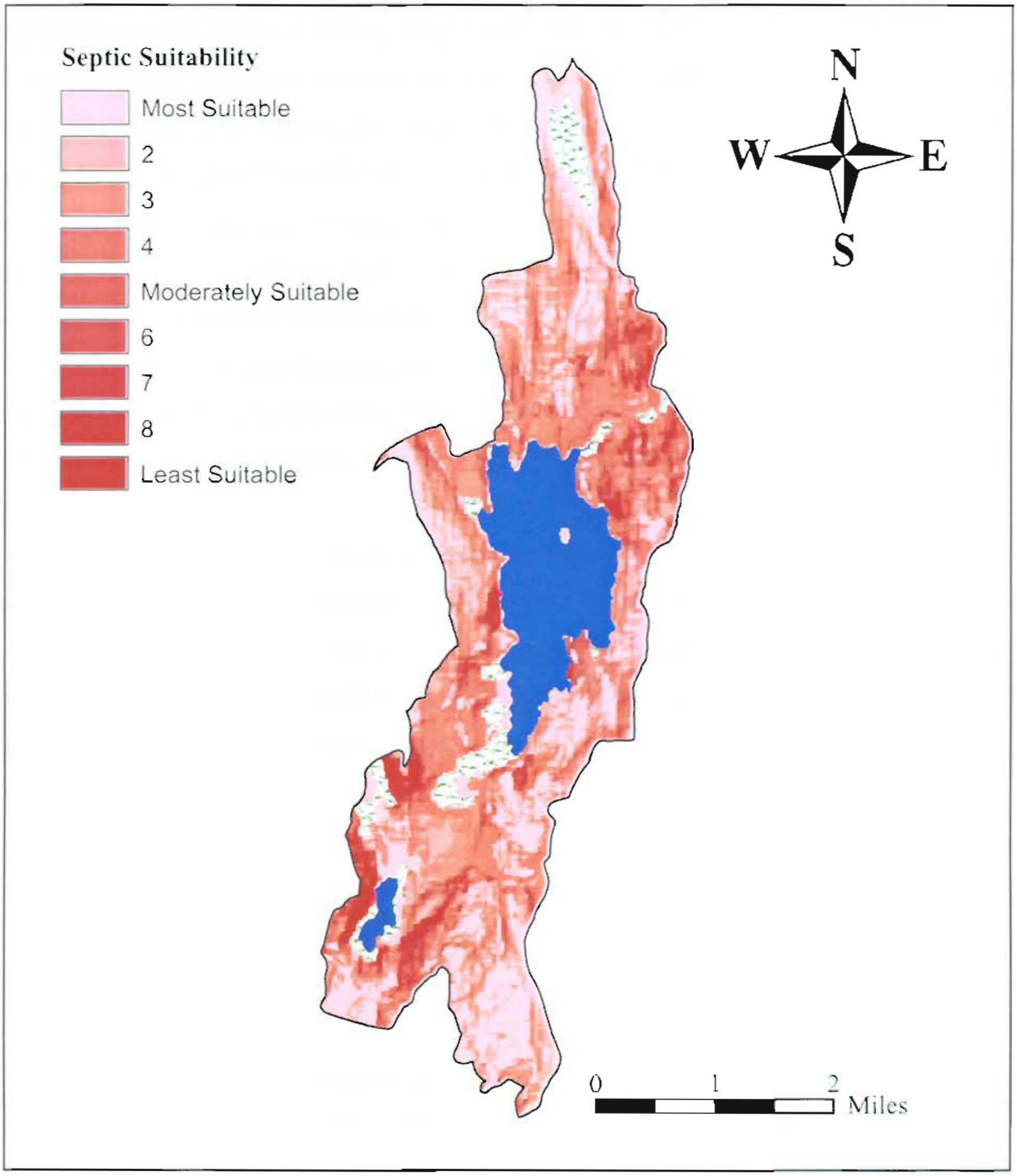


Figure 34. Septic suitability in Threemile Pond watershed. High suitability indicates areas where a septic system would most likely function effectively. Areas classified moderate and least suitable may require mitigation for a septic system to function properly. Areas with the green and white coloring indicate wetlands and are unsuitable for septic systems. Lake and wetland themes were obtained from the Maine Office of GIS (MEGIS 2003).

perforated pipes in the leach field. Here, the harmless, nutrient-rich water slowly seeps into the soil (Welch MDEP; see Background: Sewage Disposal Systems- Septic Systems).

If improperly maintained, the water may pass through the septic tank without being adequately treated by the bacteria. If it passes too quickly through the leach field, untreated microorganisms, phosphorus and nutrients can be forced into the soil and water. This effect is exacerbated when the soil is only marginally suited to accommodate septic systems. Optimal septic systems are buried in large beds with moderately permeable soil and not located on a steep slope (see Watershed Land Use Patterns: Septic Suitability). The combined effects of inadequate and improperly functioning septic systems in China, Vassalboro, and Windsor have impacted water quality in Threemile Pond negatively (Fitzgerald pers. comm.). Augusta represents about 2 percent of the Threemile Pond watershed and none of the shoreline. Septic systems for Augusta homes contribute a negligible amount of phosphorus to Threemile Pond.

Septic systems are designed to accommodate the wastewater load from a predetermined number of users. During a home renovation or expansion, a septic system should also be upgraded. There is a link between lake health and overall septic system integrity; homeowners have a responsibility to maintain their respective subsurface disposal systems. Residents in the Threemile Pond watershed can improve lake water quality and lower septic expenses by:

- Pumping the septic tank when appropriate.
- Installing a septic system that is the appropriate size for the number of users.
- Conserve water to reduce the volume of waste that the septic system must assimilate.
- Composting food waste that can load a septic system with solids that are difficult to break down
- Not pouring bleach or other antibacterial substances down the drain in quantities that would impact the bacteria breaking down waste.

Town leaders and state officials could:

- Encourage MDEP grant and/or low-interest loan programs to help residents replace failing and outdated systems.
- Mandate that homeowners prove that all septic systems are new and efficient as of 1974.
- Educate citizens on the importance of proper septic system function (Welch MDEP).

Results and Discussion

After they are installed, a Code Enforcement Officer or Plumbing Inspector does not regularly inspect most septic systems in the Threemile Pond watershed. The permitting process for a new septic system is rigorous; a Code Enforcement officer will generally visit a construction site three times before the building is complete. Once the tank is in the ground, it is the homeowner's responsibility to maintain it. Unless the system failure is so severe that neighbors call and complain, the Code Enforcement Officer (CEO) would probably never know about it (Fitzgerald pers. comm.).

The Code Enforcement Officer for the Town of China noted that the shoreline septic systems in China's portion ofThreemile Pond needed work. Many septic systems are old and do not meet the minimum setback standards for new constructions (Pierz pers. comm.).

Many of Windsor's lakeshore septic systems are grandfathered and outdated as well (Pierz pers. comm.). Lacking adequate regulations, many of these systems are old, leaky and too near the shore. Most shoreline septic systems in Vassalboro are in compliance with the town's controversial regulation requiring the replacement of all pre-1974 septic systems (Manthey pers. comm.). Consequently, some of Vassalboro's worst systems were replaced relatively recently. However, the average septic system is only designed to function for 20 to 30 years. After that point, the soils may become saturated with nutrients and the ground loses its ability to filter the effluent. Some of Vassalboro's systems have already saturated the soil with nutrients and consequently, do not work well (Manthey pers. comm.).

Several pit privies were observed around Threemile Pond during buffer strip and road surveys. Pit privies can be low-impact methods of waste disposal provided they are used infrequently and set back from the lake in moderately permeable soil (see Background: Watershed Land Use: Sewage Disposal Systems). There is limited financial aid available annually through the State to replace severely failing septic systems in situations where homeowners cannot afford the repair. Every year, Maine provides sufficient funding to replace a handful of septic systems that are likely to be impairing the Threemile Pond watershed.

<u>ROADS</u>

Introduction

Camp road maintenance is one of the most important factors in protecting a watershed from sedimentation and eutrophication. There are several factors that contribute to the high impact that

camp roads can have on lakes; the most important influence is road surface. The two general surfaces are asphalt (paved roads) and sand and gravel (camp roads). Paved roads affect watersheds by contributing runoff from winter sand and salt usage. Dust and sediment can also be easily washed off of this impenetrable surface into lakes and streams (see Background: Roads). The two most significant concerns with paved roadways in the Threemile Pond watershed are the paved driveways and major highways that are closest to the lake. Since unpaved camp roads are a much greater concern in regards to lake health, the study conducted by CEAT focused on assessing these roads and making recommendations for their remediation. Camp roads are primarily constructed out of sand and gravel, which includes particles of sediment. These particles can do great damage to a watershed when washed out of the road surface and carried into a lake or stream as storm water runs down the roadbed (KCSWCD 2000). Sediment fills in lakes, decreases clarity, and increases phosphorus levels (see Background: Phosphorus). The influx of sediment from roads increases where there are steep slopes, erosion of the roadbed, and roads that are not well crowned or graded (Figure 35).

There are techniques of road maintenance that can be used to help to properly divert water off of the surface and ensure that sediment either stays in the roadbed or is washed into the woods. Wooded areas can mitigate runoff by absorbing phosphorus particles attached to the sediment (KCSWCD 2000; see Background: Buffer Strips). The most important of these maintenance methods include proper grading and crowning, stable, correctly shaped ditches, diversions such as water bars and culverts, wooded turnouts, and buffers (KCSWCD 2000).

Methods

In the road surveys conducted by CEAT on 22-Sep-03 and 09-Oct-03, teams qualitatively assessed each road, observing the road surface, crown, erosion, and slope. Quantitative measurements of length and width were taken to calculate total acreage of roads in the watershed. Road survey teams used GPS units to record specific problem areas. The number and severity of the problem(s) on the road in relation to the acreage of the road determined if the road received a rating of good, acceptable, fair, or poor (see Appendix G). A good road had no problems identified, an acceptable road had only minor problems, a fair road had a few significant problems, and a poor road had many significant problem areas identified by CEAT. The qualitative and subjective nature of the rating system requires some additional verification. With this information, CEAT identified the most severe problems, and determined

Figure 35. This photograph illustrates the erosion that can result from runoff that is not properly diverted off the roadbed. Notice the berm that prevents water from flowing into the buffer area, and the lack of vegetation in the ditch to facilitate runoff absorption (BI 493 2003).

the total contribution that the roads in the watershed make to the phosphorus budget (see Phosphorus Budget).

Crowning and grading are the first defenses in preventing water from running down a roadway (see Background: Roads). A flat road with a smooth surface and a crown that rises 1/2 inch for each foot of road width is acceptable, and forces water quickly off the road (Figure 36). A well-graded, crowned road prevents pollution of a watershed by maintaining the integrity of the road (KCSWCD 2000). Potholes and pools of water on the roadbed weaken the road, which can produce erosion, rutting, and sediment loss. Improper or insufficient grading can also keep water on the road due to the creation of small ridges or berms, which form when material is pushed to the edge of the road. Berms also encourage erosion by preventing lateral runoff and should be removed (KCSWCD 2000).

Proper ditching can be a key component of successful runoff diversion, as ditches collect and store storm water until it can be deposited into buffers and absorbed into the ground (see Background: Roads). The best ditches are trapezoidal or parabolic, which slows water flow and prevents erosion

(KCSWCD 2000; Figure 37). A moderate amount of vegetation within the ditch also helps with absorption and flow rate, though too much material can inhibit water movement. Stones and grass are useful materials to have in ditches (KCSWCD 2000). The CEAT study assessed both the location and construction of ditches to determine if they were properly located and well constructed.

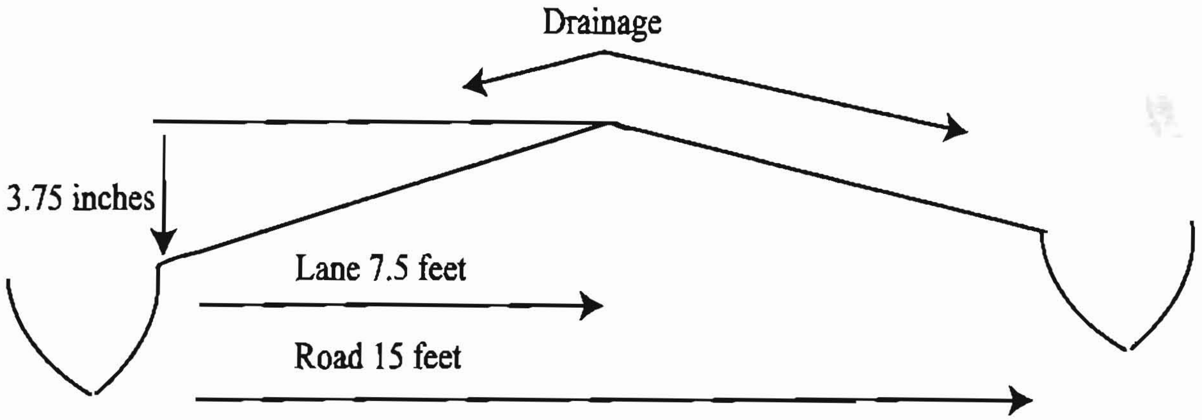


Figure 36. The ideal crown profile requires 1/2 inch of height per 12 inches of road width, which means a road width of 15 feet requires at least a 3 3/4 inch crown for optimal drainage (KCSWCD).

Diversions can work in combination with crowning to send water off roadways and into ditches and buffer strips (see Background: Roads; Buffer Strips). The most basic diversion is called a broad-based dip, which consists of a depression that runs across the width of the road followed by a lateral ridge. Water collects in the depression and runs off the road. A rubber bar can serve the same purpose and works well on roads that are plowed regularly (Figure 38). A method that requires more materials is the open top culvert, which is basically a long, three-sided wooden box, set into the roadbed to collect water.

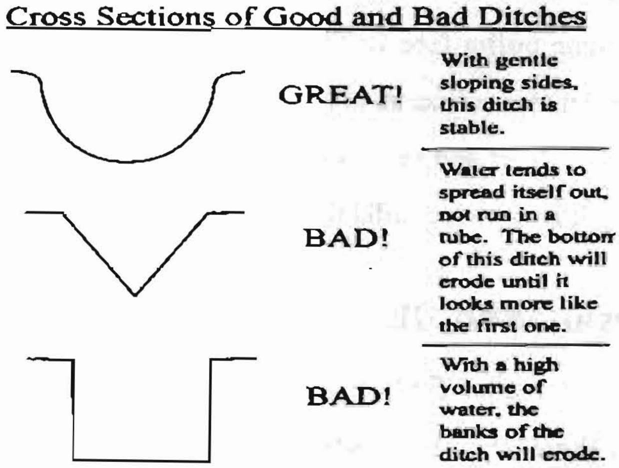


Figure 37. This diagram shows how the shape of the ditch determines how effective it is in diverting runoff (University of Maine Cooperative Extension 1995).

These structures are less successful on plowed roads (the boxes can interfere with a plow blade) and

need to be cleaned out regularly (KCSWCD 2000). In the CEAT survey, teams noted whether or not these methods were used and possible areas that might benefit from these techniques.

The final road maintenance technique that was assessed was the presence and condition of culverts. Culverts are designed to keep streams of water off the roadbed by diverting them underneath (Figure 39). Both established streams and those created during storms need to be kept off of the roadbed to prevent erosion. Methods to avoid erosion occasionally include diverting the water away from the roadbed altogether, but roads are often built in the paths of streams. A different diversion technique is required to allow successful road construction in such situations. It is important that culverts function correctly, or serious erosion can result. Failed culverts allow water to run across the road, which will simultaneously destroy the roadbed and wash sediment towards lakes and streams. Culverts are constructed out of metal, plastic, or concrete materials, and the length, width, and diameter depend on the specific nature of the road. The most important considerations are water flow, the presence of an adequate buffer (see Background: Roads), and proper maintenance, including keeping debris out of the culvert and replacing the entire structure when it is no longer effective (KCSWCD 2000).

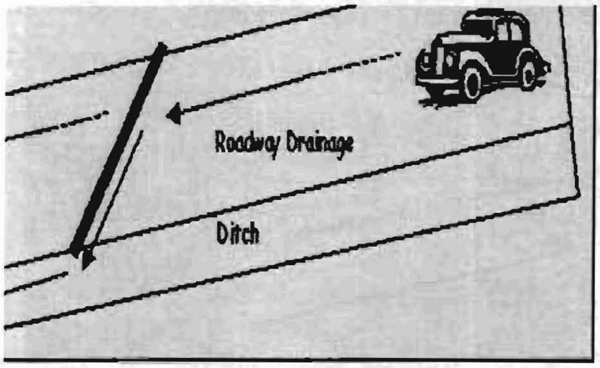


Figure 38. Rubber water bars set into road surface material are simple techniques for diverting storm water off the roadbed and reducing erosion (University of Maine Cooperative Extension 1995).

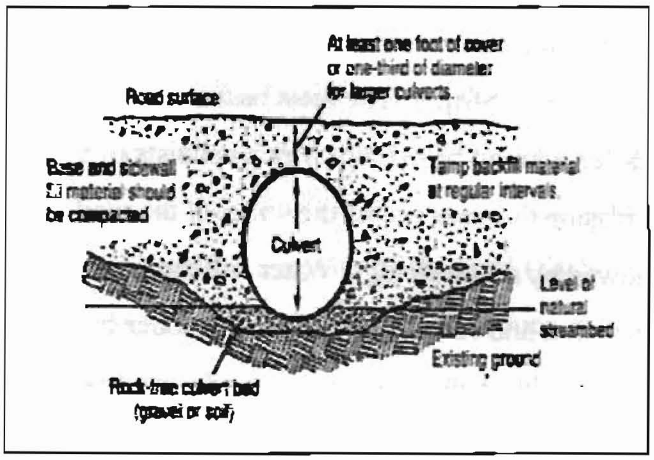


Figure 39. A culvert is the most efficient way to divert runoff under a roadway; this diagram shows the proper installation technique (Illinois Dept. of Natural Resources 2003).

Results and Discussion

Overall, CEAT road survey teams found that there are 21.62 acres of camp roads in Threemile Pond watershed and 74.34 total acres of state and municipal roads. The State of Maine and each municipality maintain state and municipal roads, respectively, while camp roads are the responsibility of residents living along

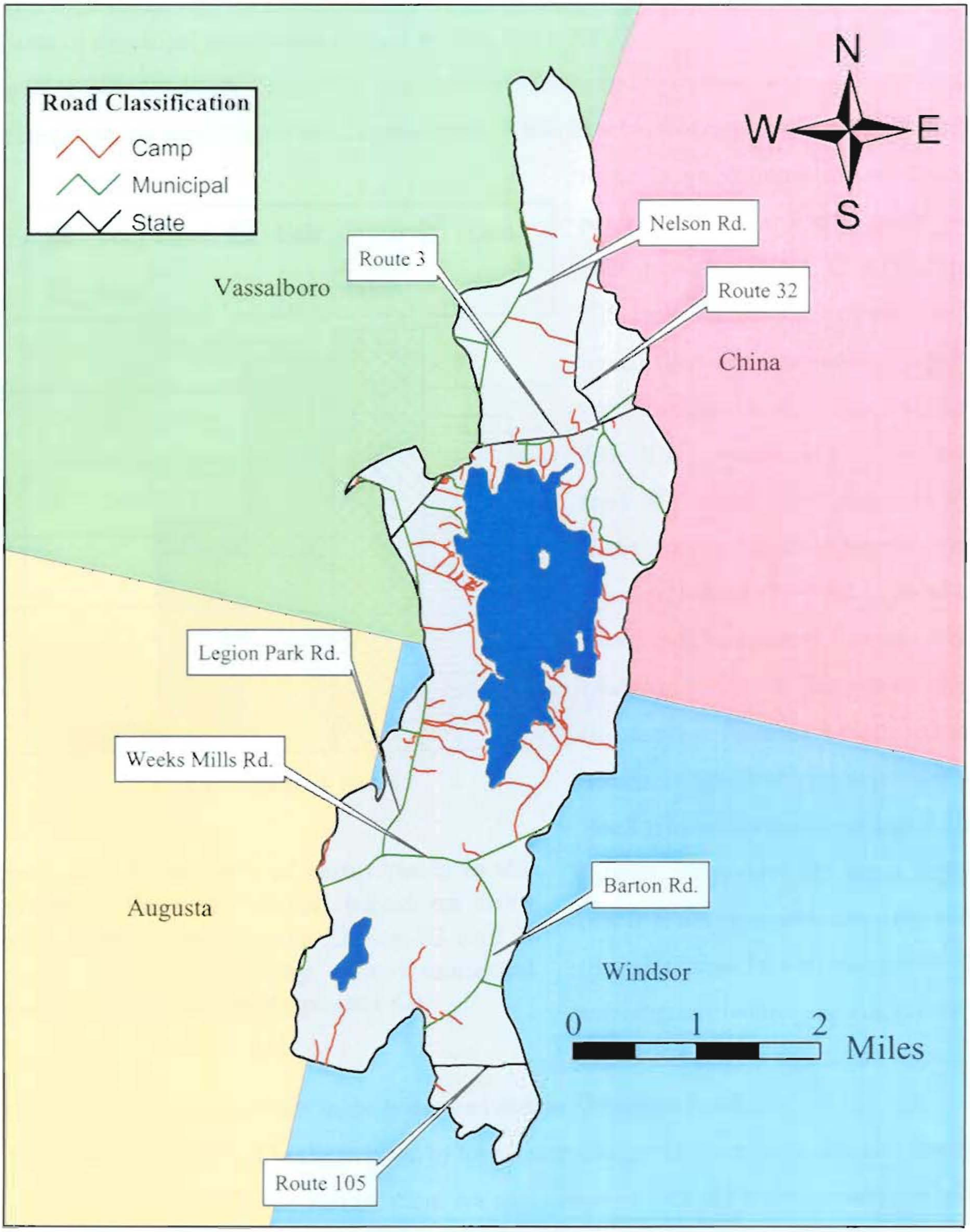


Figure 40. Roads in Threemile Pond watershed. Roads were classified as state, municipal, or camp roads based on road surveys and information from town offices and maintenance personnel. The road, watershed, and lake themes were obtained from Maine Office of GIS (MEGIS 2003).

the road. CEAT used GIS mapping to mark which roads are classified as camp roads, and which are under state or municipal jurisdiction (Figure 40; see GIS). CEAT found that 16.5 percent of camp roads were in poor condition (Figure 41). Zero percent of state and town roads were considered to be in poor condition and only 12 percent in fair condition. While 23 percent of camp roads were considered to be in good condition, almost 90 percent of state and town roads were rated good (Figure 41). CEAT also used GIS to locate the sites where specific remediation techniques are suggested for problems found in the watershed (Figure 42). It is not surprising that the camp roads of Threemile Pond watershed were in the worst condition of the three types of roads, because they are unpaved and maintained on an irregular basis. Camp roads are also more likely to be one of the largest sources of phosphorus because of their proximity to the lake (see Background: Watershed Land Use: Roads). This does not mean that the problems are impossible to rectify, or that the roads cannot be well maintained. The remediation techniques suggested by CEAT can have a significant impact on the current condition of camp roads in the watershed and on Threemile Pond.

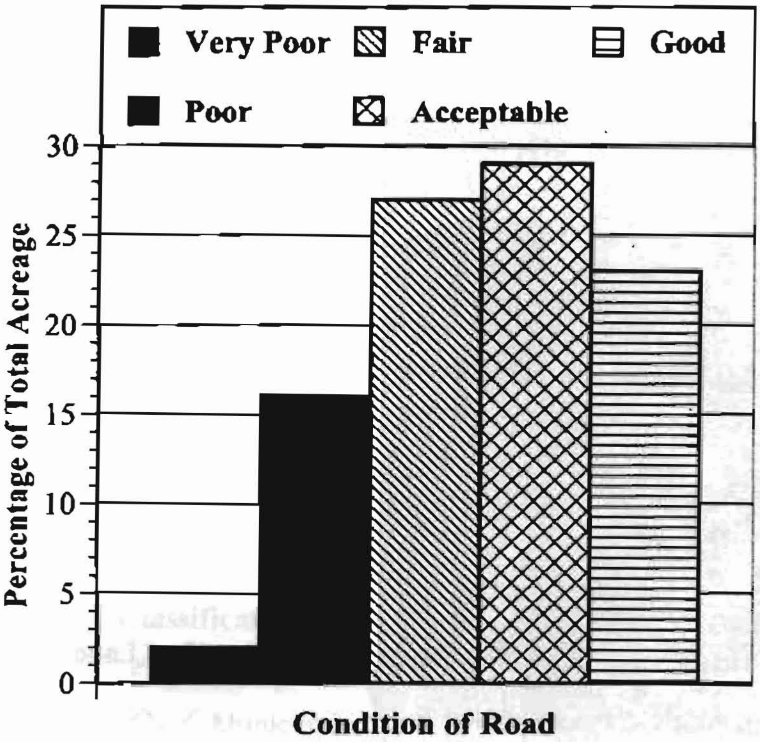


Figure 41. Conditions of camp roads in the Threemile Pond watershed based on road survey data taken between 22-Sep-03 and 9-Oct-03 by the Colby Environmental Assessment Team (see Appendix G).

Each problem area found has been listed by town name along with the specific distance from the nearest major road. The problems and solutions are suggestions to help aid in the remediation of the affected areas. The road survey was completed by CEAT 09-Oct-03.

CHINA:

Park Lane

Problem(s) and Distance from major road: Erosion; Culvert 330 m from Rte. 3 and crown 215 m from Rte. 3

Remediation: Add culvert and diversion; eliminate berms

Memory Lane

Problem(s) and Distance from major road: Erosion; intersection of Vassalboro Road (Rte. 32)

Remediation: Add diversions

Village Street

Problem(s) and Distance from major road: Missing/inadequate culvert; 450 m from Vassalboro Road (Rte. 32)

Remediation: Replace with larger culvert

Sunrise Drive

Problem(s) and Distance from major road: Inadequate diversions; intersection of Bradford Lane

Remediation: Replace small diversions with single, large diversion

Pride Rock Road

Problem(s) and Distance from major road: Severe erosion along entire length

Remediation: Improve crown, add diversions, and create adequate ditching

Sunset Lane

Problem(s) and Distance from major road: Severe Erosion; 125 m from Rockwood Drive

Remediation: Add diversion

Bradford Lane

Problem(s) and Distance from major road: Erosion; 1000 m from Windsor Road (Rte. 32)

Remediation: Re-grade and add diversion(s)

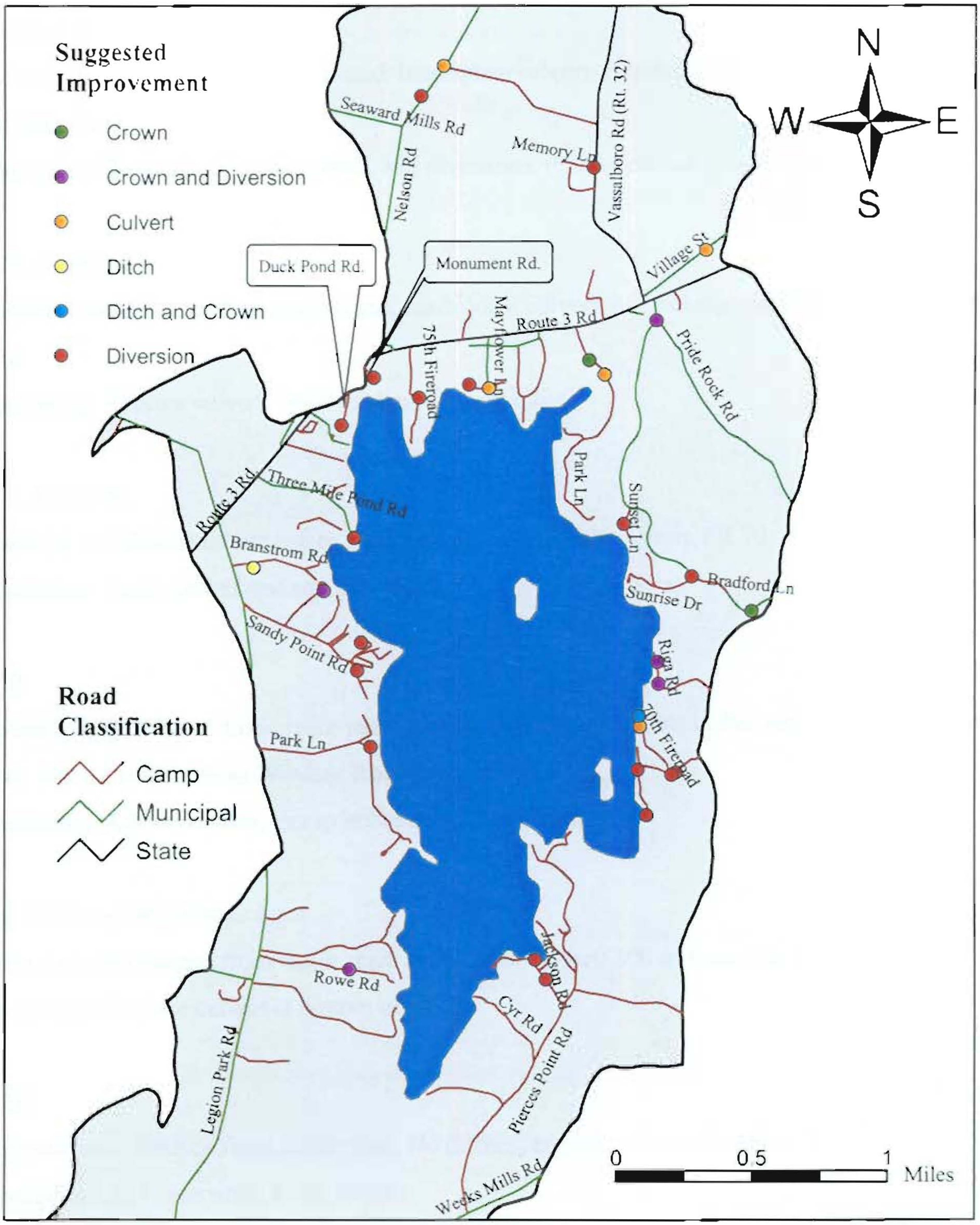


Figure 42. Suggested road improvements near Threemile Pond. The suggestions are based on road surveys conducted in September, 2003 by the Colby Environmental Assessment Team. The watershed, lake, and road themes were obtained from Maine Office of GIS (MEGIS 2003).

Riga Road (FR 71)

Problem(s) and Distance from major road: Inadequate culvert, erosion; 1150 m, 1300 m from Windsor Road (Rte. 32)

Remediation: Re-grade, improve crown, add diversions, replace culvert

FR 70, Annex #2

Problem(s) and Distance from major road: Inadequate culvert, no ditching, no diversion; 350 m from FR 70

Remediation: Replace culvert, build ditches, add water bar

FR 70 Annex #1

Problem(s) and Distance from major road: Severe erosion; 300 m from FR 70

Remediation: Build ditches and add diversions

FR 70

Problem(s) and Distance from major road: Severe erosion, inadequate buffer between road and lawn; 800 m, 830 m, 1000 m from Windsor Road (Rte. 32)

Remediation: Add diversions, riprap between road and lawns

Pond Hill Road/ Mayflower Lane

Problem(s) and Distance from major road: Inadequate culvert; 300 m from Rte. 3

Remediation: Replace culvert at bottom of hill

FR 75a

Problem(s) and Distance from major road: No ditches, erosion; 350 m from Rte. 3

Remediation: Add diversions, build ditches

Washington Boulevard

Problem(s) and Distance from major road: Runoff flows directly into pond; 100 m from Mayflower Lane

Remediation: Add diversions

Vassalboro:

Seward Mills Road

Problem(s) and Distance from major road: Heavy vegetation in ditches along entire length

Remediation: Prune vegetation in ditches

Park Lane

Problem(s) and Distance from major road: Erosion; 650 m from Legion Park Road Remediation: Add diversions

Kelly Road

Problem(s) and Distance from major road: Severe erosion; 200 m from Sandy Point Road Remediation: Add diversions, water bar

Austin Road

Problem(s) and Distance from major road: Erosion; 50 m from Sandy Point Road

Remediation: Add diversion

Pine Drive

Problem(s) and Distance from major road: Erosion, inadequate crown; 300 m from Sandy Point Road

Remediation: Improve crown, add diversion

Branstrom Road

Problem(s) and Distance from major road: Inadequate ditching; 100 m from Legion Park Road

Remediation: Improve ditch

Threemile Pond Road

Problem(s) and Distance from major road: Berms, erosion along entire length

Remediation: Remove berms, add diversions

Duck Pond Road

Problem(s) and Distance from major road: No buffer between pond and road, inadequate ditching; 250 m from Rte. 3

Remediation: Build buffer, improve ditches

Monument Road (FR 28)

Problem(s) and Distance from major road: Erosion, 100 m from Rte. 3

Remediation: Add diversion

Windsor:

Pierce s Point Road (FR 20)

Problem(s) and Distance from major road: Berms along entire length

Remediation: Re-grade, remove berms

Jackson Road (FR20 20c)

Problem(s) and Distance from major road: Berms; 350 m from Pierce s Point Road

Remediation: Re-grade, remove berms

Cyr Road (FR 20b)

Problem(s) and Distance from major road: Berms along entire length, erosion

Remediation: Re-grade, remove berms, add diversions

Rowe Road (FR 10)

Problem(s) and Distance from major road: Erosion, lack of crown; 550 m from Legion Park Road

Remediation: Re-grade, add diversion

Windsor/Augusta:

Weeks Mills Road

Problem(s) and Distance from major road: Erosion of shoulders along entire length

Remediation: Re-grade shoulders

EROSION POTENTIAL MODEL

Introduction

Erosion within a watershed is an important non-point source of nutrient loading. Runoff increases on eroded land and carries organic and inorganic soil particles, pesticides and herbicides into the lake (Chapman 1992). Soil erodibility, land use type and slope affect the amount of runoff for any given part of a watershed. Maps of these three factors in the Threemile Pond watershed were put into a weighted overlay using ArcGIS" Spatial Analyst to create an erosion model for the area. The effect that erosion in an area has on lake water quality is dependent on its proximity to the water basin. Runoff from land farther from a lake is more likely to be reabsorbed by plants and soil before reaching the open water and has a small impact on water quality. A potential impact of erosion model was created to incorporate this proximity factor into the Erosion Model.

ArcGIS" Spatial Analyst can combine the attributes of several input maps to model the cumulative effect of those inputs over a given geographic area. The user can also weigh each of the inputs according to their relative importance. The input maps must be in a raster format (see GIS: Introduction) and have similar value scales for the operation to be successful. The features within the soil, land use type and slope maps were assigned a value from 1 to 9 to signify the relative erodibility. One represented low erosion potential and 9 represented high erosion potential. This 1 to 9 scale was chosen to stay consistent with previous CEAT studies and because it accurately represents the variation of an attribute within a raster without compromising clarity.

Methods

Soils

The first map used in the erosion potential model was a digital soil series map, which was acquired from the Kennebec Soil and Water Conservation District (KCSWCD Unpublished data). A K value was assigned to each soil series to represent the erodibility. The K value is a number between 0 and 1 that quantifies erodibility based on the physical characteristics of the soil such as composition, grain size and permeability (NRCS-USDA State Office of Michigan 2003). The K values were obtained from the CEAT Webber Pond study (BI493 2003a) and from the Kennebec County Soil and Water Conservation District (KCSWCD Unpublished data). They ranged from the lowest erodibility of zero,

typified by open water and wetlands, to a higher erodibility of 0.49 for soil series Nicholville and Hartland (Table 9). The Spatial Analyst extension of ArcGIS™ automatically divided the range of K values into nine increments and assigned each increment a value between 1 (low erodibility) and 9 (high erodibility) to represent the relative erosion potential. ArcGIS" Spatial Analyst was again used to convert the soil theme from a vector format to a raster format based on this ranking. The final map had a resolution of 10 m.

Slope

The slope map created for the septic suitability model was also used for the erosion potential model (see Watershed Land Use Patterns: Residential Survey: Septic Suitability Model). It was reclassified on a 1 to 9 scale of increasing erosion potential to stay consistent with the soil map and had a resolution of 26 m. A higher slope implies higher erosion potential.

Land Use

A map of the land use types present in the watershed was the third input map for the erosion potential model. The land use map was created from Digital Orthophoto Quads (DOQs) (see Watershed Land Use Patterns: Methodology) and converted to a raster format using ArcGIS" Spatial Analyst. It had a final resolution of 20 m. Each land use type was assigned a number between 1 and 9 with 1 representing low erosion potential and 9 representing high erosion potential (Table 10). The land use types were identified and mapped by the canopy coverage and vegetation coverage visible in the DOQs (see Watershed Land Use Patterns: Methodology). Canopy coverage and vegetation coverage were also used to assign the erosion potential values and because of this parallel, the erosion values and land use types are accurate relative to each other. Vegetation reduces the amount of erosion by lessening the impact of falling rain and absorbing runoff (Dunne 1977). High velocity rain starts small soil particles moving and creates a wet crust on the soil surface, which reduces water absorption and increases runoff (Rapp 1975, Epema and Riezebos 1983). Closed canopy forests are very effective at reducing erosion while cleared fields have high potential for erosion (see Background: Watershed Land Use: Land Use Types)

Wetlands were given a value of 1 because the high water content and high vegetation coverage leaves little soil exposed. Mature forests were also assigned a value of 1 because the deep roots and continuous canopy coverage minimize erosion very efficiently. Transitional forests were assigned a 3 because the slightly more open canopy and the presence of young trees with smaller root systems

increase the chance for erosion. Reverting land was given a 4 based on the scarcity of trees and the disturbed nature of the soil and ecosystem. Pastures were given a value of 7 because of the dominance of grasses that do not shield the ground from rain and reduce water absorption. Also, the presence of livestock that disturb the soil surface and reduce vegetation may create further runoff. Residential areas were given a value of 8 because of the presence of lawns and compacted soil. Lawn runoff contains pollutants such as herbicides and fertilizers. Cleared land, cropland, and commercial or municipal land were all given a value of 9 because of the typical replacement of native vegetation with pavement or monocultures and the general disturbance in these habitats. Pavement and crop rows that are oriented down hill rather than along contours contribute heavily to runoff and erosion.

Table 10. Erosion values for the classified land use types based on the type of vegetation present. The values were adapted from the BI493 Webber Pond study (BI493 2003a).

Land Use Type	Erosion Value
Wetlands	1
Mature Forest	1
Transitional Forest	3
Reverting Land	4
Pasture	7
Residential	8
Cleared Land	9
Crop Land	9
Commercial/Municipal	9

Weighted Overlay

The soil, slope and land use type maps were weighted based on their relative contribution to erosion susceptibility and potential runoff. As with the septic suitability model, the slope was assumed to have the greatest impact because gravity is the ultimate force behind the flow of water and land erosion. Slope was weighted as having a 50 percent influence on erosion while the land use and soil maps were each weighted as having a 25 percent influence. Land use type is slightly more important for erosion potential than soil type but it is difficult to determine the quantitative difference (Dunne 1977). Every cell in each map (the size of which is determined by the resolution) had an associated erodibility value from 1 to 9. For example, in the 10 m resolution soil map, each 100 m^2 (0.02 acre) plot of land in the watershed had an associated erodibility value based on the 1 to 9 scale.

The raster calculator function in the ArcGIS" Spatial Analyst extension weighted the values in each plot accordingly and added them together (Figure 43). This resulted in the final erosion model (Figure 44). ArcGIS" Spatial Analyst allows the user to determine the output resolution within reasonable limits, and this map has the best resolution possible at 10 meters. While this gives a smooth appearance, the input map with the coarsest resolution determines the actual level of accuracy in the model. Figure 44 has a resolution of 10 m but is only accurate to the 26 m resolution of the slope map.

Potential Impact of Erosion Model

A fourth and a fifth map of distance buf fers was added to the weighted overlay described above to incorporate lake and stream proximity into the erosion potential model. In ArcGIS", a buf fer is a polygon of a specified width drawn around a feature such as a lake boundary. A 200 ft buffer was created around Threemile Pond and Mud Pond to delineate shoreline. Two hundred feet is the distance used in the house counts to define shoreline houses (see Watershed Land Use Patterns: Residential Survey: House Counts). Eight 2,100 ft buffers were created around the shoreline buffer to classify the rest of the watershed. This distance was derived by dividing the longest distance from lakeshore to watershed edge by eight (to fit on a 1 to 9 scale) and is a subjective value. The result was a map with nine buffers, one 200 ft wide and eight 2,100 ft wide, that easily fit on a 1 to 9 scale. This map was converted to a raster format and reclassified so that areas inside the 200 ft shoreline zone had a value of 9 and areas in each successive 2,100 ft zone were given the consecutive value continuing down to 1. Erosion near streams can potentially contribute high amounts of nutrients to the lake because streams quickly transport runoff directly to the water basin (see Background: Watershed Land Use: Non Shoreline Residential Areas). A fifth map of the streams in the watershed, each with a 200 ft buffer on both sides, was created to account for this. After converting it to a raster, it was reclassified so that areas inside the buffers were valued at 8 and all other areas were zero. Eight was chosen because streamside land can contribute heavily to nutrient input in a lake but lakeshore property, valued at 9, still has more of an impact.

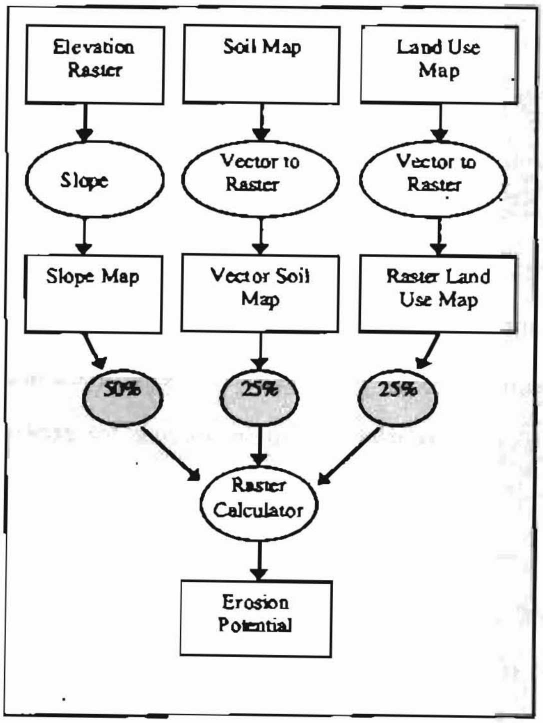


Figure 43. Flowchart visualizing the intermediary steps take to create the erosion potential model. The three input maps were converted into the raster format, weighted for their relative contribution towards erosion (shaded circles), and added together with the Raster Calculator in ArcGIS" Spatial Analyst. Figure adapted from ArcView□ Mod el Builder (ESRI 2000a).

The soil and land use type maps were then re-weighted by 20 percent each and the slope map and lake proximity map were weighted by 30 percent each to account for their relative erosion importance. Since the quantitative importance value between the four factors is difficult to calculate, these percentages

were chosen to best represent the estimated relative contribution to erosion for each input map. Slope and lake proximity are assumed to be more important factors for runoff than are soil type and land use type and were given a larger weight. The stream proximity map was weighted by 15 percent to give it moderate importance in the overlay. This percentage is subjective and pushes the total over 100 percent but the relative importance of each input is what is necessary for the weighted overlay not exact quantitative values. All five maps were added together in a weighted overlay similar to Figure 43. A map of the potential impact on Threemile Pond from erosion was the output (Figure 45). The resolution is 10 meters though it only has an accurate resolution of 26 m for the same reasons described for the erosion model.

Results and Discussion

The erosion model had a maximum of 7.5 on the 1 to 9 scale. In general, areas with erodible land use types, in combination with erodible soils, received a high erosion potential rating. Areas with high slope were also more likely to have received a high rating. The average erosion potential for the watershed falls in the low to moderate range and corresponds to 65.8 percent of the watershed area. 31.8 percent of the watershed lies in the moderate to high range while areas at high risk for erosion cover 2.4 percent of the area. The high-risk areas are located on the western shore of Mud Pond and in the northeastern part of the watershed and are likely the result of high slope and land development respectively. The areas of high development on the western shore and in the small bay on the northeastern shore of Threemile Pond fall in the moderate to high range. It also appears that many of the roads in the watershed are in moderate to highly erodible areas. This may be the result of residential and agricultural land use along the roads (Figure 26).

In Figure 44, wetlands are the very light gray areas along the shores of the lakes and in the north section of the watershed. They have very low erosion potential and are viewed as controllers of erosion rather than contributors. They are valuable because they slow down and absorb a large portion of the runoff before it enters the lake (Goldstein 2001; see Watershed Land Use Patterns: Wetlands; see Background: Watershed Land Use: Freshwater Wetlands).

The potential impact of erosion model (Figure 45) had a maximum of 8.4 on the 1 to 9 scale. 63.4 percent of the watershed is in the moderate to high range. The map looks similar to the erosion potential model but it further highlights areas surrounding the lakeshore and areas with residential and

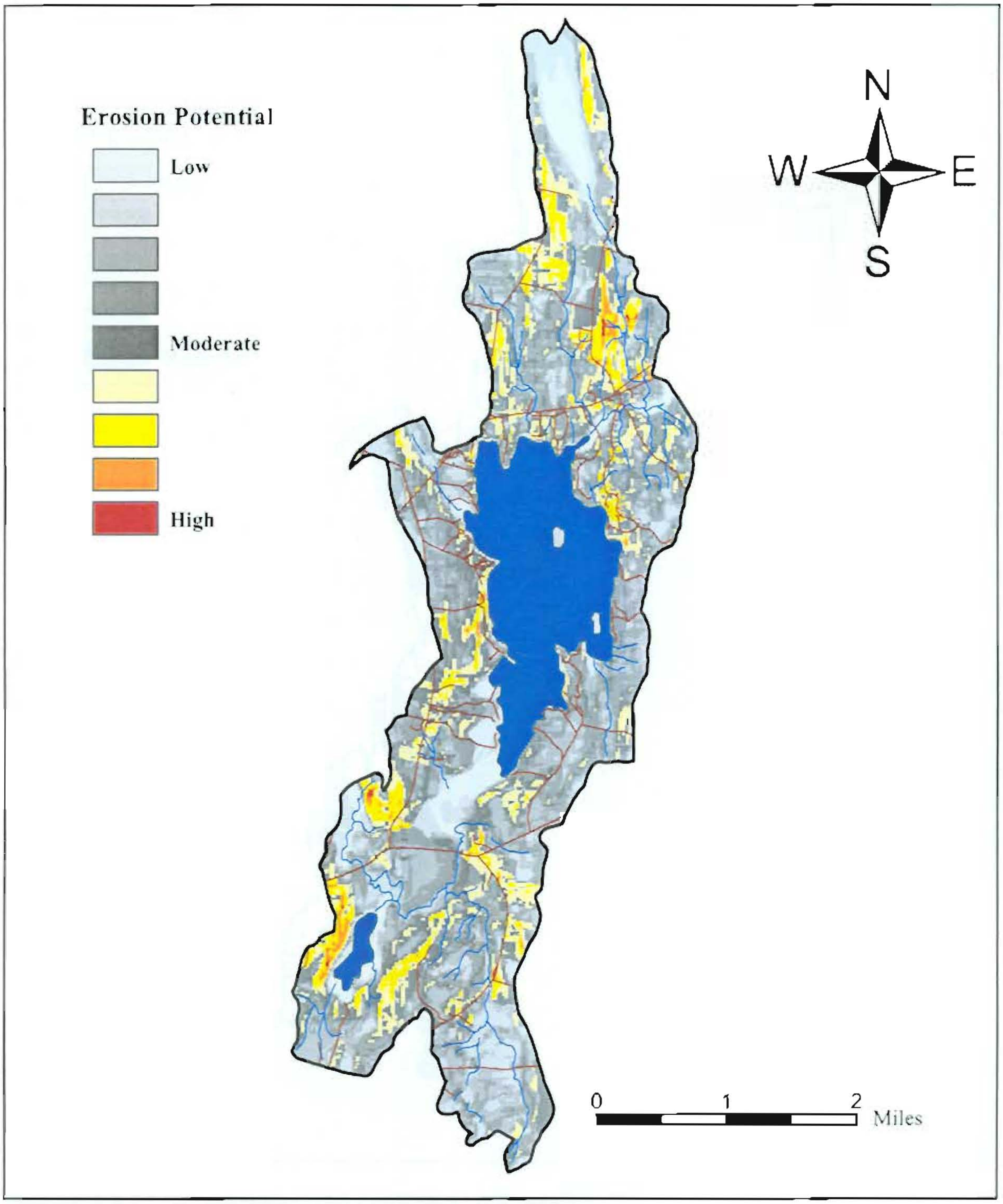


Figure 44. Erosion potential for the Threemile Pond watershed. This map is based on the erosion characteristics of soil, slope, and land use (see Land Use: Erosion Potential Model) and it has a resolution of ten meters. Areas in red and orange indicate areas that are highly suseptible to erosion. Wetlands were included and appear as the large, low erosion potential areas. The lake, streams, and watershed themes were obtained from Maine Office of GIS (MEGIS 2003).

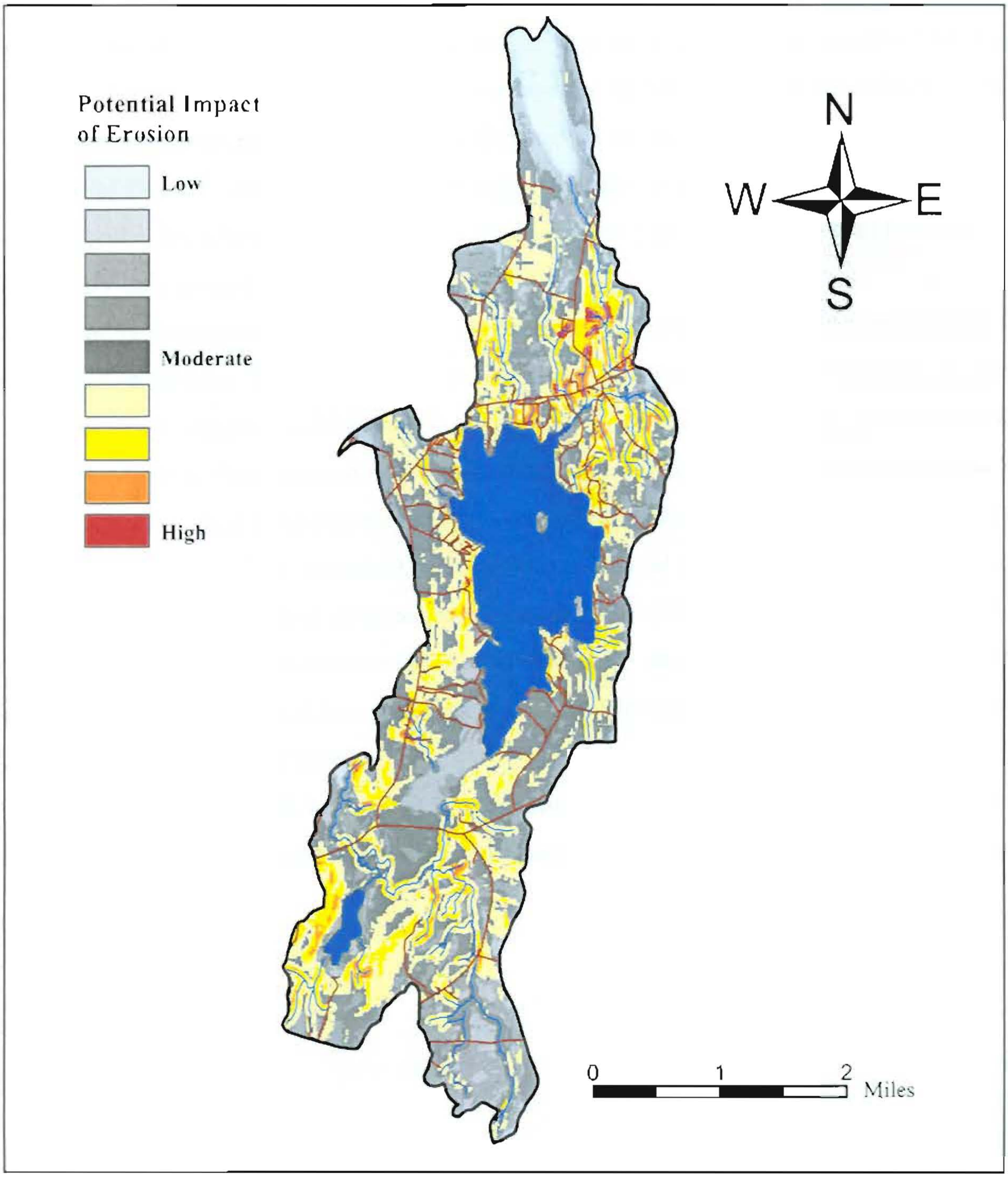


Figure 45. Potential impact of erosion as a function of proximity to the lake.
This map was created by combining the erosion potential model with a map that designated the proximity of land to open water (See Land Use: Erosion Potential Model). Erosion from areas located on highly erodible land and in close proximity to the lakes and streams will have a greater impact on the lake water quality than land farther away. The lake, streams, road and watershed themes were obtained from the Maine Office of GIS (MEGIS 2003).

agricultural development. The red, orange, and dark yellow areas indicate land that will have a larger impact on the lake through erosion than pale yellow and gray areas. Lakeshore properties potentially contribute more runoff directly into the lake than do properties further away in the watershed and much of the lake perimeter is marked as moderate to high potential impact. There are small portions at the southern end of the lake in the moderate to low category though this is potentially due to the existence of wetlands and a low slope. The very north and very south parts of the watershed are shown to contribute very little erosion to the lake.

Many of the streams in the watershed are bordered by land with a moderate to high potential for erosion impact on the lake. The impact of erosion for these areas was valued at 8 and it was weighted by 15 percent in the weighted overlay, which corresponds to an increase of 1.2 on the 1 to 9 scale. While this value is based on assumed relative importance, the addition of stream proximity into the model is helpful in locating areas that may have particularly large impacts on lake water quality. The area in the northeast part of the watershed with very high potential impact is an example. The well-developed land and the presence of moderate slopes are the reasons for the high impact potential. This is of concern because several small streams that flow directly into Threemile Pond drain the area. Erosion control programs focused here would have a large positive effect on water quality. The same is true for the northern shore of the lake.

This model may be useful in focusing future erosion control efforts. Areas with high potential impact should be encouraged to build large buffers around open land and keep roads well maintained.

PHOSPHORUS BUDGET

INTRODUCTION

The Phosphorus Loading Model was used to determine the amount of phosphorus entering the Threemile Pond watershed in 2003. The model estimates the amount of phosphorus contributed to the lake by various land use types and atmospheric inputs. The Phosphorus Loading Model is a critical assessment tool that can identify sources that contribute high levels of phosphorus. The model can also be used to make predictions of lake health in relationship to population and land use changes.

METHODS

The model used in this study of Threemile Pond was adapted from Reckhow and Chapra (1983) to approximate the total amount of phosphorus entering the lake from the Threemile Pond watershed in 2003.

$$W = (Ec_a \times A_a) + (Ec_f \times Area_f) + (Ec_t \times Area_t) + (Ec_{rv} \times Area_{rv}) + (Ec_w \times Area_w) + (Ec_{cm} \times Area_{cm}) + (Ec_{ag} \times Area_{ag}) + (Ec_c \times Area_c) + (Ec_{cr} \times Area_{cr}) + (Ec_{sr} \times Area_{sr}) + (Ec_s \times Area_s) + (Ec_n \times Area_n) + [(Ec_{ss} \times \text{capita years}_s) \times (1-SR_1)) + [(Ec_{ns} \times \text{capita years}_n) \times (1-SR_2)) + (Sd_{cs} \times Area_{cs}) + PSI$$

W represents the total amount of phosphorus entering Threemile Pond in kg/year. All of the Ec terms represent the export coefficients for inputs of total phosphorus in kg/hectare/year. Phosphorus input sources include the atmosphere (a), mature forest (f), transitional land (t), reverting land (rv), wetlands (w), commercial land (cm), agricultural land (ag), cleared land (c), camp roads (cr), state roads (sr), shoreline development (s), non-shoreline development (n), shoreline septic systems (ss), non-shoreline septic systems (ns), and sediment release (cs). Sd represents the input of phosphorus from sediment release (see Appendix E). SR_1 and SR_2 represent the soil retention capacity for shoreline and non-shoreline land, respectively. Soil retention refers to the amount of phosphorus that soil can retain. A_s represents the surface area of Threemile Pond. Areas for the various land use types were obtained using digitized orthophotoquads of the Threemile Pond watershed and ArcMap™ 8.2 (see Watershed Land Use Patterns: Methodology).

The export coefficients for shoreline and non-shoreline septic systems were multiplied by the number of capita years and by one minus the coefficient values for soil retention. The value for capita years is based on the average duration of occupancy of each residence and the average family size in the watershed. Capita year values are lower for seasonal residences because they are considered to be occupied less than year-round residences and phosphorus contribution per year is lower. Seasonal residences were estimated to be occupied for 35 days per year (Richardson pers comm.), while year-round residences were estimated to be occupied 355 days per year (BI493 2003a).

High, low, and best estimate export coefficients were assigned to each source. The coefficients were based on the original model developed by Reckhow and Chapra (1983) in a study of Higgins Lake in Michigan and from studies from similar watersheds in Maine (BI493 2000, BI493 2001a, BI493 2001b, BI493 2003). The high and low estimates compensate for the uncertainty in phosphorus loading estimates from human judgment and natural fluctuations, while the best estimate is the coefficient that CEAT felt was most accurate and fell between the low and high estimates.

Total phosphorus concentrations were calculated for Threemile Pond using the high, low, and best estimate total phosphorus loading values (W) (see Appendix F) and water budget data (see Appendix D). Reckhow and Chapra (1983) provided the equations used.

The amount of phosphorus loaded into Threemile Pond from the watershed per m^2 per year (L) was calculated by dividing the annual rate of phosphorus inflow (W, in kg/year) by the surface area of the lake (A_s, in m^2). In this equation, phosphorus from sediment release is included in W:

$$L = W/A_s$$

Annual atmospheric water loading (q_s, in m/year) was calculated by dividing the total volume of water inflow (Q_{total}, in m^3/year) by the surface area of Threemile Pond (see Appendix D).

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

The predicted ranges of phosphorus concentration (P, in ppb) were calculated by dividing the annual phosphorus loading (L) by the settling velocity of phosphorus and the areal water loading in a lake ($11.6 + 1.2\ q_s$).

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

RESULTS AND DISCUSSION

The Phosphorus Loading Model predicted a total phosphorus loading range for Threemile Pond from 672.55 kg/year to 2500.40 kg/year with a best estimate of 1324.04 kg/year (see Appendix E). A

best estimate total phosphorus concentration was calculated to be 21.53 ppb, with a range of 11.81 ppb to 38.22 ppb. In contrast, CEAT's sampling of Threemile Pond on 11-Sep-03 measured a mean concentration of total phosphorous equal to 30 ppb. (see Water Quality: Threemile Pond Water Quality Assessment: Lake Water Quality: Chemical Analysis: Total Phosphorus). The total phosphorus values recorded in the lake when phosphorus levels are at a seasonal extreme may vary significantly from the annual averages. There is confidence in the accuracy of the model as a predictive tool because the CEAT Phosphorus Loading Model predicts a concentration within the actual range sampled in Threemile Pond. The critical limit for algal blooms is 15 ppb, and all sampled and predicted values are above the limit, producing the likelihood of annual algal blooms in Threemile Pond (MDEP 2003f).

Inputs from the upstream ponds, Threecornered and Mud Ponds, are believed to contribute 196 kg of phosphorus to the lake each year through tributaries. The model shows that approximately 34 percent of the 1324.04 kg of phosphorus entering Threemile Pond annually comes from sediment release. Historically, the amount of total phosphorus being recycled internally, an estimated 452.95 kg/year, has remained fairly constant (MDEP 2003f). The CEAT Phosphorus Loading Model calculated a best estimate of internal phosphorus loading of 452.95 kg/year. The discrepancy in values is because CEAT used a Phosphorus Model that includes more specific calculations than previous models but utilizes the same coefficient of 1.0 kg/ha/year for sediment release. The phosphorus concentration varies from the Total Maximum Daily Load (TMDL) report on annual phosphorus because CEAT calculated a larger lake volume (MDEP 2003f). Both the TMDL and CEAT area maps of Threemile Pond were obtained from MEGIS. CEAT used a more accurate, updated bathymetry map to determine the average depth of Threemile Pond and discovered there is a larger volume of water in the lake than previously reported and used in phosphorus modeling for Threemile Pond. However, the current phosphorus model predicts more phosphorus needs to be removed from the lake to reach the 15 ppb critical limit than determined in the TMDL Report (MDEP 2003f). The larger lake volume and the use of the Reckon and Chapra model with a more accurate calculation of phosphorus settling velocity shows that even with the higher phosphorus loads predicted by the model, the predicted phosphorus concentration in the lake is similar to that in the TMDL study.

The largest source of phosphorus contribution to Threemile Pond is reverting land, which contributes 422.92 kg of phosphorus, or 38 percent of the annual phosphorus load (Table 11). Reverting land is the largest land use in Threemile Pond watershed, but also has a coefficient of 0.60 kg/ha/year,

which makes it a significant contributor of phosphorus. Reverting land has a canopy of less than 50 percent, which allows minimal protection from rainfall and subsequent erosion and runoff.

Table 11. Low, high, and best estimates of a nnual percent contribution to phosphorus loading in Threemile Pond from various land use types in the watershed in 2003. Percents are based on phosphorus loading projections from the Phosphorus Loading Model (See Appendix E). Percent area of each land use type is also given.

Input Categories	Percent Land	Percent Contribution		
	Area	Low	High	Best
Atmospheric Input	-	10.56	5.46	7.14
Mature Forest	15.62	4.40	2.73	3.72
Transitional Forest	11.56	16.27	13.46	13.75
Agricultural Land	26.55	11.97	6.19	11.38
Wetlands	10.03	1.12	0.93	0.95
Cleared Land	1.44	1.22	1.01	1.37
Commercial Land	0.21	0.58	0.72	0.49
Camp Roads	0.33	0.83	3.04	2.64
State/Town Roads	1.12	2.84	9.14	4.00
Reverting Land	26.25	29.58	30.59	37.49
Shoreline Development	1.52	4.29	5.32	5.43
Non-shoreline Development	5.38	6.06	9.40	3.84
Shoreline Septic Systems	-	5.31	5.18	3.60
Non-shoreline Septic Systems	-	4.95	6.83	4.18

Agricultural uses (cropland and pasture) and transitional forests contributed 14 percent and 11 percent of the annual phosphorus, respectively. Although transitional forest occupies more than twice the area of agriculture in the watershed, agriculture contributes slightly more phosphorus to the watershed from sources such as fertilizers, which carry excess phosphorus into the lake. Based on the model's best estimates, atmospheric input, as well as shoreline development, contributed significant amounts of phosphorus to the watershed. Phosphorus is a by-product of industrial production and wood-burning stoves and can be suspended in air particles and deposited in the watershed through precipitation (Reckhow and Chapra 1983). The particles can travel long distances before the effects are seen; this makes it difficult to localize the source of pollution for mitigation. Development along the shoreline triggers an increase in phosphorus loading as soil is eroded and enters the lake. Shoreline development, often expanded within meters of the water's edge, has a particularly severe impact on phosphorus

loading. Lack of proper buffering leaves minimal soil and vegetation in which to dissipate the phosphorus (see Watershed Land Use Patterns: Residential Survey: Buffer Strips).

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 an 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, water quality must be returned 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. Chemical manipulation techniques include alum treatment, ferrous treatment, calcium additions, and algicides (see Appendix K). Physical manipulation techniques include water drawdown, hypolimnetic withdrawal, dilution, hypolimnetic aeration, physical liners, dredging, and aquatic plant harvesting (see Appendix L). A final category of remediation is biological manipulation. Biological manipulation techniques consist of the manipulation of fish stocks, wetland maintenance and manipulation, and the addition of exotic plants (see Appendix M). The options most suitable for Threemile Pond have become apparent through the assessment of these remediation methods.

CHEMICAL MANIPULATION TECHNIQUES

Alum Treatment

Aluminum sulfate ($Al_2(SO_4)_3$) is a chemical treatment intended to inactivate phosphorus in the water column and impede phosphorus release from the lake sediments (Cooke et al. 1993). When aluminum sulfate is added to the water column, it dissociates and becomes hydrated to form aluminum hydroxide, $Al(OH)_3$. Aluminum hydroxide is a solid floc that absorbs and inactivates phosphorus at pH levels of 6 to 8. However, pH levels of less than 4 will result in soluble Al^{3+} and a release of any inactivated phosphorus into the water column. The solid floc falls out of the water column and forms a white blanket across the sediment. This floc blanket then seals over the sediment and inhibits phosphorus release. Aluminum sulfate is a favored method of lake remediation due to its strong phosphorus inactivation ability. Unlike similar ferrous treatments, the inactivation of phosphorus by aluminum sulfate remains unaffected even in anoxic conditions (Cooke et al. 1993).

The recommended time to treat a lake with aluminum sulfate is just after ice-out or during early spring (Cooke et al. 1993). A treatment during this period is appropriate because this is the time of year before the spring algal bloom occurs. Spring application may not necessarily be ideal because the lower water temperature could cause toxic $Al(OH)_2^+$ to accumulate. The spring season is particularly windy which may cause mixing that disrupts the floc blanket on the bottom sediment. The dose is determined by adding increments of aluminum sulfate to lake samples until the desired amount of phosphorus is removed. The dose is then calculated for the entire lake. The aluminum sulfate is applied in the hypolimnion rather than the epilimnion so as not to disrupt littoral and pelagic biota with the initial aluminum toxicity and low pH. The aluminum sulfate is only applied to areas of the lake that are deeper than 3 meters so as to avoid floc disruption by wave action (Cooke et al. 1993). Application barges carry the aluminum sulfate on board in storage tanks. Many modern applicators now have advanced imagery of the lake bottom so as to ensure a successful application to all necessary areas. The applicators deploy the aluminum sulfate around 2 to 3 meters below the water s surface. When aluminum sulfate is added, it dissociates and creates a solid floc that leaves many H^+ ions in the process. These H^+ ions will create acidic conditions if not treated with a neutralizing agent. A neutralizing agent must be applied along with the aluminum sulfate to maintain the lake s stable pH (Cooke et al. 1993).

Welch and Cooke (1999) studied twenty-one lakes treated with aluminum sulfate across the United States in order to determine the key to the longevity of some of the treatments. In some cases, the alum treatment was completely unsuccessful or lasted less than 8 years. In other cases, the alum treatment was very successful, resulting in marked improvement of water quality for 13 to 18 years (Welch and Cooke 1999). Alum treatments remove the phosphorus already in the water column and in the sediment. These sources of phosphorus are called internal loading because the P is already in the lake sediment. During anoxic conditions, the phosphorus in the sediment moves into the water column, creating nutrient rich conditions that are ideal for algal growth. External loading is new phosphorus that is entering the lake from outside sources. External loading that occurs after an alum treatment cannot be addressed. External loading must be strictly controlled to increase the longevity of the alum treatment. In the study by Welch and Cooke (1999), the major source of external loading was storm water runoff. Storm water runoff contains high levels of phosphorus. Where there was a storm water diversion system in place, alum treatments were effective for 13 to 18 years. Where diversion was not controlled, the success of the alum treatment was short-lived and lasted less than 8 years (Welch and Cooke 1999).

In the case of Annabessacook Lake in Winthrop, Maine, the lake received discharges of domestic and industrial wastes along with non-point sources of nutrients from agricultural development (Welch and Cooke 1999). This heavy external loading caused a great build-up of phosphorus in the lake water column and in the sediment. Algal blooms had been a problem in Annabessacook Lake beginning in the 1940s. In 1972, 80 percent of the municipal and agricultural wastewater was diverted from entering the lake. In 1976, more point sources were eliminated. Even with most external phosphorus eliminated, the lake experienced algal blooms. The aluminum treatment was chosen to handle the internal phosphorus loading of the lake. The alum treatment was applied in 1978 and lasted 13 years until 1991. This treatment was deemed successful (Welch and Cooke 1999).

Aluminum sulfate treatment is relatively expensive. The 1988 treatment of Threemile Pond cost $170,240 to treat with a high-speed system (Cooke et al. 1993). The high-speed barges hold over 11,250 kg of alum and require fewer stops to refill. The barges are also equipped with precise LORAN navigation systems, which allow one operator to accurately apply 115 m^3 of alum in 15-meter wide swaths. This high-speed system is approximately half the cost of application with a traditional barge design (Cooke et al. 1993).

Alum treatment may work very effectively under specific conditions but it must be constantly monitored to ensure that toxic levels of aluminum are never reached. Aluminum is very sensitive to changes in pH (Cooke et al. 1993). Low pH levels can lead to toxic, soluble forms of aluminum such as $Al(OH)_2^+$ and Al^{3+}, which can pose a serious threat to lake biota. Since alum is applied below the epilimnion, lake biota in the epilimnion are threatened by exposure from the continuous mixing of polymictic lakes. Softwater lakes are extremely vulnerable to decreases in pH due to misuse of buffering agents. Currently, the most common buffering agent is sodium aluminate. At pH levels below 6, the aluminum becomes soluble and reactivates the phosphorus, releasing it into the water column (Cooke et al. 1993).

Calcium Additives

Calcium carbonate, $CaCO_3$, and calcium hydroxide, $Ca(OH)_2$, can be added to a lake to inactivate phosphorus (Cooke et al. 1993). When pH, Ca^{3+}, and P levels are high, calcium carbonate forms solid hydroxypatite, $Ca_{10}(PO_4)_6(OH)_2$. Phosphorus binds strongly to hydroxypatite at high levels of pH. However, if CO_2 levels increase and pH falls, the hydroxypatite becomes soluble and it will release phosphorus (Cooke et al. 1993).

Calcium additives have no dosage requirements because there are no immediate consequences of overuse as there are in aluminum treatments (Cooke et al. 1993). Addition of large doses of calcium hydroxide over several years would result in high pH levels that could be damaging to biota. Application methods are less strict than those of aluminum sulfate primarily because calcium additives present no threat to the littoral and pelagic biota of the epilimnion (Cooke et al. 1993).

Slaked lime, $Ca(OH)_2$, was added to the surface waters of the dimictic and eutrophic Frisken Lake in British Colombia (Cooke et al. 1993). The slaked lime was added from June to August 1983 and again in May 1984. Once the calcium carbonate precipitate was formed, Secchi disk transparency increased greatly and phosphorus precipitation was significant. The precipitate later dissolved and released phosphorus back into the water. Frisken Lake had previously used copper sulfate but this calcium treatment worked equally well without the indiscriminate toxicity of the algicide, copper sulfate, to the biota as well as the potentially dangerous buildup of copper in the sediment (Cooke et al. 1993).

Since calcium additives are especially effective at pH levels greater than nine, this treatment could only be used in hard water lakes. The calcium additives will begin to release phosphorus at pH levels lower than nine (Cooke et al. 1993). As seen in Frisken Lake, the calcium treatments will not last for the long term but can be used as a substitute for algicide treatments. Unlike aluminum, calcium is not toxic when in its soluble form, which makes it a safer, but very limited in the locations where it can be effective.

Ferrous Additions

Like alum additions, ferrous additions ultimately lead to chemical reactions with the phosphorus in the lake, such that the phosphorus is bound within the product of the reaction. Fe (III) will combine with oxygen, hydroxyl, and water to form $Fe(OH)_3$. This iron (III) hydroxide will bind to the loose phosphorus in the water column and will form a precipitate. However, because the precipitate is relatively unstable, anoxic conditions will cause the phosphorus to be released (Bouchard pers. comm.). Ferrous addition augments the concentration of iron in the water column and increases the potential for sedimentation of the phosphorus (Theis 1979). A ferrous addition to a lake can serve as a remediation technique because it reduces the phosphorus available for algae.

When applying iron to a lake system, it is important to consider the necessary proportion of iron to phosphorus levels in the lake. A 3:1 ratio of iron to phosphorus has been shown to be optimal for phosphorus precipitation (Cooke et al. 1993). Another crucial consideration in this technique is the

control of pH levels. The level of pH is crucial because the effectiveness of this ferric reaction could be decreased in the presence of high pH (Cooke et al. 1993).

A relatively successful iron addition involved the application of $FeCl_3$ to the upper 15 to 20 centimeters of sediments of a shallow lake in the Netherlands (Cooke et al. 1993). The treatment was effective for three months, during which time phosphorus concentrations were reduced. The return to normal concentrations after the three months was attributed to wind storms and high external loading (Cooke et al. 1993).

However, a ferrous treatment is a relatively weak remediation technique, primarily because of the instability of the precipitate that is formed. When stratification occurs and conditions become anoxic, the iron precipitate layer can easily break down and release phosphorus back into the water column (Bouchard pers. comm.). In addition, Cooke et al. (1993) report that there have been no successful examples of long-term control of phosphorus with additions of iron salts. However, they report that the injection of ferrous salts into hypolimnetic aerators is a technique that shows promise (Cooke et al. 1993).

Algicides

Algicides target actual algal cell growth. They act by controlling the physical algal bloom, rather than the problematic high phosphorus levels responsible for the bloom. The major algicide that has been used in lake restoration is copper sulfate ($CuSO_4$). Copper inhibits algal photosynthesis, effectively killing the algae (Moore and Thornton 1988). This technique may be effective at killing the algae, but the relief is often brief and continued application is required if a more long-term result is desired.

The application of $CuSO_4$ is often done by placing the granules in a burlap or nylon bag and allowing the material to dissolve by towing the bags behind a boat. The liquid chelated form of the $CuSO_4$ is longer lasting and may remain in solution longer than the granule form (Moore and Thornton 1988). This algicide is illegal for common use in Maine; however, special legislation was passed to allow the permitting of its usage on a case-by-case basis (Bouchard pers. comm.).

There are few successful examples of algicide treatment because the technique is effective for such a short time. One example of an effective short-term treatment was the surface application of copper sulfate solutions to Casitas Reservoir, California (Cooke et al. 1993). This treatment effectively controlled periphyton for approximately four weeks. Copper sulfate treatments of nuisance algae are frequently considered successful for the short term (Cooke et al. 1993).

There are many drawbacks to the use of algicides. Although the lake may appear to be clean and algae-free after algicide applications, it still has high levels of phosphorus and the potential for future blooms. This remediation technique is temporary and only clears the lake for a very short amount of time. This is because within waters high in organic matter, the copper can quickly be lost from solution and is no longer effective (Moore and Thornton 1988). Although there is temporary elimination of one type of nuisance algae species, often another species becomes dominant or the eliminated species rebounds to equal or higher levels than the original bloom (Cooke et al. 1993). Expense is a very important consideration in the decision to use algicides. As of 10 years ago, each dose of the chelated granular form of $CuSO_4$ is \$346 to \$1432/ha, and because of this, algicides are considered to be a very costly treatment (Cooke et al. 1993). With the necessity of continued applications, algicide treatment is a very expensive endeavor. Most importantly, copper sulfate is toxic, attributing to the illegality of its common use. There are many undesirable consequences of algicide treatment. Hansen and Stefan (1984) report that 58 years of algicide treatment in a series of Minnesota lakes resulted in dissolved oxygen depletions, fish kills, toxic copper accumulation in the sediments, tolerance by some forms of algae, and undesirable effects to fish and the prey community (Moore and Thornton 1988).

PHYSICAL TREATMENTS

Water Removal Techniques

Hypolimnetic Withdrawal

Hypolimnetic withdrawal works by selectively exporting water from the hypolimnion of a lake (Cooke et al. 1993). This technique can be performed on stratified lakes that are experiencing anaerobic conditions in the hypolimnion. Hypolimnetic withdrawal also aims to increase the dissolved oxygen in the deep hypolimnion as well as remove nutrient-rich waters that can cause algal blooms. Increasing the dissolved oxygen prevents anoxic conditions in lakes. Anoxic conditions limit the habitat for many fish species and result in the release of phosphorus, toxic metals, ammonia, and hydrogen sulfide from the sediment (Cooke et al. 1993). Phosphorus is the primary concern when dealing with eutrophication in lakes because it is the limiting nutrient in algal growth. A decrease in phosphorus loading reduces the occurrence of problematic algal blooms. Hypolimnetic withdrawal can be an effective and long-term remediation technique for slowing the eutrophication process of a lake. Once the total phosphorus in the hypolimnion is reduced, it is often followed by the decrease in total phosphorus of the epilimnion.

However, if external loading is not controlled and phosphorus continues to enter the lake, hypolimnetic withdrawal will not be effective in improving lake water quality.

In order to build and operate a hypolimnetic withdrawal system, a pipe must be installed from the deep hypolimnion layer to the outlet of the lake. A dam may be needed at the outlet of the lake for this method to work. A dam helps to maintain the necessary water pressure differential (Cooke et al. 1993). There have also been instances where an outlet channel is cut and a pipe is laid to extract water from the hypolimnion (Firmage pers. comm.) Once the pipe is installed, a pump must be used to prime the pipe and begin the flow of hypolimnetic water. Once this flow is initiated, the pump is often no longer necessary and the hypolimnetic withdrawal system works independently. This method of hypolimnetic withdrawal will result in a smaller hypolimnetic layer and a greater epilimnion. There is another method of withdrawal that results in a hypolimnetic exchange. This exchange can help maintain the normal stratification of lakes by piping inlet water straight into the hypolimnion rather than letting it flow naturally into the epilimnion. For this exchange method to work, a pipe would need to be installed from the inlet into the deep hypolimnion. Also, a dam will be needed to maintain the pressure differential needed to direct the inlet flow (Cooke et al. 1993).

Hypolimnetic withdrawal was used effectively in the United States at Lake Wononskopomuc, Connecticut (N,rnberg et al. 1987). The withdrawal pipe was installed at the deepest basin of the lake at 15 meters and discharged at a rate of 0.9 m^3/min. This discharge rate was able to replace the lakes hypolimnetic volume in 5.6 months. Over five years after starting withdrawal, hypolimnetic total phosphorus decreased from 400 µg/l to less than 50 µg/l. Epilimnetic total phosphorus decreased from 24-30 µg/l to 10-14 µg/l. Algal blooms of *Oscillatoria rubescens* were eliminated by the withdrawal treatment. Not only was internal loading reduced, but dissolved oxygen increased greatly. The days of anoxia decreased from 50 to 65 days to less than 30 days (Nurnberg et al. 1987).

Hypolimnetic withdrawal is a relatively inexpensive remediation measure if the lake is outfitted with a dam. As mentioned before, a dam can be used to maintain the water pressure needed to selectively siphon the water from the hypolimnion. If a dam is not in place, costly pumping could be used instead. A pump is energy and maintenance intensive whereas a dam requires relatively low operational costs. The cost of an outlet channel fitted with a pipe would be high and labor intensive (Firmage pers. comm.).

Hypolimnetic withdrawal is not without its drawbacks. The discharge water will be very high in phosphorus and very low in dissolved oxygen. This outflow of poor quality water could possibly result

in similar water quality issues downstream. This discharged water may seriously disrupt fisheries and recreational areas. The problem may be solved in one lake but at a cost to other lakes and streams. The discharge must be monitored or directed to a large body of water such as the ocean or a river where it can be diluted. The discharged hypolimnetic water could also be mechanically cleaned and naturally aerated in the rapids of a stream to prevent damage to other bodies of water (Cooke et al. 1993).

Dilution

Dilution and flushing is a remediation technique that works by increasing the water exchange rate in order to dilute the limiting nutrient. This method requires a large source of low nutrient dilution water. The flushing of clean water into the lake will ideally result in a decrease in the total phosphorus, which will limit nutrients and result in a decrease of algal biomass. Dilution and flushing also controls internal loading of phosphorus (Cooke et al. 1993).

In order to use this method of lake remediation, the lake must be near a large source of low-nutrient water. The source of dilution water must have significantly less nutrients than the lake being treated. If a large source of low-nutrient water is available nearby, a diversion system must be implemented either through the use of canals or pumps. External loading of phosphorus must also be controlled to create a significant change in water quality (Cooke et al. 1993).

A relatively successful case of the dilution and flushing method is the case of Green Lake in Seattle (Cooke et al. 1993). The lake is located in a metropolitan area with a high population density and high development surrounding it. The lake dilution was instituted in 1962 using the city's domestic water supply from two Cascade Mountain streams. Dilution was an appropriate remediation technique because the city water infrastructure was already in place. The clean water supply could be easily transported to the lake site. The flushing rate to the lake was increased threefold from 0.88 to 2.4 times/year. In the years following the start of dilution, there was a marked improvement in chlorophyll *a*, total phosphorus, and Secchi disk visibility. Chlorophyll *a* decreased nearly 90 percent from 45 to 3 µg/l. Water visibility increased from about 1 m to an average of 4 m. Lastly, total phosphorus decreased from 65 to 20 µg/l. Lake water quality declined in the 1970s as a result of significant decreases in dilution water inputs (Cooke et al. 1993).

Dilution and flushing are effective and relatively inexpensive where facilities and dilution sources are readily available. However, if the dilution source is the domestic water supply, water costs are fairly high. In some cases, sources of low-nutrient water are abundant and the only costs incurred would be those of piping or diversion systems (Cooke et al. 1993).

In general, dilution and flushing measures are observed to be very effective in decreasing phosphorus and improving the lake water quality. Dilution and flushing have drawbacks similar to those of hypolimnetic withdrawal. The discharge must be directed to a large water body where the nutrient rich water can be diluted without severely damaging the water quality (Cooke et al. 1993). If no water body exists, then there is a risk of damaging other lakes and streams that are downstream of the flushed lake. As in hypolimnetic withdrawal, the discharge could be aerated and mechanically cleaned to prevent such damage, but this would be done at an additional cost (Cooke et al. 1993).

Drawdown

Water level drawdown is a remediation technique primarily used for reservoirs and small ponds (Cooke et al. 1993). Water level drawdown can be used to manage fish populations, control macrophytes, make repairs to dams or docks, or allow easier access for other remediation techniques such as dredging and sediment covers. A drawdown will stimulate fish productivity by eliminating monocultures of aquatic plants while high densities of forage fish are reduced through predation. As a result of drawdown, individual sizes of game fish would increase greatly while there would be a reduction in planktivorous fish (Cooke et al. 1993). These changes in fish stock would result in clearer water, a decrease in algal blooms, and improved sport fishing. Drawdown is a remediation method that can also help control aquatic plants. The drawdown exposes root systems to dry and freezing or dry and hot conditions which results in the elimination of unwanted aquatic plants (Cooke et al. 1993). Winter drawdowns prove to be more successful due to the lack of moist soil and the decreased runoff. Drawdown can also encourage certain plant growth that attracts waterfowl to the habitat. The bare mudflats can serve as a seedbed for emergent species that would have otherwise not been able to grow. Lastly, water drawdown can be used to easily and cheaply install physical liners to the bottom sediment, place rip-rap on the banks, and maintain dams and docks (Cooke et al. 1993).

Water level drawdown is one of the least expensive remediation measures. Drawdown also reduces the cost of other remediation measures such as dredging and physical liners by allowing easy access to the lake bottom. As with hypolimnetic withdrawal and dilution, a dam is needed to control the flow and depth of the lake. Also, the lake must be of a relatively small size so that a significant decrease in water volume can be attained and then subsequently replaced when the drawdown period is over. There must also be a place to divert the discharge. The discharge must be diluted so as not to transfer significant nutrients to other lakes and streams.

Water level drawdown may have adverse effects such as algal blooms that result from the oxidation of organic matter or possibly a high phosphorus content of added water after the drawdown. Another danger associated with drawdown, if done at the wrong time, is fish kill related to low dissolved oxygen. Drawdowns are also responsible for great changes in the density and diversity of benthic invertebrates. The sediment drying and freezing associated with water level drawdowns results in a destruction of much of the benthic fauna and a retardation of the recolonization by many species (Cooke et al. 1993).

Dredging

A purely mechanical technique used for lake remediation is dredging. Dredging involves the direct removal of the lake's nutrient-rich sediment (Peterson 1979). The theory behind dredging is that if enough of the nutrient-rich sediment is removed, the release of phosphorus (the internal loading) from the remaining sediment could be reduced. There are two major ways that dredging can be successful: 1) if enough sediment is removed, such that the new upper layer of sediment is substantially lower in nutrients, or 2) if massive amounts of sediments are removed, such that the entire bathymetry of the lake is altered, changing the thermal profile (Peterson 1979; Bouchard pers. comm.). Dredging would require an initial sediment core profile to assess the amount of nutrients within the sediment before actual sediment removal could occur. Such predicative measures are necessary for the efficient removal of the proper type and amount of sediment.

This physical technique has been tried in several lakes, and sections of large lakes have been dredged, but to date, no major Maine lakes have used this technique (Bouchard pers. comm.). In Lake Trummen, Sweden, a successful dredging project reduced phytoplankton diversity and production levels, increased Secchi disk transparency by nearly 50 cm, and completely eliminated one of the nuisance algae species (Peterson 1979). This project involved the removal of 0.5 m of sediment, dredged uniformly from the basin. A year later, an additional 0.5 m was removed. This removal and deepening of the basin greatly reduced total phosphorus and total nitrogen in the following years (Cooke et al. 1993). The benthic community did not appear to be permanently harmed since dominant species were found in larger numbers after the dredging event (Peterson 1979).

Despite the apparent benefits of this method, dredging is very disruptive and not aesthetically pleasing, often creating more serious environmental effects than it attempts to remedy. Dredging temporarily stirs up the sediment, and can often resuspend the nutrient rich sediment throughout the water column. In the long term, dredging can also disturb the benthic fauna, deplete oxygen levels,

reduce primary production, alter temperature, and ultimately increase nutrient levels by the resuspension of sediments (Peterson 1979). Also, in a shallow lake in Germany, researchers found that the success of dredging is quite variable. Without the reduction of external phosphorus loading, dredging may only be a temporary restoration technique, followed by a slow return to the original high phosphorus condition. They suggest that despite some apparently successful short-term dredging techniques, the question still remains whether the phosphorus cycle would return to normal after dredging (Kleeberg and Kohl 1999).

An additional drawback to dredging is its high cost. The mean dredging cost for a northeast lake restoration project, calculated in 1979, is $5.63 per cubic meter (Peterson 1979). In 1989, costs for dredging a uniform 0.5 m of sediment from China Lake, a much larger lake than Threemile Pond, were calculated by the Maine Department of Environmental Protection, and were found to be too expensive to even consider the technique. In addition to cost and the deleterious environmental effects, an appropriate disposal site for the sediment removed from the lake is a very important consideration. In fact, the high cost for dredging in New England results largely from the high cost of land for disposal (Peterson 1979).

Hypolimnetic aeration

Hypolimnetic aeration can be used to oxygenate the hypolimnion of lakes to prevent anaerobic activity. Artificial aeration refers to processes that directly add or mix oxygen into the water (Fast 1979). This aeration can be achieved by injecting air through a diffuser or through a bubbler (Fast 1979). This technique aims at disrupting the redox cycle such that Fe(III) is formed at the sediment-water interface. Fe(III) can complex with phosphate, making less phosphorus available for release (Theis 1979). In essence, hypolimnetic aeration prevents the breakdown of the iron phosphate complex and ties up the phosphorus. The objective of one type of hypolimnetic aeration is to raise the oxygen content of the hypolimnion without destratifying or warming the water column (Cooke et al. 1993). Another type of hypolimnetic aeration aims at circulating the water and destratifying the water to bring oxygen from the surface water to the anoxic hypolimnion (Bouchard pers. comm.). Regardless of the type of aeration, internal loading of phosphorus should decline with the common establishment of aerobic conditions near the sediment surface (Cooke et al. 1993).

Hypolimnetic aeration was used somewhat successfully in Togus Pond, Maine, just southwest of Threemile Pond. Water quality in this lake was improved through the use of the destratification type of

aeration. Secchi disk transparency increased and algal blooms appeared to subside (Bouchard pers. comm.). A 1970 American Water Works Association survey of 26 water suppliers who used aeration further detailed the potential success of hypolimnetic aeration (Fast 1979). This survey found that despite only seven percent of the water suppliers reporting decreased algal blooms, 90 percent of the suppliers were satisfied with their destratification systems. This suggests that improvements in other conditions must have compensated for the lack of effect upon algal growth (Fast 1979). Although little documentation exists about the successful use of the non-destratifying technique of aeration in the control of algae, there is evidence that it can control phosphorus release from sediments (Moore and Thornton 1988).

A serious drawback to destratification aeration is the potential for circulating fresh water past the sediment layer and increasing the rate of internal phosphorus loading. Although phosphorus concentrations in deep water are reduced, destratification has also been shown to be ineffective in reducing algal blooms and primary production (Fast 1979). This is likely because the rate of phosphorus exchange may be increased. Ultimately this phenomenon could undermine the aeration of the hypolimnion, because, while phosphorus is being tied up with Fe(III), it is also leaching back out at a similar or more rapid rate (Bouchard pers. comm.). Also, in destratifying a lake, the cold water is effectively eliminated (Fast 1979). This could be particularly undesirable when considering cold water fisheries such as trout, which depend upon the natural stratification of the lake system (Fast 1979). The data on the success of the non-destratifying method of aeration are incomplete because the mechanism of this method is very complex (Fast 1979).

Treatments with hypolimnetic aeration are fairly expensive, with expected first year installation and operational costs being approximately \$2.50 per kg O_2, or \$6,500 per hectare in 1993. However, the long-term costs decrease after installation and can be relatively modest (Cooke et al. 1993). A 2002 study of Canyon Lake in California showed that two axial-flow aerating pumps, cited at \$25,000 per aerator, and an air injection system, cited at \$250,000, were necessary for its remediation (Fast 2002). The yearly cost to maintain the aeration system was significantly less, at \$35,000 for a seven to twelve month period (Fast 2002). Costs for aerating a lake would therefore depend on the size of the lake, the volume of anoxic water, and the type of aerating system used.

Physical Liners

Physical liners and sediment covers can be used as a remediation technique to physically cap the sediment layer to minimize phosphorus release. Materials such as polyethylene, polypropylene, aquascreen, sand, gravel, burlap clay, or fly ash from coal production could be used to create a physical barrier (Theis 1979, Cooke et al. 1993). The most effective materials are gas permeable screens, which trap the phosphorus underneath. There are several benefits to physical liners including their confinement to specific lake areas, the lack of onshore disturbance, the lack of toxic substance release, and their relatively simple installation (Cooke et al. 1993). Because physical liners allow a more particular application, they are a useful remediation technique in lakes with specific phosphorus problem areas. Liners can be used throughout an entire lake, but liners may be especially effective in areas such as beaches, boat launch waters, and other areas where external loading or mixing is especially prominent.

An example of the successful addition of a physical liner was the use of fly ash in Lake Charles East, Indiana. A 2 to 5 cm layer of fly ash was applied to particular areas of the lake. With this liner, the hypereutrophic lake achieved dampened phosphate release as well as lower phosphorus levels available for release (Theis 1979).

Physical liners do have their disadvantages, however. Physical liners do not correct the cause of the lake water quality problem; phosphorus levels still remain (Cooke et al. 1993). Also, physical liners are difficult to apply, remove, and may rip or balloon during application. Scuba divers are often needed for application and some covers, in order to be effective, must be periodically removed for cleaning (Moore and Thornton 1988). Physical liners are often only temporary, and disturbance must be minimized to avoid breaking the sediment seal and allowing leaching of phosphorus through the cap, regardless of the liner type (Cooke et al. 1993). In recreational lakes, the stirring and use of anchors by motorboats could render a seal useless by puncturing or disturbing the cap. Most liners range from $12,000 to $30,000 per hectare, which is extremely expensive if an entire lake needs to be sealed (Cooke et al. 1993).

Aquatic Plant Harvesting

Another form of physical lake remediation is aquatic plant harvesting. This technique involves the removal of the phosphorus-containing biomass. When the aquatic macrophytes die and decompose, they contribute to the nutrient budget in the lake ecosystem (Asaeda et al. 2000). If enough of the phosphorus budget of the lake is tied up in the plant biomass, then the removal of the biomass can be an

effective way of reducing phosphorus in the lake. In a study in Florida, researchers showed that macrophytes, as a contributor to the phosphorus budget, can act as regulators of the nutrient concentrations within shallow, warm lakes (Brenner et al. 1999).

The size of the lake must be relatively small, so that a substantial amount of phosphorus is in the biomass. This would ensure that harvesting actually removes a worthwhile percentage of the phosphorus within the lake. Burton et al. (1979) state that harvesting can be successful if 1) macrophyte densities are high, 2) phosphorus input is less than $1 g/m^2/yr$, 3) a majority of the lake surface is covered by macrophytes, and 4) harvest does not reduce the production of macrophytes during the following years.

In addition to these requirements, harvesting also requires the purchase of a weed eater to harvest the plants. This harvesting must be done annually, to continually remove the nutrient-containing biomass. Finally, the huge amount of nutrient-rich biomass must be deposited in an acceptable location away from the shoreline so nutrients don t drain back into the lake.

If these requirements can be met, aquatic plant harvesting can be effective in some situations. In Lake Swartvlei, South Africa, for example, a study found that phosphorus released in macrophyte decomposition could be reduced by at least 75 percent, and that phosphorus leaching could be reduced by half within ten years, if the aquatic plants were removed through harvesting (Asaeda et al. 2000). In removing nutrients, the researchers concluded that aquatic plant harvesting could lead to potential lake restoration.

However, such requirements often impede the success of aquatic plant harvesting in lake remediation. Because many northern lakes are deep, cold, and lack density of macrophytes, Burton et al. (1979) suggest that plant harvest will restore very few northern US lakes. In addition, they suggest that aquatic plant harvest could cause severe environmental impacts upon the lake ecosystem. Harvesting can cause resuspension of sediments and detritus, phosphorus leaching from severed floating stems, decreased evapotranspiration, and increased light penetration (Burton et al. 1979). Mechanical methods of biomass removal have been cited by others to be largely unsuccessful because fragments remain and regrowth can be rapid, contributing further to phosphorus accumulation. The temporary removal of aquatic plants is considered costly, disruptive, and ineffective (Caffrey and Monahan 1999). Current removal costs of aquatic plants remain the same as costs cited in 1993, ranging from $1,000 to $2,000 per hectare (Cooke et al. 1993).

BIOLOGICAL CONTROL

Fish Stock Manipulation

Fish stock manipulation, along with other biomanipulation measures, shows the greatest promise for the long-term control of lake eutrophication (Cooke et al. 1993). Fish stock manipulation is a biocontrol method that alters the populations of certain fish to attain the desired levels of zooplankton and phytoplankton. Phytoplankton are preyed upon by the zooplankton. Zooplankton populations must be kept healthy to control algal blooms. Biomanipulation techniques can naturally manage lake water quality without the use of unnatural chemicals. Fish are easier to manipulate than nutrients, but they often require continuous management. In order for fish stocking to succeed, the habitat and prey population in the lake must be suitable to the introduced species. Further understanding of biocontrol measures may eventually eliminate the need for chemical treatment as well as mechanical control of pelagic algal blooms (Cooke et al. 1993).

Three groups of fish that can alter the structure of their ecosystems are: planktivorous fish, benthivorous fish, and piscivorous fish (Lammens 1999). The planktivorous fish eat larger species of zooplankton. This results in a decrease in the zooplankton population and an increase in phytoplankton population. With phytoplankton populations left unchecked, the transparency in the lake is likely to decrease. Ideal growing conditions and nutrient availability will lead to algal blooms. Alewives, for example, are planktivorous fish that feed primarily on larger zooplankton. The zooplankton grazing rates on phytoplankton increase as the size of the zooplankton individual increases (Cooke et al. 1993). Planktivorous fish selectively remove the best predators of bloom-forming phytoplankton.

Benthivorous fish are bottom dwellers that eat primarily invertebrates in the substrate (Lammens 1999). Their constant foraging on the bottom may control the establishment of new macrophytes. However, these fish stir up the bottom in search of their food. This suspension of solids leads to an increased turbidity, which results in a higher internal loading of phosphorus (Lammens 1999).

Piscivorous fish feed primarily on fish that are 10 to 40 percent of their body length (Lammens 1999). Since piscivorous fish feed on small fish rather than on the zooplankton, the zooplankton are available to control the phytoplankton more effectively. The zooplankton populations remain healthy and capable of keeping the phytoplankton populations from reaching algal bloom sizes. This results in greater water clarity (Lammens 1999).

There are five ways to conduct fish stock manipulation. The first method is to increase the stocking of piscivores in an effort to decrease planktivores. The next four methods deal with fish killing or removal. Induced winter fish kill can eliminate the fish in the lake through suffocation during the frozen winter season. The ice is covered with an opaque material that allows no light through. Without light, the plants in the lake can no longer oxygenate the water and fish can no longer survive. The problem with such a fish kill is the decomposition of dead fish and the release of nutrients that may result in algal blooms. Dead fish should be removed to prevent such a nutrient release as well as other negative aesthetics such as dead fish washed up on shore. Rough fish removal is a method that requires trapping or netting of all the fish in the lake. This method is labor intensive and expensive. It also requires a flat bottom with no obstructions to snag the nets. Fish poisons can also be added to eliminate a fish community before restocking. Rotenone, a fish poison, is not only toxic to fish but to zooplankton as well. Lastly, water level drawdown can also be used as a method of subjecting fish to conditions that would greatly reduce or eliminate their populations. As many of these methods show, the most ideal condition for control is the complete removal of the fish, followed by calculated restocking (Cooke et al. 1993). In one extreme case in Lake Zwemlust in the Netherlands, the lake was completely drained and 100 percent of the fish were removed (Lammens 1999).

Fish stock manipulation is a relatively inexpensive way to control algal blooms. Manipulation of the fish stock may result in favorable levels of zooplankton and phytoplankton, but this method does not address the actual phosphorus problem in the water. Biomanipulation techniques are a good way to manage high phosphorus lakes for greater clarity but they fail to reduce phosphorus levels. This method could be paired successfully with phosphorus inactivation or removal techniques that cooperatively ensure greater lake water quality.

Addition of Nutrient Absorbing Plants

Introduced plants can be a tool to remove nutrients and improve lake water quality. The introduced or exotic plants must be able to survive and flourish during the growing season but must not survive the winter and reproduce. These exotic plants are used to trap phosphorus in their biomass. Exotic plant biomass can be harvested at the end of the growing season and then disposed of away from the lake.

A potential exotic plant for Maine is the water hyacinth. Water hyacinth can survive during the summer but the cold of the winter kills it. Mats of water hyacinth could be raised and harvested to

remove phosphorus. Water hyacinth has yet to be used in Maine due to state regulations involving introduced species (Bouchard pers. comm.)

This technique is labor intensive because it involves the labor of harvesting the wet biomass and locating a proper disposal site. This technique must also be conducted annually to continue removing phosphorus. This technique is designed for small and relatively shallow bodies of water. Exotic aquatic plants would have little effect on the phosphorus levels of a large lake and would have a greater impact on smaller ponds. The cost of this method and the actual amount of removed phosphorus must be considered before proceeding with exotic plant use. The expense of such a technique may not be worth the benefits. There is also the potential for the survival of a hardy invasive species that could upset the balance of the local ecosystem (Bouchard pers. comm.).

Wetlands Maintenance and Manipulation

Wetlands maintenance and manipulation is becoming increasingly important as more and more wetland areas are destroyed or threatened by development (see Background: Watershed Land Use: Wetlands). Natural wetlands are currently being destroyed at an alarming rate (Cooke et al. 1993). This loss has led to floods, soil loss, species extinctions, diminishing groundwater tables, and pollution of lakes. Wastewater pollution can destroy the wetlands ecosystem. Wetlands serve as important buffers between water inflow and the lake, filtering as much as 90 percent of suspended solids. The wetland slows the water down so that the solids fall to the bottom. Natural wetlands act as nutrient sinks when the wetlands plants are experiencing high growth rates, but they may also act as nutrient sources when the plants die and decompose. Wetlands cannot act as a consistent nutrient sink. In the case of Lake Wingra, Wisconsin, 83 percent of the incoming phosphorus was retained by the wetland. This retention occurred during the summer when algal blooms are usually at their worst (Cooke et al. 1993).

Although natural wetlands are greatly preferred, artificial wetlands can be constructed (Cooke et al. 1993). One type of artificial wetland directs inflow though sediment and emergent plants. The second type of artificial wetland requires inflow to go through permeable sediment or gravel bed with submerged vegetation. One advantage to having an artificial wetland is the increased ability to harvest plants and remove sediment with more freedom from government natural wetlands protection. In this way, the wetland can be kept fairly young and can be constantly growing and absorbing nutrients. As mentioned before in the water level drawdown section, water level drawdown can be used to encourage

new growth of emergent plants, such as cattail or reeds, along the shore and on bare mudflats (Cooke et al. 1993).

Plants can be introduced to wetlands to decrease the rate of inflow as well as aid in phosphorus absorption (Connor 1995). In Kezar Lake, New Hampshire, wild rice was planted in the wetland in 1985 and 1986 to decrease the phosphorus levels in the lake. The wetlands manipulation was initially effective as a nutrient sink. After a few months, the removal of phosphorus became poor because plant growth had slowed. The wetlands did serve as sedimentation buffer zones as well as great wildlife habitat. The cost of the wild rice implementation was $250 (Connor 1995). This study suggests that artificial wetlands that are intended for harvest may serve as a useful and natural way to remove phosphorus from the lake.

As shown above, some wetland manipulation can be very inexpensive. Unless an efficient system of annual harvesting and disposal is in place, the benefits may not be significant enough to outweigh the costs. Natural wetlands maintenance and manipulation can help maintain a sedimentation buffer and provide an exceptional wetlands habitat, but phosphorous absorption is not seasonal depending on the rate of plant growth.

OTHER POSSIBILITIES

Another possibility in the restoration of lakes is the combination of several different remediation techniques. By combining a number of techniques, lake management can be effectively catered to the particular situation of a specific lake.

For example, Bautzen Reservoir, Germany, was found to be a lake where CO_2 was the limiting factor in the competition between bloom-forming cyanobacteria and other non-bloom-forming, eukaryotic phytoplankton (Deppe et al. 1999). CO_2 was injected into the hypereutrophic waters with aerators to determine the effect of the increased CO_2 levels on the water quality and algal production in the lake. This novel form of biological control resulted in conditions that favored the non-bloom-forming phytoplankton over the cyanobacteria. Then a ferrous addition was used in the lake to precipitate the phosphorus in the water column. This two-part treatment was extremely successful at drastically reducing the concentrations of phosphorus in the entire body of water (Deppe et al. 1999).

Another widely used combined technique involves the initial dredging of a lake, followed by biological manipulation of the fish stocks, supplemented with a final technique involving macrophyte monitoring (Madgwick 1999, Phillips et al. 1999). This tri-fold technique has been used predominantly

in the Norfolk Broads, United Kingdom, where severely eutrophic lakes respond well to this multi-faceted approach (Madgwick 1999, Phillips et al. 1999).

An additional unique remediation technique is the use of barley straw to minimize production of algae. Short-lived algal inhibitors are released during the aerobic decomposition of the barley straw (Caffrey and Monahan 1999). The exact mechanism behind this inhibition is unknown, but the technique is considered to be environmentally friendly because it is selective against planktonic and filamentous algae (Caffrey and Monahan 1999). The method of application is important in this technique because of the direct relationship between the surface area and the amount of released algal inhibitors (Barrett 1999). This technique also requires aerobic conditions to allow for decomposition of the straw. Barley straw has been used successfully in reservoirs and canals. The Royal Canal in Ireland was treated with bales of barley straw at 50 meter increments along its banks, resulting in a decrease in algal biomass from the time the straw was added (Caffrey and Monahan 1999). As long as the barley straw was present, no filamentous algae were reported. Another study of 100 barley straw treatments in the U.K. and Ireland found that algal control was most effective in smaller water bodies (Caffrey and Monahan 1999). This technique has also been used to some extent in the United States in small farm ponds.

Despite these successes of barley straw, its use as a restoration technique is likely cosmetic. The barley straw does not alter the phosphorus content within the lake; rather it inhibits the growth of the algae and falls into the category of an algicide. An additional consideration is that the waterlogged straw would have to be removed to eliminate the phosphorus within its biomass from the lake system. The time and costs associated with the removal of barley straw make it apparent that this remediation technique has its disadvantages. Larger bodies of water, including many Maine lakes, would require the removal of an enormous amount of wet straw (Bouchard pers. comm.).

APPLICATIONS TO THREEMILE POND

From this extensive list of remediation techniques, only a few seem truly feasible in the remediation of Threemile Pond. This section evaluates many techniques that were determined by CEAT to be inappropriate for Threemile Pond. However, there are several techniques that are recommended for the remediation of Threemile Pond. Remediation techniques are summarized according to their applicability to Threemile Pond: those that are not feasible and those that are feasible (see Appendix N).

Ferrous addition is a feasible technique, but because of the high potential for the precipitate to separate into its individual components, its effectiveness is questionable. The addition of iron (III)

does not seem to be a sensible remediation technique for Threemile Pond, particularly when compared to other techniques.

Like the ferrous additions, the use of calcium additions is not a feasible remediation technique in Threemile Pond because of their instability with the phosphate ion. No calcium additions have been conducted in Maine because an extremely large amount of calcium would be needed in such soft water lakes (see Water Quality: Chemical Analysis: Hardness; Bouchard pers. comm.). Hard water lakes are more appropriate for calcium additions because of the chemical reactions involved (Cooke et al. 1993). In the Adirondacks, in New York, lime was required to be applied in addition to the calcium to maintain pH, which controlled acid decomposition (Bouchard pers. comm.). The high potential for resuspension of the phosphorus combined with the pH and alkalinity problems associated with calcium addition render this technique useless in a lake such as Threemile Pond.

Algicides, such as copper sulfate, are also not a reasonable remediation technique for Threemile Pond. Algicides do not rid the lake of its internal phosphorus-loading problem. The toxicity of copper sulfate accumulation to fish is an aspect of algicide use that is particularly significant to Threemile Pond. Because fishing and recreational activities are so important to Threemile Pond users, the extremely temporary relief from algae blooms may not outweigh the serious negative effects and costs of algicides.

Barley straw is not a feasible remediation technique in Threemile Pond, primarily because of the size of the lake. A huge amount of barley straw would have to be applied and then replaced once the straw was rotted completely. The cost to remove such a huge amount of waterlogged biomass can be expensive and time-consuming (Bouchard pers. comm.). Because the barley straw acts like an algicide, and does not affect the phosphorus levels in a lake, this technique becomes even less applicable to Threemile Pond.

Aquatic plant harvesting is not a realistic technique for use in Threemile Pond, also because of its size. With an area of 458 hectares and an average depth of 5.18 meters, it would be impractical to harvest Threemile Pond. The total phosphorus that would be removed with the biomass would be inconsequential compared to the rest of the lake. Because most of Threemile Pond is too deep for macrophyte growth, macrophytes do not grow densely enough to justify their harvest as a means to reduce phosphorus. Aquatic plant harvesting should not be considered to be a potential restoration technique for Threemile Pond because of the cost, the disruption, and the potential ineffectiveness of the technique.

The introduction of exotic plants is also not a practical form of remediation for Threemile Pond. Plants can often prove to be more hardy than expected and may be able to survive the winter, and in effect, may out compete the natives. Mats of hyacinths, for example, would likely not be successful in Threemile Pond, because of the high macrophyte density required to make a significant impact in phosphorus reduction. In a shallower pond, such mats may be more feasible (Bouchard pers. comm.). Such non-native plants could also pose a problem because of permits and regulations that limit their introduction.

None of the water removal techniques (water drawdown, hypolimnetic withdrawal, and dilution) would be feasible in Threemile Pond because the lake has no dam. The construction of a dam would be expensive, labor-intensive, and temporarily destructive. In the case of dilution, the addition of lower nutrient water is required, and a source of such water does not exist in the area surrounding Threemile Pond. In addition, the nutrient-rich water that would be removed using these techniques would ultimately end up in Webber Pond, shifting the problem further down the lake series. Webber Pond, with eutrophication problems of its own, would become increasingly eutrophic with such a high influx of phosphorus-containing water. The water could be aerated and stripped of nutrients prior to addition into Webber Pond, but this technique would be extremely expensive and would require long-term management and maintenance (Bouchard pers. comm.).

Dredging is not particularly feasible for remediation of Threemile Pond. With a volume of 22.3 million cubic meters, Threemile Pond would require an extraordinarily expensive dredging project to restore natural nutrient levels, even with advances in technology. The questionable effectiveness, the deleterious environmental effects, the high cost, and the difficulty in relocating the removed sediment make dredging an unfavorable option for the remediation of Threemile Pond.

Physical liners are partially feasible in Threemile Pond, but could not be considered a primary remediation technique for this lake. In a recreational lake like Threemile Pond, the destruction that can occur to the liner from boat usage and anchoring, make this technique impractical. However, parts of the lake, which may be designated through additional research as particularly susceptible to phosphorus leaching from the sediment, may benefit from physical liners. The cost of physically lining the entire lake is exorbitant because Threemile Pond has an area of over 400 hectares. Due to the high per hectare price of liners, physically lining all of Threemile Pond would not be economically feasible.

The destratification technique of hypolimnetic aeration does not appear to be a feasible option for Threemile Pond because of minimal evidence that it reduces algal blooms, due to the potential that

this technique could increase the rate of phosphorus release. However, the less invasive form of hypolimnetic aeration, which does not disturb the surface and maintains stratification, may be suitable for remediation of Threemile Pond. This technique could artificially stratify the weakly stratified Threemile Pond, and, in increasing the hypolimnion, could increase the potential for aeration. In aerating only the hypolimnion, the rate of iron precipitation would not be counteracted by the increased rate of phosphorus leaching, as in the destratification technique. Under high oxygen and iron conditions, hypolimnetic aeration could actually inactivate phosphorus and perhaps promote some algae control in Threemile Pond (Moore and Thornton 1988). This technique could work in Threemile Pond, although the cost may act as an initial deterrent. In 1990, hypolimnetic aeration of a lake the size of Threemile Pond would have cost approximately $2,732,000 with the installment of 32 aeration units (Cooke et al. 1993). However, current costs will have significantly decreased with the advancement in aeration technology. A new technique, discovered in 1993, may currently reduce the estimated cost by $1 per kg O_2 for each aeration unit (Cooke et al. 1993). Despite the apparent high cost, modern techniques and additional analysis could make hypolimnetic aeration a worthwhile restoration technique for Threemile Pond.

Alum treatment appears to be one of the most feasible remediation techniques for Threemile Pond. The reported potential for long-term success and the stability of the aluminum phosphate that results from the chemical reaction with aluminum may make alum treatment the ideal candidate for use in Threemile Pond. The failed prior treatment that was conducted at Threemile Pond in 1989 was likely a result of inadequate management and application. The treatment may have failed because the deep sediments (below 3.5 m) were underdosed, and the shallow sediments (above 3.5 m) were overdosed (Bouchard pers. comm.). In addition to the depth-dosing problem, the entire lake was likely underdosed (Bouchard pers. comm.). Areas of the lake with a depth above 3 m could receive a higher dose of alum and less alum could be added to areas with depths below 3 m (Figure 23). With more precise and thorough application, especially to the deeper areas of Threemile Pond, an alum treatment could be potentially very effective at reducing the phosphorus available for release. The failure of the past alum treatment has necessitated the re-evaluation of the technique and shows how alum application can be changed. With modern techniques such as Geographic Information Systems, the alum treatment could be differentially dosed depending upon the time and locations within Threemile Pond that go anoxic. If the alum is applied properly and differentially, it is likely that the phosphorus within the water column will precipitate out and the phosphorus within the sediment will become covered in flock. The phosphorus

already present in Threemile Pond would no longer be available for algae production. A revisited and well-managed treatment of alum could be a definitively useful and long-term technique in the remediation of Threemile Pond.

Overall, most forms of biological manipulation appear to be very applicable to Threemile Pond and its restoration. However, the most feasible forms of biological manipulation are fish stock manipulation and wetland preservation and manipulation. Wetland preservation is extremely feasible, but its actual impact on phosphorus levels may not make it a sufficient technique in Threemile Pond on its own. Threemile Pond already has wetlands preserved within the watershed and the maintenance of this land would be possible and beneficial. Manipulation of the wetlands, with the addition of phosphorus absorbing plants, is an interesting form of remediation and could be worth further investigation.

Fish stock manipulation is a very reasonable remediation technique because Threemile Pond is already regularly stocked with fish (see Background: Threemile Pond Characteristics: Biological Perspective: Fish Stocking). The manipulation favoring piscivorous fish would not be a drastic change from what is already being added into the lake. However, the alewives that are currently being introduced are planktivorous fish, which eat the zooplankton. The addition of planktivorous fish may allow the bloom-forming phytoplankton to thrive through this decrease in phytoplankton predators, whereas if the planktivorous alewives were removed, the zooplankton may be able to keep the algae blooms in check. In addition, if the stock could switch to more piscivorous fish, this alternative would benefit both fishermen and people seeking improved lake quality. This stock shift would likely not have such a dramatic impact on the ecosystem of the lake because introductions are already present. One could expect that a sufficient manipulation of fish stocks would shift the food web enough to reduce bloom-forming phytoplankton. The manipulation of fish stocks in Threemile Pond could be a very promising and feasible remediation technique.

Combinations of any of the techniques mentioned should be considered because multi-step approaches have proven successful (Caffrey and Monahan, 1999, Deppe et al. 1999, Madgwick 1999, Phillips et al. 1999). However, the combination of several techniques increases the complexity of the treatment, and in doing so, could increase the potential for ineffectiveness. Such combinatorial techniques can be extremely lake-specific and could prove to be well tailored to the needs of Threemile Pond. Additional research would be required to determine the particular combination of techniques appropriate for Threemile Pond.

FUTURE PROJECTIONS

POPULATION TRENDS

HISTORIC POPULATION TRENDS

The three Maine towns that make up the majority of the Threemile Pond watershed, China, Vassalboro and Windsor, share common historic population trends (Figure 46). These trends are characteristic of many rural Maine towns. In the early 1800s, the towns experienced fast growth as bustling farming communities (Town of China 1987). In the ten years from 1820 to 1830, the population of China more than doubled. During this time, Vassalboro and Windsor were also growing, but at a more steady rate. In the mid-1800s each town witnessed an out-migration due to the increasing amount of land available for settlement in the West. Following declining populations for almost a century, in the 1930s the towns started to see an increase in population and some development. The populations have increased steadily since the 1930s and continue to today. In the 2000 U.S. census, Vassalboro had a population of 4,047 and China had a population of a 4,106. Windsor was almost half their size with a population of 2,204. Between 1990 and 2000, the population of Windsor increased by 16 percent while the populations of Vassalboro and China only increased by 10 percent.

FUTURE POPULATION TRENDS

The populations of the three towns have been growing steadily since the 1930s and more rapidly since the 1970s (Figure 46). According to the Kennebec Valley Council of Governments (KVCOG 2003), the populations of China, Vassalboro and Windsor will continue to increase. Based on historical data and current growth rates, China is predicted to have a population of 5,500 by 2020, a 34 percent increase from 2000 (KVCOG 2003). The population of Windsor is predicted to reach 2,800 by 2020, a 27 percent increase from 2000 (KVCOG 2003). Vassalboro has the smallest projected population growth rate. In 2020, the population is predicted to reach 4,800, an 18 percent increase from 2000 (KVCOG 2003). The steady growth is predicted to continue for at least another 20 years.

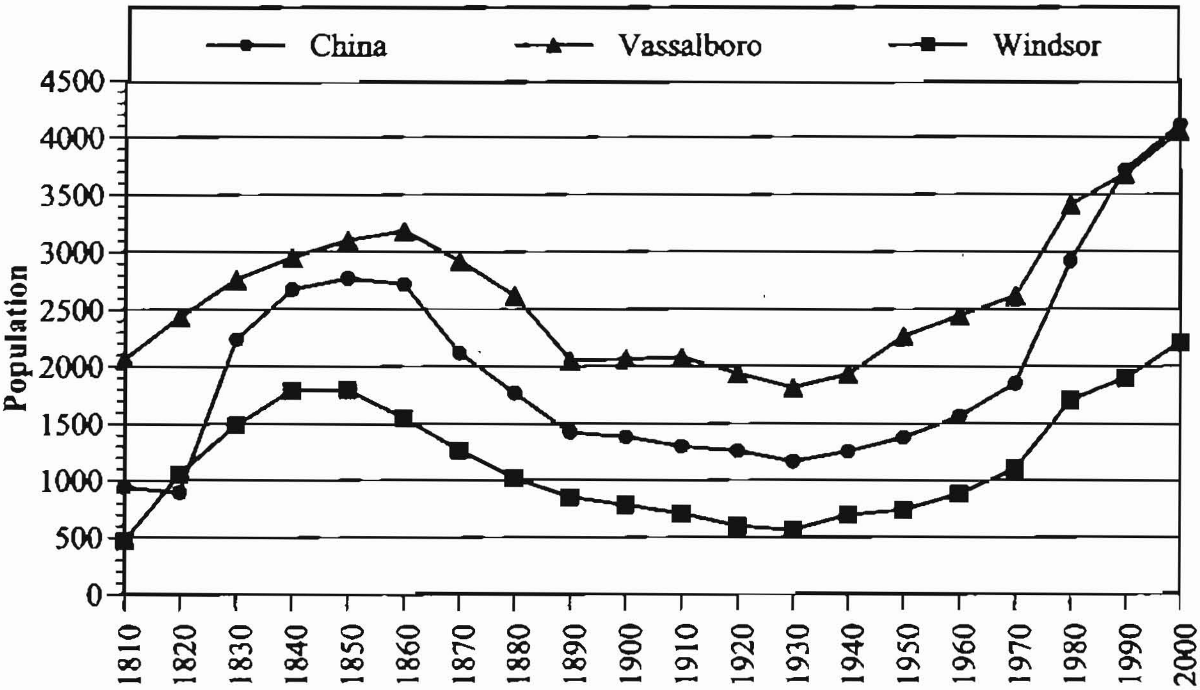


Figure 46. Population trend for the towns of China, Vassalboro and Windsor from 1810 to 2000. Data obtained from Maine census data- population totals (Fogler Library 2002a).

GENERAL DEVELOPMENT TRENDS

The region surrounding the Threemile Pond watershed should expect growth and development to continue at a similar pace as in the past decade. Historical Census Bureau data and the town offices of China, Vassalboro and Windsor confirm that more homes are built every year and the population is slowly rising (USCB 2003; see Future Projections: Population Trends). The pace of moderate growth will likely have positive and negative effects on the water quality of Threemile Pond. However, it is difficult to estimate precisely how Threemile Pond will be affected by development.

As commercial, residential, and municipal development increases, more roads will be built and the area of impervious surfaces within the Threemile Pond watershed will rise. This elevates the potential for erosion and phosphorus-rich runoff to enter the lake. More commercial developments, such as the recent commercial expansion at the intersection of Route 3 and Route 202 in Vassalboro, could increase phosphorus-containing sediment runoff (Fitzgerald pers. comm.).

The market for second homes in Maine continues to grow and many urban dwellers are looking to buy or build a camp or retirement house near a lake. Although the growth potential is unknown, there is little indication that this demand will shrink in the near future. More septic systems and subsurface wastewater disposal systems will be built near the lake as the number of houses increase.

On 18-Sep-03, Colby's EnvironmentalAssessment Team surveyed all of the shoreline homes on Threemile Pond. The total number counted was 203. Tax maps from the three towns of China, Windsor and Vassalboro show a total of 219 lots. Sixteen undeveloped lots were found by subtracting the number of homes from the number of total lots. This small number suggests limited development potential, but it is misleading. Many existing lots are large enough to subdivide. Already, some residences have expanded into compounds as families grow and build multiple camps on a single lot.

The past several decades have been characterized by a decline in agriculture in the Threemile Pond watershed (see Watershed Land Use Patterns: Agriculture). Nutrient-rich farm runoff can be a major source of phosphorus and can accelerate the process of eutrophication. Today, there are no chicken farms actively producing manure, eliminating a historical source of nutrient pollution (Manthey pers. comm.).

New development has an ambiguous overall effect on phosphorus loading in Threemile Pond watershed. Agriculture is declining, new homes are being built and existing homes are being renovated, expanded or converted to year-round dwellings. When property is substantially altered or changes

ownership, homeowners in China, Windsor, and Vassalboro must prove that their septic systems are functional and new as of 1974. Gradually, newer, more efficient models are replacing the old, leaky septic systems. The average quality and quantity of subsurface disposal systems is rising around Threemile Pond. Furthermore, more homeowners are learning about the efficacy of buffer strips. Buffer strips inexpensively lower external phosphorus loading and may offset the increased nutrients from development.

Towns are increasingly aware of the direct and indirect economic value of Threemile Pond. Lakeshore property values are tied to lake water quality; the recreational value of the pond plummets during a severe algal bloom (Bouchard pers. comm.). Town leaders and citizens are realizing that maintaining these values requires a holistic understanding of Threemile Pond watershed. For example, the Town of China has set a phosphorus control ordinance for all new development, stating that new structures in the Threemile Pond watershed must maintain vegetated buffer strips and export no more than 0.031 pounds of phosphorus per year (Town of China 2003). An important step towards holistic watershed management is a community understanding that everyone's actions within the watershed impacts water quality.

PHOSPHORUS BUDGET PROJECTIONS

METHODS

The 2040 projection of the phosphorus budget was calculated by making educated predictions about future land use changes (Table 12). CEAT predicts a continued decline in agricultural land, at approximately the same rate as was seen between 1956 and 1998 (Figure 28). The decrease will probably be counteracted by an increase in the area of non-shoreline development, reverting land, and transitional forest. Some agricultural land will likely be allowed to revert to forest, while other land will be used for residential development.

Summary of projected land use changes used in future Phosphorus Loading Model:

Mature Forest	7.25 acre decrease
Transitional Forest	309.02 acre increase
Reverting Land	379.58 acre decrease
Agriculture	449.39 acre decrease
Cleared Land	118.45 acre increase
Wetlands	10.63 acre decrease
Residential Land	368.32 acre increase

CEAT used the same phosphorus budget coefficients in the projection as in the current Phosphorus Loading Model.

RESULTS AND DISCUSSION

Using CEAT future land use projections, the Phosphorus Loading Model predicted a total phosphorus concentration range of 11.64 ppb to 38.70 ppb with a best estimate of 20.75 ppb for Threemile Pond. Based on the best estimates for land use contributions in the watershed, reverting land and transitional forest would contribute the highest percentage of phosphorus (46.33 percent), and make up 50.39 percent of the watershed in 2040 (Table 12). The two largest sources of phosphorus are not a result of cultural land use. This places much greater importance on controlling cultural phosphorus loading, since non-cultural loading cannot be mediated. The best estimate of phosphorus concentration

in Threemile Pond predicted by the model for 2040 (20.75 ppb) is lower than the best estimate for 2003 (21.53 ppb). Changes in land use would have a slight positive impact on the total phosphorus concentration, but sediment release is the largest contributor of phosphorus to the pond. Shoreline and non-shoreline development would be larger phosphorus contributors in the future, increasing from 5.43 percent to 6.22 percent and 3.84 percent to 9.35 percent, respectively. Agricultural input would decrease from 11.38 percent to 6.04 percent. Reverting land has the highest percentage of phosphorus loading in 2003 (37.49 percent). Though it remains the top contributor in 2040, its percent contribution will decrease to 31.94 percent.

Threemile Pond is well above the Maine DEP critical phosphorus concentration of 15.0 ppb at which algae blooms start to occur, and any increase in the concentration is one step further away from better lake water quality.

Table 12. Projected 2040 low, high and best estimates of annual percent contribution to phosphorus loading in Threemile Pond from various sources. The data indicate an expected future increase in residential land resulting in a decrease in agriculture, as well as an increase in forest. Estimates also reflect natural forest successional changes. Future land area changes were estimated by the Colby Environmental Assessment Team (CEAT) by using the 1956 and 1998 land use maps (Figures 25 and 26). Percents are based on phosphorus loading projections from the Phosphorus Budget (see Appendix E). Percent area of each land use is also given.

Input Categories	Percent Land Area	Percent Contribution		
		Low	High	Best
Atmospheric Input	-	10.87	5.37	7.57
Mature Forest	15.46	4.58	2.72	3.99
Transitional Forest	30.97	14.69	7.25	14.39
Agricultural Land	4.68	6.93	5.48	6.04
Wetlands	9.65	1.14	0.91	1.00
Cleared Land	3.16	2.81	2.22	3.26
Commercial Land	0.37	1.10	1.30	0.96
Camp Roads	0.32	0.85	2.99	2.80
State/ Town Roads	1.10	2.92	8.98	4.24
Reverting Land	20.62	24.46	24.15	31.94
Shoreline Development	1.61	4.76	5.64	6.22
Non-shoreline Development	12.07	14.31	21.20	9.35
Shoreline Septic Systems	-	5.46	5.09	3.82
Non-shoreline Septic Systems	-	5.10	6.71	4.44

RECOMMENDATIONS

WATERSHED MANAGEMENT

BUFFER STRIPS/EROSION

- Many shoreline lots have inadequate buffer strips. To minimize phosphorous runoff into the lake, steps should be taken to:
    - Cover the length of the shoreline with native shrubs, grasses and trees.
    - Allow the buffer to stretch as far back as possible from the lake.
    - Protect the shoreline itself from erosion, with aquatic plants or riprap.
- Future building and development must be carefully planned to:
    - Minimize potential nutrient loading in areas with high erosion potential. Refer to the erosion potential map to identify these areas.
    - Minimize impervious surfaces like roofs, parking lots and driveways

ROADS

Camp roads should be regularly maintained and improved, with a focus on the problem areas identified during this study.

- Highest priority goes to roads in close proximity to the lake, due to the potential to contribute to phosphorus levels in the lake.
- Hire DEP certified contractors to conduct all roadwork.
- For all road construction, maintenance and improvement, measures such as grading, crowning, ditching, and diversions should be utilized to limit sediment runoff.
- Limit all road construction in the watershed, particularly within the shoreline zone.

SEPTIC SYSTEMS

- Homeowners can minimize septic system impact on Threemile Pond by:
    - Following all local and state septic regulations.

- Regularly checking and pumping septic tanks.
- Upgrading or replacing the subsurface wastewater disposal systems when the property is expanded or winterized.

LAND USE

- Limit shoreline development and enforce regulations
- Monitor new residential and commercial development to ensure its compliance with codes and regulation
- Retain forested areas, especially on the shoreline to help reduce phosphorus inflow to the lake
- Surround cleared areas with silt fences or hay to prevent erosion and phosphorus runoff

BOAT RAMP

- Use the public boat launch; private, unpaved boat launches are significant sources of erosion and runoff.
- In order to minimize nutrient loading, all boat should be launched from the public boat launch, then driven to homeowners' mooring or dock.

IN-LAKE MANAGEMENT

- In-lake remediation techniques can be expensive, but the eutrophic status of Threemile Pond may demand such mitigation.
- Biological manipulation through fish stock manipulation is a practical means of controlling the phytoplankton population, ultimately improving lake water quality.
- Hypolimnetic aeration prevents phosphorus-releasing anaerobic conditions by augmenting dissolved oxygen levels.
- With proper management and specific application, an alum treatment can effectively reduce the amount of phosphorus in the sediment available for release.

COMMUNITY AWARENESS AND EDUCATION

- Residents living within the Threemile Pond watershed have a great impact on the overall health of the watershed. Further education could provide residents with the tools to reduce the impact of individual residences.
- The China Lakes Region Alliance, along with the towns of China, Vassalboro, and Windsor, could host watershed education workshops for community members. The workshops would provide interaction between the instructors and participants through discussion and hands on activities.
- The China Lakes Region Alliance could provide community demonstrations of best management practices. This would allow the community an opportunity to see how individuals can control non-point source pollution.
- Fact sheets and brochures could be distributed to homeowners living within the watershed. These sheets would provide the community with information about watershed health and practices that lessen residential impact on the watershed.
- Posters and displays about watersheds and best management practices could be placed in the various town offices and schools. These displays would raise awareness within the community.
- Copies of the CEAT study "The Status of Threemile Pond" could be made available to the residents of the Threemile Pond watershed at the town offices and libraries.

MONITORING AND REGULATIONS

- Consistent monitoring of phosphorus levels and transparency in the spring, summer and fall. Continue participation in Maine Volunteer Lake Monitoring Program.
- Limit phosphorus entering Threemile Pond by not using fertilizer, or only using low phosphorus fertilizer in shoreline areas. Shoreline residents should also consider using low phosphate soap and detergent.
- Protect existing wetlands to maintain their capacity as a natural buffer. Maintain high standards for future shoreline development.
- Continue the work of the Threemile Pond Association and China Region Lakes Alliance.
- Consider regulating the maximum annual phosphorus load allowed by each lot.

GRANTS AND FUNDING

- There are several sources available that could offer funding for lake restoration of Threemile Pond.

- The Maine Department of Environmental Protection (DEP) website suggests several grants and loans with links to additional information. The website can be accessed at http://www.state.me.us/dep/blwq/grants.htm
    - This website includes information about: Non-point source Water Pollution Control Grants (Section 319 of Federal Clean Water Act; Small Community Grant Program (SCG) for replacement of malfunctioning septic systems; other non-DEP affiliated programs (Watershed Management Assistance Grants and Nutrient Management Loans); and a Watershed Protection Grant for junior high/high school action projects.

- The State of Maine's Natural Resource ProtectionAct 480-N concerning Lake Restoration and Protection Fund offers funding of lake remediation projects.

  Contact: Office of Revisor of Statutes
  7 State House Station
  State House Room 108
  Augusta, ME 04333-0007

- For additional information:

  Contac Maine DEP: Lake Assessment Section at (207)-287-3901.

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LITERATURE CITED

Allen, J.D. 2003. Modern Causes of Species Extinction: Habitat Destruction. School of Resources and Environment. University of Michigan, Ann Arbor, Michigan, www.personal.umich.edu/~dallan/nre220/outline6.htm. Accessed 10/24/03.

Asaeda, T., V.K. Trung, and J. Manatunge. 2000. Modeling the effects of macrophyte growth and decomposition on the nutrient budget in Shallow Lakes. Aquatic Botany. 68:217-237.

Barrett, P.R.F., J.W. Littlejohn, and J. Curnow. 1999. Long-term algal control in a reservoir using barley straw. Hydrobiologia 415: 309-313.

BI493. 1988. Environmental Analysis of China Lake. Department of Biology. Colby College. Waterville, ME.

BI493. 1989. An Analysis of the Factors Influencing Eutrophication within the China Lake Watershed. Department of Biology, Colby College, Waterville, ME.

BI493. 1995. Land Use Patterns in Relation to Lake Water Quality in the Salmon Lake Watershed. Department of Biology, Colby College, Waterville, ME.

BI493. 1997. Land Use Patterns in Relation to Lake Water Quality in North Pond Watershed. Department of Biology, Colby College, Waterville, ME.

BI493. 1999. Land Use Patterns in Relation to Lake Water Quality in the Great Pond Watershed. Department of Biology, Colby College, Waterville, ME.

BI493. 2000. Water Quality in East Pond: Factors Contributing to Algal Blooms and Strategies for Remediation. Department of Biology, Colby College, Waterville, ME.

BI493. 2001a. Land Use Patterns in Relation to Lake Water Quality in the Lake George and Oaks Pond Watershed. Department of Biology, Colby College, Waterville, ME.

BI493. 2001b. Land Use Patterns in Relation to Lake Water Quality in the Lake Wesserunsett Watershed. Department of Biology, Colby College, Waterville, ME.

BI493. 2003. Land Use Patterns in Relation to Lake Water Quality in the Webber Pond Watershed. Department of Biology, Colby College, Waterville, ME.

BLWQ. 2003. List of Lakes that commonly bloom (transparency < 2.0 meters) in Maine. Bureau of Land and Water Quality. Maine Department of Environmental Protection. Augusta, Maine. www.maine.gov/dep/blwq/doclake/repbloomlist.htm. Accessed 11/01/03.

Boardman, S.L. 1867. The Agriculture and Industry of the County of Kennebec, Maine. Kennebec Journal Office, Augusta, ME.

Bouchard, R. 2000. The Economics of Lakes: More on Dollars and Sense. Lakes Assessment Section. Maine Department of Environmental Protection. Augusta, ME. 20 pp.

Bowen, G., E.A. McBean, G. Mulamoottil and Z. Novak. 1996. Urban Intensification and Environmental Sustainability: The Maintenance of Infiltration Gradients. In: Wetlands: Environmental Gradients, Boundaries and Buffers. Lewis Publishers, Boca Raton, FL. 298 pp.

Boyd, C.E. 2000. Water Quality: An Introduction. Kuwer Academic Publishers, Boston, MA. 330 pp.

Brenner, M., T.J. Whitmore, M.A. Lasi, J.E. Cable, and P.H. Cable. 1999. A Multi-proxy Trophic State Reconstruction for Shallow Orange Lake, Florida, USA: Possible Influence of Macrophytes on Limnetic Nutrient Concentrations. Journal of Paleolimnology 21:215-233.

Burton, T.M., D.L. King, and J.L. Ervin. 1979. Aquatic Plant Harvesting as a Lake Restoration Technique. In: United States Environmental Protection Agency. Lake Restoration: Proceedings of a National Conference: August 22-24, 1978. Minneapolis, MN.

Caffrey, J.M. and C. Monahan. 1999. Filamentous Algal Control Using Barley Straw. Hydrobiologia 415:315-318.

Carlson, R.E. and J. Simpson. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society. 96 pp.

Cashat, J.P. 1984. Design and Maintenance of Unpaved Roads. Unpaved Roads 115:154-158.

Chapman, D. (ed). 1992. Water Quality Assessment. Chapman and Hall, Ltd, New York, NY. 585 pp.

Chapman. D. (ed). 1996. Water Quality Assessments: A Guide to the Use of Biota, Sediments, and Water in Environmental Monitoring (2nd ed.) E and FN Spon, London, England. 626 pp.

China, Town of. 1987. Comprehensive Plan. China, ME.

China, Town of. 2003. Town of China Land Development Code. China, ME.

Chiras, D.D. 1994. Environmental Science-Action for a Sustainable Future. Benjamin and Cummings Publishing Company, Reading, MA. 549 pp.

Connor, J. 1995. Phosphorus inactivation and wetland Manipulation improve Kezar Lake, NH. United States Environmental Protection Agency. Office of Water. Number 1. Concord, NH. 6 pp.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. 2nd Ed. Lewis Publishers, Boca Raton, FL. 548 pp.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1986. Lake and Reservoir Restoration. Butterworth, Boston, MA. 392 pp.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. 2nd Edition. Lewis Publishers: Boca Raton, FL. 548 pp.

Cooper, G. P. 1942. A Biological Survey of Lakes and Ponds of the Central Coastal Area of Maine. Fish Survey Report 5 to the Maine Department of Inland Fish and Game. The Augusta Press. Augusta, ME.

Dahl, T.E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. www.npwrc.usgs.gov/resource/othrdata/wetloss/ wetloss.htm. Accessed11/2/03

Davis, R.B., J.H. Bailey, M. Scott, G. Hunt, and S.A. Norton. 1978. Descriptive and comparative studies of Maine lakes. Life Sciences and Agriculture Experiment Station. NTIS. Technical Bulletin 88. 337 pp.

Dennis, J. 1986. Phosphorus Export From a Low Density Residential Watershed and an Adjacent Forested Watershed. Maine Department of Environmental Protection, Augusta, ME.

Deppe, T., K. Ockenfeld, A. Meybohm, M. Optitz, and J. Benndorf. 1999. Reduction of *Microcystis* blooms in a hypereutrophic reservoir by a combined ecotechnological strategy. Hydrobiologia. 408/409:31-38.

Dobson, C. and G.G. Beck. 1999. Watersheds: A Practical Handbook for Healthy Waters. Firefly Books. Buffalo, NY. 152 pp.

Dominie, D.R. 1981. Webber, Threemile, Threecornered Pond Diagnostic/Feasibility Study. Maine Department of Environmental Protection. Augusta, ME. 75 pp. and appendices.

Dunne, T. 1977. Studying patterns of soil erosion in Kenya. FAO Soil Bulletin 33, 109-122. In: R.P.C. Morgan. (ed.) 1986. Soil erosion and its control Van Nostrand Reinhold Co, New York. 311 pp.

Eaton, A.D., L.S. Clesceri, and R.T. Greenberg. 1995. (19th ed). Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, D.C. 769 pp.

Ellsworth, D. 2002. Threats to Global Biodiversity. Global Change: Human Impacts. University of Michigan. www.globalchange.umich.edu/ globalchange2/current/lectures/biodiversity/ biodiversity.html. Accessed 11/14/03.

EPA Office of Wetlands, Oceans, & Watersheds. 2003. Wetlands. www.epa.gov/owow/wetlands/. Accessed 9/28/03.

EPA. 2000. 2000 National Water Quality Inventory. Chapter 8. Costs and Benefits of Water Quality Protection. †United States Environmental Protection Agency. Washington, D.C. www.epa.gov/305b/2000report/. Accessed 11/14/03.

EPA. 2003. Know Your Watershed. Environmental Protection Agency. Washington, D.C. www.cfpub.epa.gov/surf. Accessed 11/02/03.

EPA. 2003. Volunteer Lake Monitoring: A Methods Manual. United States Environmental Protection Agency. Office of Water. EPA440-4-91-002. Washington, D.C. www.epa.gov/owow/monitoring/volunteer/lake/. Accessed 11/24/03.

Epema, G.F. and H.T. Riezebos. 1983. Fall velocity of water drops at different heights as a factor influencing erosivity of simulated rain. In: J. de Ploey, (ed.) Rainfall simulation run off and soil erosion Catera Verlog, Braunschweig 214 pp.

ESRI. 2000a. Model Builder: For ArcView™ Spatial Analyst. Environmental Systems Research Institute, Inc., Redlands, CA. 182 pp.

ESRI. 2000b. Your Internet Guide to Geographic Information Systems. Environmental Systems Research Institute Inc. www.gis.com/index.html. Accessed 9/20/03.

ERSI. 2001. Using ArcGIS™ Spatial Analyst. Environmental Systems Research Institute, Inc., Redlands, CA.

Fast, A.W. 1979. Artificial Aeration as a Lake Restoration Technique. In: United States Environmental Protection Agency. Lake Restoration: Proceedings of a National Conference: August 22-24, 1978. Minneapolis, MN.

Fogler Library. 2002a. Maine Census Data Population Totals. County Population Search Results. www.library.umaine.edu/census/countysearch.asp. Accessed 11/6/03.

Fogler Library. 2002b. Maine Census Data Population Totals. Minor Civil Division Population Search Results. www.library.umaine.edu/census/townsearch.asp. Accessed 11/6/03.

Frey, D.G. 1963. Limnology in North America. University of Wisconsin Press, Madison, WI. 734 pp.

Goldman, C. and A.J. Home. 1983. Limnology. McGraw-Hill Inc., New York, NY. 464 pp.

Goldstein, N. 2001. Constructed wetlands for erosion control. Erosion Control. www.forester.net/ec_0105_constructed.html#top. Accessed 11/03/03

Gottle, A. and E.H.M. Sene. 1997. Protective and Environmental Functions of Forests. www.fao.org/forestry/foda/wforcong/publi/PDF/V2E_T00.PDF. Accessed 11/2/03.

HACH. 1997. DIR 4000 Spectrophotometer Instrument Manual 5th ed. HACH Company, Loveland, CO. 347 pp.

HACH. 1999. 2100P Portable Turbidimeter Instrument and Procedure Manual 7th ed. HACH Company, Loveland, CO.

Hanson, M.J. and H.G. Stefan. 1984. Side effects of 58 years of copper sulfate treatment of the Fairmont Lakes, Minnesota. Water Resource Bulletin 20:889-900.

Harper, D. 1992. Eutrophication of freshwaters principles, problems, and restoration. Chapman and Hall, London. 327 pp.

Hem, J.D. 1970. Study and Interpretation of the Chemical Characteristics of Natural Water. United States Government, Printing Office, Washington, D.C. 363 pp.

Henderson-Sellers, B. and H.R. Markland. 1987. Decaying Lakes. John Wiley and Sons, Chicester, Great Britain. 254 pp.

Hillel, D. 1991. Environmental Soil Physics. Academic Press, New York, NY. 771 pp.

Illinois Department of Natural Resources. 2003. Forestry Best Management Practices for Illinois. www.siu.edu/~ilbmp/img31.jpg. Accessed 11/06/2003.

Institute of Water Research. 1997. Forest Land Cover Effects on Water Quality. www.iwr.msu.edu/edmodule/water/forqual.htm. Accessed 10/29/03.

Keenan, L.W and E.F. Lowe. 2001. Determining ecologically acceptable nutrient loads to natural wetlands for water quality improvement. Water Science & Technology 44:289-294.

Kennebec County Soil and Water Conservation District. 2000. Camp Road Maintenance Manual: A Guide for Landowners. Maine Department of Environmental Protection, Bureau of Land and Water Quality, Augusta, ME. 54 pp.

Kingsbury and Deyo. 1971. A Reprint of the History of the Town of Vassalboro: from Kingsbury and Deyo's Illustrated history of Kennebec County, Maine, published in 1892. Vassalboro Historical Society, Vassalboro, Maine.

Kleeberg, A. and J. Kohl. 1999. Assessment of the long-term effectiveness of sediment dredging to reduce benthic phosphorus release in shallow Lake Muggelsee (Germany). Hydrobiologia 394: 153-161.

KVCOG. 2003. Central Maine Regional Information: Cities and Towns. Kennebec Valley Council of Governments. http://www.kvcog.org/citiestowns.html Accessed 11/10/03.

Lammens, E.H.R.R. 1999. The central role of fish in lake restoration and management. Hydrobiologia 395/396:191-198.

Lampert, W. and U. Sommer. 1997. Limnoecology: The Ecology of Lakes and Streams. Oxford University Press. New York. 382 pp.

Lea, F., T. Landry, and B. Fortier. 1990. Comprehensive Planning for Lake Watersheds. Androscoggin Valley Council of Governments, Lewiston, ME.

Lerman, A. 1978. Lakes-Chemistry, Geology, Physics. Springer-Verlag, New York, NY. 363 pp.

Loeb, S.L. and A. Spacie. 1994. Biological Monitoring of Aquatic Systems. Lewis Publishers, Boca Raton. 381 pp.

Louisiana State University. 2000. Louisiana Geographic Information Systems Council. GIS Primer www.lagic.lsu.edu/gisprimer/images/examples/datalayers. Accessed 11/17/03.

LWRC. 2002. State of Maine Action Plan for Managing Invasive Aquatic Species. Land and Water Resource Council and Interagency Taskforce on Invasive Aquatic Plants and Nuisance Species. October 10, 2002. www.maine.gov/dep/blwq/topic/invasives/invplan.htm. Accessed 11/02/03.

Madgwick, F.J. 1999. Restoring nutrient-enriched shallow lakes: integration of theory and practice in the Norfolk Broads, UK. Hydrobiologia 408/409:1-12.

Maine Forestry Service. 2003. Maine's Changing Forests. www.maine.gov/doc/mfs/woodswise/timeline.html. Accessed 11/3/03

Maine Lakes Charts. 2001. Threemile Pond Bathymetry Map. Maine Lakes Charts, Inc., Gardiner, ME.

Maine Lake Charts. 2002. Threemile Pond Map. Maine Lakes Charts, Inc. Gardiner, ME.

Maitland, P.S. 1990. Biology of Fresh Waters. Second ed. Chapman & Hall, New York, NY. 276 pp.

Marvinney, R. and W. Thompson. 2000. A Geologic History of Maine. Maine Department of Conservation. www.state.me.us. Accessed 10/27/03.

MDC. 1983. Land Use Plan. Land Use Regulation Commission, Maine Department of Conservation, Augusta, ME.

MDC. 1996. Glacial History of Maine: Aquifer mapping. www.state.me.us/doc/nrimc/pubedinf/factsht/hydro/aquifmap. Accessed 10/27/03.

MDC. 2003. Maine Natural Areas Program: Management of Invasive Non-native Plants in Maine. Bureau of Geology and Natural Areas. Maine Department of Conservation. www.state.me.us/doc/nrimc/mnap/programs/invasives.html. Accessed 11/02/03.

MDEP. 1990. Comprehensive Planning for Lake Watersheds. Maine Department of Environmental Protection, Augusta, ME. 54 pp.

MDEP. 1991a. Progress Report, Augusta, ME: Threemile Pond Restoration Project. Maine Department of Environmental Protection. July 1, 1987 - March 31, 1990.

MDEP. 1991b. Proposed Ammendments to the Subdivision Ordinance for the Town of Dedham. Maine Department of Environmental Protection, Augusta, ME.

MDEP. 1992a. Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development. Maine Department of Environmental Protection, Augusta, ME.

MDEP. 1992b. State of Maine Guidelines for Municipal Shoreline Zoning Ordinances. Maine Department of Environmental Protection, Augusta, ME.

MDEP. 1996. Lakes Assessment. Maine Department of Environmental Protection. Augusta, ME. www.maine.gov/dep/blwq/docmonitoring/lake/index.htm. Accessed 11/01/03.

MDEP. 1997. A Home Owner's Guide to Environmental Laws Affecting Shorefront Property in Maine's Organized Towns. Maine Department of Environmental Protection, Augusta, ME. 27 pp.

MDEP. 1998. Maine Shoreland Zoning: A Handbook for Shoreland Owners. Maine Department of Environmental Protection, Augusta, ME.

MDEP. 2001. China Lake Total Maximum Daily Load. Final Lakes TMDL Report. Maine Department of Environmental Protection. Augusta, ME. DEPLW 2001-20.

MDEP. 2002a. Explanation of Lake Water Quality Monitoring Report. Maine Department of Environmental Protection, Augusta, ME.

MDEP. 2002b. Water Quality Summary: Threemile Pond. Maine Department of Environmental Protection. Augusta, ME. Revised 03/02.

MDEP. 2003a. Distribution of Water Quality Data for Maine Lakes. www.state.me.us/dep/blwq/doclake/vmrep98/appa98.htm. Accessed 13/11/03.

MDEP. 2003b. Documented Infestations of Invasive Aquatic Plants in Maine. Maine Department of Environmental Protection. Augusta, ME. www.maine.gov/dep/blwq/topic/invasives/doc.htm. Accessed 11/02/03.

MDEP. 2003c. Eleven Banned Invasive Aquatic Plants. Maine Department of Environmental Protection. Augusta, ME. www.maine.gov/dep/blwq/topic/invasives/invlist.htm. Accessed 11/02/03.

MDEP. 2003d. MIDAS Lakes Database. Maine Department of Environmental Protection. Augusta, ME.

MDEP. 2003e. State Agencies Take Action to Protect Messalonskee Lake from Milfoil. Maine Department of Environmental Protection. Augusta, ME. www.maine.gov/tools/whatsnew/index.php. Created July 3, 2003. Accessed 11/02/03.

MDEP. 2003f. Threemile Pond PCAP-TMDL Report. Maine Department of Environmental Protection and Maine Association of Conservation Districts. Maine DEPLW 2002-0558. Augusta, ME. Revised 09/03/03.

MDEP. 2003g. Threecornered Pond PCAP-TMDL Report. Maine Department of Environmental Protection and Maine Association of Conservation Districts. Maine DEPLW 2002-0562. Augusta, ME. Revised 09/04/03.

MDEP. 2003h. Water Quality Summary: Unity Pond, Unity. Maine Department of Environmental Protection. Augusta, ME. pearl1.library.umaine.edu/narratives/pdf/5172.pdf. Revised 02/01. Accessed 10/24/03.

MDHS. 1983. Site Evaluation for Subsurface Waste Water Disposal Design in Maine (second edition). Maine Department of Human Services, Augusta, ME.

MDHS. 1988. State of Maine Subsurface Wastewater Disposal Rules- Chapter 241. Department of Human Services, State House, Augusta, ME.

MDIFW. 2002. Fishes of Maine. Maine Department of Inland Fisheries and Wildlife. Sidney, ME.

MDIFW. 2003a. Illegal fish stockings threaten Maine lakes and rivers. Maine Department of Inland Fisheries and Wildlife. Sidney, ME. www.state.me.us/ifw/fishing/illegal%20stocking.htm. Accessed 11/14/03.

MDIFW. 2003b. Invasive Aquatic Plants. Maine Department of Inland Fisheries and Wildlife. Sidney, ME. www.state.me.us/ifw/wildlife/milfoil.htm. Accessed 11/01/03.

MDIFW. 2003c. Threemile Pond file. Maine Department of Inland Fisheries and Wildlife. Sidney, ME. Accessed 09/26/03

MDOT. 1986. Roadway Fundamentals for Municipal Officials. Maine Department of Transportation, Augusta, ME.

MEGIS. 2003. Maine GIS Data. Maine Office of GIS. apollo.ogis.state.me.us/catalog/catalog.asp Accessed 11/03/03.

MEPC. 1996. Maine Environmental Priorities Project. Report from the Steering Committee. Maine Environmental Priorities Council. Augusta, ME. www.state.me.us/dep/mepc/rankrept.htm. Accessed 11/18/03.

Michaud, M., (ed.) 1992. Camp Road Maintenance: A Guide for Landowners. Kennebec County Soil and Water Conservation District. NTIS, 2nd Edition, Augusta, ME. 54 pp.

Ministry of Agriculture and Forestry, New Zealand. 2002. About Control of Soil Erosion. www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/land-management/erosion-risks/discussi.htm. Accessed 10/28/03.

MLURC. 1976. Comprehensive Land Use Plan. Maine Land Use Regulation Commission, Maine Department of Conservation, Augusta, ME.

Moore, L. and K. Thornton, eds. 1988. North American Lake Management Society. Lake and Reservoir Restoration Guidance Manual. United States Environmental Protection Agency. Environmental Research Laboratory, Corvallis, OR..

NatureServe. 2003. Plants and Animals. Species search. †NatureServe. Explorer. www.natureserve.org/explorer. Accessed 11/23/03.

NCDC. 2003a. Augusta State Airport Annual Precipitation Data 1993-2003. National Climatic Data Center. www.ncdc.noaa.gov/oa/ncdc.html. Accessed 10/03/03.

Nebel, B.J. 1987. Environmental Science: The Way the World Works. Prentice-Hall, Englewood Cliffs, NJ. 671 pp.

Niering, W.A. 1985. Wetlands. Alfred A. Knopf Inc., New York, NY. 638 pp.

NRCS-USDA State Office of Michigan. 2003. Technical Guide to RUSLE use in Michigan. www.iwr.msu.edu/~ouyangda/rusle/k_factor.htm. Accessed 11/02/03.

Nurnberg, G.K., R. Hartley, and E. Davis. 1987. Hypolimnetic Withdrawal in two North American lakes with anoxic phosphorus release from the sediment. Water Research, 21:923-928.

Overcash, M.R. and J.M. Davidson. 1980. Environmental Impact of Nonpoint Source Pollution. Ann Arbor Science Publishers, Inc., Ann Arbor, MI. 449 pp.

Pearsall, W. 1993. Understanding Maine's Lakes and Ponds: A Guide for the Volunteer Monitoring Program. Maine Department of Environmental Protection, Division of Environmental Evaluation and Lakes Studies, Augusta, ME. 46 pp.

Phillips, G., A. Bramwell, J. Pitt, J. Stansfield, and M. Perrow. 1999. Practical application of 25 years' research into the management of shallow lakes. Hydrobiologia 395/396:61-76.

Plantinga, A.J., T. Mauldin, and R.J. Alig. 1999. Land use in Maine: Determinants of past trends and projections of future changes. United States Department of Agriculture Forest Service. www.fs.fed.us/pnw/pubs/rp_511.pdf. Accessed 11/12/03.

Prescott, G.C. 1969. Ground-water favorability areas and surficial geology of the lower Kennebec River Basin, Maine. Hydrological Investigations Atlas HA-337. U.S. Department of the Interior, U.S. Geological Survey, Washington, D.C.

Rapp, A. 1975. Soil erosion and sedimentation in Tanzania and Lesotho. Ambio 4, 154-163. In: R.P.C. Morgan, (ed.) 1986. Soil erosion and its control Van Nostrand Reinhold Co, New York, NY. 311 pp.

Reckhow, K.H. and S.C. Chapra. 1983. Engineering Approaches for Lake Management. Butterworth Publishers, Boston, MA. 340 pp.

Robbins, A.P. 1971. The History of Vassalborough, Maine. Vassalboro, ME.

SAM and MDIFW. 2002. Be Aware of Aquatic Invaders. Sportsmans' Alliance of Maine and Maine Department of Inland Fisheries and Wildlife. Sidney, ME. www.maine.gov/dep/blwq/topic/invasives/invmaterial.htm. Accessed 11/01/03.

Schuetz, J.F. 1998. Economic Values and Impacts Associated with Access Users' Recreational Use of Maine's Great Ponds. Thesis for the Degree of Masters in Science. Graduate School. University of Maine, Orono, ME.

Scott, M. 1997. Handwritten note on a letter assessing the smelt die-off following the 1988 aluminum sulfate treatment to Threemile Pond. Threemile Pond file. Maine Department of Inland Fisheries and Wildlife. Sidney, ME. Accessed 09/26/03.

Smith. C. and D. Witherill. 1999. Increasing the Use of Non-Phosphorus Fertilizer in Maine. Report to the Maine Legislature's Joint Standing Committee on Natural Resources. Division of Watershed Management. Maine Department of Environmental Protection. Augusta, ME.

Smith, R.L. and T.M. Smith. 2001. Ecology and Field Biology. Wesley Longman, Inc., San Francisco, CA. 771 pp.

Stancioff, E. 1996. Clean Water: A Guide to Water Quality Monitoring For Volunteer Monitors of Coastal Waters. Maine-New Hampshire Sea Grant Marine Advisory Program. Orono, ME. 71 pp.

Stednick, J. 1991. Wildland Water Quality Sampling and Analysis. Academic Press, New York, NY. 217 pp.

Strand, J.A. and S.E.B. Weisner. 2001. Morphological plastic responses to water depth and wave exposure in an aquatic plant *(Myriophyllum spicatum).* Journal of Ecology. 89:166-175.

Theis, T.L. 1979. Physical and Chemical Treatment of Lake Sediments. In: United States Environmental Protection Agency. Lake Restoration: Proceedings of a National Conference: August 22-24, 1978. Minneapolis, MN.

Thompson, G. and J. Coldrey. 1984. The Pond. The MIT Press. Cambridge, MA. 256 pp.

Trivedi, B.P. 2002. Cold War Military Technologies Have Devastated Global Fish Populations. National Geographic. Washington, D.C. www.news.nationalgeographic.com/news. Accessed 11/06/03.

United States Census Bureau 2000. Census 2000 Data for the State of Maine Online. www.census.gov. Accessed 09/29/03.

United States Geological Survey. 2003. Explanation of Hardness. http://water.usgs.gov/owq/ explanation.html. Accessed 11/02/03.

University of Maine Cooperative Extension. 1995. Office of Water Quality. www.umaine.edu/ waterquality/ lakeasyst/camp_roads.htm. Accessed 11/06/03.

University of Maryland. 1999. Agriculture and the Chesapeake Bay. www.inform.umd.edu/ ManureNet/water.htm. Accessed 10/28/03.

US Fish and Wildlife Service. 1998. Report to Congress on the Status and Trends of Wetlands in the Conterminous United States 1986 to 1997. www.nwi.fws.gov/bha/SandT/ SandTReport.html. Accessed 11/3/03.

USDA. 1978. Soil Survey of Kennebec County Maine. United States Department of Agriculture, Washington, D.C. 87 pp.

USEPA 1980. Design Manual-On Site WasteWater Treatment and Disposal Systems. United States Environmental Protection Agency, Office of Water Program Operations, Office of Research and Development, Municipal Environmental Research Laboratory, Washington, D.C.

USEPA. 1990. Chapter 4: Predicting Lake Water Quality. The Lake and Reservoir Restoration Guidance Manual. United States Environmental Protection Agency, Washington, D.C.

Van Strien, M.T. 1975. China, Maine Bicentennial History including 1984 revisions. Weeks Mills, ME.

Vassalboro, Town of. 2003. Town of Vassalboro Shoreland Zoning Ordinance. Vassalboro, ME.

Welch, B. (Ed.) MDEP. Septic Systems: How They Work and How to Keep Them Working. Maine Department of Environmental Protection. Augusta, ME.

Welch, E.B. and G.D. Cooke. 1999. Effectiveness and longevity of phosphorous inactivation with alum. Journal of Lake and Reservoir Management, 15:5-27.

Wetzel, R. and G. Likens. 2000. Limnological Analyses. Springer, NY. 429 pp.

Whitney, S.H. 1887. The Kennebec Valley. Sprague, Burleigh and Flynt, Augusta, ME.

Wild, A. 1993. Soils and the Environment: an Introduction. Cambridge University Press, Cambridge, England. 287 pp.

Williams, J.E., C.A. Wood, and M.P. Dombeck. 1997. Watershed Restoration: Principles and Practices. American Fisheries Society. Bethesda, MD. 561 pp.

Williams, S. 1992. A Citizen's Guide to Lake Watershed Surveys: How to Conduct a Nonpoint Source Phosphorus Survey. Congress of Lake Associations and Maine Department of Environmental Protection, Yarmouth, ME.

Windsor, Town of. 2003. Town of Windsor Shoreland Zoning Ordinance. Windsor, ME.

Woodard, S.E. 1989. The Effectiveness of Buffer Strips to Protect Water Quality. Civil Engineering Department, University of Maine, Orono, ME.

APPENDIX A. WATER QUALITY MEASUREMENTS AND TESTS

List of measurements or tests for all characterization, spot, and tributary sites on Threemile Pond by sample date. Characterization sites were chosen to develop a physical and chemical profile of the lake. Spot sites were chosen because of their proximity to possible problem sites. The tributaries tested were the only ones flowing on the testing date. See Threemile Pond site map for site locations (Figure 9). Tests conducted in the field are marked with an asterisk (*). All other analyses except total coliform[1] were conducted in the Colby Environmental Laboratory.

Measurement or Test	Sample Date	Sample Site
Physical Measurements		
DO/Temperature*	11-Sep-03	1, 3
Flow Rate*	11-Sep-03	9, 10, 11, 12
Transparency*	11-Sep-03	1, 2, 3
Total Dissolved Solids*	11-Sep-03	1, 2, 3, 7, 8, 9, 10, 11, 12
Turbidity*	11-Sep-03	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Conductivity	11-Sep-03	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
True Color	11-Sep-03	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Chemical Analyses		
Alkalinity	11-Sep-03	1, 2, 3
Hardness	11-Sep-03	1, 2, 3
pH*	11-Sep-03	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Nitrates	11-Sep-03	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Phosphorus	11-Sep-03	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
	15-Aug-03	1, 2, 3
Total Coliform[1]	11-Sep-03	1, 5

[1] Water samples were sent to Northeast Laboratories, Winslow, ME for analysis.

APPENDIX B. QUALITY ASSURANCE

The Threemile Pond study followed a quality assurance plan that standardized the procedures of the BI493 environmental consultants.

Bottle Preparation

1. All samples bottles for total phosphorus analysis were triple acid rinsed with 1:1 HCl:E-pure water before use to avoid contamination of the sample.
2. A one to one ratio of HCl is 1 L of E-pure water and 1 L of concentrated hydrochloric acid.
3. If an epicore sample was taken, the mixing bottle was triple acid rinsed before sampling and E-pure rinsed after sampling was completed.

Approaching Site

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

Surface Sampling

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

Secchi Disk

1. Use Aqua-scope to view the disk.
2. Lower until the disk disappears from view, then record the depth. Lower the disk an extra meter, then bring it back into sight and 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)
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. The depth finder must be pointed straight down. Record this depth.
5. Repeat process once.

Conductivity

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

Turbidity

1. Use the cleaned sample cells included with the portable turbidimeter.
2. Follow surface sampling procedure.

3. Place water sample on ice in cooler.

Acidification of Hardness Samples

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

Acidification of Nitrate Samples

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

Using pH Meter

A. Calibration (Before any testing is done, the pH meter must be calibrated using a 2-point calibration method at pH 4 and pH 7. This should be done once during the testing day, as long as the meter s calibration is not accidentally deleted).
    1. Press the POWER button. The pH meter automatically enters the measurement.
    2. Apply the pH 7 solution by opening the sensor guard and wetting the entire probe.
    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 done calibrating.
    4. After calibration, rinse the sensor thoroughly with E-pure.
    5. Repeat calibration for pH 4.
    6. Check that the probe is working properly by measuring aerated deionized water. The meter should give a value of 5.65.
    7. Be sure to rinse the probe with distilled water prior to and following each measurement.

B. Measurement.
    1. Lift the lid to 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 (DO) Meter

1. Calibrate the meter in the saturated air chamber after the proper warm-up time.

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

Mid-depth and Bottom Sample

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

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 lower the tube 1 m below the thermocline (determined from the DO/temperature profile).
3. For shallow depths lower the tube to 1 m from the bottom.
4. The tape marks indicate 1 m.
5. Crimp the tubing just above the water (best done by bending it tightly and then holding it in one s hand).
6. Pull the tubing up making sure that the excess tubing goes into the water 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 raising the tubing and move towards the draining end.
10. Repeat process three times, draining all of the water into the epicore mixing bottle.
11. Pour about 125 ml of this water into two PMP 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.

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 more accurate readings (hold up and down arrows at the same time). A time bar will move across the screen. When it reaches the far side, a new average velocity will be displayed.
4. Divide the topography of the stream into equal sections and measure the flow in each segment.

Global Positioning System (GPS)

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

Quality Control Sampling

1. E-pure samples were spiked with a known amount of concentrated standard and run against a standard curve to confirm accuracy of technician before water samples were analyzed for each test. This accuracy test was repeated until the values of the test samples were within 10 percent of each other.
2. Duplicate samples were taken every tenth sample to test the accuracy of sampling procedures.
3. Samples were split every tenth sample in the laboratory to test lab procedure.

Total Phosphorus

1. For every ten samples, splits and duplicates were collected or made.
2. Standard solutions of known concentrations were made with every testing to ensure lab precision.
3. Reagent blanks were used to make a standard curve to determine the concentration of phosphorus studied. The standard curve should have a minimum of six points.
4. The accuracy of the Absorbic Acid method used for total phosphorus analysis has a detection point less than 1 ppb.
5. Water samples were preserved for analysis by being digested with sulfuric acid and ammonium peroxydisulfate and then autoclaved at 15 psi for 30 minutes.
6. Analysis was conducted within 28 days of sampling date.

Hardness

1. For every ten samples, splits and duplicates were collected or made.
2. The water samples were persevered for analysis by adding nitric acid in the field until the pH was less than 2.
3. A HACH titration method, adapted from the EDTA Titrimetric Method, was used to measure hardness (HACH 1997).
4. The limit of detection for the HACH DR/4000 spectrophotometer Hardness test is 0.03 ppm $CaCO_3$. The range of the test is 0.03 ppm to 4.00 ppm $CaCO_3$.
5. Analysis was conducted within six months of sampling date.

Alkalinity

1. One duplicate sample was taken for every ten samples.
2. The Potentiometric Method was used to analyze the samples (Eaton et al. 1995).

3. Analysis was conducted within 14 days of sampling date.

Color

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

Conductivity

1. One duplicate sample was taken for every ten samples.
2. Results should not vary more than 1 μmhos/cm^2.
3. Deionized water should read less than 1 μmhos/cm^2.
4. The water sampler was used at the desired depth.
5. The water sample was poured into the appropriately labeled conductivity bottle.
6. A Model 31A YSI Conductance Bridge was used to measure conductivity.
7. Analysis was conducted within 28 days of sampling date.

Turbidity

1. Turbidity was measured using the HACH 2100P Portable Turbidimeter (HACH 1999).
2. Analysis was conducted in the field using the calibrated instrument (calibrated with three standards).

Nitrates

1. For every ten samples, splits and duplicates were collected or made.
2. Nitrates were analyzed using the HACH UV Direct Reading and the HACH DR/4000U spectrophotometer (HACH 1997).
3. The limit of detection for the test is 0.2 ppm NO_3-N. The range for the test is 0.0 ppm to 10.2 pm NO_3-N.
4. Analysis was conducted within 48 hours of sampling date.

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

Water quality results for surface samples collected from sample sites on Threemile Pond and at adjacent tributary sites were obtained by the Colby Environmental Assessment Team. Characterization sites were chosen to develop a chemical and physical profile of the lake. Spot sites were chosen due to their proximity to areas where land use patterns might affect water quality. The tributaries tested were the only ones flowing on the testing date. Conductivity, true color, turbidity, pH, alkalinity, hardness and total dissolved solids data were obtained for all characterization sites and selected spot and tributary sites. Sample sites on Threemile Pond were sampled on 11-Sep-03. See Threemile Pond site map for sampling locations (Figure 9). All samples are surface readings unless otherwise noted. Duplicate samples taken in the field for quality assurance are also noted. See Quality Assurance Plan for methodology.

Site	Conductivity (μMHO/cm)	True Color (SPU)	Turbidity (NTU)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Total Dissolved Solids (ppm)
Characterization							
1	40.00	6.00	1.22	6.89	42.60	2.98	40
1	41.00[d]	6.00[d]	3.52[B]	-	42.60[d]	-	-
2	45.00	12.00	1.65	6.55	47.80	4.84	40
2	-	-	1.97[B]	-	-	5.02[d]	-
3	45.00	11.00	1.34	7.10	36.20	3.32	50
3	-	-	1.69[B]	6.92[d]	-	-	-
3	-	-	1.58[d, B]	-	-	-	-
Spot							
4	56.00	7.00	0.97	7.10	-	-	-
5	54.00	12.00	1.05	7.26	-	-	-
6	49.00	23.00	1.39	7.17	-	-	-
7	53.00	21.00	1.64	6.92	-	-	40
8	51.00	30.00	2.34	7.75	-	-	40
Tributary							
9	59.00	10.00	1.48	7.09	-	-	60
10	58.00	8.00	1.30	6.89	-	-	50
11	122.00	51.00	7.36	6.79	-	-	100
12	61.00	29.00	3.53	6.70	-	-	50

[d] Duplicate

[B] Bottom sample

APPENDIX D. WATER BUDGET VALUES AND CALCULATIONS FOR THREEMILE POND

Parameters	Units	Value
Runoff[a]	meters/year	0.622
Evaporation[b]	meters/year	0.56
Precipitation[c]	meters/year	1.012
Land Area[d]	square meters	24,813,954.5
Lake Area[d]	square meters	4,645,730.0
Average Depth[e]	meters	5.4
I_{net} Threemile Pond[f]	cubic meters/year	17,534,324.3
Q Threemile Pond[g]	cubic meters/year	20,135,933.1
Q (Total)[h]	cubic meters/year	30,257,072.5
I_{net} Mud Pond	cubic meters/year	1,447,741.2
I_{net} Threecornered Pond	cubic meters/year	8,371,935.0
I_{net} Anderson Pond	cubic meters/year	301,463.2
Sum: Pond Inputs	cubic meters/year	10,121,139.4
Flushing Rate[i]	flushes/year	1.10

[a] NKRPC. Unpublished Report. North Kennebec Regional Planning Commission.

[b] Prescott, G. C. 1969. Ground-water favorability areas and surficial geology of the lower Kennebec River Basin, Maine. Hydrological Investigations Atlas HA-337. U.S. Department of the Interior. U.S. Geological Survey. Washington D.C.

[c] Ten year precipitation average (1993-2002) taken from the Augusta State Airport NOAA station, approximately 11 miles from Threemile Pond.

[d] MEGIS. 2003. Maine GIS Data. Maine Office of GIS. Apollo.ogis.state.me.us/catalog/catalog.asp. Accessed 11/03/03.

[e] Maine Lakes Charts, Inc. 2001. Threemile Pond bathymetry map.

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

[g] Q Threemile Pond = I_{net} Threemile Pond + (Evaporation x Lake Area)

[h] Q (Total) = Q Threemile Pond + I_{net} Mud Pond + I_{net} Threecornered Pond + I_{net} Anderson Pond

[i] Flushing Rate = (I_{net} Threemile Pond + I_{net} Mud Pond + I_{net} Threecornered Pond + I_{net} Anderson Pond) / (Average Depth x Lake Area)

APPENDIX E. PHOSPHORUS MODEL EQUATION

$$W = (Ec_a \times Area_s) + (Ec_f \times Area_f) + (Ec_t \times Area_t) + (Ec_{rv} \times Area_{rv}) + (Ec_w \times Area_w) + (Ec_{cm} \times Area_{cm}) + (Ec_{ag} \times Area_{ag}) + (Ec_c \times Area_c) + (Ec_{cr} \times Area_{cr}) + (Ec_{sr} \times Area_{sr}) + (Ec_s \times Area_s) + (Ec_n \times Area_n) + [(Ec_{ss} \times \#\ capita\ years \times (1-SR_1)) + (Ec_{ns} \times \#\ capita\ years_n \times 1-SR_2))] + (Sd_{cs} \times Area_{cs})$$

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

Estimated Range = 0.10-0.25 Best Estimate = 0.16

This coefficient was modified from past studies done on central Maine lakes (BI493 1999, BI493 2000, BI493 2001, BI493 2002). One factor that was taken into account was the very low level of industry in the area, which results in few point sources of airborne particulates. This decreases phosphorus deposition from the atmosphere.

Ec_f = export coefficient for mature forests (kg/ha/yr)

Estimated Range = 0.05-0.15 Best Estimate = 0.10

There are deciduous and coniferous forests in the watershed, but the mature deciduous forests are slightly more numerous than the coniferous. Coniferous trees contribute less phosphorus to a watershed than deciduous, because they do not produce leaf litter. The coefficient was made slightly higher than it would have been for coniferous forests. Mature forests have a low export of phosphorus in general because they reduce runoff and soil erosion. The canopy reduces the velocity of rain that hits the ground and root systems hold soil in place.

Ec_t = export coefficient for transitional land (kg/ha/yr)

Estimated Range = 0.08-0.20 Best Estimate = 0.18

Transitional forests were defined by 50 percent canopy cover. Most of the transitional forests in the Threemile Pond watershed are made up of deciduous species. There is more open land than in mature forests, which could increase phosphorus loading. The coefficient is higher than that for mature forests.

Ec_{rv} = export coefficient for reverting lands (kg/ha/yr)

Estimated Range = 0.20-1.0 Best Estimate = 0.60

Reverting land results from old fields that are in succession to forest. It has a higher export coefficient than mature or transitional forest, because it is comprised of areas with less than 50 percent canopy cover. There is well-developed groundcover, which helps reduce phosphorus export.

Ec_w = export coefficient for wetlands

Estimated Range = 0.02-0.08 Best Estimate = 0.04

In the Threemile Pond watershed, the wetlands are highly vegetated. This helps them to act as phosphorus sinks, which gives them a low export coefficient. There are numerous wetlands in the watershed.

Ec_{cm} = export coefficient for commercial and municipal lands (kg/ha/yr)

Estimated Range = 0.50-3.00 Best Estimate = 1.00

There are very few businesses in the area, and none of them are near the lakeshore. This is why the export coefficient is relatively low. Impervious areas associated with businesses contribute to runoff and an increase in phosphorus export.

Ec_{ag} = export coefficient for agricultural land

Estimated Range = 0.25-1.0 Best Estimate = 0.50

Agricultural land in the Threemile Pond watershed is divided between pastures and cropland. Phosphorus release from cropland is higher than that for pastures, because often crops are fertilized. The straight rows of cropland allow water to flow more smoothly and faster than it would through pastureland.

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

Estimated Range = 0.15-0.60 Best Estimate = 0.40

Cleared land has higher erosion potential than forests or otherwise vegetated land. This results in greater contributions of phosphorus to the watershed. Small

amounts of cleared land far removed from the lakeshore account for the low export coefficient.

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

Estimated Range = 0.45-8.00 Best Estimate = 3.40

Fewer camp roads were poor in the Threemile Pond watershed than Webber pond, even though several were in poor condition. This accounts for the lower export coefficient, because roads that are in poor condition will contribute more phosphorus to the lake than those that are in good condition.

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

Estimated Range = 0.45-7.0 Best Estimate = 1.5

State roads are generally paved, and impervious. However, they are kept in better condition than camp roads and are farther away from the lake.

Ec_{s} = export coefficient for shoreline development (kg/ha/yr)

Estimated Range = 0.50-3.0 Best Estimate =1.5

There was high variability in the buffer quality and depth surrounding Threemile Pond. Most houses lacked sufficient buffers, which can allow large amounts of runoff into Threemile Pond.

Ec_{n} = export coefficient for non-shoreline development (kg/ha/yr)

Estimated Range = 0.20-1.5 Best Estimate = 0.3

Non-shoreline development consists of year-round houses that contribute more phosphorus than seasonal ones. However, there is little residential development in the watershed. The topography is quite flat, which helps to reduce runoff into Threemile Pond.

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

Estimated Range = 0.40-1.20 Best Estimate = 0.50

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

Estimated Range = 0.30-1.0 Best Estimate = 0.40

SR_1 = soil retention coefficient for shoreline residences

Estimated Range = 0.65-0.45 Best Estimate = 0.55

The following equation was used to calculate the amount of phosphorus entering Threemile Pond on a yearly basis (W). The equation takes into account land use patterns, soil quality, land area, population and residential development as sources contributing to phosphorus loading in Threemile Pond.

SR_2 = soil retention coefficient for non-shoreline residences

Estimated Range = 0.90-0.80 Best Estimate = 0.85

Sd_{cs} = coefficient for sediment release (kg/ha/yr)

Estimated Range = 0.6-1.3 Best Estimate = 0.90

Areas of Land Use Components:

A_s = area of Threemile Pond = 503.28 ha

$Area_f$ = area of mature forest = 419.34 ha

$Area_t$ = area of transitional forest = 712.88 ha

$Area_{rv}$ = area of reverting land = 704.86 ha

$Area_w$ = area of wetlands = 269.23 ha

$Area_{cm}$ = area of commercial land = 5.56 ha

$Area_{ag}$ = area of agricultural land = 310.27 ha

$Area_c$ = area of cleared land = 38.76 ha

$Area_{cr}$ = area of camp roads = 8.75 ha

$Area_{sr}$ = area of state and town roads = 30.08 ha

$Area_s$ = area of shoreline residential land = 40.87 ha

$Area_n$ = area of = area of non-shoreline lots = 144.47 ha

APPENDIX F. PREDICTIONS FOR ANNUAL MASS RATE OF PHOSPHORUS INFLOW

The phosphorus-loading model used by CEAT shows the yearly total phosphorus input as loading per unit lake surface area calculated in kg/ha. The total phosphorus inflow (W) is divided by the surface area of Threemile Pond (A_s) (Reckhow and Chapra 1983). For this study, sediment phosphorus release was included in W:

$$L = W / A_s$$

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

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

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

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

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

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

P = total phosphorus concentration (ppb)

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

$A_s = 5{,}032{,}800\ m^2$

$Q_{total} = 29{,}955{,}609.32\ m^3$

$q_s = 4.00$ m/yr

Low Estimate:

W = 672.55 kg/yr

$L = 1.34 \times 10^{-1}$ kg/ha/yr

P = 11.81 ppb

Best Estimate:

W = 1324.04 kg/yr

$L = 2.63 \times 10^{-1}$ kg/ha/yr

P = 21.53 ppb

High Estimate:

W = 2500.40 kg/yr

$L = 4.97 \times 10^{-1}$ kg/ha/yr

P = 38.22 ppb

APPENDIX G. ROAD SURVEY FORM USED TO NOTE CHARACTERISTICS OF ALL ROADS SURROUNDING THREEMILE POND. CREATED BY CEAT 2002.

OVERALL ROAD SURVEY DATA SHEET

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

ROAD LENGTH (MILES):	
AVERAGE WIDTH (FEET):	
OVERALL SLOPE (degrees)	
TOTAL # OF WATER DIVERSIONS:	
TOTAL # OF MISSING WATER DIVERSIONS:	
TOTAL # OF CULVERTS:	
TOTAL # OF MISSING CULVERTS:	

DESCRIBE CROWN:
DESCRIBE DITCH CONDITION:
DESCRIBE ROAD SURFACE CONDITION: surface material:
BASIC SUMMARY:

OVERALL GRADE good acceptable fair poor very poor

APPENDIX G. CONT. ROAD SURVEY DATA SHEET FOR PROBLEM AREAS

Please address these issues for the following problem areas:

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

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

APPENDIX H. PERSONAL COMMUNICATION

Roy Bouchard: Coordinator, Maine Lake Assessment and Invasive Species Department, Maine Department of Environmental Protection

Russ Cole: Professor of Biology, Colby College

David Firmage: Professor of Biology, Colby College

Betsy Fitzgerald: Code Enforcement Officer, Vassalboro, ME

David Halliwell: Lakes Program, Maine Department of Environmental Protection

Reb Manthey: China Region Lakes Alliance

John Perry: Stock Enhancement Division, Maine Department of Marine Resources

Scott Pierz: Code Enforcement Officer, Town of China, Maine

Jenna Richardson: China Region Lakes Alliance

Nate Sylvester: Lakes Program, Kennebec County Soil and Water Conservation District

Dan Tierney: Teaching Assistant, Department of Biology, Colby College

William Woodward: Maine Department of Inland Fisheries and Wildlife, Sidney, Maine

APPENDIX I. BUFFER STRIP SURVEY

Date: ______________ Surveyors: ______________ Section: ______________

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

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

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

Slope: 50%=22.5°; 25%=11.25°

APPENDIX J. RESIDENTIAL SURVEY FORM

Residential Survey

Date:________

Surveyor's Name(s): ____

	Residences < 200 ft from TMP		Residences > 200 ft from TMP		
Road Name	**# Seasonal**	**# Year-round**	**# Seasonal**	**# Year-round**	**Other**

APPENDIX K. SUMMARY OF SELECTED CHEMICAL MANIPULATION TECHNIQUES FOR LAKE REMEDIATION

Remediation Technique	Focus of Technique	Ideal Usage Requirements
Alum Treatment	Phosphorus (P) in water column and in sediment	Depth >3m[1] Prior control of P influx
Ferrous Treatment	P in water column and in sediment	Depth >3m Prior control of P influx
Calcium Additives	P in water column and in sediment	Depth >3m Prior control of P influx; Hard water
Algicides	Algal cell growth	Low potential for toxic copper buildup[1]; Legal issues

[1]Bouchard pers. comm.

APPENDIX L. SUMMARY OF SELECTED PHYSICAL MANIPULATION TECHNIQUES FOR LAKE REMEDIATION

Remediation Technique	Focus of Technique	Ideal Usage Requirements
Water Drawdown	Removal of nutrient rich hypolimnetic water	Dam; Discharge area
Hypolimnetic Withdrawal	Removal of nutrient-rich hypolimnetic water	Dam or Pump; Discharge area
Dilution	Replaces nutrient-rich water with new water	Dam; Source of inflow
Hypolimnetic Aeration	Aerates to prevent anaerobic activity	None, wide applicability
Physical Liners	Covers sediment layer to prevent P release	Little to no disturbance; Small sized areas
Dredging	Removal of accumulated nutrient-rich sediment	Flexible ecosystem; Area for excess sediment
Aquatic Plant Harvesting	Removal of P containing biomass	Weed-eater; Annual harvesting necessary[1]; Substantial P in biomass[2]

[1]Firmage pers. comm.
[2]Bouchard pers. comm.

APPENDIX M. SUMMARY OF SELECTED BIOLOGICAL MANIPULATION TECHNIQUES FOR LAKE REMEDIATION

Remediation Technique	Focus of Technique	Ideal Usage Requirements
Manipulation of fish stocks	Food web manipulation to obtain favorable levels of phytoplankton[1]	Lake must accommodate added species; Legal issues
Wetlands maintenance and manipulation	Creation of buffer zone that settles and absorbs P out of water runoff[2]	Intact wetlands; P absorbing plants, native or exotic
Addition of exotic plants	Trapping and removing P using introduced species[3]	Lake must accommodate added species; Harvesting and disposal; Plants must remove substantial P[3]

[1]Lammens 1999
[2]Connor 1995
[3]Firmage pers. comm.

APPENDIX N. SELECTED NON-APPLICABLE REMEDIATION TECHNIQUES TO THREEMILE POND

Remediation Technique	Applicable to Threemile Pond?	Costs and Disadvantages
Aquatic Plant Harvesting	Not Feasible	Very expensive; Temporary; Threemile does not have enough P in biomass[1]; Interruption of bio-cycles
Dredging	Not Feasible	Very expensive; Sediment profile required[1]; Disposal site for sediment; Not aesthetically pleasing
Barley Straw	Not Feasible	Fairly cheap; Threemile is too big[1]
Dilution	Not feasible	Expensive dam construction; Outflow to Webber Pond; No clean inflow
Algicides (copper sulfate)	Not feasible	Temporary; Environmentally detrimental[1]
Water Drawdown	Not feasible	Expensive dam construction; Discharge is problem
Hypolimnetic Withdrawal	Not feasible	Expensive dam construction; Webber pond receives outflow (downstream monitoring), tricky management

[1]Bouchard pers. comm.

APPENDIX N. CONTINUED SELECTED APPLICABLE REMEDIATION TECHNIQUES TO THREEMILE POND

Remediation Technique	Applicable to Threemile Pond?	Costs and Disadvantages
Alum Treatment	Feasible	Relatively expensive (1989 cost = $170,240)[1]; Failed attempts in past
Biological manipulation	Feasible	Relatively inexpensive; Potential ecological imbalances; Introduced species threat
Hypolimnetic Aeration	Feasible	Relatively expensive; Installation plus maintenance costs[2]; Does not directly remove P
Wetland Maintenance and Manipulation	Feasible	Cheap; May not be significant reduction in P
Ferrous Treatment	Feasible	Relatively expensive; Dissolves under anoxic conditions[1]
Physical Liners	Partially Feasible	Relatively inexpensive; Not aesthetically pleasing; Deterioration and leaching possible[1]

[1]Cooke et al. 1993
[2]Bouchard pers. comm.