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A Watershed Analysis Of Salmon Lake And McGrath Pond: Implications For Water Quality And Land Use Management

Colby Environmental Assessment Team, Colby College

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A WATERSHED ANALYSIS OF SALMON LAKE AND MCGRATH POND

IMPLICATIONS FOR WATER QUALITY AND LAND USE MANAGEMENT

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

Top row: Katherine Orrick, Emily Griffoul, Amanda Lindsay, Emma Gildesgame, Amy Holmen, Jordan Schoonover, Katie Lebling, Rachael Panning, Jenny Brentrup, Sarah Hart, Jessica Balukas. Bottom row: Michael Bienkowski, Andy Oakes, Ben Rooney, Taylor Tully, Ian McCullough, Anders Nordblom.
Not pictured: Professors Dr. David Firmage, Dr. F. Russell Cole and Teaching Assistant Tracey Greenwood

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Watershed Assessment of Salmon Lake and McGrath Pond Executive Summary

Colby Environmental Assessment Team
Colby College, Waterville, ME 04901

In the summer and fall of 2009, the Colby Environmental Assessment Team (CEAT) studied the water quality of Salmon Lake and McGrath Pond, located in the Belgrade Lakes Region of Maine. The physical, chemical and biological characteristics of water quality were measured and analyzed to evaluate the current health of these lakes. Water quality data collected during the summer and fall of 2009 were compared with data from previous years to study the historic water quality trends. Land use patterns in the Salmon/McGrath watershed were also examined to investigate their impact on the lake water quality.

The water quality trends suggest an improvement in the transparency of Salmon Lake and McGrath Pond over the last 34 years. Improvements in transparency have been greater for McGrath Pond than for Salmon Lake. In 1975, McGrath Pond and Salmon Lake had transparencies of 4 m and 5 m, respectively. In 2009, both water bodies had transparencies of approximately 5.5 m. Data from 2009 show the productivity of Salmon Lake to be higher. Consequently the threat of eutrophication is higher in Salmon Lake than in McGrath Pond. Mean phosphorus levels recorded in this study were 13 ppb for Salmon Lake and 10.6 ppb for McGrath Pond. In September of 2009, phosphorus levels at the deepest part of Salmon Lake approached 300 ppb compared to less than 10 ppb for McGrath Pond. Phosphorus from the bottom can be mixed into the water column during spring and fall mixing events. When phosphorus levels exceed 12-15 ppb, the lake is at risk for algal blooms. The last recorded algae bloom in Salmon Lake was in 2002-2003.

The decreasing trends in productivity of Salmon Lake and McGrath Pond indicate decreasing levels of phosphorus, but concentrations are still near the 12-15 ppb tipping point, at which algal blooms may occur. Algal blooms can be detrimental to the health of organisms in the lake, may decrease the aesthetic value of the lake and can reduce the value of shoreline homes. Efforts should be taken to decrease nutrient levels in the water. Salmon

Lake is much more likely to develop algal blooms than McGrath Pond because of higher phosphorus levels.

In late summer 2009, Salmon Lake experienced very low dissolved oxygen levels in the hypolimnion—the bottom layer of lake water. The lack of oxygen on the bottom during the summer months is due to stratification of the water column, which prevents mixing of oxygen rich water from the surface. When the lake is stratified and mixing is not occurring, existing oxygen on the bottom of the water column is depleted by populations of decomposers that thrive because of the availability of organic matter in aging lakes.

Following is a brief summary of findings from the 2009 CEAT study of Salmon Lake and McGrath Pond and their watershed:

- Salmon Lake and McGrath Pond have a combined surface area of 2,043 hectares (ha). Salmon Lake has one deep basin, with the deepest point of the two lakes reaching 17.4 m. The deepest section of McGrath Pond reaches 7 m.
- The recent discovery of Eurasian watermilfoil in Kozy Cove of Salmon Lake is particularly troubling for Great Pond because water flows from Salmon Lake to Great Pond by way Kozy Cove and Hatchery Brook. Once discovered, the Maine Department of Environmental Protection took actions to eradicate the presence of Eurasian watermilfoil in Kozy Cove, on the southeast side of Salmon Lake. Because the majority of Salmon Lake and McGrath Pond is shallow (less than 8 m) and invasive macrophytes such as Eurasian watermilfoil prefer shallow water for colonization and establishment, these lakes are at high risk of invasive species colonization. Continued monitoring and vigilance of volunteers, researchers and residents is critical for the prevention of further invasive species establishment.
- The mean epicore phosphorus concentration in Salmon Lake and McGrath Pond was 13.0 ppb and 10.6 ppb respectively. The largest external contributors to phosphorus loading as percentages of the total external load into the water body are shoreline residential septic systems (14.9%), atmospheric input (13.1%), cropland (11.1%), shoreline development (10.1%), non-shoreline development (9.1%), logged areas (8.7%) and youth camp septic systems (8.6%).

- Salmon Lake and McGrath Pond have a flushing rate of 0.47 flushes per year, based on the water budget calculated by CEAT, with 66% of water inputs coming from runoff and 34% from precipitation.
- Land use has undergone several changes in the period between 1965/66 and 2007:
    - Non-shoreline residential area has increased 142.9% and now covers 135 ha of the watershed. Shoreline residences have increased by only 29.5% (54.9 ha), likely because much of the shoreline was already developed by 1965/66.
    - CEAT estimates that there are 19 shoreline lots that could be developed. There are also other non-shoreline areas where potential development might occur within the watershed. Limits to development include lack of municipal sewage and water treatment, the topography of the watershed, shoreline zoning ordinances and the current economic downturn.
    - Agricultural land decreased 60.1% since 1965/66, which is consistent with trends in surrounding watersheds and throughout central Maine.
    - Logged area in the northwestern part of the watershed has increased significantly, from 3.3% to 8.2%.
    - Forested land in the watershed has significantly decreased from 71.5% to 65.1% (a decrease of 71 ha) due to logging and development.
    - High impact development, which includes commercial and municipal land uses, increased from 2.23 ha in 1965/66 to 14.2 ha (0.69%) in 2007.
- There are 66 camp roads, 3 state roads and 12 town roads in the Salmon/McGrath watershed. Camp roads cover 13.2 miles, and state and town roads cover 27.7 miles. Many of the camp roads could have a negative impact on the watershed due to their proximity to the shoreline. Camp roads are generally privately owned and maintained by residents living on each road. Many camp roads fall into disrepair because residents lack the funding and knowledge of road repair to keep the road well maintained.
- Based on the CEAT road survey, over half of the camp roads are in fair (35%) or poor (23%) condition, and are likely contributors of phosphorus into the lake. These roads will continue to pose problems, if they are not repaired and maintained. Likewise, further degradation of roads currently rated as good (15%) or acceptable (27%) could

increase phosphorus loading into the lake. Regular road maintenance can prevent significant nutrient-loading problems from developing.

- Specific problems found during the road survey were recorded and suggestions of how to address these problems are included in the report. Common problems with roads include presence of tire ruts and potholes, missing or damaged culverts and ditches and loose surface material, which should be repaired to minimize erosion.
- Septic systems installed before 1974 may contribute more phosphorus to the lake than newer systems because they were not designed to meet the current Maine regulations. CEAT anticipates that installation of new, more efficient septic systems will accompany new construction as the population in the watershed increases over the next 20 years. Soil types throughout the watershed have been rated by the Kennebec County Soil and Water Conservation District as *very limited* for septic suitability, which suggests that many septic systems in the watershed may be at high risk for leaching phosphorus into the lake. Both old and new septic systems should be maintained properly to minimize phosphorus leaching into the lake and degradation of lake water quality.
- There are 611 residential properties in the Salmon/McGrath watershed. There are 275 shoreline houses and 336 non-shoreline houses. An estimated 385 of these houses were built pre-1974 and 226 post-1974. Houses built prior to 1974 do not have to meet current zoning and septic regulations established by the State of Maine.
- Buffer strips must be maintained to reduce nutrient loading and to protect water quality. CEAT found that 25% of shoreline lots on McGrath Pond and 26% of the shoreline lots on Salmon Lake had poor buffer quality (69 lots total). Improvements of existing buffer strips or creation of new buffer strips are necessary on 86% of the lots in Salmon Lake and McGrath Pond (219 lots were rated poor, fair, or acceptable). Riprap should be installed where necessary.
- CEAT found that 63% of shoreline houses have lawns, many of which extend all the way to the shoreline. Lawns contribute five to ten times more phosphorus to the lake than a naturally vegetated buffer. Lawns fail to allow the natural process of runoff absorption because their roots systems are so dense. In addition to contributing to

nutrient loading, lawns are often treated with fertilizers and pesticides, which reduce lake water quality.

- Our shoreline survey recorded 24 private boat launches in the watershed. Private dirt and sod boat launches are of particular concern because they can be significant areas of nutrient loading, erosion and siltation. There is also one public boat launch at the southwest side of Salmon Lake.
- The U.S. Census Bureau estimates that the current population of Belgrade, one of the towns included in the watershed, is 3,213 residents. The population of Belgrade is expected to grow to 4,100 by 2020. Oakland has a current population of 6,184 and has a predicted 2020 population of 7,500 residents. The mean age of the population in both towns is increasing as people move into the area upon retirement. The number of high school graduates is remaining constant in Belgrade and increasing in Oakland. The towns are both "bedroom communities" for people working in Waterville and Augusta.
- The McGrath Pond/Salmon Lake Association works to preserve and protect water quality of these lakes while promoting their responsible use. They monitor the water quality of the lake on an ongoing basis. The lake association participates in the Maine Department of Environmental Protection Lake Smart Program, which certifies properties that meet specific requirements to reduce runoff and nutrient loading. The Belgrade Regional Conservation Corps, a program associated with the Belgrade Regional Conservation Alliance, works to identify and mitigate point and non-point sources of nutrient loading into the lakes through volunteer programs. These proactive measures taken by the lake association are commendable and should be continued.

Although the phosphorus levels in Salmon Lake and McGrath Pond are currently at acceptable levels, they are very close to values indicating an unhealthy lake. Efforts need to be taken to mitigate future nutrient loading and preserve water quality. Increased development in the watershed will likely increase phosphorus levels in the lake. Consequently, development around the shoreline should be limited and regulated. As development does occur, consideration needs to be taken not only to limit the amount of phosphorus that will be added by land use conversion and to find ways to reduce phosphorus elsewhere. Roads and shoreline buffers should also be maintained to minimize erosion and to help prevent nutrients from entering the lake through sediment runoff. Educating the public regarding the impact of their actions on lake water quality is important. Awareness of proper maintenance and remediation techniques should also be addressed. Salmon Lake and McGrath Pond are part of the Belgrade Lakes chain. The water leaving Salmon Lake flows directly into Great Pond and ultimately into Snow Pond (Messalonskee Lake) and out to the Kennebec River. The water quality is important not only to the local ecosystem, but also to the lower Belgrade Lakes chain. CEAT recommends close collaboration with neighboring lake associations and the Belgrade Regional Conservation Alliance to help protect the water quality of Salmon Lake and McGrath Pond and other lakes in the region.

WATERSHED ASSESSMENT INTRODUCTION

GENERAL NATURE OF STUDY

Much of Maine's culture revolves around the more than 5,700 lakes and ponds in the state (MDEP 2005a). From swimming to canoeing, Maine families derive great pleasure from opportunities afforded by lakes. However, with increased human activity in and around these vibrant water bodies comes a very real danger: water quality degradation. It is essential that Maine lakes and their watersheds be studied to identify problems associated with human activity and to determine possible solutions.

Eutrophication a natural process, but can be human-accelerated that leads to increased nutrient loading into the lake, is currently among the most harmful forms of lake degradation in the Salmon/McGrath watershed. An increase in nutrients, especially limiting nutrients, results in an increased ability for bacteria, algae and plant life to grow. When plankton, algae and aquatic plants die, they are decomposed by bacteria and fungi, a process which uses large quantities of dissolved oxygen. This use of oxygen in decomposition can deplete available dissolved oxygen in the lake to levels that can harm plants and fish, especially in deep locations (Dodds and Welch 2000). In Maine lakes, the nutrient that limits the rate of eutrophication and plant, algae and bacteria growth is phosphorus (MDEP 2008a). Unfortunately, many human activities near the lake, including residential and commercial development, farming and transportation, can hasten the loading of phosphorus into the water body (Carpenter, Caracoet et al. 1998 and Baker, Schussler et al. 2008).

Salmon Lake and McGrath Pond, located in Belgrade and Oakland, ME, are important resources to this region due to their recreational, tourism and ecological values. With a watershed of over 2,043 hectares (ha), Salmon Lake and McGrath Pond are sources of outdoor recreation for hundreds of families as well as a valuable source of income for the local communities. This study, performed by the Colby Environmental Assessment Team (CEAT) in fall 2009, examines the impacts of various human activities and land uses in the watershed and their effects on the water quality of Salmon Lake and McGrath Pond. The study identifies specific problems contributing to the degradation of water quality within the Salmon/McGrath watershed and provides recommendations to help remediate them.

BACKGROUND

Lake Characteristics

Distinction Between Lakes and Ponds

Lakes and ponds are inland bodies of standing water created either naturally through geologic processes or are artificially created by humans (Smith and Smith 2009). Lakes and ponds differ in their size and depth profiles: lakes have greater surface area and depth than ponds (Smith and Smith 2009) and generally develop vertical stratification and horizontal zonation. Ponds do not. Horizontal zonation divides lakes into zones based on sunlight penetration and vegetation growth. The littoral, or shallow-water, zone is the area in which sunlight can penetrate to the bottom, allowing vegetation to grow from the substrate. The deep-water area, where plants are unable to grow, is divided into the upper limnetic and lower profundal zones. Ponds do not have this zonation and are shallow enough that vegetation can be rooted throughout the bottom sediment (Smith and Smith 2009). The vertical stratification found in lakes depends on water density differences that occur as a result of temperature. Because water is most dense at 4° C, deep lakes will stratify with 4° C water on the bottom and warmer water toward the surface. Ponds and shallow lakes do not stratify because disturbance from wind and waves causes constant mixing and temperature circulation.

General Characteristics of Maine Lakes

Lakes are a vital natural resource in Maine, as they provide fresh water for drinking, swimming, fishing, livestock and agriculture (Davis, Bailey et al. 1978). Lakes provide important habitats for wildlife such as fish, birds and mammals. Maine lakes also draw tourists to the state throughout the year.

The majority of Maine lakes were formed during the Wisconsonian glaciation of the Pleistocene Epoch (Davis, Bailey et al. 1978). Glacial activity in Maine has left most lake basins comprised of glacial till, bedrock and glaciomarine clay-silt. It is difficult for vegetation to grow on these deposits and the underlying granite bedrock, making most of Maine's lakes relatively nutrient poor. The movement of glaciers in Maine was predominantly towards the southeast, carving out lakes in a northwest to southeast direction

(Davis, Bailey et al. 1978). This orientation, along with lake surface area and shape, plays a fundamental role in the effect of wind on the water body because it influences lake turnover, or the mixing of thermal layers.

Most lakes in Maine are located in lowland areas among hills, many of which are heavily forested (Davis, Bailey et al. 1978). These forests may be threatened by logging and increased development pressure. Residential development of watersheds and increased construction of lake recreation facilities may pose significant threats to water quality in many lakes and ponds in Maine. In watersheds where agricultural practices are not widespread, both residential development and forestry are among the most acute sources of anthropogenic Salmon\McGrath nutrient loading (Davis, Bailey et al. 1978).

In Maine, many factors influence lake water quality. These include, but are not limited to, location within the state, length of time that water stays within the soil (known as "residence time"), wetland influences and bedrock chemistry (Davis, Bailey et al. 1978). Terrestrial and aquatic vegetation and the presence of unique habitat types, such as wetlands, may also affect water quality. Depth and surface area can affect temperature and turnover in the lake, which will ultimately influence water quality.

Annual Lake Cycles

Water decreases in density at temperatures above and below 4° C, allowing ice to float on the surface of lakes and ponds and warm water to rise above cold water. In the summer, direct solar radiation warms the upper levels of the water column to form the epilimnion, which hosts the most abundant floral communities (Davis, Bailey et al. 1978). The photosynthetic capabilities of these aquatic plants create an oxygen-rich stratum. However, available nutrients in the epilimnion can be depleted by algal populations growing there and may remain depleted until the turnover of the water column in early fall (Smith and Smith 2009). The process of lake turnover is summarized in Figure 1.

Below the epilimnion is a layer of sharp temperature decline, known as the metalimnion (Smith and Smith 2009). Within this stratum is the most rapid change in temperature in the lake, called the thermocline. The thermocline separates the epilimnion from the hypolimnion, the lowest stratum of a lake. The hypolimnion, only found in deeper lakes, is beyond the depth at which sufficient light can penetrate to facilitate effective photosynthesis (Figure 1). Most decomposition of organic material takes place in the substrate below the hypolimnion through both aerobic and anaerobic biological processes. Aerobic processes require oxygen while anaerobic processes do not. Aerobic bacteria break down organic matter more quickly than anaerobic bacteria, but also can significantly deplete the oxygen in the deeper parts of the lake (Figure 1; Davis, Bailey et al. 1978).

As the weather becomes colder, water temperature decreases and wind facilitates thermal mixing until the vertical temperature profile of the water column is uniform. This event, known as turnover, re-oxygenates the lower depths of the lake and mixes nutrients throughout the strata. Cold water near the surface can hold higher levels of oxygen, which is redistributed throughout the water column by turnover. Through this process, oxygen is distributed to the deeper parts of the lake and is made available to the organisms living there. A similar turnover event also occurs in the spring (Smith and Smith 2009). A lake that has two turnover events per year is classified as dimictic, whereas shallow lakes that may turn over at anytime of the year are known as polymictic.

For the four to five months of winter, stratification in Maine lakes is reversed. The coldest water, as ice, floats on the surface while the warmest water is about 4 °C and sinks to the bottom. Significant snow cover on the ice may affect the photosynthetic processes underneath by blocking some of the incoming solar radiation. Ice cover also prevents diffusion of oxygen into the water. These two factors decrease photosynthetic activity and reduce overall oxygen production by phytoplankton, which can decrease oxygen levels enough to cause significant fish kills (Smith and Smith 2009).

After the ice has melted in the spring, solar radiation warms the upper stratum of the lake. The freshly melted water sinks and a new layer of colder water forms the upper stratum. The sun warms this water and the process continues until the water column is uniform in temperature and oxygen and nutrients are mixed throughout the water column. As late spring approaches, solar radiation increases, stratification occurs and temperature profiles return to those found in the summer months in dimictic lakes, preventing different layers of the water column from mixing (Smith and Smith 2009).

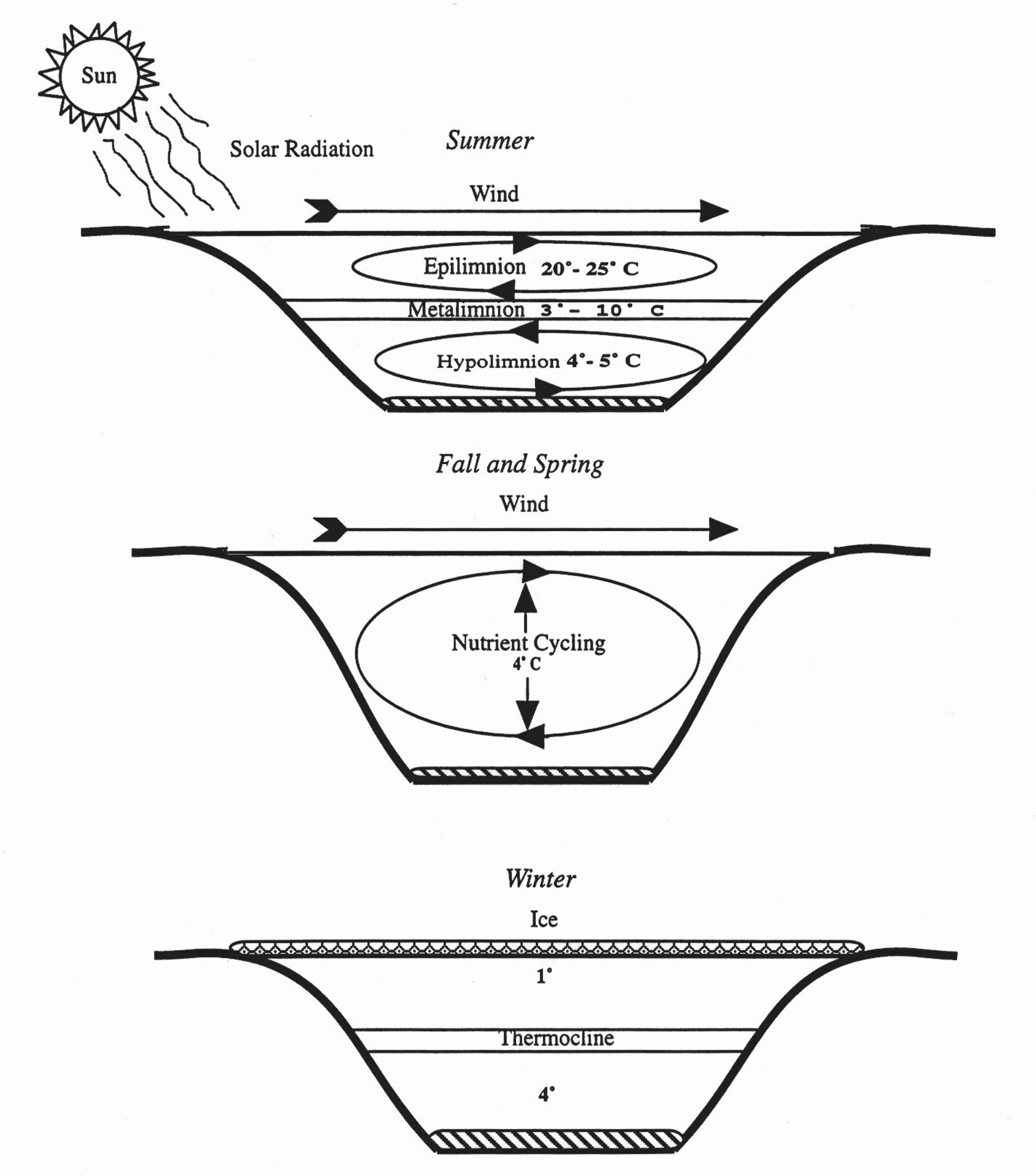

Figure 1. Mixing by means of lake turnover in dimictic lakes. During the summer, lakes are stratified into three layers (epilimnion, metalimnion and hypolimnion). During the fall and spring, the isothermal temperature and density facilitate lake turnover and the redistribution of nutrients. In the winter,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

Trophic Status of Lakes

Lakes are divided into four major trophic states based on the amount of nutrients available in the water: oligotrophic, mesotrophic, eutrophic and dystrophic (Table 1; Maitland 1990). The mesotrophic characterization is not included in Table 1 because it is referred to as a transitional stage between oligotrophic and eutrophic states (Chapman 1996). Oligotrophic lakes tend to be deep and oxygen-rich with steep-sided basins, creating a low surface to volume ratio. They are low in suspended solids such as nitrates and, more importantly, phosphorus, the limiting nutrient for plant productivity in most freshwater ecosystems. The shape of a lake can also influence its productivity; steep-sided oligotrophic lakes are not conducive to extensive growth of rooted vegetation because there is little shallow margin for attachment (Table 1).

Eutrophic lakes are nutrient-rich and have a relatively high surface to volume ratio when compared with oligotrophic lakes (Maitland 1990, Chapman 1996). These lakes have a large phytoplankton population that is supported by the increased availability of dissolved nutrients. Low dissolved oxygen levels at the bottom of eutrophic lakes result from decomposers using oxygen. Anoxic conditions trigger the release of phosphorus and other nutrients from the bottom sediments, resulting in their recycling through the water column (Chapman 1996). This phosphorus release and recirculation stimulates further growth of phytoplankton populations (Smith and Smith 2009). Eutrophic lakes tend to be shallow and bowl-shaped as a result of sediment loading, allowing for the establishment of rooted plants in shallow areas.

Dystrophic lakes have slightly lower water quality and receive large amounts of organic matter from the surrounding land, particularly dead organic matter known as humic materials (Smith and Smith 2009). The large quantity of humic materials can stain 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 overwhelms the habitat with plant growth, filling in the basin and ultimately developing the area into a terrestrial ecosystem (Goldman and Home 1983).

Eutrophication is a natural process; lakes begin as oligotrophic and, after a long period of aging, become terrestrial landscapes (Niering 1985). This process is greatly accelerated by anthropogenic activities that increase nutrient loading. The United States Environmental

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

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 loads of suspended solids, especially organic material
- Progression from a diatom population to a population dominated by cyanobacteria and/or green algae
- Decreasing light penetration (increasing turbidity)
- Increasing phosphorus concentrations in the sediments (Henderson-Sellers and Markland 1987).

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

Phosphorus and Nitrogen Cycles

In freshwater lakes, phosphorus and nitrogen are the two major nutrients required for the growth of algae and macrophytes (Smith and Smith 2009). Each nutrient has its own complex chemical cycle within the lake (Overcash and Davidson 1980). Understanding these cycles is necessary to devise better techniques for controlling high nutrient levels.

Phosphorus is the most important limiting nutrient for plant growth in freshwater ecosystems (Maitland 1990). Phosphorus naturally occurs in lakes in minute quantities measured in parts per billion (ppb). However, due to the high efficiency with which plants can assimilate phosphorus, normal phosphorus concentrations are sufficient for plant growth (Maitland 1990). Multiple sources of phosphorus exist external to the lake and in the lake sediments (Henderson-Sellers and Markland 1987, Williams 1992). The cycle of phosphorus 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 found in lakes: 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 limits plant growth. DP is converted to PP through the process of primary production and is incorporated into organic matter such as plant and animal tissues. PP then gradually settles into the hypolimnion in the form of dead organic matter. PP can be converted back to DP through aerobic and anaerobic processes. In the presence of oxygen, PP will be converted to DP through decomposition by aerobic bacteria. In anoxic conditions, less efficient anaerobic decomposition occurs, resulting in byproducts such as hydrogen sulfide, which is toxic to fish (Lerman 1978).

An important reaction occurs between DP and the oxidized form of iron, Fe (III) in oxygenated water (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. When oxygen levels at the sediment-water interface are decreased, Fe (III) is reduced to Fe (II) and DP is released back into the water. 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.

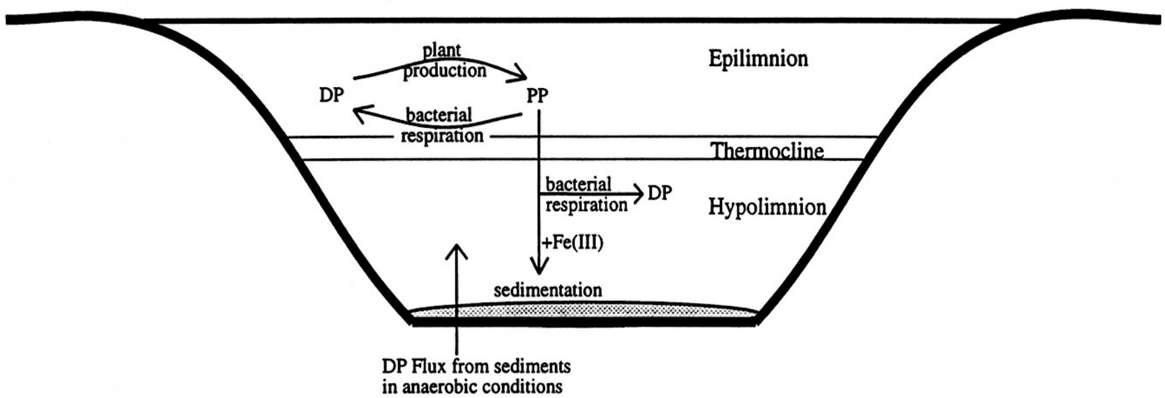

Figure 2. A model of the cycle of the major forms of phosphorus, dissolved (DP) and particulate (PP), within a lake ecosystem. The sedimentation of DP through complexation with Fe (III) contributes to the build-up of DP in the sediments. Note the production of DP in the hypolimnion due to bacterial decomposition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

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 in the lake can be an even larger source of phosphorus than external inputs. Nutrients are generally inhibited from mixing into the epilimnion by stratification during the summer. As a result, DP concentrations accumulate in the lower hypolimnion until fall turnover. During fall turnover, water temperatures become more uniform and wind mixes the water, resulting in a large movement of nutrients from the bottom of the lake to the upper layers and creating the potential for algal blooms. Algal blooms can occur when phosphorus levels rise above 15 ppb. If an algal bloom occurs, DP is converted to PP in the form of algal tissues. The algae die as winter approaches and the dead organic matter settles to the bottom where PP is converted back to DP and reaccumulates. This allows for another large influx of nutrients to surface waters during spring turnover (Bouchard, pers. comm.).

Nitrogen, the other major plant nutrient, is usually not the sole limiting factor for plant growth in a lake, but still plays an important role in the formation of algal blooms; high concentrations of nitrogen can lead to algal blooms in the presence of phosphorus (Chapman 1996). Available nitrogen exists in lakes in three major chemical forms: nitrates (NO_3^-), nitrites (NO_2^-) and ammonia (NH_3) (Figure 3).

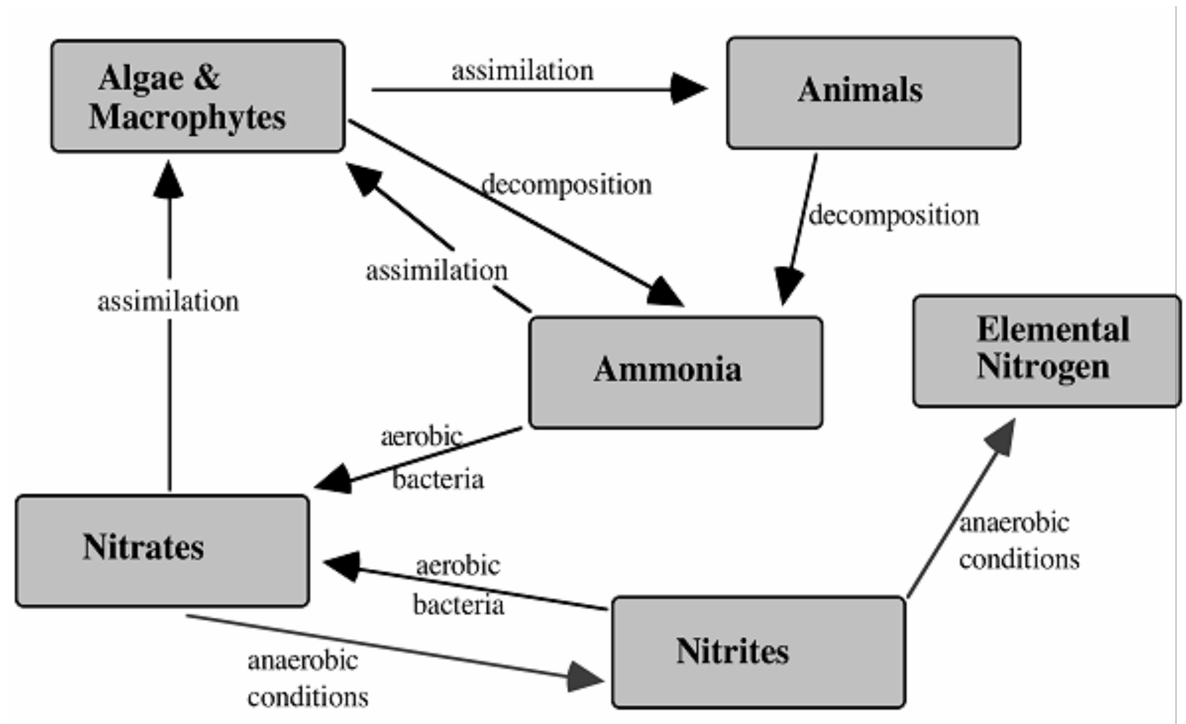

Figure 3. Various forms of nitrogen that occur in the nitrogen cycle within a lake ecosystem. It is important to note that in aerobic conditions both ammonia and nitrites are converted to nitrates, which are available for use by plants.

The majority of free nitrogen in a lake exists in the form of nitrates (Maitland 1990), a form that is directly available for assimilation by algae and macrophytes. In eutrophic lakes, there may be so much algae and macrophyte growth that most of the nitrates in the lake are incorporated into plant tissues (Maitland 1990). However, plants cannot use nitrites directly. In aerobic conditions, nitrate-forming bacteria convert nitrites to nitrates. Nitrates can be also reduced to form ammonia, a compound that enters the lake ecosystem as a product of the decomposition of plant and animal tissues and waste and is processed in one of three ways: assimilation into tissues, conversion to nitrates, or reduction to nitrites.

Macrophytes can assimilate ammonia directly into their tissues. Under oxygen-rich conditions, aerobic bacteria will convert ammonia directly to nitrates, the more usable form of nitrogen. Anaerobic decomposition, characteristic of the sediments of stratified lakes, can reduce nitrates to nitrites. If 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 and the aerobic or anaerobic conditions in the water must be considered to understand the availability of this nutrient for plant growth.

Once nutrients have built up in a lake, eliminating them is a challenging task. Several in-lake mitigation techniques exist to deal with the problem of excessive nutrients. None of these techniques is without disadvantages, but for lakes with serious algal growth problems they may become necessary (Henderson-Sellers and Markland 1987). The ideal method for controlling nutrients in a lake is to regulate and monitor the input sources before they become problematic. The natural processes of nutrient cycling and uptake by flora and fauna can compensate for nutrient inputs without further accelerating eutrophication of the lake.

Watershed Land Use

Land Use Types

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

Nutrients naturally bind to soil particles; if eroded into a lake, nutrient-rich soil will add to its nutrient load, hastening the eutrophication process and leading to algal blooms (EPA 1990). Different land use types vary in the amount of erosion and runoff they produce and therefore have different effects on nutrient loading in lakes. Assessment of land-use within a watershed is essential to determining factors that affect lake water quality.

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

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

Residential areas pose a significant threat to lake water quality. These areas generally contain lawns and impervious surfaces, such as driveways, parking spaces or rooftops that reduce percolation and increase surface runoff. Due to their proximity to lakes, shoreline residences are often direct sources of nutrient loading into the water body.

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

The use of chemicals in and around the home is potentially harmful to water quality. Products associated with cleared and residential land include fertilizers, pesticides, herbicides and detergents that often contain nitrogen, phosphorus, other plant nutrients and other

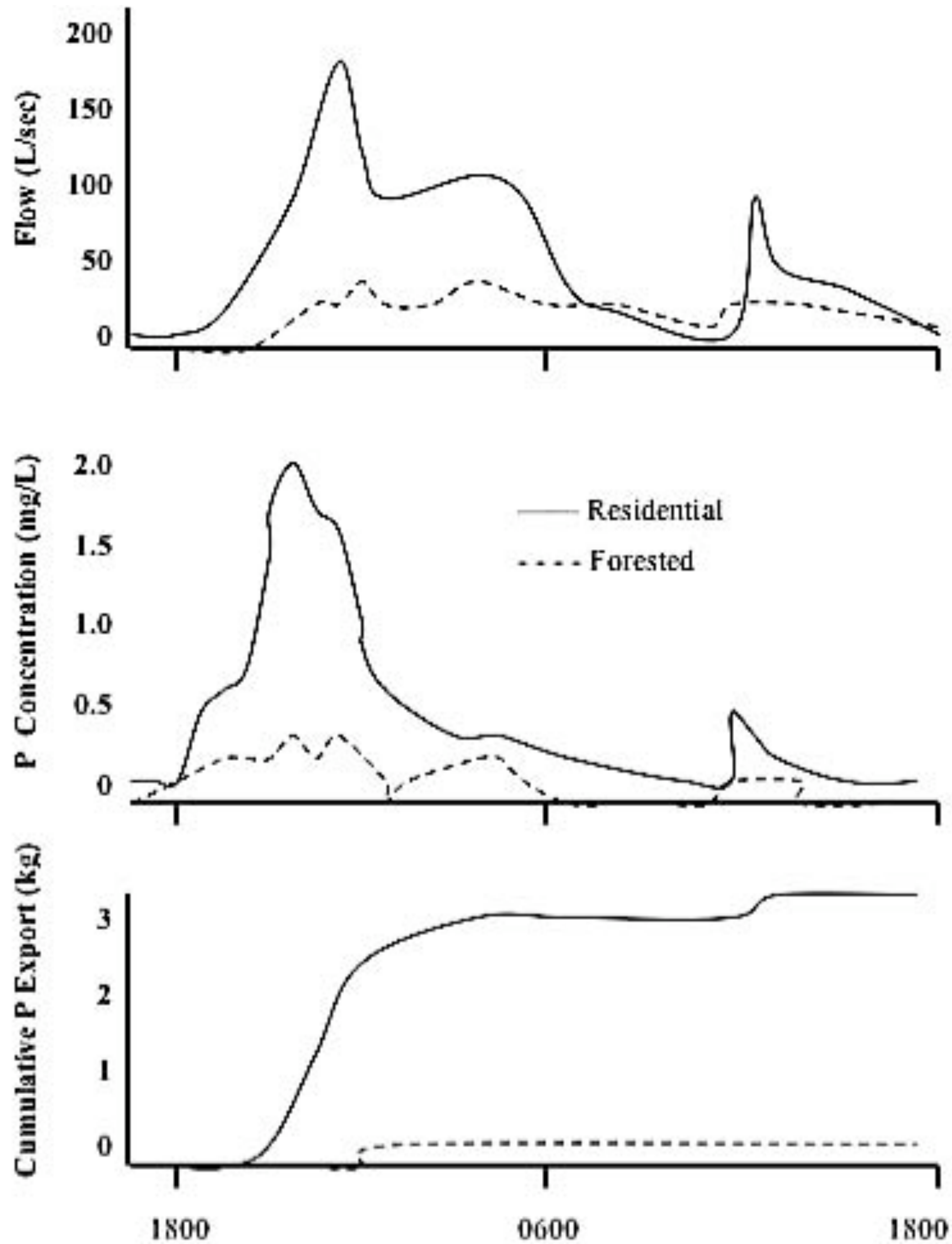

Figure 4. Comparisons of runoff after an April rainstorm in two neighboring watersheds near Augusta, ME. Top: volume of immediate runoff over a 12 hour period; middle: phosphorus concentration in the runoff; bottom: total amount of phosphorus exported into local streams and lakes from the storm (Dennis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

chemicals. These products can enter a lake by leaching directly into groundwater 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 many adverse effects on water quality. It should be noted that more environmentally friendly soaps and detergents containing low phosphorus levels are now available and are recommended (Figure 4; MDEP 1992a). Septic systems associated with residential and commercial land can contribute significant amounts of nutrients to the lake when improperly designed, maintained or used (EPA 1980). Proper treatment and disposal of nutrient-rich human waste is essential to maintaining high lake water quality.

Commercial uses of forested land can have detrimental effects on lake water quality. Activities that remove the cover of the canopy and expose the soil to direct rainfall increase erosion. Two studies by the Land Use Regulation Commission on tree harvesting sites noted that erosion and sedimentation problems occurred in 50% of active and 20% of selected inactive logging sites (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 (MDEP 1990).

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

Buffer Strips

Buffer strips play an important role in absorbing runoff because they help to control the amount of nutrients entering a lake (MDEP 1990). Excess nutrients, such as phosphorus and nitrogen, can promote algal growth and hasten eutrophication (MDEP 1990). Suggested buffer strip width is dependent on, but not limited to, steepness of slope, soil type and exposure, pond watersheds, floodways and areas designated as critical for wildlife (City of Augusta 1998).

A good buffer should have several vegetation layers and a variety of plants and trees to maximize the benefit of each layer (MDEP 1990). Native vegetation forms the most effective buffer. Trees and their canopy layer provide the first defense against erosion by reducing the impact of rain and wind on the soil; their deep root systems absorb water and nutrients while maintaining the topographical structure of the land. The shallow root systems of the shrub layer also aid in absorbing water and nutrients and help to hold the soil in place. The groundcover layer, including vines, ornamental grasses and flowers slows surface water flow and traps sediment and organic debris. The duff layer, which consists of accumulated leaves, needles and other plant matter on the forest floor, acts as a sponge to absorb water and trap sediment. Duff also provides a habitat for many microorganisms that break down plant material and recycle nutrients (Figure 5; MDEP 1990).

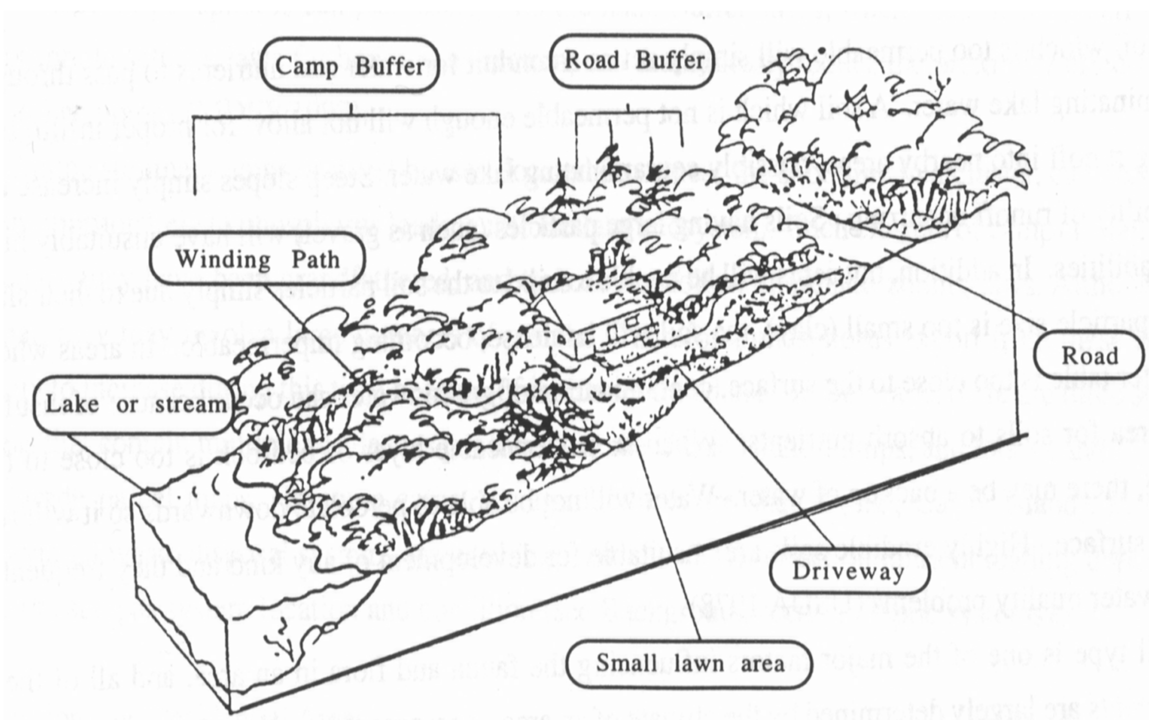

Figure 5. Diagram of an ideally buffered home.

An ideally buffered home should have a winding path down to the shoreline. This allows runoff to be diverted into the woods where it can be absorbed by the forest litter rather than channeled into the lake on the impacted trail (Figure 5). The house itself should be set back at least 100 ft from the shoreline and have a dense buffer strip composed of a combination of canopy trees, understory shrubs and groundcover between it and the water. To divert runoff effectively, the driveway should be curved rather than straight and should not lead directly toward the water.

Slopes within a buffer strip that are on a slope of less than 2% are most effective at slowing down the surface flow and increasing absorption of runoff (MDEP 1998c). Steep slopes are susceptible to heavy erosion and may render buffer strips ineffective. In addition to buffer strips, riprap can be an effective tool for preventing shoreline erosion because it protects the shoreline and adjacent shoreline property from heavy wave action (MDEP 1990). Riprap consists of three primary components: the stone layer, the filter layer and the toe protection. The stone layer consists of rough, large, angular rock. The filter layer is composed of a special filter cloth that allows groundwater drainage and prevents the soil beneath the riprap from washing through the stone layer. The toe protection prevents settlement or removal of the lower edge of the riprap. Riprap depends on the soil beneath it for support and should be built only on stable shores or bank slopes (MDEP 1990).

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, which can adversely affect water quality in a short period of time. Clearing forests to construct roads and buildings with impervious surfaces increase runoff that carries nutrients from agricultural, residential and industrial products (such as detergent, fertilizer and sewage) into the lake. Since phosphorus and nitrogen are the limiting nutrients to algal growth and algal growth affects the trophic state of a lake, increases in phosphorus and nitrogen in the water column from these sources can lead to a decrease in lake water quality and eventual eutrophication. Total phosphorus loading into 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 phosphorus loading model projects the impact that various factors may have on phosphorus loading and generates predictions of lake responses to changes in land use. The accuracy of the assumptions determines the accuracy of the predictions (EPA 1990).

Soil Types

Nutrient loading in a lake ecosystem is partially a function of surrounding soil characteristics. Physical characteristics of soil (permeability, depth, particle size, organic content and the presence of an impermeable layer or "fragipan"), as well as environmental features (slope, mean depth to the water table and depth to the bedrock) are important to consider when determining 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 are those which have medium permeability, moderate slopes, deep water tables, low rockiness, organic matter and no impermeable layer. These soils characteristics prevent extreme erosion and runoff of dissolved and particulate nutrients (USDA 1992). In areas where the soil does not meet these criteria, development, forestry or agricultural use should be considered carefully prior to implementation of a project.

Zoning and Development

The purpose of shoreline zoning and development ordinances is to control water pollution, protect wildlife and freshwater wetlands, monitor development and land use, conserve wilderness and anticipate the impacts of development (MDEP 1998c). Shoreline zoning ordinances regulate development along the shore in a manner that reduces the chances for adverse impacts on lake water quality. Uncontrolled development along the shoreline can result in a severe decline in water quality that is difficult to correct. In general, these regulations have become more stringent as increased development has caused water quality to decline in many watersheds (MDEP 1992b). If no comprehensive plan or town ordinances have been enacted, the state regulations are used by default.

Shoreline Residential Areas

Shoreline residential areas are of critical importance to water quality because of their proximity to the lake. This study considered houses less than 250 ft from the shoreline to be shoreline residences. Any nutrient additives from residences (such as fertilizers) have only a short distance to travel to reach the lake. Buffer strips along the shore are essential in acting as sponges for the nutrients flowing from residential areas to the lake (Woodard 1989). Residences that have lawns leading directly down to the shore have no barriers to slow runoff, allowing phosphorus to pass easily into the lake. Buffer strips, when used in conjunction with appropriate setback laws for house construction, can dramatically reduce the effects of shoreline residences on the lake (MDEP 1992b).

Seasonal residences, especially older ones located on or near the shoreline in a cluster, can contribute disproportionately to phosphorus loading into the lake ecosystem. Such clusters of camps usually exist because they were built before shoreline zoning laws were passed and are legally non-conforming. Although seasonal, they may accommodate large numbers of people during the summer. Phosphorus export from these areas is likely to increase during periods of heavy use. The location and condition of septic systems also affects the nutrient loading from these plots (see Subsurface Wastewater Disposal Systems).

Non-shoreline Residential Areas

Non-shoreline residential areas (greater than 250 ft from the shoreline) can also have an impact on nutrient loading but generally less than that of shoreline residential areas. Runoff, carrying fertilizers and possibly phosphorus-containing soaps and detergents, usually filters through buffer strips consisting of forested areas several acres wide, rather than a few feet wide. In these cases, phosphorus has the opportunity to be absorbed into the soils and vegetation. The majority enter the forest nutrient cycle rather than entering the lake.

Residences located up to one half mile away from the lake can potentially supply the lake with phosphorus when poorly constructed roads persist. Runoff collected on roofs and driveways may travel unhindered down roads or other runoff channels (i.e. boat launches) to the lake. Although non-shoreline homes do not have as significant of an impact as shoreline residences, watersheds having large residential areas with improper drainage can have a significant effect on phosphorus loading.

Tributaries can make non-buffered, non-shoreline residences as much of a nutrient loading hazard as a shoreline residence. Phosphorus washed from residential lawns without buffer strips can enter into a stream and eventually into the lake. Restrictions and regulations similar to those for shoreline residences apply to non-shoreline homes that are located along many streams.

Subsurface Wastewater Disposal Systems

Subsurface wastewater disposal systems are defined in the State of Maine Subsurface Wastewater Disposal Rules as devices and associated piping, including treatment tanks, disposal areas, holding tanks and alternative toilets, which function to dispose of wastewater in the soil (MDHS 2002). These systems are generally found in areas with no municipal disposal systems, such as sewers. Examples of these subsurface disposal systems include pit privies, holding tanks and septic systems.

Pit Privy

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

Holding Tank

Holding tanks are watertight, airtight chambers, usually with an alarm, which hold waste for periods of time. The tanks are durable and made of either concrete or fiberglass (MDHS 2002). The minimum capacity for a holding tank is 1,500 gallons. These must be pumped or they could back up into the structure or leak into the ground, causing contamination. Although purchasing a holding tank is less expensive than installing a septic system, the owner is then required to pay to have the holding tank pumped on a regular basis.

Septic System

Septic systems are the most widely used subsurface disposal system. The system includes a building sewer, treatment tank, effluent line, disposal area, distribution box and is often connected to a pump, which enables effluent to be moved uphill from the shoreline to a more suitable leach field location (Figure 6; MDHS 1983).

A septic system is an efficient and economical alternative to a sewer system, provided it is properly installed, located and maintained. Septic systems that are not installed or located

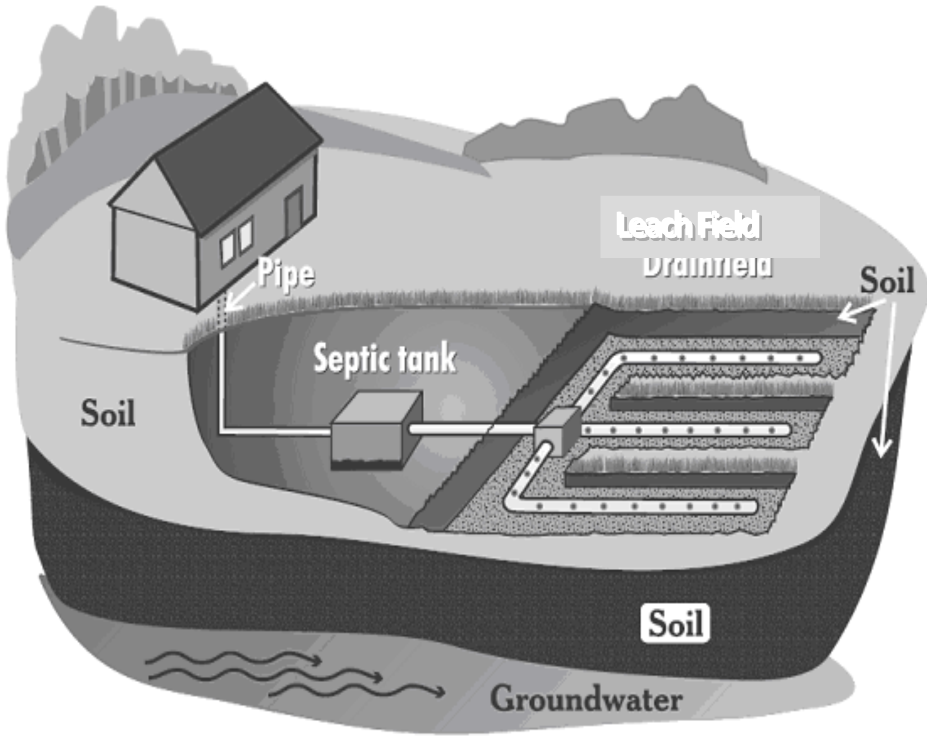

Figure 6. Cross-section of a typical septic system showing a septic tank and drainfield (EPA 2005).

properly lead to nutrient loading and groundwater contamination. The location of the systems and the soil characteristics determine the effectiveness of the system.

The distance between a septic system and a body of water should be sufficient to prevent contamination of the water by untreated septic waste. However, many parcels of land are grandfathered, which means their septic systems were installed before the passage of current regulations. Those systems may be closer to the shore than is currently permitted; any replacement systems in these grandfathered areas must follow 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 have a greater rate of respiration than anaerobic bacteria. Unfortunately, aerobic bacteria are also more susceptible to condition changes.

Tanks containing aerobic bacteria require more maintenance, more energy to pump in fresh air and are more expensive. Septic tanks rely on anaerobic bacteria. Solids are held until they are sufficiently decomposed and suitable for discharge (MDHS 1983). As the physical, chemical and biological breakdowns occur, scum and sludge are separated from the effluent (Figure 6). Scum is the layer of grease, fats and other particles that are lighter than water and move to the top of the treatment tank. Baffles trap scum so that it cannot escape into the disposal area. Sludge is composed of the solids that sink to the bottom of the tank. Over time, much of the scum and sludge is broken down by anaerobic digestion. The effluent then travels through the effluent line to the disposal area.

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

BOD is the oxygen demanded by decomposers to break down organic waste in water. Organic matter will increase if there is contamination from human and animal wastes. As the amount of organic material increases, BOD increases. If the BOD depletes dissolved oxygen, species within a lake may begin to die. If the flushing rate is low, reduced dissolved oxygen levels and increasing organic matter could become problematic.

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

Reducing the chances of clogging will allow septic systems to be most efficient. Year-round residents should have their septic tanks pumped every three to five years, or when sludge fills half the tank (MDEP 2003). 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 because they are not easily broken down by the microorganisms and fill the septic tank too quickly. The disposal of chemicals such 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 the beneficial 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, greener grass over the disposal field and slow drainage are symptoms of a septic system that has been subject to heavy use and is not functioning properly.

When constructing a septic system, it is important to consider soil characteristics and topography to determine the best location. An area with a gradual slope (10 to 20%) that allows for gravitational pull on the effluent is often necessary for proper sewage treatment (MDHS 2002). A slope that is too gradual causes stagnation. A slope that is too steep drains the soil too quickly, cutting treatment time short and preventing water from being treated properly. Adding or removing soils to change the slope is one solution to this problem.

Soils containing loam, sand and gravel allow the proper amount of time for runoff and purification (MDHS 1983). Soils should not be too porous or water will run through them too quickly and will not be sufficiently treated. Depth of bedrock is another important consideration. If the bedrock is too shallow, waste will remain near the soil surface. Fine soils such as clay do not allow for water penetration, causing wastewater to run along the soil surface untreated. Adding loam and sand to clay containing soils can help alleviate this problem. In the opposite case, if a soil drains too quickly, loam and clay can be added to slow down the filtration of wastewater.

Federal, state and local laws are in place to protect land and water quality. The federal government sets minimum standards for subsurface waste disposal systems. States can then choose to make their rules stricter, but not more lenient, than federal guidelines. The Maine Comprehensive Land Use Plan sets standard regulations that each city and town must follow (MLURC 1976). Individual municipalities have the ability to establish their own comprehensive land use plan in accordance with the state regulations. However, many towns develop local ordinances that consider specific issues, such as shoreline zoning. The Maine Department of Environmental Protection (MDEP), Maine Department of Conservation (MDC) and local Code Enforcement Officers are responsible for overseeing the enforcement of these laws.

Since 1974, state mandates have prevented septic systems from being installed without a site evaluation or within 100 ft from the high water mark. Other regulations state that there must be no less than 300 ft between a septic system disposal field and a well that uses more than 2,000 gallons of water per day (MDHS 2002). The original slope of the site of a septic system also may not exceed 20%. These regulations are in place for the safety of people living in the watershed and for the benefit of the aquatic ecosystem.

Roads

Roads can significantly contribute to the deterioration of water quality by adding phosphorus to runoff and channeling runoff into the lake (KCSWCD 2000). Roads may allow easy access for runoff of nutrients and organic pollutants into the lake via improperly constructed culverts and ditches. Improper road construction and maintenance can increase the nutrient load entering the lake.

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

Road construction should try to achieve the following long-term goals: minimize the surface area covered by the road, minimize runoff and erosion with proper drainage and the placement of catch basins (as well as culverts and ditches) and maximize the lifetime and durability of the road (MDEP 1990). A well-constructed road should divert surface waters into a vegetated area to prevent excessive amounts of surface runoff, phosphorus and other nutrients from entering the lake. Items that should be considered before beginning construction include: road location, road area, road surface material, road cross-section, road drainage (ditches, diversions and culverts) and road maintenance (MDEP 1992a).

Although the State of Maine has set guidelines to control the building of roads, road location is typically determined by the area in which homes are built (MDEP 1990). All roads must be set back at least 100 ft from the shoreline of a lake if they are for residential use and 250 ft for industrial, commercial, or other non-residential uses involving one or more buildings (MDEP 1991).

When designing a road, future use is a very important factor to consider. A road should be constructed no longer than is absolutely necessary and a particular road should not be extended past the last structure that is to be serviced by that road. The width of a road, which is often based upon the maintenance capabilities of the area, must also be considered (Cashat 1984). Proper planning that includes maintenance concerns is an effective, practical and economical way to develop the road area (Woodard 1989).

Road surface material is another important factor to consider in road construction. Studies have shown that phosphorus washes off paved surfaces at a higher rate than from sand and gravel surfaces (Lea et al. 1990). On the other hand, sand and gravel roads erode more quickly and have the potential for emptying more sediment and nutrients into a body of water. Consequently, pavement is chosen for roads with a high volume of traffic. Sand and gravel are typically used for roads in low traffic areas or seasonal use areas. Both types of roads need proper maintenance. Gravel road surfaces should be periodically replaced and properly graded so that a stable base may be maintained and road surface erosion minimized.

The road cross section is another important factor to consider when planning road construction. A crowned road allows for proper drainage and helps in preventing deterioration of the road surface (MDOT 1986). This means that the road will slope downward from the middle, towards the outer edges. This crown should have a slope of 0.13 to 0.25 inches per foot of width for asphalt and 0.50 to 0.75 inches per foot of width for gravel roads (Michaud 1992). This slope allows the surface water to run off the road on either side as opposed to remaining on the road surface and running along its entire length. Road shoulders should also have a slightly steeper cross slope than the road itself so that runoff can flow into a ditch or buffer zone (Michaud 1992).

The drainage off a road and the land that surrounds it must also be considered during construction or maintenance projects. Ditches and culverts are used to help drain roads into buffer zones where nutrients added by the road can be absorbed by vegetation or filtered through soil. These measures are also used in situations for handling runoff that may be blocked by road construction. Ditches are necessary along wide or steep stretches of road to divert water flow to areas where it can be absorbed. Ideally, they are u-shaped, deep enough to gather water and do not exceed a depth to width ratio of 2:1. The ditch should be free of debris and covered with abundant vegetation to reduce erosion (Michaud 1992). Ditches must also be constructed of riprap or soil that will not be easily eroded by the water flowing through them.

Culverts are pipes that are installed beneath roads to channel water in proper drainage systems. The most important factor to consider when installing a culvert is size. Culverts must be large enough to handle the expected amount of water that will pass through it during the peak flow periods of the year (KCSWCD 2000). If this is not the case, water will flow over and around the culvert and wash out the road. This may increase the sediment load entering the lake. The culvert must be set in the ground at a 30° angle down slope with a pitch of 2 to 4% (Michaud 1992). A proper crown above the culvert is necessary to avoid creating a low center point and damaging the culvert. The standard criterion 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. After diverting runoff into wooded or grassy areas, natural buffers are used to filter sediment and decrease the volume of water by infiltration before it reaches the lake (Michaud 1992). Efficient installation and spacing of diversions can also reduce the use of culverts.

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

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. Animal wastes can also be sources of excess nutrients (Williams 1992). To minimize these problems, there are ordinances that prohibit new tilling of soil and new grazing areas within 100 ft of a lake or river. Problems can still exist in areas that were utilized for agriculture prior to the enactment of these ordinances by the State of Maine in 1990. According to the Mandatory Shoreline Zoning Act, these areas can be maintained as they presently exist, which 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. Spreading manure can lead to nutrient loading, especially in winter when the ground is frozen and nutrients do not have a chance to filter through the soil. To help prevent these problems, the state has passed zoning ordinances, which prohibit the storage of manure within 100 ft of a lake or river (MDEP 1990). The Nutrient Management Act also prohibits the spreading of manure on agricultural fields during the winter season (Nutrient Management Act 2006). Towns may provide subsidies as an incentive for compliance if the problem is large enough but these solutions do not address the problem of livestock that defecate close to bodies of water. One solution for this problem may be to put up fences to keep the animals away from the edge of a lake or pond.

Runoff containing fertilizers and pesticides may also add nutrients and other pollutants to a lake. Fertilizing only during the growing season and when storms are not expected can address this problem. Pesticides may also have negative impacts on water quality.

Alternative methods of pest control may be appropriate, including biological controls such as integrated pest management and intercropping, the practice of planting alternating rows of different crops in the same field.

Forestry

Forestry is another land use factor that can contribute to nutrient loading through erosion and runoff. The creation of logging roads and skidder trails may direct runoff into a lake. The combination of erosion, runoff and pathways can have a large impact on the water quality of a lake (Williams 1992). There are state and municipal shoreline zoning ordinances to address these problems. They specify that timber harvesting equipment, such as skidders, cannot use streams as travel routes unless the streams are frozen and traveling on them causes no ground disturbance (MDEP 1990). Clear-cutting within 75 ft of the shoreline of a lake or a river running to the lake is prohibited. At distances greater than 75 ft, harvest operations cannot create clear-cut openings greater than 10,000 ft^2 in the forest canopy and if they exceed 500 ft^2, they must be at least 100 ft apart. These regulations are intended to minimize erosion (MDEP 1990), but in order for these laws to be effective they have to be enforced. This may be a difficult task for towns lacking the resources necessary to hire staff to regulate forestry. Also, illegal practices may occur and negatively impact lake water quality.

Successional Land

Succession refers to the replacement of one vegetative community by another, resulting in a mature and stable climax community (Smith and Smith 2009). An open field ecosystem moves through various transitional stages before it develops into a mature forest. The earliest stages of open field succession involve the establishment of smaller trees and shrubs throughout a field. Intermediate and later successional stages involve the growth of larger, more mature tree species. The canopy becomes more developed, allowing less light to reach the forest floor. A developed canopy also slows rainfall, reducing its erosion potential. This land type, in which a forest is nearing maturity and contains over 50% tree cover, is referred to as transitional forest. Mature forest is defined as areas of closed canopy that predominantly contain climax species.

Wetlands

Several different types of wetlands may be found in a watershed. A bog is dominated by shrubby vegetation, large quantities of sphagnum moss and typically has a low level of productivity (Lewis 2001). 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 are rich with vegetation that is rooted in the ground and grows above the surface of the water (Brennan and Withgott 2005). Swamps are characterized by waterlogged soils inhabited by either woody or shrub plant species and often occur near forested areas (Brennan and Withgott 2005). Wetlands are important because they provide a habitat for a variety of animals, including waterfowl and invertebrates (Brennan and Withgott 2005).

The type of wetland and its location in a watershed are important factors to consider when determining whether the wetland acts as a nutrient sink, preventing nutrients from entering a lake or as a nutrient source, contributing nutrients to a lake (Washington State Department of Ecology 1998). It is important to note that one wetland may be both a source and a sink for different nutrients and may vary across different seasons, depending on the amount of input to the wetland. Vegetation diversity within a wetland is important because different flora absorb different nutrients. For this reason, shrub swamps are better nutrient sinks than many other types of wetlands. When nutrient sink wetlands are located closer to the lake, their nutrient 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 and help moderate the impacts of erosion near the lake.

Wetlands are important transitional areas between lake and terrestrial ecosystems. As wetlands usually have a water table at or above the level of the land and contain non-mineral substrates such as peat, wetland soil is periodically or perpetually saturated with water. Growing in this partially submerged habitat is hydrophytic vegetation, which has adapted for life in saturated and anaerobic soils (Chiras 2006). Wetlands 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 efficient nutrient uptake by their vegetation (Niering 1985, Smith and Smith 2009). Finally, wetlands have the potential to absorb heavy metals and nutrients from various sources including mine drainage, sewage and industrial wastes (Chiras 2006).

Although there are regulations controlling wetland use, a lack of enforcement leads to development and destruction of wetlands. Wetland areas should be protected by the Resource Protection Districts and other means, which prevent development within 250 ft of the wetland. Due to their location, wetlands along the shoreline may be prone to illegal development (Chiras 2006). A decrease in wetlands will have negative effects on the water quality of a lake due to increased runoff, erosion and decreased natural buffering (Table 2).

Table 2. Descriptions of site characteristics and plant populations of different types of freshwater inland wetlands (Smith and Smith 2009).

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

Salmon Lake and McGrath Pond Characteristics

Watershed Description

Salmon Lake and McGrath Pond are located in the Belgrade Lakes Region of Kennebec County, Maine. Two main basins, McGrath Pond to the north and Salmon Lake to the south, are connected by a narrow channel and were considered a single water body for this study. These two basins were historically separate, but a dam constructed and maintained by the Dams Committee of Oakland, Belgrade and Rome located at the outlet stream flowing from Salmon Lake into Great Pond raised the water level sufficiently to inundate the streambed that formerly separated the two water bodies. The watershed falls within the towns of Belgrade and Oakland. Howland Hill (214 m), Bickford Hill (155 m) and Mutton Hill (166 m) comprise the three highest elevations in the watershed, and all three lie along the northwest edge of the watershed. Salmon Lake and McGrath Pond have a combined surface area of 470 ha, a mean depth of 5.5 meters and a total volume of 31,192,385 m^3 (PEARL 2009e, 2009f). The maximum depth of 17.4 m occurs in the southeast basin of Salmon Lake (PEARL 2009e, 2009f). The lake is classified as dimictic because the water column stratifies in the summer months and remixes during the spring and fall.

The Belgrade Lakes Region consists of an interconnected chain of seven shallow to medium-depth lakes including East Pond, North Pond, Great Pond, Messalonskee Lake and Long Pond in addition to Salmon Lake and McGrath Pond. Each lake comprises part of a hydrologic chain that originates in East Pond and flows through North Pond into Great Pond. Great Pond drains into Long Pond, from which water flows into Messalonskee Lake, the Kennebec River and, ultimately, the Atlantic Ocean. Although Salmon Lake and McGrath Pond drain into Great Pond via an outlet stream called Hatchery Brook on the southwestern shore of Salmon Lake, their combined water body receives no inputs from the surrounding lakes. Numerous permanent and ephemeral tributaries drain into the water body but these are fed exclusively by groundwater and runoff from within the watershed boundary. While McGrath Pond is considered to be in good health based on water transparency and total phosphorus concentrations, Salmon Lake falls slightly below average for these parameters and is susceptible to algal blooms (MVLMP 2004). Additionally, Salmon Lake has drawn recent public attention due to an infestation of Eurasian watermilfoil (*Miriophyllumspicatum*) in the outlet cove to Great Pond. Extensive shoreline development and worsening algal blooms in neighboring lakes have also raised concerns about excessive nutrient loading, deteriorating water quality and the impact of declining oxygen levels on fish populations in Salmon Lake and McGrath Pond (see Background: General Nature of the Study).

Historical Land Use Trends

Historically, central Maine was covered almost entirely by forests of hemlocks, beech and maples (Foster, Motzkin et al. 1998). Conversion of forested land for industrial, commercial and residential purposes increases the chance that neighboring water bodies will receive excess nutrients, especially phosphorus, via surface runoff that may impact the health of the lake ecosystem. Nutrient loading into most central Maine lakes comes primarily from non-point sources (Firmage, pers. comm.), meaning that nutrient sources are distributed throughout the watershed and that nutrients from numerous sources may be incorporated into runoff before being carried into a water body. Non-point sources contrast with point sources, from which a pollutant is emitted directly into the watershed and can be regulated at the source. Development of forested areas compounds the non-point source nutrient loading problem because it removes natural vegetation that would otherwise slow the rate of runoff flow and allow the soil to reabsorb excess nutrients (see Background: Land Use Types). Examining how land use trends develop and change over time can aid in the understanding and evaluation of nutrient loading within the watershed (Davis, Bailey et al. 1978).

Prior to the 1930's, the Belgrade Lakes Region was inhabited primarily by year-round residents making their living on small, family-owned farms. An economic boom following the Second World War lured many young, local veterans away from agriculture toward new job opportunities in commerce and industry (Plantinga 1999). The resulting decline of agriculture caused much of the surrounding cropland to be reclaimed by forest. From 1872 to present, forested land has increased from 53% to over 90% of Maine's total land area due to the occurrence of succession on abandoned agricultural land (Plantinga 1999).

Development since the 1960's has focused largely on seasonal residential and recreational land uses. Many towns in the Belgrade Lakes Region approved the subdivision of agricultural land for residential development and camp road construction on the grounds that doing so would promote municipal and economic growth (Davis, Bailey et al. 1978).

Commercial summer camps and parks for tennis, golf and recreation have also been developed in the watershed. Impacts of development are most acute when population and facility use increase during the summer months. Additionally, septic systems associated with development can add nutrients to the surrounding soil (see Background: Septic Systems). These nutrients may eventually percolate, via groundwater, into the water body. Finally, activities associated with development, including land clearing, sewage disposal and building construction, contribute directly to nutrient loading into the water body (see Background: Watershed Land Use).

Davis et al. (1978) demonstrated that agriculture and residential development have the greatest impact on water body health. Changing water quality can be linked to changes in the surrounding land use, especially if these changes involve the conversion of natural vegetation for land uses with high nutrient loading potential. A thorough analysis of past and present land use trends in relation to water quality can be used to evaluate potential sources of excess nutrients and to predict the sensitivity of lake water quality to different types of development in the Salmon/McGrath watershed.

Biological Features

Introduction

The Salmon Lake/McGrath Pond watershed is comprised of wetlands, coniferous, deciduous and mixed forests, streams and small ponds which each provide habitat for a variety of flora and fauna, both aquatic and terrestrial. Shoreline and non-shoreline development around the lake affects species that depend on the habitat within the watershed. Development also affects the water quality of the lake especially through phosphorus loading via runoff associated with fertilizers, sewage and other human activities. Excess phosphorus may lead to algal blooms that negatively affect the dynamics of the lake (see Background: Watershed Land Use). Algal blooms are also unappealing for lake users and lakeshore residents because they may cause a green film on the surface, and also inhibit fishing by reducing the transparency of the water. Based on current phosphorus levels, Salmon Lake and McGrath Pond are currently classified as mesotrophic lakes because they are in the transitional stage between oligotrophy and eutrophy (see Background: Lake Characteristics: Trophic Status of Lakes).

Native Aquatic Flora/Fauna

Salmon Lake and McGrath Pond provide habitat for many species of aquatic plants and animals. Aquatic macrophyte species observed in Salmon Lake and McGrath Pond include Common Bulrush (*Spircusacutus*), Watershield (*Braseniaschreberi*), Yellow pond lily (*Nupharadvena*) and Floating brownleaf (*Potamogetonnatans*). Aquatic macrophytes are defined as aquatic plants large enough to be seen with the naked eye and are an important component of any freshwater ecosystem because they provide food, shelter and oxygen for aquatic organisms. They also provide an important ecosystem service by utilizing phosphorus in the water, which reduces the availability of this nutrient to algal species. However, an abundance of macrophytes may be a biological indicator of excess nutrients within the lake (Lacoul and Freedman 2006).

Fish Stocking

Fish stocking in Maine lakes is under the jurisdiction of the Maine Department of Inland Fisheries and Wildlife (MDIFW) which maintains a widespread fish-stocking program to provide anglers with more recreational opportunities across the state. The program, implemented in the mid-1800s, has resulted in the introduction of many non-native species and an expansion of the range of several native fish species (Boucher 2004). During 2009, 2,400 brook trout were stocked in Salmon Lake and McGrath Pond between 22-April and 29-October (PEARL 2009c).

In addition to the brook trout stocked by the MDIFW, there are currently 14 species of native and non-native fish in Salmon Lake and McGrath Pond (see Table 3); PEARL 2009c). Many of these species have individual management plans designed by the MDIFW or are covered under a multi-species management plan to ensure that these fisheries remain available for future generations (MDIFW 2009c). The plans may be for a specific species or may cover several species such as the Minor Sportfish Management Plan and the Non-sport and Commercial Management Plan (MDIFW 2009c). Those species with a specific management plan are often major sportfish or are threatened or endangered species. Recreational fishing is an important activity in Salmon Lake and McGrath Pond because it brings many short-term visitors that spend money locally through renting equipment and/or cottages or cabins. In addition, many seasonal and year-round residents use the lake for fishing. The brook trout stocked by the MDIFW, as well as largemouth and smallmouth bass are especially popular with recreational anglers (MDIFW 2009b).

Table 3. **List of fish species found in Salmon Lake and McGrath Pond. Species are identified as either native or non-native to Maine and status of a management plan in Maine is indicated (MDIFW 2009a; MDIFW 2009c).**

Common Name	Scientific Name	Native or Non-native to Maine	Management Plan in Maine?
American eel	*Anguilla rostrata*	Native	Covered under non-sport and commercial plan
Brook trout	*Salvelinus fortinalus*	Native	Yes (species specific)
Brown bullhead	*Ameiurus nebulosus*	Native	Covered under minor sport-fish plan
Chain pickerel	*Esox niger*	Native	No
Golden shiner	*Notemigonous crysoleucas*	Native	No
Pumpkinseed sunfish	*Lepomis gibbosus*	Native	Covered under minor sportfish plan
Rainbow smelt	*Osmerus mordax*	Native	Covered under non-sport and commercial plan
White perch	*Morone americana*	Native	Yes (species specific)
White sucker	*Cotostomus commersoni*	Native	No
Yellow perch	*Perca flavescens*	Native	Covered under minor sportfish plan
Black crappie	*Pomoxis nigromaculatus*	Non-native	Covered under minor sportfish plan
Brown trout	*Salmo trutta*	Non-native	Yes (species specific)
Largemouth bass	*Micropterus salmoides*	Non-native	No
Smallmouth bass	*Micropterus dolomieu*	Non-native	No

Invasive Plants

The introduction of non-native aquatic macrophyte species can have a detrimental impact on the health of a lake, especially if these species are aggressive or quick growing. These invasive species are not subject to the natural controls such as predation and diseases that deter the growth of native species (MDEP 2005b). They may displace native plants and dominate the lake waters due to this advantage. The growth of these species is detrimental to the natural ecosystem but also negatively affects recreation and aesthetics by entangling boat motors and by inhibiting fishing and swimming (MDEP 2005b). Many of these species are spread via fragments carried on boats or other equipment or by fragmentation within water, which allows fragments to become established in new locations. Fragments may also spread to connected water bodies via water currents. Some of these invasive species are also introduced through water and wetland gardens or the aquarium plant trade when they are accidentally released into the environment (MDEP 2002a).

The Maine Department of Environmental Protection (MDEP) has established a list of eleven species of aquatic plants that are banned in the State of Maine. It is illegal to sell, propagate or introduce these species to Maine waters and violators must pay a fine (MDEP 2009b). Four of these species, Hydrilla *(Hydrillaverticillata)*, Variable leaf watermilfoil *(Myriophyllumheterophyllum)*, Curly leaf pondweed *(Potamogetoncrispus)* and Eurasian watermilfoil *(Myriophyllumspicatum)*, have been reported in Maine lakes (Appendix A; MDEP 2008e). Currently, Maine is experiencing less of a problem with invasive aquatic plant species than other states in the United States, with reported infestation in only 29 of its 5700 lakes and ponds. There are currently two banned invasive plant species found in Kennebec County: Variable leaf watermilfoil and Eurasian watermilfoil.

Eurasian watermilfoil was discovered in the outlet cove of Salmon Lake in August 2008, and the Maine DEP has implemented their Rapid Response Plan in order to keep this infestation under control (MDEP 2008b). Eurasian watermilfoil is considered especially dangerous because of its rapid growth rate and its ability to reproduce via fragmentation, which makes it virtually impossible to exterminate once introduced (MDEP 2005b). Once Eurasian watermilfoil is established, it forms dense mats that entangle boat motors, impair fishing and swimming, reduce water quality and potentially reduce the value of shoreline property (MDEP 2005b). The location of this infestation is also cause for concern because it is in the outlet cove leading to Great Pond and, if not controlled quickly, Eurasian watermilfoil could potentially spread to the other Belgrade Lakes (MDEP 2009b).

Geological and Hydrological Natural History

The geography of central Maine was shaped largely by the advance and retreat of the Laurentide ice sheet during the Wisconsinian glaciation from 100,000 to 10,000 years before present (ybp) (Davis, Bailey et al. 1978). From its origin in northern Canada, the ice sheet fanned out across the northern portion of the continent. At its maximum extent, roughly 20,000 ybp, the ice margin spanned from the Midwest to Long Island, New York and covered all of New England to a depth of several thousand feet (Dyke and Prest 1987). Between 30,000 and 20,000 ybp, the ice sheet spread across Maine in a southeasterly direction (see Background: General Characteristics of Maine Lakes). Landscapes were altered dramatically by the grinding action of the ice sheet on the underlying substrate. Fragments of rock and debris were transported by the moving glacier and re-deposited further south. At the apex of glaciation, the ice sheet extended several hundred miles into what is now the Gulf of Maine before beginning a receding trend back toward the northwest (Dyke and Prest 1987).

Deglaciation concurrent with a climatic warming trend began around 21,000 ybp (Davis, Bailey et al. 1978). Deglaciation was marked by a retreat of the melting ice sheet to the northwest, with the ice margin reaching as far north as central Maine roughly 14,000 ybp (Dyke and Prest 1987). During this period, depression of the continental crust under the weight of the ice sheet allowed the Atlantic Ocean to inundate the newly deglaciated landscape. Channels of sediment-laden melt water running seaward through the base of the glacier left long, ridge-like deposits called eskers as the glacier retreated. Glacial sediments deposited by melt water percolating along the glacier-substrate margin accumulated in ridges, called moraines, oriented northeast to southwest. The presence of the ice sheet to the northwest of these features continued to depress the underlying land, creating an alternating pattern of moraines separated by basins as the glacier retreated (Borns, Doner et al. 2004). Following deglaciation, isostatic rebound of the continental crust caused the coastal margin to recede back to the southeast as previously inundated landscapes rose above sea level. Basins left by the retreating glacier formed a large network of lakes when they filled with water from glacial melting and precipitation (Borns, Doner et al. 2004).

Glacial patterns of sedimentation are responsible for the current composition of sediment substrates in Maine lake beds, and have important implications for lake water quality. As the ice margin retreated, marine inundation of newly deglaciated land allowed fine-grained melt water sediments to linger suspended in the seawater column longer than the heavier particles of coarse sand and glacial till, which settled quickly (Borns, Doner et al.

2004). Eventual deposition of this fine-grained material covered southern Maine bedrock with a layer of clay substrate called the Presumpscott formation. Amirbahman, Pearce et al. (2003) noted that the Presumpscott formation comprises the bottom substrate of many Maine lakes, particularly those that experience eutrophication problems. Davis et al. (1978) observed that clays provide a substrate for nutrient deposition, and that anthropogenic disturbance of lake sediments may cause nutrient fluxes into the water column.

History of Lake Management

The Maine Department of Inland Fisheries and Wildlife recorded the first water quality problems in McGrath Pond and Salmon Lake in 1926 when the landlocked salmon hatchery experienced a problem of low dissolved oxygen (Nichols, Sowles, et al. 1984). Low dissolved oxygen caused the hatchery to close in 1942. In the fall of 1971, a local landowner reported to the Maine Department of Environmental Protection (MDEP) that an algal bloom had developed (Nichols, Sowles et al. 1984). In 1975, after another algal bloom was report, the MDEP began limnological studies of Salmon Lake and McGrath Pond. The MDEP identified agriculture, a logging operation and the town of Oakland landfill as sources of nutrient loading.

Algal blooms occurred again in 1976, 1977 and 1979 (Nichols, Sowles et al. 1984). The MDEP with the United States Geological Survey conducted additional lake and watershed surveys in 1978 and 1979. The sources of nutrient loading identified were a large dairy farm and a lumberyard, and it was determined that Oakland landfill was an insignificant contributor.

The McGrath Pond/Salmon Lake Association was formed in the 1970's to preserve and protect the water quality of these lakes while promoting their responsible use (MPSLA 2009). The lake association works with the Maine Department of Environmental Protection (MDEP) and the Maine Volunteer Lake Monitoring Program (MVLMP) to monitor water quality. Water quality data have been collected since 1975. Water quality tests include dissolved oxygen levels, Secchi disk transparency, total phosphorus, chlorophyll-a and color.

In 1987, The United States Department of Agriculture, the United States Department of Environmental Protection, the MDEP and the landowners funded the Salmon Lake Restoration Project to reduce runoff and nutrient loading from these locations (Sowles 1987).

There were no measurable improvements in lake water quality within two years of the completion of the restoration project.

The Colby Environmental Assessment Team (CEAT) conducted a watershed survey of Salmon Lake and McGrath Pond in 1994 (CEAT 1994).CEAT concluded that the overall water quality was healthy. Nutrient levels in both Salmon Lake and McGrath Pond indicated moderate productivity. Recommendations were made to continue to reduce runoff and nutrient loading.

In 1997, the Maine Legislature authorized a "comprehensive watershed protection program" (Title 5 MRSA). This bill directed the Maine Land and Water Resources Council to classify lakes as high priority for management based on the degree of threat from non-point source pollution to water quality, threat to aquatic habitat and the possibility of restoration. In 1998,the Maine Land and Water Resources Council classified Salmon Lake and McGrath Pond as a priority lake and placed it on Maine's Non-point Source Priority List (MDEP 1998a).

In 1998, the MDEP, Belgrade Regional Conservation Corp and volunteers conducted a watershed survey to identify sources of non-point source pollution and nutrient loading. They identified 131 sites that contributed to non-point source pollution and lowered lake water quality (MPSLA and MDEP 1999). The sites included sources of phosphorus and soil erosion on private residential property, state and town roads, driveways and commercial establishments. MDEP granted the Belgrade Regional Conservation Alliance funding for the development of a watershed management plan.

In 2003, KCSWCD received a 319 Grant from the MDEP to reduce non-point sources of pollution by installing best management practices to prevent erosion and runoff (KCSWCD 2008b). The KCSWCD, McGrath Pond/Salmon Lake Association, Belgrade Regional Conservation Alliance, Conservation Corp, Maine Department of Environmental Protection and watershed residents worked together to identify and remediate sources of pollution and nutrient loading in the Salmon/McGrath watershed. They completed all three phases of the project in 2007 and remediated a total of 89 sites. The project effectively reduced the sources of pollution to Salmon Lake and McGrath Pond. The results of Phase 3 included installation of best management practices at 19 sites, reduced the pollution load by

13.85 tons of sediment, 14.01 pounds of phosphorus, 27.88 pounds of nitrogen per year and restored 620 feet of shoreline along Salmon Lake and McGrath Pond (KCSWCD 2008b).

Since 2007, after the completion of the Load Abatement Project Phase III, best management programs continue to be implemented. The Belgrade Lakes Conservation Corps (BLCC) continues to identify and remediate sources of non-point pollution (Kallin, pers. comm.). BLCC has been reducing pollution in the Salmon Lake and McGrath Pond since 1996 and provided labor for the Load Abatement Project (Kallin, pers. comm.,; KCSWCD 2008b).The BLCC is organized and funded by the Belgrade Regional Conservation Alliance. BLCC provides free labor to landowners wanting to reduce potential nutrient loading from their property. Landowners submit applications with specific projects that will reduce runoff into the lake.

The McGrath Pond/Salmon Lake Association continues to work to improve lake water quality (Swanson, pers. comm.). The lake association is part of the MDEP Lake Smart Program. Landowners receive Lake Smart certification when their property meets specific requirements that reduce runoff and nutrient loading. Requirements including improving buffers, boat loading docks, paths and driveways.

STUDY OBJECTIVES

Introduction

The goal of this study is to provide a comprehensive examination of Salmon Lake and McGrath Pond, and its associated watershed. The Colby Environmental Assessment Team(CEAT) investigated land use patterns and the impact of each on lake water quality. CEAT conducted road, house, and shoreline buffer surveys, analyzed water quality, and assessed potential impacts of land use. The goal of this study was to identify sources of pollution entering into the water body and to assess the impacts on Salmon Lake and McGrath Pond. These data will help assess the overall health of the ecosystem and provide information suggesting how the water quality of Salmon Lake and McGrath Pond can be protected and improved in the future.

Land Use Assessment

Land use patterns within a watershed area can significantly impact the water quality of nearby water bodies. Different land uses contribute different nutrient loading amounts and runoff rates, and these factors can affect the water quality. Some land uses, such as different types of vegetation, are considered beneficial for water quality because they contribute fewer chemicals or pesticides than developed land, and they act as a filter for runoff by collecting pollutants that might otherwise have ended up in the water body. Other land uses, such as different types of developed land, may have a greater impact on water quality because they tend to contribute nutrients, facilitate erosion and generally do not absorb water or runoff as readily as other land use types such as vegetated land. To determine the land use patterns of the Salmon/McGrath watershed, aerial photographs from 1965/66 and 2007 were cross-referenced with other sources and digitized using a Geographic Information System (ArcGIS®). Digitized maps were used to create visual interpretations of the data. From these maps the area of each land use type could be determined, and historic and current uses of the watershed could be compared. Maps of watershed characteristics were also created to determine some of the factors that contribute to water quality.

Water Quality Assessment

In order to determine the impact of different land use types on lake health and assess the overall quality of Salmon Lake and McGrath Pond, CEAT conducted water quality tests on water samples taken from Salmon Lake and McGrath Pond throughout the summer and fall of 2009. These samples were analyzed for a variety of chemical, physical, and biological characteristics. Additionally, depth measurements were taken to create a bathymetry map. These measurements provide information on the health of the water body.

Predictions and Recommendations

This study provides information on the current condition of Salmon Lake and McGrath Pond based on land use and water quality assessments. The impacts of different land use types on water quality are examined and models of the future can be made to determine the necessary plan to preserve the condition of the water body.

ANALYTICAL PROCEDURES AND RESULTS

INTRODUCTION TO GIS

A GIS is a Geographic Information System that combines hardware, software and data to allow the user to store, analyze and present these data. Its main functions are to store data referenced to a specific geographic location and to allow the user to create maps that analyze and present these data. The Colby Environmental Assessment Team (CEAT) used ArcGIS® version 9.3.1, produced by Environmental Systems Research Institute (ESRI) to create the maps of the Salmon/McGrath watershed (ESRI 2009). Using GIS allows data to be presented visually, displaying patterns that may not be as visible through charts or graphs. Aside from mapping, GIS can also combine numerous layers of data to create a model. Modeling is especially helpful when trying to understand complex relationships and answer questions that relate to multiple geospatial factors.

Within GIS, there are two types of datasets: raster and vector. Vector data are generally displayed as points, lines or polygons for discrete datasets such as locations of specific geographic features, including sampling site locations, roads or land use types. The sample site, the road quality rating and land use maps were made with vector datasets (see Water Quality Assessment: Water Quality Study Sites, Watershed Development Patterns: Roads and Land Use Analysis). Each vector layer in GIS has an attached attribute table, which contains the data that constitute each layer stored in chart format. Common data types found in the attribute table include Global Positioning System (GPS) coordinates, soil types, road quality ratings and land use types. Much of the data used to generate the maps in this study were downloaded from several online sources, including the Maine Office of GIS and the Natural Resources Conservation Service. Aerial photos were also analyzed using GIS to determine land use trends in the watershed over time. To be suitable for use in GIS, photos were digitized, or classified into polygons corresponding to different land use types within the watershed (see Land Use Analysis: Methods). Geographical coordinates were collected using handheld GPS devices and were recorded in the Universal Transverse Mercator (UTM) coordinate system. The UTM system divides the earth into 60 different zones, which are numbered east to west and lettered north to south (USGS 2001). Distances from the equator and the central meridian of the zone are used to specify locations. In comparison to the latitude-longitude system, UTM causes less distortion of the earth as it is translated from a sphere to a two-dimensional representation because zones are very narrowly divided (USGS 2001).

Unlike vector data, raster data are used for continuous datasets, such as elevation or depth that are constantly changing (ESRI 2009). Raster data are represented in grids, with options to set cell size so that each cell is a single pixel. Data for raster images are stored in matrix form and each cell corresponds to a specific location in space and is given a numeric value. This numeric value is related to a certain condition, so all areas that meet that specific requirement would be the same color. For instance, a condition could be elevation of 20 ft, so all locations with an elevation of 20 ft would have corresponding raster pixels that are the same color.

Raster and vector datasets are map layers, which act like overlays and can be added to a map to show relationships between different features in a specific area. A map layer contains data that pertain to the same subject and consists of the same data type, such as streams and tributaries layer or an elevation layer. Oftentimes, many different layers are placed on top of one another to make certain relationships visible. For example, the road layer for the watershed could be placed on top of the streams and tributaries layer to reveal which roads cross which tributaries and may cause increased phosphorus loading into the water body. Models are created by combining multiple layers of data and determining the relative weight of each dataset based on the relative significance of that data to the process being investigated. In this study, septic suitability, development impact, erosion potential and erosion impact models were made, each to answer questions regarding how different geospatial factors work together to create certain trends in the Salmon/McGrath watershed. For example, the Erosion Potential Model (see Watershed Development Patterns: Erosion Potential Model) contained slope data, land use data and soil type data. Each factor was weighted according to the relative amount it contributes to the susceptibility to erosion of a location. The model combined all three of these factors to show overall erosion potential.

GIS is a powerful tool that was used to create a variety of maps and models in this study. GIS was used because all the data collected for the Salmon/McGrath watershed are linked to a specific location in the watershed or water body. The maps and models created as a part of this study are designed to show present trends in the lake and the watershed. They allow one to visualize where improvements could be made to reduce damage to the water quality of the lake.

LAND USE ANALYSIS

Introduction

Land use patterns are one of the primary predictors of phosphorus concentrations in a water body (Robertson 1996). Different land uses types can expose or protect soils from erosion (see Background: Watershed Land Use). Determining, mapping and studying these land use types can enable projections of amounts of sediment and nutrient loading. High erosion rates increase the amount of nutrient-carrying sediments that enter the water body (Drewry, Newham et al. 2008, Hejduk 2008). Increases in land use types that have high phosphorus loading potentials such as agriculture, residential and other developed areas and roads are strongly correlated with increased nutrient loading in a watershed (Boggess, Donner et al. 1995, Robertson 1996, Robertson, Graczyk et al. 2006). Land use types that prevent erosion tend to be rich in vegetation (e.g., coniferous, deciduous and mixed forest) and can be used as buffer strips between the water body and land areas with higher rates of erosion.

The development in the Salmon/McGrath watershed is similar to the development of many small towns in Maine. Belgrade and Oakland, Maine, the two towns within the watershed, grew from hunting grounds to small towns by the end of the eighteenth century (Town of Belgrade 2009, Town of Oakland 2009). Crops, such as wheat, corn and string beans, became prevalent in the area. Industries, including the manufacturing of axes and scythes, logging, tanneries and textiles, were once present in Belgrade and Oakland. Over time, industry and agriculture waned in the area and were replaced by full-time and part-time residential areas (Town of Belgrade 2009, Town of Oakland 2009). This transformation from industry and agriculture to residential development had the potential to alter the overall water quality of Salmon Lake and McGrath Pond.

Choices involving which types of vegetation to plant and the size of the vegetated area are two of a limited number of ways in which residents can directly affect water quality. Soil type, annual precipitation, topography and the dimensions of a water basin are all factors that influence how a lake ages, but how residents work with these fixed parameters determines how rapidly the process of eutrophication progresses. Land use management decisions at the state and local levels lead to zoning laws that frame the overall management plans for the water quality in lakes such as Salmon Lake and McGrath Pond. Within the framework of the regulations, individual landowners decide how to use the natural resources on their lot. These decisions will influence lake water quality. The purpose of this section is to provide individuals, commercial owners and town officials with information regarding the potential impacts of different land use types on the water quality of Salmon Lake and McGrath Pond. By providing information on historical and current land uses, a better understanding of land use patterns and their effects are understood. This provides accurate information to alter behavior to the best practices to mitigate negative effects of land use type in the Salmon/McGrath watershed.

Methods

To gain a comprehensive understanding of the potential trends and effects of the land use changes in the Salmon/McGrath watershed, the Colby Environmental Assessment Team (CEAT) collected both historical (1965-66) and recent (2003-07) aerial photography of the watershed. CEAT scanned historical aerial photographs from the Colby College Biology Department Archives (Colby College 1965, Colby College 1966). The combination of the two historical years was a product of neither year covering the entire watershed. These photographs were georeferenced using ArcGIS® and mosaiced together using ERDAS IMAGINE creating a seamless historical aerial view of the watershed. However, historical photographs were unavailable for some areas within the watershed. As a result, there were areas not analyzed in the southern and northern points on the historical land use map. The historical photos were used to create a historical land use data layer for ArcGIS® analysis.

An updated National Agriculture Imagery Program (NAIP) file from 2003 and a Digital Orthophoto Quadrangle (DOQ) file from 2007 of the watershed were downloaded from the Maine Office of GIS. These files were used to determine the current land use trends in the watershed so they could be compared with the historical land use trends. The DOQ was used as the predominant map throughout the identifying process due to its higher resolution. The map was also produced in 2007, which is four years later than the NAIP in 2003, providing more recent data. The NAIP and DOQ images were taken in different seasons, spring and summer respectfully, allowing the pictures to be cross-referenced for higher accuracy. The main advantage of having photographs from two seasons was that the DOQ photographs were taken in the spring before the trees had leaves. This timing allowed for deciduous forest to be easily distinguished from coniferous forest as well as mixed forest. However, deciduous forests were difficult to distinguish from successional land in the DOQ image because both had sparse-looking vegetation during the spring. Using the NAIP image allowed CEAT to accurately characterize each area. The current images were also used as a cross-reference with the historical. Because of low-resolution quality in the historical photographs, differentiating forest types was impossible in some instances. Approximately forty years transpired between the historical and current images, but this was deemed too small of a time period for forest types to change from a deciduous to a coniferous forest. However, there is the possibility that successional land changed into a mature forest, so these areas were scrutinized closely for change. By integrating various components of each image, greater accuracy was obtained in areas that were not easily distinguishable.

Bing (2005) and Google maps (2005), both search engine websites, were utilized for their high-resolution aerial photographs to cross-reference the NAIP and DOQ images. The Bing photographs were angled, a feature not present in NAIP or DOQ images, which allowed CEAT to increase their accuracy for analyzing questionable land use types, such as residential and commercial. The aerial photograph presents a layout of the property and the structural properties of the buildings. However, large residential and small commercial structures have similar signatures. An angle allows garages to be visible, which is an indication of a residence rather than a business. A United States Geological Survey (USGS) topographical map from 1955 designating residence locations in the Salmon/McGrath watershed was also utilized to cross-reference data (USGS 1956). In the historical aerial photographs, the low-resolution caused problems distinguishing houses from surrounding open land. Using the geological database map, houses could be identified and inferred. A ten-year period was deemed too small for many existing houses to be destroyed.

ArcGIS 9.3® software was used for the majority of the data analysis and map creation. Microsoft Excel® was used as support for calculating percentages of land use types, and Delta Graph® was used to create tables and figures. The aerial photographs were used as a background reference to improve accuracy of polygon digitizing. CEAT members identified visual parameters for each land use type and used these parameters to characterize each land use type (see Appendix B). Each definition was refined several times to reflect changes between the historical and current map. This increased accuracy in identifying land and increased consistence between team members. Because of the difference between high and low-resolution aerial photography, definitions were broadened for the historical map. Specific definitions could be distinguished for the current map when they were unable to be accurately defined in the historical map. To decrease discrepancies between the two maps, similar land use types from the current map were combined for the historical map.

Using ArcGIS®, each polygon boundary was created as an overlay to its location on the aerial photographs. Both the historical and current maps were divided into four quadrants so each analyst could work individually. The characterization of each zone was reviewed to assure consistency. Each polygon created was assigned a land use type for analysis. Data collected included area covered, percent change and change between time periods. Final maps show land use patterns for the watershed in 1965/66 and 2007 (Figures 7 and 8**)**. Along with the historical and current maps, a land use change map was also created to illustrate the positive and negative changes in the land use patterns between the two time periods (see Land Use Types: Trends and Changes in Land Use Types from 1955-66/2007).

Land Use Definitions

Recreational

Youth Camp – Seasonally functioning camp with many different facilities connected by a network of roads. Recreational fields are prevalent as well as cottage clusters. Does not include large sections or forests that are on camp property.

Golf Course – A large landscaped area with manicured lawns. There is a small cluster of trees and other obstacles, such as sand traps.

Park – Looks similar to lawns but has a recreational function. Can have some human-made structures present and may include some impervious surfaces such as parking lots.

Developed

Commercial – Land associated with high levels of impervious surfaces (e.g., parking lots, access roads, buildings) and used for economic purposes.

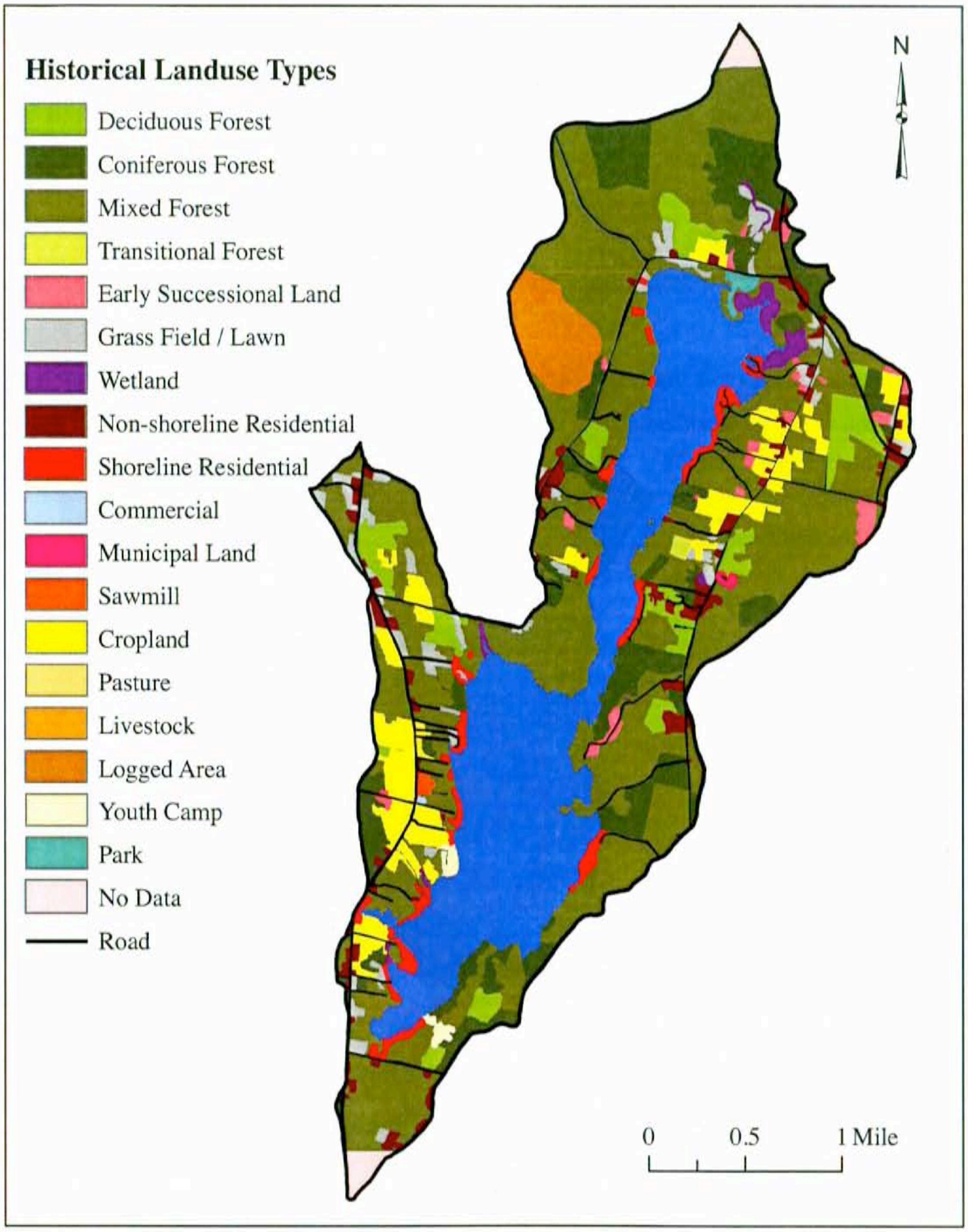

Figure 7. Historical land use types for the Salmon/McGrath watershed area in 1965/1966. Land use polygons were determined and digitized using historical aerial photographs taken in May 1965/1966.

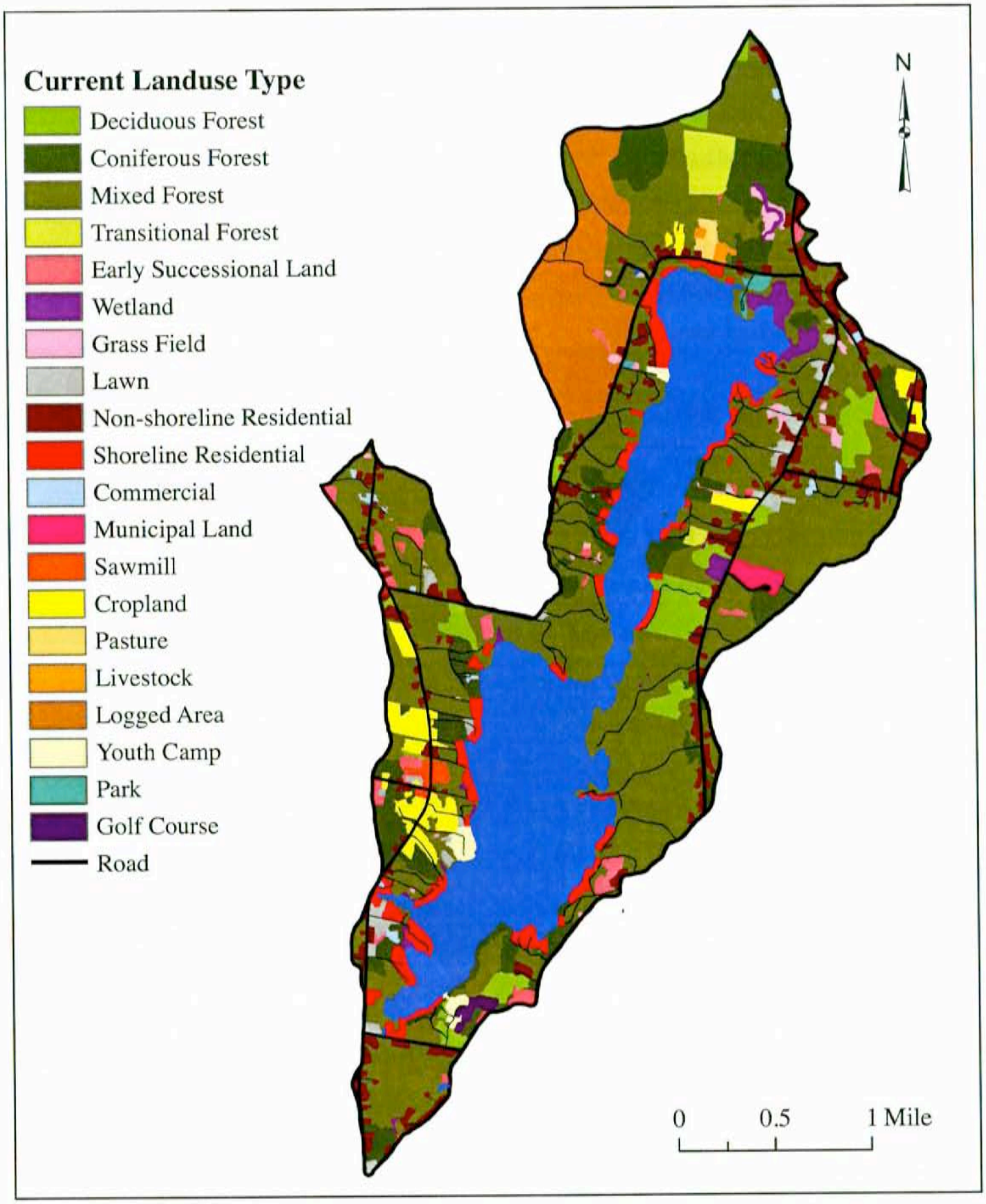

Figure 8. Land use types for the Salmon/McGrath watershed. Aerial photographs from the Digital Orthophoto Quadrangles (DOQ) and the National Agriculture Imagery Program (NAIP) were used to determine landuse types. A layer was digitized using the photographs and colors were chosen to represent distinct land use types.

Municipal Land – Many impervious surfaces and used for town functions.

Sawmill – A place where raw lumber is milled into boards and useable wood. Large structures and equipment visible.

Agricultural

Cropland – Grass fields with visible rectangular patches of crops or visible crop rows. This does not include agricultural buildings such as barns and silos.

Pasture – Land covered by grass with the purpose of creating pasture. Defined by visible fence lines, but does not include livestock and buildings pertaining to livestock.

Livestock – A place where larger animals (cattle, horses, etc.) are kept for human use. Animal pens and buildings visible in common area.

Vegetation Types

Deciduous Forest – Canopy cover is greater than 75%. Distinguished by absence of leaves in autumn, winter and beginning of spring.

Coniferous Forest – Canopy cover is greater than 75%. Most trees are coniferous. Trees have darker color and the forest is generally denser than deciduous forest.

Mixed Forest – Canopy cover is greater than 75%. Forest comprised of both deciduous and coniferous trees. Forest can have small patches of coniferous and deciduous trees.

Transitional Forest – Forest range from 50-75% canopy cover. Canopy and vegetation are of varying heights and species.

Successional Land – Forest with less than 50% coverage but is in the process of transitioning into a mature forest.

Wetland – Transitional zones between land and water bodies. Identified by distinct low growth vegetation and darkened saturated soil.

Open Land

Grass Fields – Little or no vegetation other than short grass. Refuse in the form of gravel can be present.

Logged Area – Area of thinned forest, with irregular dirt roads that weave through a forest framework.

Lawn – Little vegetation, usually an area with grass and a few areas of larger vegetation (trees/bushes). Area is not regenerating and could be manicured. Often found near developed land, especially near residential areas.

Residential

Non-Shoreline Residential – Developed land farther than 250 feet from the shoreline. Housing usually has driveways and surrounding lawn. Does not include forest or open lawn that might be part of the property but is not adjacent to the house.

Shoreline Residential – Developed land within 250 feet from the shoreline. Housing usually has driveways and surrounding lawn. Does not include forest or open land that might be part of the property but is not adjacent to the house.

Roads

Paved Roads – Can be state or municipal roads. They have a higher regular use and are often wider than camp roads. This type of road includes highways and these roads go longer distances to connect developed areas.

Camp/Dirt Road – Usually are side roads off paved roads leading to residential or less developed areas. This includes camp roads. Roads are not as straight or as wide as paved roads and are often composed of dirt or loose gravel. Many camp roads often lead to the lakeshore.

LAND USE TYPES

Visual examples of different land use types can be found in aerial photographs in Appendix B.

Vegetation Types

Mature forest

Mature forests have at least 75% canopy cover. They have a high density of trees and high levels of stratification. Several types of mature forests exist in the watershed. These include deciduous, mixed and coniferous forests.

Current and Historical Definitions and Identifying Characteristics

Deciduous Forests have the majority of the canopy comprised of deciduous trees. Indicator species in central Maine include Maple, Ash, Beech, Oak, Birch and Aspen. Deciduous trees lose their leaves in autumn. They are differentiated from coniferous forests by looking at

Digital Orthophoto Quadrangle (DOQ) aerial photos. The DOQ photos were taken in early spring, before deciduous trees had any leaves. Conifers retain their needles year round.

<u>Coniferous Forests</u> have the majority of canopy vegetation comprised of coniferous trees. Coniferous trees retain leaves all year round. Indicator species in central Maine include Pine, Hemlock, Cedar and Spruces. They are distinguished from deciduous trees by their denser canopy cover and darker foliage in the summer and green leaf presence during the other seasons.

<u>Mixed Forests</u> consist of a combination of coniferous and deciduous trees. Neither type accounts for more than 75% of total canopy tree cover. Structurally, a mixed forest consists of either small patchy clusters of deciduous trees and coniferous trees, and/or a more constant heterogeneous mix where coniferous and deciduous trees are interspersed.

Impact

Forests covered most of Maine and the Salmon/McGrath watershed before human settlement. As the predominant natural habitat, forests play an integral role in the health of the watershed. It is estimated that forests covered 92% of Maine in 1600 (Irland 1988). Due to human development this number decreased to approximately 40% in 1880, yet by 1995 forested land had increased to 74%. This increase resulted from a loss of agricultural land and more preservation and conservation efforts in Maine (Irland 1988). Forests have many positive ecological effects in a watershed, which include stabilizing soils, regulating water flow runoff, reducing nutrient loading and sequestering carbon. Additionally, forests provide essential habitats for many different species (see Background: Forestry).

Forested areas act as efficient buffers around the water body due to their high structural complexity and biomass. Root systems, especially shallow roots, act as drag to runoff by slowing it down and by facilitating absorption (Whisenant 2005, Reubens, Poesen et al. 2007). Deep roots stabilize slopes and can absorb water deeper into the ground. Duff, the layer of accumulated plant matter on the forest floor, can act as a sponge by absorbing and slowing the flow of water. Duff and root systems hold particles in place and provide a protective barrier against runoff. Canopy layers catch precipitation and slow its speed to reduce erosion capability (Levia and Frost 2006). Forested areas have much lower levels of storm water runoff and five to ten times lower phosphorus levels than that of developed land (Dennis 1983).

Different forest types have different effects and buffering capabilities on the watershed. Coniferous forests retain their canopy layer throughout the winter and have a denser canopy layer than deciduous trees. Deciduous trees have a denser sub-canopy, which can be especially beneficial during heavy rainfall. However, leaf litter from deciduous trees contributes to more phosphorus loading into the lake. In general, the best type of mature forest for a specific area is the type that is found there naturally (see Background: Forestry).

Results

The majority of land cover in both the Salmon Lake watershed and McGrath Pond watershed in 1965/66 and 2007 was comprised of mature forests (Figures 7 and 8**)**. Mature forests accounted for 72% of the Salmon/McGrath watershed in 1965/66 and 65% in 2007 (Figure 9). For a comparison, the mean area of forested land in previous CEAT (Colby Environmental Assessment Team) studies on the Belgrade lakes was 74%. These previous studies include Messalonskee Lake (1998), Great Pond (1999), East Pond (2000), and Long Pond (2006/7). Mixed forests comprised 75% of the total forested land in 1965/66 (855 ha) and 2007 (780 ha). Coniferous forests and deciduous forests comprised 8.8% and 3.4% respectively in 1965/66, and in 2007 they accounted for 7.0% and 5.6% of the total watershed. In the current land use map, deciduous forests and coniferous forests are found in small isolated sections within the mixed forests (Figures 7 and 8). Most of the coniferous forest habitat is located the northern portion of the McGrath Pond watershed. During both time periods, these forested areas were evenly dispersed throughout the watershed. There was at least a net loss of 74 hectares between 1965/66 and 2007 (Table 4; Figure 10). Due to a lack of data in the historical map, we were not able to determine the land-use types in 16.2 hectares of the northern and southern tips of the watershed. By cross-referencing the current and historical photographs, we inferred that there was probably mature forest present in these parts of the watershed in 1965/66. The total forested area in 1965/66 was probably closer to 1187 hectares, and the mature forest loss between 1965/66 was probably closer to 90 hectares. Most of the forest lost in the watershed was converted into logged land and developed land (Table 5).

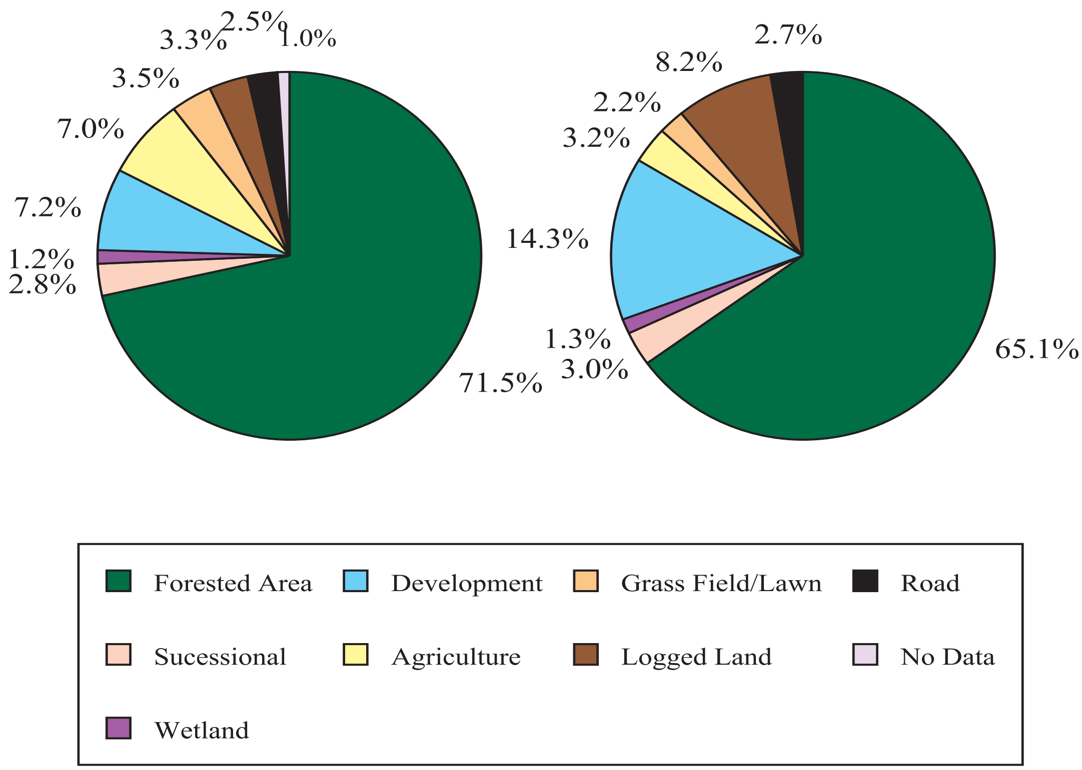

Figure 9. Percent land cover of Salmon/McGrath watershed for 1965/66 and 2007 as determined using aerial photographs obtained from the Colby Environmental Assessment Team and the United States Department of Agriculture and Digital Orthophoto-Quadrangles obtained from the Maine Office of Geographic Information Systems, respectively.

The shoreline data indicated that mature forests were not as common along the shore as they were throughout the entire watershed. In total, mature forest only accounted for 58% (8.3 miles) of the total shoreline in 1965/66 and 47% of the total shoreline (6.7 miles) in 2007 (Table 6). Mixed forest again accounted for the majority of mature forest along the shoreline, totaling 63% and 80% respectively during these years.

Successional

Current and Historical Definitions and Identifying Characteristics

<u>Early Successional Land</u> is comprised of reverting and regenerating land. Reverting land is at the beginning stages of forest succession. The vegetation is sparse and very low. It can resemble open lands, except it has more vegetation than reverting land. Regenerating land

Table 4. Comparison of area (ha) of historical land use in 1965/66 to current land use in 2007 within Salmon/McGrath watershed and the percentage change between them.

Land use Type	Historical (ha)	Current (ha)	Percent Change
Forested Area	1171.1	1096.5	-6.4
Successional	47.9	44.2	-7.7
Wetland	18.9	20.8	10.1
Non-shoreline Residential	55.6	135.0	142.9
Shoreline Residential	42.4	54.9	29.5
Commercial/Municipal	2.2	14.0	529.2
Sawmill	2.6	5.7	118.8
Cropland/Agriculture	110.6	44.2	-60.1
Grass Field/Lawn	54.6	42.2	-22.7
Logged Land	51.4	129.1	151.3
Camp	6.8	8.5	26.0
Golf Course	n/a	4.8	n/a
Park	4.2	3.8	-10.7
Road	39.3	43.3	10.3
No Data	16.2	n/a	n/a

has higher and denser vegetation, but has less than 50% canopy cover. In many cases, successional land can be in a rectangular shape due to development or logging that took place on the land prior to the beginning of successional growth.

Transitional Forests are at the final stages of forest succession. Transitional forests have between 50-75% canopy cover. The canopy and vegetation are of varying heights and species. They are usually located within an area of mature forest or adjacent to developing land. Transitional forests are usually comprised of coniferous and deciduous trees.

Impact

Successional land provides many of the same positive buffering effects on a watershed as mature forests, but to a lesser degree. Transitional forests have better buffering capabilities than earlier successional land because they have more stratification and biomass. Successional areas indicate the conversion of human altered land back to the natural habitat and provide an example of land cover improvement within a watershed.

Forested Land

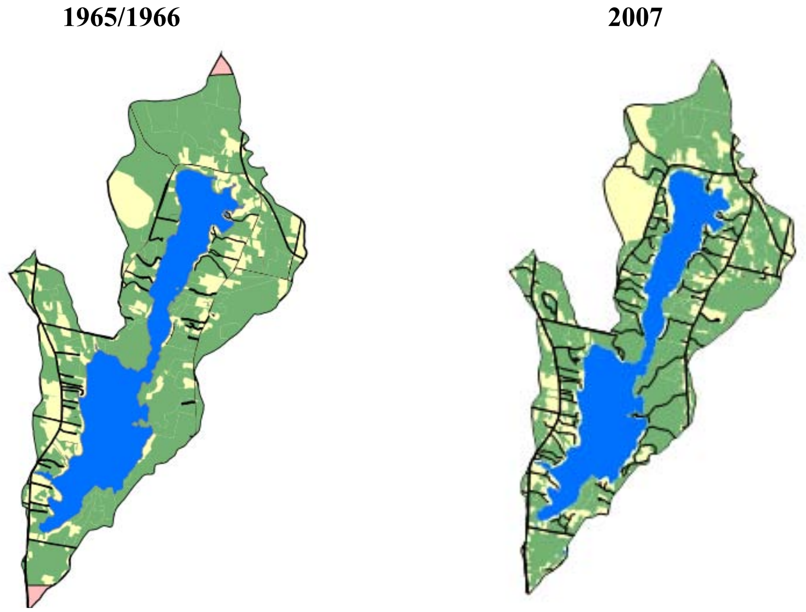

Figure 10. Comparison of forested areas in the Salmon/McGrath watershed. Forested area refers to all mature and transitional forests and decreased 80 ha, assumes that the area represented by the no data sections in the historical map were forested.

Table 5. Land use types that changed the most drastically from 1965/66 to 2007 in the Salmon/McGrath watershed. Each land use type is broken down into number of hectares (ha) of the 1965/66 area that was converted to particular land types in 2007.

1965/66 Land Use	Land Use Converted in 2007 (ha)							
	Recreational	Cleared	Developed	Forest	Logged	Grass Fields/ Lawns	Road	Agriculture
Recreational	n/a	0.0	0.3	1.1	0.0	0.0	0.2	0.0
Cleared	0.1	n/a	8.1	12.9	0.0	4.8	0.4	2.7
Developed	0.4	0.0	n/a	35.0	0.0	1.0	2.9	0.7
Forest	6.9	2.5	72.5	n/a	76.7	0.8	15.0	1.0
Logged	0.0	0.0	0.0	0.0	n/a	0.0	0.0	0.0
Grass Fields/Lawns	0.1	0.4	4.7	11.6	0.0	n/a	0.4	0.0
Road	0.1	0.0	4.0	12.1	0.0	0.4	n/a	0.7
Agriculture	0.2	4.6	14.7	28.1	0.0	14.2	2.9	n/a

Table 6. Comparison of historical land use in 1965/66 to current land use in 2007 along the shoreline (mi) of Salmon Lake and McGrath Pond and the percentage change in the present land use types.

	Residential	Youth Camp	Forest	Wetland	Grass Fields/ Lawns	Cropland
Historical (mi)	4.6	0.3	8.3	1.1	0.1	0.2
Current (mi)	6.1	0.4	6.9	0.7	0.0	0.0
Percent difference	11.7	1.0	-8.2	-2.5	-0.4	-1.5

Results

Successional land occupied roughly 3% of the watershed in both 1965/66 and 2007 (Figure 9). Transitional forests accounted for roughly half of the successional land in the Salmon/McGrath watershed, 23 ha and 21 ha respectively, in 1965/66 and 2007 (Table 4).

The two areas where transitional forests were found did not change from 1965/66 to 2007 (Figure 7, Figure 8). The largest single area of successional land was a transitional forest found in the northern part of the watershed. This land has signs of previous logging but resembles transitional land now. Early successional land accounted for just over 21 ha in 1965/66 and increased slightly to 27 ha in 2007 (Table 4). These small land areas indicate that the conversion of human-altered land back to forested land has not been prevalent in these 52 years. However, there was a change in the distribution on successional land in the watershed between 1965/66 and 2007 (Figures 7 and 8). In 1965/66, most of the successional land was found in the northeast portion of the watershed in Oakland, but by 2007 successional land had become more evenly distributed throughout the watershed. This change in successional land demonstrates the small yet ongoing conversion of developed land back into forests. In both time periods, CEAT found no successional land on the shoreline (Figures 7 and 8).

Wetlands

Current and Historical Definitions and Identifying Characteristics

CEAT defined wetlands as the transitional zones between land and water bodies. These areas are identified because their soils are saturated with water all year long. Wetlands can be forested or primarily consist of peat mosses, bushes, rushes and sedges.

Impact

Because peat moss and porous soils characterize wetlands, these habitats are able to retain a great deal of water. Wetlands function as a sink for nutrient runoff and other pollutants, which can positively affect the water quality of nearby ponds and lakes (MDEP 2009c). The numerous niches in wetlands support diverse wildlife, including rare and endangered species as well as keystone species, like the beaver that has the ability to shape and transform the wetlands (see Background: wetland).

Results

In 1965/66, wetlands accounted for 18 ha of the watershed, and in 2007 they accounted for 21 ha. Most of this growth in wetland area can be tied to the difference between historical and current photographs and the quality and visibility in each as opposed to an actual change in wetland distribution. Wetlands account for roughly 1% of the shoreline but probably play a disproportionate role in improving the water quality of the watershed. Forested wetlands exist in the watershed, and the total hectares of wetland as given by the Maine DEP are much larger than our value because the Maine DEP includes forested wetland areas in their calculation. However, CEAT made land type characterizations based on the effects that the specific land use type would have on the water body and felt that forested wetland should be characterized under forest and not wetlands. Figure 7 and Figure 8 show the land uses for the watershed area from 1965/66 and 2007, respectively. Wetlands are designated as purple polygons.

Recreational

Recreational land is defined by the presence of athletic fields and associated open land. The land can be used for commercial purposes such as youth camps or municipal purposes such as parks. Though the processes to alter these camps and parks are different due to their management practices, the impacts to the watershed are similar.

Camps

Current and Historical Definitions and Identifying Characteristics

Youth Camps are a seasonally functioning area with many different buildings and recreational uses. Youth camps typically have multiple buildings with different uses, such as housing and recreational fields. There is usually a network of roads connecting different cottage clusters, other impervious surfaces and recreational sites. The defined area does not include large sections of forests that may be on the camp property (see Appendix B).

Impact

Youth camps have the potential of introducing nutrients into the water body. This trait is due to their large area, close proximity to the water body and potential erosion as well as septic impacts by the number of campers and staff. With a large area of impervious surfaces, camps can produce significant runoff. This runoff in combination with the proximity of a camp to the water body can have significant impact on water quality. The increased septic usage can also add nutrients into the water body if not properly managed. Potential septic system impact is directly correlated with the number of users of the system. Large youth camp populations have the capacity to have considerable septic usage, so potential impact on the water body could be high. This peak activity occurs in summer months when algal productivity is highest (Wassink 1959). If not properly managed, youth camps can have significant negative impacts on a water body. However, steps can be made to mitigate these impacts, such as installing proper septic systems, creating extensive buffers, and decreasing the amount of impervious surfaces.

Results

Youth camps' web sites and personal communications were used to create a summary to accurately monitor changes in size and land use practices of youth camps.

The Maine Golf and Tennis Academy (Camp Kennebec)

The Maine Golf and Tennis Academy is located on the southeastern tip of Salmon Lake. The youth camp is primarily a five-day overnight camp operating for three of the summer months. The total population of the camp can reach up to 250 campers and 75 staff (Lavenson, pers. comm.). There are 30-35 buildings on the premises. Historically the camp extracted water directly from the lake and treated it with chlorine. However, due to changes in the health and safety code, the camp switched to using well water. There are seven playing fields including one soccer field, two baseball fields, three clay tennis courts and a basketball court. These fields have a greater potential for runoff than natural forested land. Their nutrient loading potential is increased by the close proximity to the shoreline.

Camp Modin

Camp Modin is located in the middle of the western shore of Salmon Lake. The youth camp was converted into an overnight camp in the late nineties (Camp Modin 2009). The total population of the camp can reach up to375 people during the summer, not including staff. There are 160 staff employed by the camp, but not all staff members live on the premises. There are 26 buildings on the premises as well as five clay tennis courts, two soccer fields, three baseball fields, a volleyball court and a lacrosse field. The majority of courts and fields is located close to the shoreline and has the potential to add nutrients into the water body. Camp Modin also has a medium-sized beach on the shoreline.

Camp Tracy

Camp Tracy is located on the northwest shore of McGrath Pond. The Boys and Girls Club and the Y.M.C.A are overseers of the camp. The camp holds a day population of 100-115 campers as well as 20 counselors from late June to late August (Carter, pers. comm.). There is also an overnight population of 30 campers in a three-week cycle and 10 counselors on site throughout the summer. Though the camp owns 67 acres, only three acres are developed with buildings or fields (Camp Tracy 2009). An extensive trail system is located throughout the property including near the shoreline, which is properly buffered to reduce nutrient loading. Camp Tracy also has a moderately sized beach, which is connected to the greater camp by a large pathway.

All three youth camps located in the watershed predate 1965 (Figures 7 and 8). Through this long-standing relationship among the camps and the area, positive land use practices should be built upon. With all three youth camps located on the shoreline there is heavy recreational use. Through unmitigated land use practices over the course of time, negative impacts could alter the condition of the water quality. Poor water quality would lead to undesirable swimming conditions as well as undesirable views. These factors are unfavorable for both the youth camps and the residences in the watershed.

Since 1965, no camps have been added or removed from the watershed, so any changes in land area that occurred between 1965-2007 was the result of the three original camps expanding or shrinking. An additional land use type since 1965-66 is a golf course at the Maine Golf and Tennis Academy. A golf course is defined as a large landscaped area with manicured lawns and obstacles (see Land Use Analysis: Land Use Definitions). Routine maintenance is conducted on the golf course, but chemical use is unknown.

The total historical land use for youth camps was calculated at 6.8 ha, while the current land use was 8.5 ha (Table 6). This is an increase in area of 1.8 ha. However, this does not include the area of the golf course. With an area of 4.9 ha, the total area of land affected by camps is 6.5 ha greater than the historical area of land affected by camps. This is a 0.4% increase in space between 1965-66 and 2007 within the total area of the watershed. The loss of forested land was the main contributor to the increase in camps. Recreational land, youth camps and parks increased by 6.9 ha through the reclamation of forested area (Table 6). Other contributing areas, including agriculture and open land, totaled less than 0.8 ha. The implications of a larger area are higher use of septic systems, more impervious surfaces, and increased phosphorus loading from the golf course. This increase in area also affected the area bordering the shoreline. The original shoreline border was 0.3 miles, which increased to 0.4 miles (Table 6). This is an increase of 95% of youth camp area bordering the watershed. Increasing the buffer area along the shoreline boarder will help augment the effects of youth camps on the water quality.

Individually, each youth camp grew in the watershed. CEAT defined this growth by an increase in open land and not total property owned. It is unknown whether the total area of ownership did increase, but only areas altered from their original state would affect the watershed. Therefore the analysis only calculated a change in the area of the youth camp based upon manipulated land and not a change in ownership. The Maine Golf and Tennis Academy grew from 3.6 ha to 8.1 ha. This is predominately because of the construction of the golf course, which added an additional 4.8 ha. Camp Modin increased from 3.2 ha to 5.1

ha. Camp Tracy also increased from 0.4 ha to 1.5 ha. Increases in cleared land may have a negative impact on the water quality of the lake if not properly buffered.

Parks

Current and Historical Definitions and Identifying Characteristics

Parks are defined as land that looks similar to open land but has a recreational function. They may have man-made structures present and include some impervious surfaces such as parking lots (see Appendix B).

Impact and Results

The sole park in the Salmon/McGrath watershed is located on the northern shore of McGrath Pond (Figures 7 and 8). Historically, this park was privately owned and an access fee was charged to launch boats. However, the Town of Oakland purchased the land, converted it into a public space and removed the boat launch capability. Athletic fields and a large parking lot lead to a path that slopes towards the water body. Walking trails and an open field are located below the athletic fields on the way to the water body. The aerial photographs show little change in area over the approximately 40-year period. The original area of the park was 4.2 ha in 1965-66 and decreased to 3.8 ha in 2007 (Table 4). This is due to the addition of trees and the reduction of open land. The additional forested land is found on the inner ring of the lower field. This change will have a minimally positive impact on the water quality because the park is adjacent to the water body. An increase in the buffer quality would help reduce nutrient loading from the park into the water body.

Open Land

Current and Historical Definitions and Identifying Characteristics

Grass fields are comprised of grass. They are not regenerating because they are mowed throughout the year. They could have been cleared for agriculture or other purposes in the past and may be used for human development in the future. Grass fields show no signs of agricultural purposes from aerial photos, but that does not mean agricultural practices do not take place on this land. Hayfields are included in this land type. Grass fields are usually rectangular in form and located between residential property and forests.

Lawns have grass as the main vegetative cover, interspersed with bushes and trees. Lawns are landscaped and mowed, which means they are not regenerating. Frequently, they are found in or between residential properties and usually have no future development purposes.

Historical Definitions and Identifying Characteristics

Fields and lawns are classified as the combination of grass fields and lawns. Due to the poor image quality of the historical photos, CEAT could not distinguish between lawns and grass fields and felt it would be more accurate to use a broader definition. Appendix B shows that both types of open land appear bright white and are not distinguishable.

Impact

Open land, lacking vegetative complexity and biomass, does not provide nearly the same buffering or ecological qualities as a forest. Loss of root systems amplifies erosion and decreases groundwater absorption. Lack of duff and forest layering expose the soil to possible weathering, and this too increases erosion and runoff (see Background: Forestry). For the most part, lawns have been or will be utilized for agriculture or development. Grass fields can have various degrees of impact on the watershed depending on their size. Large scale clearing can make forest succession very difficult (Alegre 1986). It can also lead to fragmentation of neighboring lands and help facilitate the destruction of nearby forests. Prior use of the land can also be important in determining soil composition and soil structure. If the land was originally cleared for farming, it may have been tilled and all of the roots and rocks could have been removed. Also, chemicals and fertilizers used from farming can still be present in the soil, and this can increase erosion and nutrient loading from the open land (Alegre 1986).

Lawns have more buffering capabilities than grass fields because they have more vegetation. Most open land is located near houses and much of it is actually located on residential property, which means lawns have some of the same effects as residential land. Because both land use types can have highly negative impacts on the watershed, the location of these land use types is very influential. Steeper slopes have a naturally higher potential to erode, and these effects are exacerbated in cleared and open land. If these land use types are far away from the shoreline and not on sloped land, their effects can be minimal.

Results

CEAT found the net decrease of open land to be beneficial to the health of the watershed. Grass fields and lawns accounted for 3.5% of the watershed in 1965/66 but decreased to 2.2% in 2007 (Figure 9). The watershed lost 21 ha of open land between 1965 and 2007 in total. Most of this open land was converted into forests and most of the new open land came from agricultural areas (Table 5).

Overall the changes from open land area are positive. In 2007, lawns accounted for 1% (22 ha) of the watershed and grass fields accounted for 0.6% (13 ha). Most open land was located near the highly developed areas in Belgrade and Oakland. There was little to no open land on the shoreline and very little open land within 250 feet of the shoreline in 1965/66 and 2007 (Figures 7 and 8).

The Shoreland Zoning Ordinances of Belgrade and Oakland state that no harvesting may occur within 75 ft, horizontal distance, of the shoreline, except to remove safety hazards (Town of Belgrade 1991, Town of Oakland 1995). Within 100 ft of the shoreline, harvesting is only allowed if clear cutting is not performed. After 100 ft, clear cut harvesting is allowed, but clear areas cannot exceed 10,000 ft^2 and areas greater than 5,000 ft^2 must be separated by a 100 ft buffer.

Logged Land

Current and Historical Definitions and Identifying Characteristics

Logged Land is land that was recently or is currently being logged. The land usually has irregular dirt roads that weave through the forest framework. Logged land can vary depending on how extensive the logging practices were in the area. If the area is clear cut, it can structurally resemble agricultural land or grassland but is distinguishable by tree stumps that are visible on logged land. If these areas are very selectively cut, then logged land can resemble more of a thinned forest as it does in the Salmon/McGrath watershed.

Impact

The impact of logged land depends on what type of logging has taken place. Clear-cut logging can resemble cleared land, except that if stumps are not removed, some roots systems and vegetative cover will remain. Selective logging, where much of the forest is kept intact, can resemble a transitional forest. However, the negative effects of logged land can vary depending on the types of management practices that are conducted. Erosion impacts can be increased by use of heavy equipment, skidder trails, the removal of heavy trees and log yards (MDOC 2009). All these effects can be amplified when these practices take place near tributaries. At tributaries the possibility for erosion and direct nutrient loading is much greater. Additionally, nutrients such as phosphorus, nitrogen and carbon that had previously been incorporated as living tissues are now readily carried off when the forest is logged (Hazlett, Gordon et al. 2007). Under Best Management Practices (BMP), a standard for more environmentally conscious logging, harvesting equipment cannot use streams as travel routes, nor can any form of logging take place in the tributaries. However, in 2000, the Maine Department of Conservation reported that BMP were only practiced in 41% of logging operations in Maine (MDOC 2009). Similar to open and grass fields, the negative effects for the watershed associated with logging are exacerbated by steep inclines.

Results

Logged land in the Salmon/McGrath watershed increased 151% from 1965/66 to 2007. In 1965/66 it accounted for 3.3% (51 ha) of watershed, and in 2007 it accounted for 8.2% (129 ha) of watershed. In both 1965 and 2007, all of the logged land was found in the northwest portion of the McGrath Pond watershed (Figures 7 and 8). This land use comprised of one large area, which means it can have many negative impacts on the mature forest around the area. Although logging has increased dramatically in the past 52 years, this increase has taken place further from the water body, in areas of lower potential impact (Figures 7 and 8; see Watershed Development Patterns: Erosion Impact Model). As mentioned above, the effects of logging depends on the type of logging, the management practices and the abundance of nearby tributaries. All of the logged land in the Salmon/McGrath watershed was selectively cut. Although some of the forest structure is still intact, the extensive network of skidder trails has greatly thinned its original density (see Appendix B). The logged land is not adjacent to the water body, but there are numerous tributaries that run through the logged area straight into the water body (Figure 8), and these two factors create the potential for high levels of erosion and runoff.

The only other current logging operations reported in previous CEAT studies of the Belgrade Lakes Region were found in the Great Pond watershed and accounted for 1.9% of its watershed in 2000. Previous CEAT studies done on East Pond (2000), Long Pond (2006, 2007) and Messalonskee Lake (1998) did not report logging operations between 1965/66 and their publication years. North Pond (1997) showed signs of previous logging but no new logging developments had taken place as of 1997. The logged land in the Great Pond watershed is adjacent to the logged land in the Salmon/McGrath watershed, suggesting that virtually all of the logged land in the Belgrade Lakes Region is found in this area.

Agriculture

Cropland

Current and Historical Definitions and Identifying Characteristics

Cropland is land that is cleared for the purpose of planting and cultivating crops. It is distinguished by visible rectangular patches with crops or visible crop rows.

Impact

Cropland can contribute a variety of nutrients to the water body because of the many chemicals that may be applied to crops. Phosphorus and nitrogen, which are present in fertilizers, and other chemicals from pesticides are easily washed into rivers and lakes and can lead to algal blooms, eutrophication, decreased dissolved oxygen, fish kills and loss of biodiversity (USGS 2009b). Phosphorus clings to soil particles and is washed with soil particles into water sources. Nitrogen becomes nitrate when dissolved in water. Additionally, cleared, drained and tilled land is susceptible to excessive erosion. Crops are not as dense as other types of groundcover and are less adept at keeping soil and nutrients from running off than other types of vegetation, like forest.

Results

Cropland comprised of 110.6 ha in 1965, which is 5.4% of total watershed area. It comprised of 44.2 ha in 2007, which is 2.2% of the total watershed area. This represents a 60.1% decrease in cropland area between these years. Figures 7 and 8 show the land uses for the watershed area from 1965/66 and 2007, respectively. Cropland is designated by yellow polygons.

Pasture

Current and Historical Definitions and Identifying Characteristics

Pasture is defined as land that is open with the purpose of pasturing livestock. Some distinctive features include visible fence lines, livestock and buildings pertaining to livestock and hay fields. In the Salmon/McGrath watershed, the horse boarding facility on the north end of McGrath Pond is adjacent to a pasture.

Impact

Similar to cropland, pasture is susceptible to erosion and runoff because it lacks natural, thick vegetation that acts as a buffer. Similarly, it is often treated with fertilizers and pesticides. Livestock tramp down the soil, lowering the chance of water being absorbed, inhibiting the growth of new plants, and causing erosion, which potentially allows sediments to enter the water body. Additionally, since pasture is generally used for livestock, the effects of livestock activities are also apparent in pasture, which is discussed below.

Results

The amount of land used for pasture in 1965/66 is unknown. The quality of historical photographs made it difficult to distinguish from other types of field and open land. Pasture was incorporated into the definition of open field (see Open Field) for the historical land use. This land use type accounted for 4.4 ha in 2007, which is 0.22% of the total watershed area. Figures 7 and 8 show the land uses for the watershed area from 1965/66 and 2007, respectively. Pasture is designated by peach polygons.

Livestock

Current and Historical Definitions and Identifying Characteristics

Livestock areas are defined as places where large domestic animals, such as cattle, horses or pigs, are kept for human use. This land is usually adjacent to pasture and has some similar characteristics, such as visible fence lines and the presence of animals and barns. In the Salmon/McGrath watershed, an example of livestock is the horse boarding facility in the northern part of McGrath Pond.

Impact

Livestock can contribute phosphorus and nitrogen from their manure to the water body through runoff. Additionally, bacteria such as *E. coli* can contaminate the water and sicken animals and people. Also, residual pharmaceuticals fed to animals to increase growth and health leach out of the manure and can be washed into the water body. Livestock also contribute to erosion by eating vegetation that would otherwise hold soil in place, trampling vegetation and making the land more susceptible to wind and water erosion because of the lack of vegetation and reduced absorption.

Results

In 1965/66, the amount of land in the watershed devoted to livestock is unknown since it could not be determined from aerial photographs. Livestock areas accounted for 2.8 ha in 2007, which is 0.14% of the total watershed area. Figure 8 shows the land uses for the watershed area in 2007. Livestock is designated by dark orange polygons.

Residential

Residential areas can have significant impacts on the quality of a water body for a variety of reasons. Problems with erosion arise from disrupting and reforming the landscape. The topography of the watershed is affected when land is leveled and cleared for the purpose of building each residence. Additionally, once land is cleared, sediment can accumulate in water bodies through erosion due to lack of sufficient buffer between it and the water body (USGS 2008). This sedimentation causes turbidity and can clog drains and channels. Runoff from lawn and garden fertilizers, household chemicals and oil are picked up by water traveling downhill and accumulate in the lake, which negatively impacts the water quality (Michigan State University Extension 2008). In addition, water heats up as it runs over impervious surfaces or pavement and can cause thermal shock to aquatic life when it reaches the water. Lastly, salt and sand are used in winter to keep roads safe for driving, but the salt can wash into the lake and be detrimental to the health of the water body; the sand may increase sedimentation (Michigan State University Extension 2008).

Shoreline

Current and Historical Definitions and Identifying Characteristics

The Maine DEP defines shoreline residential land as land with a residence within 250 ft of the shoreline, and CEAT used the same definition. The developed area associated with a shoreline residence is estimated at 0.5 acres. This land use type includes the residence, driveways and surrounding lawn. The calculated area does not include forest or field that might be part of the property but is not adjacent to the house.

Results

This land use accounted for 42.4 ha and 2.1% of the total watershed area in 1965/66 and 54.9 ha and 2.7% of the total watershed area in 2007. This represents a 29.5% increase in area of this land use. Figures 7 and 8 show the land uses for the watershed area from 1965/66 and 2007, respectively. Shoreline residences are designated by bright red polygons.

Non-Shoreline

Current and Historical Definitions and Identifying Characteristics

The Maine DEP defines non-shoreline residential land as land with a residence farther than 250 ft from the shoreline, and CEAT used the same definition. The estimated developed area of a non-shoreline residence is 1 acre per house. This land use type is usually associated with driveways, houses and surrounding lawns. The area calculated does not include forest or field that might be part of the property but is not adjacent to the house.

Results

This land use type accounted for 55.6 ha in 1965/66, which was 2.7% of the total watershed area and 135 ha in 2007, which was 6.6% of the total watershed area. This represents a 142.9% change in area. Figures 7 and 8 show the land uses for the watershed area from 1965/66 and 2007, respectively. Non-shoreline residences are designated by dark red polygons.

Developed

Developed land includes areas used for commercial, municipal and residential purposes. In general, developed land is dominated by human-made structures, roads, parking areas, landscaped areas or other characteristics that indicate a significant human impact. There are a variety of nutrient loading opportunities associated with developed land, including the presence of household, industrial and landscaping chemicals, which often contribute to the nutrient load of nearby water bodies. Additionally, the high levels of impervious surfaces contribute to increased erosion and runoff. The change in area from 1965/66 to 2007 of developed land including commercial, municipal, and residential land is represented in Figure 11.

Commercial

Current and Historical Definitions and Identifying Characteristics

CEAT defined commercial land as land associated with high levels of impervious surfaces, such as parking lots, access roads and buildings with commercial operations. Commercial areas potentially contribute a variety of pollutants to the water body. For example, an auto shop may contribute engine oil, gasoline or paint that is picked up in runoff and carried into the water body. Also, the high level of impervious surfaces prevents water from being absorbed into the ground and allows it to accelerate as it flows towards the water body, causing erosion and carrying nutrients.

Results

Some examples of commercial land found in the Salmon/McGrath watershed include a rest stop, an auto body shop, a commercial horse barn and a sawmill. Commercial land accounted for 0.6 ha and 0.03% of the watershed area in 1965/66and 6.2 ha and 0.30% of the watershed area in 2007, which is a significant increase in the area of commercial land. Figures 7 and 8 show the land uses for the watershed area from 1965/66 and 2007, respectively. Commercial is designated by light blue polygons.

Sawmill

Current and Historical Definitions and Identifying Characteristics

One example of commercial land use in the Salmon/McGrath watershed is the sawmill. The sawmill is an industrial site where raw lumber is milled into boards and processed wood for building materials. This land use type is identified by the presence of trucks, wood, sawdust and log piles. The site also has various small buildings for storage and visible lumber processing equipment.

Impact

Sawmills have the potential for negative impacts on a watershed in addition to the impacts of other types of commercial and municipal land. These impacts can be minimized with proper procedures and care. Sawmills produce a lot of waste, including sawdust, scrap wood, worn-out plant equipment as well as oil and various chemicals used for processing wood. These forms of waste, especially sawdust, can be saturated with chemicals, and in some cases the chemical levels in the sawdust residue can be higher than that of municipal waste. If these residues are not stored or managed correctly, they can become part of runoff during rainstorms and contaminate the nearby habitats and the water body (DELM 1995, MOE Ontario 2008).

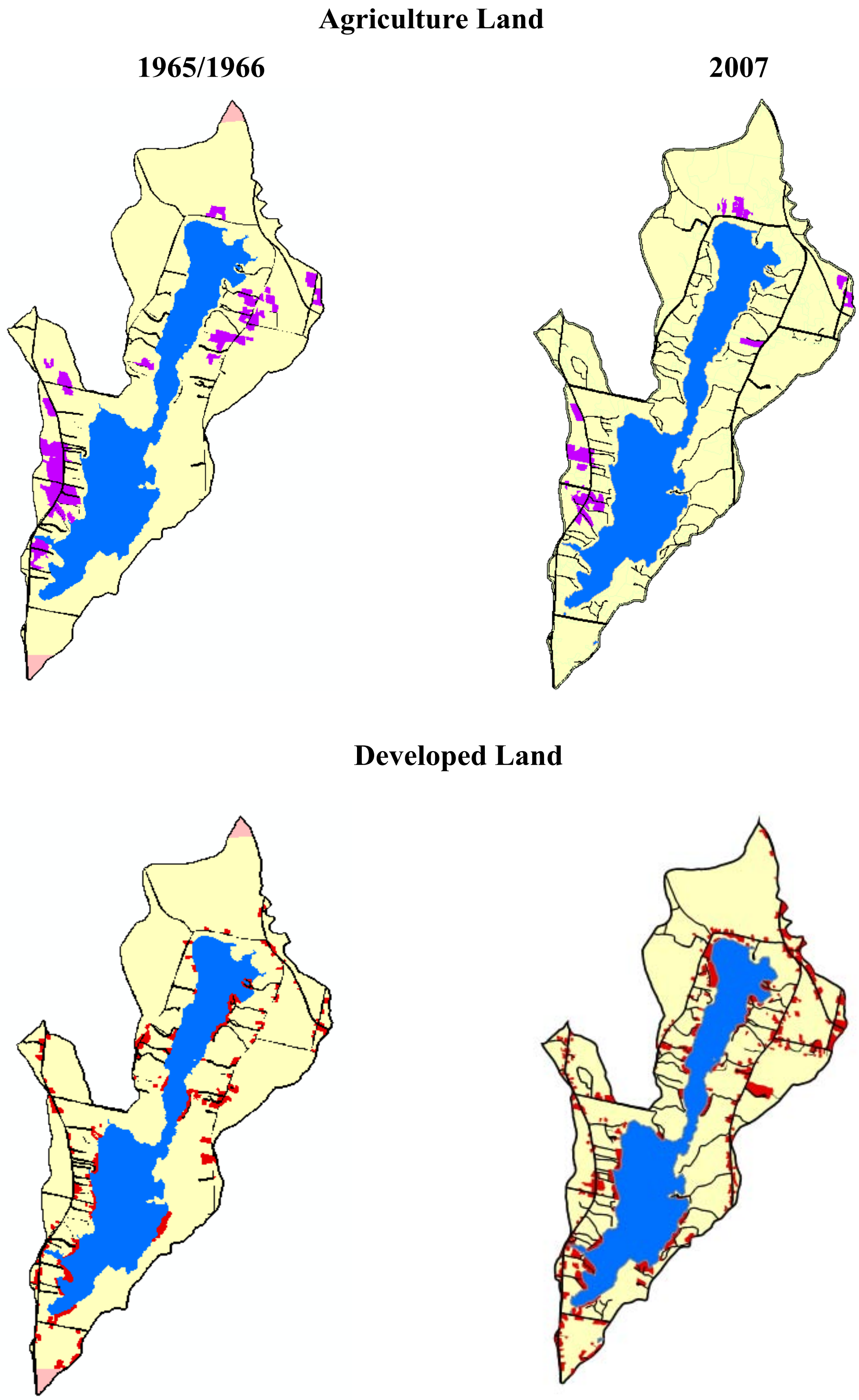

Figure 11. Comparison of different land use types. Agricultural land refers to pasture, cropland, and livestock and decreased from 111 ha to 44 ha. Developed land refers to residential, commercial, municipal and industrial areas and increased from 103 ha to 210 ha.

Results

The one sawmill in the region, Tukey's Sawmill, has grown considerably since 1965/66. It has been in operation since 1945 (CEAT 1994.). The mill does not fall under shoreline zoning policies because it is located outside of the shoreline zone. The owner has no recollection of any complaints or problems as reported in 1994 when the first CEAT study was conducted, and Peter Kallin, the executive director of the Belgrade Regional Conservation Alliance, also has no recollection of complaints since then. A study conducted in 1984 reported elevated phosphorus levels in the tributary near the sawmill (Nichols, Sowles et al. 1984). In 1965/66 the sawmill area was approximately 2.7 ha and in 2007 it was approximately 5.7 ha, making it the largest piece of developed land in the Salmon/McGrath watershed. The sawmill is located in Belgrade and is only a few hundred yards from the western shoreline of Salmon Lake. In 2007, it accounted for 0.4% of total land in the watershed. Figures 7 and 8 show the land uses for the watershed area from 1965/66 and 2007, respectively. The sawmill is designated by a bright orange polygon.

Municipal

Current and Historical Definitions and Identifying Characteristics

CEAT defined municipal land as land used for town purposes. Municipal land, like commercial land, is associated with high levels of impervious surfaces but represents a different type of land use than commercial land. Municipal land can include buildings that are not used as residencies and have less impact on water quality than industrial or other commercial purposes. However, municipal land may incorporate many different uses with a wide range of nutrient loading potential, so it is important to examine the actual examples of municipal land in the Salmon/McGrath watershed to make an accurate prediction of the impact of this land use.

Impact

Municipal land includes parks, the effects of which were discussed earlier (see Camps and Parks), but also landfills and transfer stations, the effects of which are more severe. For example, landfills can potentially contribute a lot of pollutants to the water body because until the 1970s, they generally consisted of an unlined pit. As water percolates through this pit, it dissolves waste and picks up various chemicals before seeping out and moving down slope towards a water body (Indiana University Northwest 2003). Hazardous wastes that are not supposed to end up in landfills do, despite laws regulating their disposal (Loizidou and Kapetanios 1993). Batteries, which leach a variety of heavy metals, and pressure treated wood, which leaches arsenic, are often found in landfills. Volatile organic compounds (VOCs), which vaporize at room temperature and are often carcinogenic, can also be in liquids found in landfills and leach into water sources (Loizidou and Kapetanios 1993).

Results

In the Salmon/McGrath watershed, the two instances of municipal land are the park in the northern tip of McGrath Pond and the Town of Oakland waste transfer station on the eastern side of McGrath Pond. The waste transfer station was formerly the Oakland Town Dump, but it was capped and buried to become a landfill. Waste is now trucked to the Penobscot Energy Recovery Company (PERC) incinerator in Orrington. Oakland monitors its landfill with test wells to ensure that groundwater is not affected by the landfill. Municipal land accounted for 1.7 ha in 1965/66, which is 0.08% of the total watershed and 7.9 ha in 2007, which is 0.4% of the total watershed. Figures 7 and 8 show the land uses for the watershed area from 1965/66 and 2007, respectively. Municipal land is designated by hot pink polygons.

The area of commercial and municipal land combined increased 529.2% from 1965/66 to 2007.

Roads

State, Camp, and Municipal Roads

Current and Historical Definitions and Identifying Characteristics

State roads are paved roads that are maintained by the state and are more frequently used than municipal roads. They are wider, go longer distances and connect developed areas. This type of road includes highways.

Camp/dirt roads are usually side roads that lead to residential or less developed areas. This includes youth camp roads. Camp roads are not as straight or wide as paved roads.

Municipal roads are paved roads maintained by local municipalities.

Impact

The roads within the Salmon/McGrath watershed for 2007 were digitized using the Digital Ortho Quadrangles (DOQ) and National Agriculture Imagery Program (NAIP) digital images and cross-referenced with images from the website Bing. The historical road data were found using the 1965/66 aerial photographs. The total area of roads for the 2007 land use map was calculated with ArcGIS® by processing the data with measurements collected on the roads during the road survey (see Appendix E). CEAT conducted the road survey in 2009. Though the land use maps were based off of 2007 roads, it was assumed that the road width did not change from 2007-2009. Roads are an important land use type that has a strong impact on the health of the lake (Gregersen, Folliottet et al.2007). Roads are impervious surfaces that can cause severe soil erosion and hold many pollutants, which can be channeled through runoff toward or away from the water body (Gregersen, Folliott et al. 2007). Roads have a proportionally larger impact of phosphorus loading on a water body than their actual area (Gregersen, Folliott et al. 2007).

Results

The area of roads in the watershed covered 39.3 ha in 1965/66 and 43.3 ha in 2007, increasing from 2.5% to 2.7% of the watershed (Figure 9). The roads built after 1965/66 were built in forested areas (Table 6). While this is a small percentage of the total area, roads contribute a disproportionate amount of nutrients and pollutants into the lake (Gregersen, Folliott et al. 2007). Camp/dirt roads contribute largely to the runoff because of their proximity to the water. In comparison to other watersheds in the Belgrade Lake Region, the Salmon/McGrath watershed has a much higher percentage of roads. The roads of Great Pond, Long Pond South, and Long Pond North are 0.8%, 0.7% and 1.8% of their watershed, respectively. Depending on the quality of the roads, especially camp roads, this 2.7% of the watershed area could produce substantial amount of runoff and nutrient loading into the water body (Gregersen, Folliott et al. 2007).

Trends and Changes in Land Use Type from 1965/66 - 2007

The total Salmon/McGrath watershed is 2,040 ha, with the water body accounting for 458.1 ha. The water body occupies 22.4% of the area in the watershed. The watershed around Salmon Lake is 1121 ha and 922.9 ha for McGrath Pond. Along with the historical (Figure 7) and current (Figure 8) maps, a map was also created to represent the changes from 1965/66 to 2007 (Figure 12).

The nature of the shoreline of Salmon Lake and McGrath Pond changed from 1965/66 to 2007 (Figure 12). The 14.1 mi perimeter consisted of residential land, youth camps, forested land, wetlands, open land and cropland in 1965/66 and presently there is no longer any open land or cropland on the shoreline of either Salmon Lake or McGrath Pond (Table 5). The residential development and youth camp land along the shoreline were the only land use types that increased. Residential land increased by 11.7% (1.49 mi), and the youth camp land increased by 0.95% (0.12 mi). The other land use types, the forested area, wetlands, open land and cropland, all decreased. The largest reduction was the 8.2% (1.4 mi) of forested areas (Table 5). Most of the forested areas were replaced by residential land. This change strongly affects the water body because it originally was a low impact land use type and is now a high-impact land use. Shoreline residential areas tend to have a high phosphorus loading potential because of their close proximity to the water body. The addition of shoreline residences replaced important buffer zones made up of forested areas that naturally filtered out nutrients and sediments.

Many land use changes occurred from 1965/66 to 2007. The loss of cropland, grass fields and forested areas were due to the increase in commercial, municipal and residential areas (Table 6). These high impact land use types contribute a disproportionate amount of phosphorus to the water body. This issue is further analyzed in the phosphorus model section of this report (see Appendix H). Residential land, commercial land and logged land all increased over 100% (Table 4). These three types of land use have a relatively high potential of adding phosphorus into the water body. This is especially true for shoreline residential areas because of their proximity to the water body.

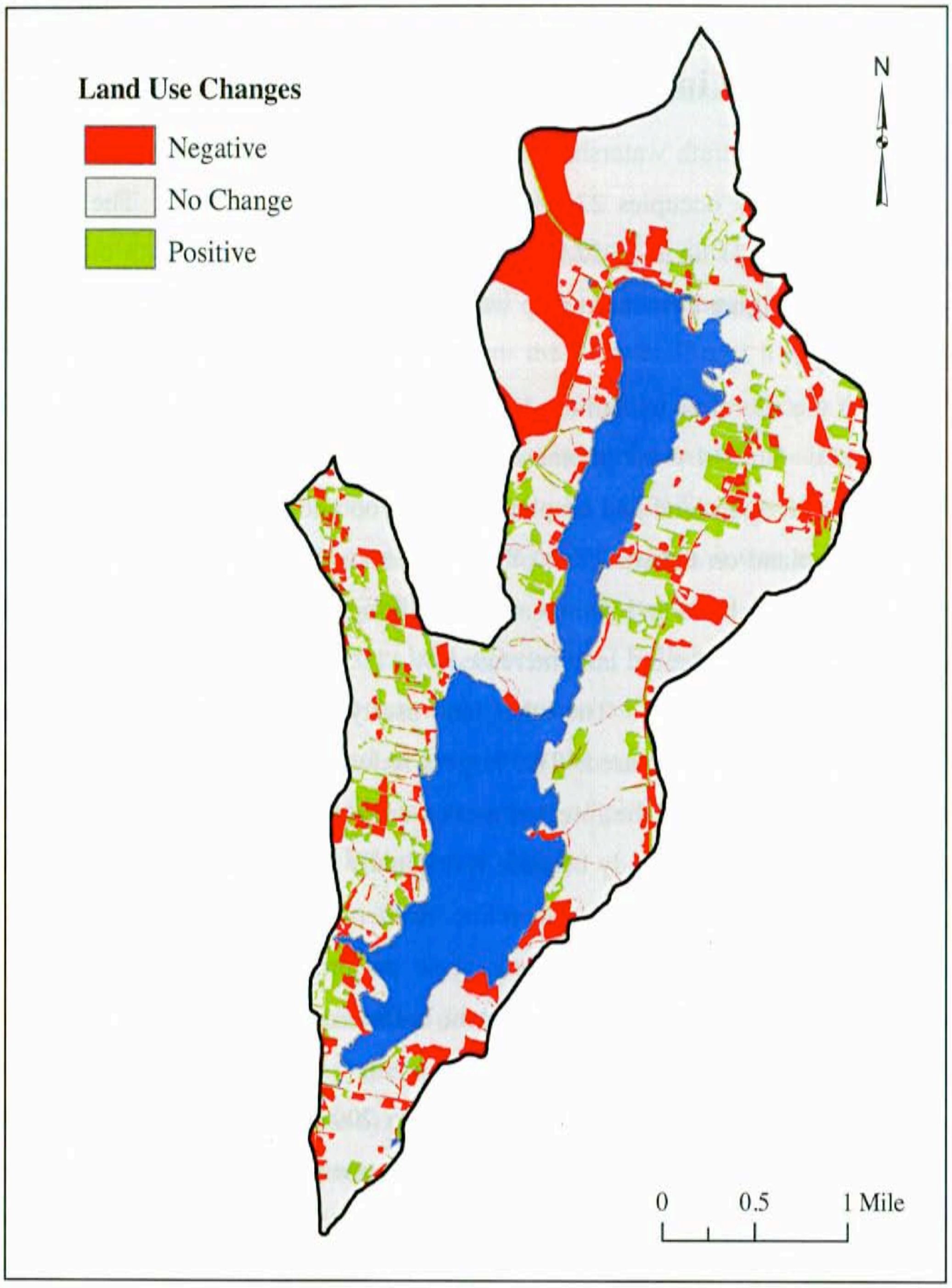

Figure 12. Areas of land use change in the Salmon Lake McGrath Pond watershed from 1965/1966 to 2007. Positive, negative and no land use change was determined by the erosion potential rating (Table-IIID3-1). If the phosphorus loading potential increased the area is labeled as 'Negative', if the phosphorus loading potential stayed the same it was labeled as 'No Change' and if the phosphorus loading potential decreased it was labeled as 'Positive'.

The most significant change was the 91.9 ha increase in residential areas, going from 6.2% of the watershed to 12.0% (Table 4; Figure 9). The non-shoreline residences increased by 79.4 ha, and the shoreline residences increased by 12.5 ha. This may be due to the limited space along the shoreline compared to more space away from the shoreline.

The second most significant change was the 74.6 ha decrease in forested areas (Figure 10). Forested areas went from 71.5% of the watershed to 65.0% (Figure 9). Most of the areas that were once forest became developed areas or logged land (Table 5). Forests are a natural buffer that helps protect the water body from nutrient runoff. This change from a positive land use type to a negative land use type causes a higher phosphorus loading potential.

Overall, the majority of the watershed had either a neutral change or did not change at all (Figure 12). A neutral change means, with accordance to phosphorus loading, its impact to the water body did not change from 1965/66-2007. There were 256.1 ha of negative land use change from 1965/66-2007 and 154.6 ha of positive change (Figure 12).

Open land and cropland, another high impact land use type, has dropped 78.8 ha (Table 4). 39.7 ha of this land returned to forested areas, and 35.0 ha were converted into developed land (Table 5). This is especially visible on the west side of Salmon Lake (Figure 10). These changes could decrease phosphorus loading in the watershed.

Wetland areas have not increased significantly between the two time periods (Table 4). While there appears to be a 10.11% increase, the Maine Department of Environmental Protection did not increase the buffer distance for wetlands protection. CEAT determined the wetlands only by the aerial photographs. If there was more vegetation cover in either 1965/66 or 2007 then the wetland areas may have appeared larger when no size difference actually occurred. The use of aerial photography meant CEAT did not include forested wetlands because they were not visible. The total area of wetlands in the watershed is more abundant than reported in this study.

All the youth camps in the Salmon/McGrath watershed have expanded, with a 26.0% increase overall (Table 4). This does not include the 4.8 ha golf course for Maine Golf and Tennis Academy, which was originally mixed forest. When including the golf course, youth camps have increased by 96.7% (13.3 ha). The youth camp and golf course expansion could potentially lead to higher phosphorus loading because of their proximity to the water body and high number of people.

Logged land has significantly increased since 1965/66. The 151.3% (77.7 ha) increase in land has drastically reduced the forested land in the watershed (Table 5). The logged area is concentrated in the Northwest portion of the watershed, and this land use was not found anywhere else (Figure 8).

Overall development in the watershed has increased. Youth camps, municipal, logged, residential, roads and commercial lands, including the sawmill, all increased in area over the last 41/42 years. This is especially true with commercial and municipal land use types, which increased by 529.19% (11.8 ha) (Table 4). A very large portion of this developed land was originally forested area (Table 5).

WATERSHED DEVELOPMENT PATTERNS

Residential Development

Residential Zoning

Introduction

The State of Maine classifies Salmon Lake and McGrath Pond as great ponds because they are larger than ten acres (MRSA Title 38 Sections 435-49). The Mandatory Shoreland Zoning Act regulates human development along the shore of all great ponds. Maine State Legislature enacted the Mandatory Shoreland Zoning Act in 1971 to protect water quality, wildlife habitats, and archeological sites and to conserve public access (MRSA Title 38 Sections 435-49). The intent of this zoning act is to protect natural resources and beauty of shoreland in Maine and has a direct impact on protecting the water quality of Salmon Lake and McGrath Pond.

Regulations

Municipalities may enact their own shoreland zoning ordinances. The Maine Revised Statutes gives authority for municipal shoreland ordinances under Title 38 sections 435-49 (MRSA Title 38, Sections 435-49). Municipal ordinances must comply with the Shoreland Zoning Act of 1971 and its amendments found in Title 38 of the Maine Revised Statute or they may enact regulations more stringent than Title 38. The Towns of Belgrade and Oakland have Shoreland Zoning Ordinances that comply with state statutes (Town of Belgrade 1991; Town of Oakland1995). Belgrade and Oakland have the Shoreland Zoning Ordinances to protect the health of water bodies, natural and historical resources and to conserve natural beauty. These ordinances are designed to anticipate and respond to the impact of development in shoreland areas.

The Natural Resources Protection Act allows the Maine Department of Environmental Protection (MDEP) to facilitate research, development management practices and environmental standards that will protect natural resources of Maine (MRSA Title 38, Sections 435-49). Municipalities work with the MDEP to ensure that their ordinances and approval of building permits follow environmental standards (Fuller, pers. comm.).

Shoreline Zoning

The Shoreland Zoning Ordinances apply to all land in the shoreland zone of Salmon Lake and McGrath Pond (Town of Belgrade1991, Town of Oakland1995). The State of Maine defines the shoreland zone as "all land areas within 250 feet, horizontal distance, of the normal high-water line of any great pond, or river; within 250 feet, horizontal distance, of the upland edge of a freshwater wetland; and within 75 feet, horizontal distance, of the normal high-water line of a stream" (MRSA Title 38, Sections 435-49, Town of Belgrade 1991, Town of Oakland 1995). All properties within these perimeters must comply with the Municipal Shoreland Zoning Ordinances.

The Shoreland Zoning Ordinances for the Towns of Belgrade and Oakland regulate construction and development (Town of Belgrade 1991, Town of Oakland 1995). This includes the construction of septic systems, roads and driveways, the placement of buildings, erosion and sedimentation control, the clearing of vegetation, remodels and conversion from seasonal to year-round. Non-conforming structures built prior to 1970 are "grandfathered in" and are exempt from compliance requirements. The ordinances do apply to "grandfathered" structures if the owner were to remodel or expand the size of the building. Municipal code enforcement officers inspect properties for compliance with the Shoreland Zone Ordinances and Maine Revised Statutes.

House Count

Introduction

Residential development is a very important characteristic when studying the impact of land use patterns on lake water quality. Every building brings additional people, demand for services and the potential for nutrient loading to Salmon Lake and McGrath Pond. Each of these residences generates waste and potential nutrient loading. We quantified this characteristic by performing a residential survey to count the homes inside the boundaries of the watershed. This survey included both shoreline and non-shoreline houses within the watershed, as well as municipal and commercial properties.

Regulations

In accordance with the 1971 Mandatory Shoreland Zoning Act, municipalities established comprehensive plans that regulated shoreland zoning and development. One important regulation dictates that all houses must be built 100 ft back from the high water line of a great pond (MDEP 1992b). Houses built before 1971 were not required to conform to the 1971 laws regarding shoreland development because they were built before the laws existed. Specifically, they could be built within 100 ft of the high water line of the lake and continue to use a septic waste disposal system that does not meet current septic regulations. These houses are known as "grandfathered properties." In addition to the setback, no house can exceed 35 ft in height and the coverage of the lot with impervious structures cannot be greater than 20%. There are strict rules on building accessory structures that are addressed on a case-by-case basis (MDEP 1992b). If a house is grandfathered in and not conforming to the laws established in 1971, owners may still add on to their existing structure but have fewer options than a conforming lot. Non-conforming septic systems do not need to be replaced until they fail.

Methods

Data for the residential survey were gathered in two separate ways. First, we performed a shoreline survey in which all lots, as well as undeveloped areas, were assigned GPS points (see Appendix D). Three factors were considered that affect the potential phosphorus loading of residences. These were relative age of the house (pre 1974 vs. post 1974), distance from shore (inside vs. outside of 250 ft mark from the water) and usage (year-round vs. seasonal). The year 1974 refers to the law mandating that septic systems must be permitted and approved in order to be built.

The age of the house is significant because it will provide us with an idea of the index of quality of the septic systems. Distance from the water is important because structures closer to the water body can have a greater impact on phosphorus loading and water quality degradation. House usage was broken down into seasonal versus year-round use. Seasonality varies depending on age of owner as well as other factors; however, the mean summer season lasts for roughly 90 days, from Memorial Day to Labor Day (Swanson, pers. comm.). This length of use is important because it defines how long each year that waste is being put into a septic system and whether or not there are time periods where more effluent is being emitted than others.

Houses were counted during the shoreline survey if they were within 250 ft of the water. Then their relative age, period of usage and other important characteristics were documented. These attributes were assessed based on observation of characteristics such as presence of a foundation, chimney or firewood to denote year-round usage. Following this survey, a road and house count survey was conducted for the entire watershed (see Appendix C) using similar principles as the shoreline survey. The objective of this survey was to count all houses inside the watershed as well as record the characteristics noted in the previous study. In addition, problem areas for residences, driveways and commercial areas were recorded with GPS points and described by attached comments (see Watershed Development Patterns: Roads).

These data and town tax cards on Salmon Lake and McGrath Pond were consulted to determine the correct total house count. GIS and maps from the website Bing helped us confirm areas where comments from the shoreline survey denoted a unique area. We then contacted youth camps to determine which of all the commercial properties would count towards the total number of houses in the watershed. The summation of these data provided us with the final house count breakdown.

Results and Discussion

In the Salmon/McGrath watershed there are a total of 611 homes. These include 8 commercial properties, which were all assumed to have one septic system each. This assumption seems accurate as the amount of people that use these facilities most likely does not exceed that of a large family. There are 275 shoreline residences and 336 non-shoreline residences. 385 structures were thought to be built before 1974 and 226 were built after. Finally, there are 446 year-round houses and 165 seasonal homes in the watershed (Table 7). Houses closer to the water have the potential to have a greater effect on the degradation of water quality than those farther away from the lake. This is because there is less distance between the house and the water for nutrients to be absorbed into the ground and kept out of the water. Although there are more non-shoreline houses in the watershed than shoreline ones, it is important to note that over two-thirds of the shoreline houses were built before 1974. This means that they are grandfathered properties and may have a less effective septic system or are not set back the currently required distance from the water.

Table 7. A breakdown of the total number of houses in the Salmon/McGrath watershed into their age and usage based on their location from the shore of the water body.

Characteristic	Shoreline	Non-Shoreline
Pre 1974	208	177
Post 1974	67	159
Year-round	110	336
Seasonal	165	0

A little over half of the shoreline houses are seasonal and every non-shoreline house is year round. Seasonal houses are occupied for roughly a quarter of the year. Because they are used only part of the year, these residences provide less waste that could degrade the lake. The trend of finding more year-round homes further from the shoreline coincides with development patterns in similar watersheds. Rick Swanson, the president of McGrath Pond/Salmon Lake Association, stated that more and more seasonal houses were being converted into year-round ones (Swanson, pers. comm.). This poses a problem because as a house converts from seasonal to year-round use, the septic system receives roughly four times the usage and can have a major impact on water quality. The fact that all non-shoreline houses are becoming or already became year-round may seem unlikely; yet with year-round houses being found along the shoreline, it is a feasible concept.

There were a few problem areas in the watershed. To be specific, these areas include poor driveways and houses built too close together. Some driveways are too steep and others have potholes that are prone to standing water. Some driveways are also constructed in a manner that causes erosion and degradation. These problems have obtainable solutions and can really make a difference in the watershed. There are many potential factors for nutrient loading in the water body and it is important to consider everything when designing a lot.

Buffer Strips

Introduction

A vegetated buffer strip is an area of vegetation between the built environment and the water that catches sediment and non-point source pollution before it reaches the water body (MDEP 1998b; see Background: Buffer Strips). The ideal buffer strip contains a variety of vegetation types that work together to reduce the erosive impact of raindrops, promote evaporation and infiltration, and filter out pollutants (MDEP1998b). For maximum effectiveness, a buffer should cover the entire length of the shoreline and have a depth of 50-250 ft back from the water, depending on the slope of the lot (MDEP 1998b). In most cases, a buffer depth of 50-100 ft is sufficient to remove all nutrients, sediment and pollutants from runoff (Krigger, Wildinson et al. 2001). Vegetated buffer strips play an essential role in protecting the water quality of a lake. Surveying the status of buffer strips can help indicate the impact of residences on overall water quality and highlight areas where improvements are needed.

Regulations

The Mandatory Shoreland Zoning Act of 1971 prohibits removal of vegetation within 75 ft of the shoreline (MRSA Title 38, Sections 435-49). Within 100 ft of the lake, there may not be an opening in the forest canopy that exceeds 250 sq. ft. A winding footpath less than 6 ft wide is allowed, as is selective cutting of trees as long as a well-distributed stand is maintained. Within the entire shoreland zone, no more than 40% of the volume of trees over four inches in diameter at breast height may be removed within a 10-year period (MRSA Title 38, Sections 435-49). Additionally, activities such as removing or displacing soil and repairing permanent structures within 75 ft of the shore require a permit under the Natural Resources Protection Act (Truesdale 2008).

Methods

A shoreline survey was conducted on 24-September-09 to assess the quality of buffer strips for Salmon Lake and McGrath Pond. CEAT traveled around the lakes in six boats, pausing offshore from each house to take GPS coordinates and evaluate the following factors: the distance of the house from the shoreline, the depth of the buffer back from the shoreline, the percent of the shoreline covered by the buffer, the slope of the lot, the severity of shoreline erosion, the length of the lot along the shoreline, the presence or absence of specific characteristics such as docks and lawns, and the need for riprap (see Appendix D). Coordinates were also recorded to mark undeveloped areas of natural vegetation along the shoreline, but these areas were not evaluated in the buffer strip survey due to the lack of buildings and the presence of natural vegetation.

To compare buffers in different areas of the lake, a weighted total rating was calculated by summing the buffer depth, buffer percent along the shoreline, slope and shoreline erosion values. The amount of the shoreline that is covered by the buffer directly affects its effectiveness, so buffer percent along the shoreline was given more weight in the rating by multiplying these values by 1.2. Slope is a factor that cannot be improved by the homeowner, so it was given less weight in the rating by multiplying these values by 0.8. Lower values corresponded to better buffer quality. Once calculated, the weighted total values were compared with photos and notes from the survey to develop buffer categories labeled “excellent,” “acceptable,” “fair” and “poor” (Figure 13).

Each lot was assigned to a category based on its weighted total value. The weighted totals were then mapped in ArcGIS® using the GPS points. Other factors relevant to nutrient loading were analyzed separately from the buffer quality. These factors included house distance from the shoreline, lot length along the shoreline, presence of specific characteristics (e.g., docks, lawns, boat launches, etc.) and the need for riprap.

Figure 13. Examples of a lot from each of four buffer quality categories on Salmon Lake and McGrath Pond. (a) Poor - sloping lawn stretches all the way to the shore. (b) Fair - lacks a shrub layer and has low vegetation density. (c) Adequate - dense, uninterrupted layer of herbaceous vegetation. (d) Excellent - dense layer of trees, shrubs and herbaceous plants between the building and the lake. Photos from CEAT shoreline survey conducted on 24-September-09 (see Appendix D).

Results and Discussion

Surveyors evaluated 271 developed lots during the shoreline survey. Only 254 lots had sufficient data to calculate a weighted total value for buffer quality. Of these, 35 lots were classified as having excellent buffer quality, 94 as acceptable buffer quality, 56 as fair buffer quality and 69 as poor buffer quality (Figure 14). The percent of lots in each buffer category was calculated for Salmon Lake and McGrath Pond separately. McGrath Pond had a higher percentage of excellent buffers than Salmon Lake (Figure 14). In general, the distribution of buffer quality in Salmon Lake and McGrath Pond was similar to that found by other studies conducted in the Belgrade Lakes Region (CEAT 1997, 1998, 1999, 2000, 2006, 2007). GIS

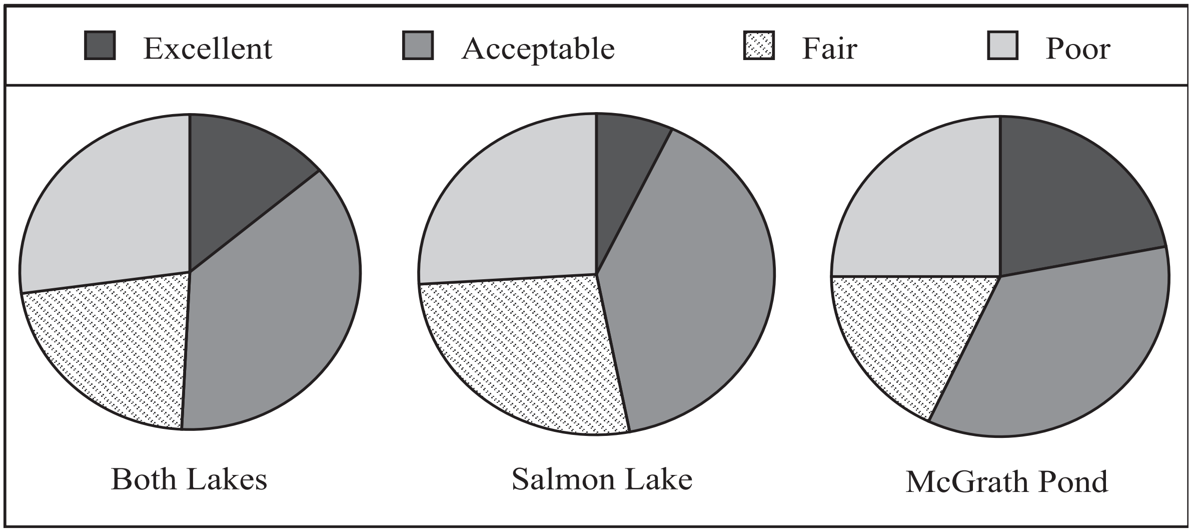

Figure 14. Percent of lots in each buffer quality category for both Salmon Lake and McGrath Pond combined and for each lake individually. Data were collected in the shoreline survey conducted by CEAT on 24-September-09 (see Appendix D).

was used to show the spatial distribution of buffer quality ratings for McGrath Pond (Figure 15) and Salmon Lake (Figure 16). Excellent buffers are concentrated in the northwest corner of McGrath Pond, though examples of excellent buffers can be found throughout the lakes (Figure 13d**)**. The 35 lots with excellent buffer ratings will only require routine maintenance to preserve buffer quality. However, our survey identified 219 lots that would benefit from improvement of the existing buffer or creation of a buffer where none currently exists. 21 undeveloped areas of varying size were identified during the survey (Figures 15 and 16). Using GIS, it was estimated that there are 13 undeveloped lots on Salmon Lake and 6 on McGrath Pond that are eligible for future development.

Though the distance of a house from the water cannot be altered, it affects the impact of the lot on the water quality of the lake. House distance was evaluated for 262 lots, and each house was assigned to a distance range (Figure 17). CEAT estimated that 100 houses are located within 25 feet of the shoreline. When houses are this close to the water, it is difficult to establish an effective buffer strip. Furthermore, the septic systems for these homes may be in close proximity to the water, which increases their potential contribution to nutrient loading (see Background: Sewage Disposal Systems). No houses within 10 ft of the

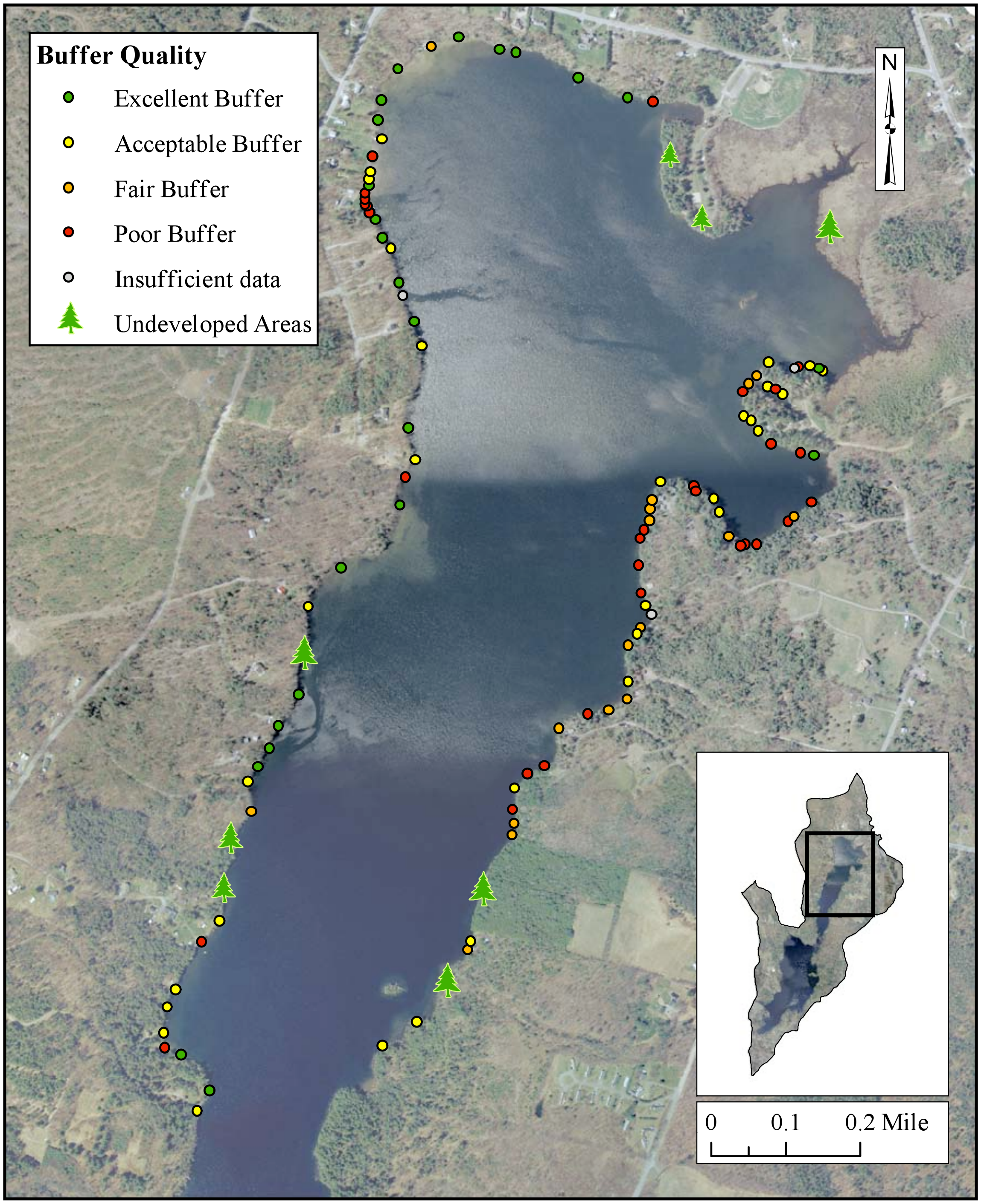

Figure 15. Buffer quality ratings for shoreline residences on McGrath Pond. Dots corresponding to quality ratings represent individual residential buffers. Quality ratings are based on a weighted sum of buffer depth, percentage of shoreline covered by the buffer, buffer slope and observed shoreline erosion. Futher details can be found in Watershed Development Patterns: Residential Development: Buffer strips.

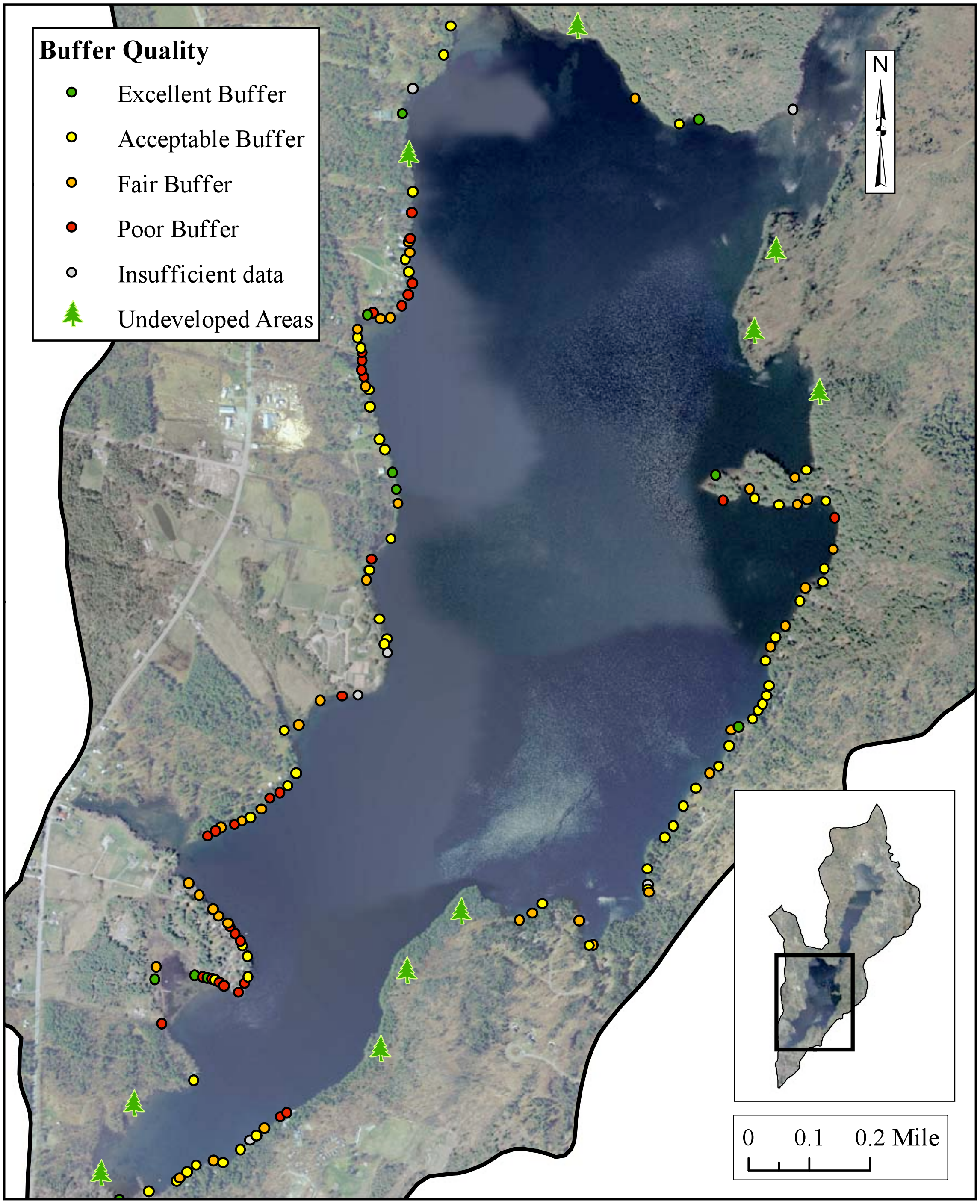

Figure 16. Buffer quality ratings for shoreline residences on Salmon Lake. Dots corresponding to quality ratings represent individual residential buffers. Quality ratings are based on a weighted sum of buffer depth, percentage of shoreline covered by the buffer, buffer slope and observed shoreline erosion. Further details can be found in Watershed Development Patterns: Residential Development: Buffer Strips.

shoreline had excellent buffers, and few houses within 50 ft were rated as excellent (Figure 17). However, houses that are a greater distance from the shoreline can also have fair to poor buffer quality (Figure 13a).

The lot length along the shoreline affects the number of houses possible on the shoreline and the distance between them. CEAT analyzed the length of 254 lots. 62 lots were estimated to be less than 60 ft long; only 31 lots were greater than 180 ft in length (Figure 18). The current shoreland zoning ordinances mandate a minimum lot length along the shoreline of 200 ft (Town of Belgrade 1991, Town of Oakland 1995). CEAT found that 223 lots are less than 180 ft long and do not meet this standard. These 223 lots were grandfathered in when the shoreland zoning ordinances were passed. One of the purposes of these regulations was to prevent the development of areas where several houses are in close proximity to each other, but such areas are present in the Salmon/McGrath watershed due to grandfathering (Figure 19c). These areas may be of concern for nutrient loading because there may not be sufficient natural vegetation to absorb runoff effectively, and the amount of nutrients entering the lake may be concentrated over a small area. However, large lots can also be significant contributors to nutrient loading if their buffer quality is poor because they affect a large area (Figure 13a). There were nine lots over 180 ft in length with poor buffer quality (Figure 18).

Our survey identified the presence or absence of other characteristics that may directly impact or serve as indicators of water quality (Table 8). 73% of the lots evaluated contained one or more docks, which is not surprising for shorefront properties. Most docks did not appear to contribute to nutrient loading, though some had worn paths along the side that could be conduits for runoff. 63% of the lots contained lawns, and many of these lawns stretched all the way to the water (Figure 13a). Lawns are not effective buffers (MDEP 1998a), and they contribute five to ten times as much phosphorus as naturally vegetated areas (Woodard and Rock 1991),so this statistic raises concern. 34% of the lots contained aquatic macrophytes growing offshore, which could be indicative of high sediment and nutrient loading (EPA 2009). 34% of the lots contained patches of bare soil, and 19% contained a beach. Areas of bare soil and beaches can be sources of erosion and sedimentation, particularly if the bare soil is part of a footpath to the lake (Figure 19d; see Background: Buffer Strips). Based on the survey conducted by CEAT, there are 24 boat launches in

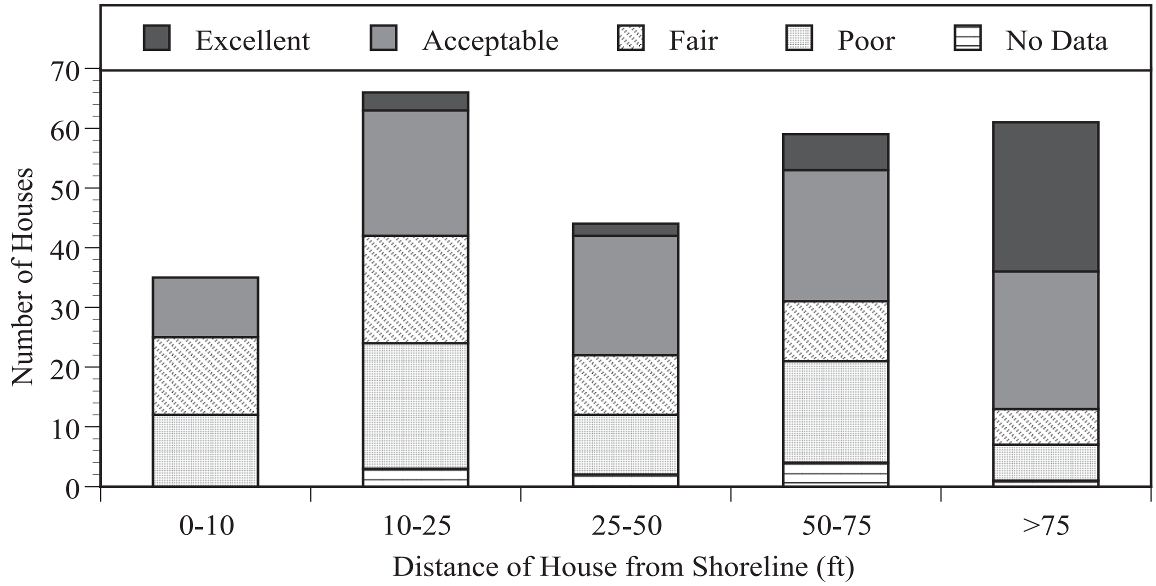

Figure 17. The distribution of house distances from the shoreline along Salmon Lake and McGrath Pond, as estimated during the CEAT shoreline survey conducted on 24-September-09 (see Appendix D). The proportion of houses in each distance category assigned a specfic buffer quality rating is shown.

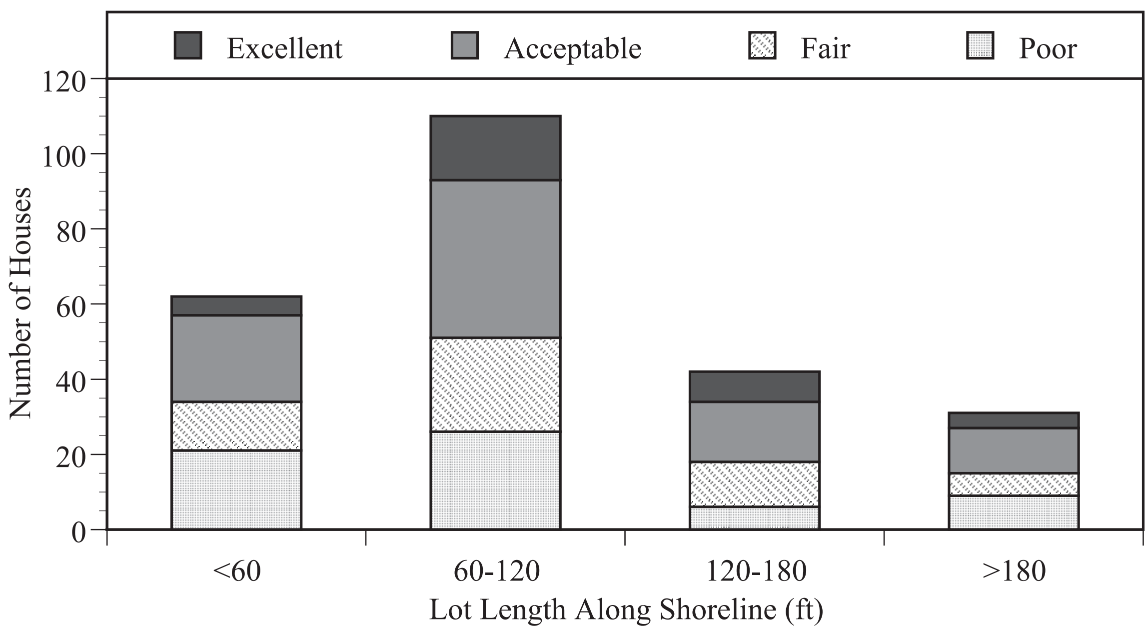

Figure 18. The distribution of lot length along the shoreline for Salmon Lake and McGrath Pond, as estimated during the CEAT shoreline survey conducted on 24-September-09 (see Appendix D). The proportion of houses in each lot length category assigned a specific buffer quality rating is shown.

Figure 19. Examples of potential problem areas along the shorelines of Salmon Lake and McGrath Pond. (a) Private boat launch, which can provide a conduit for runoff to enter the lake. (b) Private boat launch connected to a steep uphill road where runoff can flow from the house directly in the water with no impediments. (c) Short lot lengths with houses close together, which may result in concentrated nutrient loading. (d) Straight path from the house to the shore. Photos from the CEAT shoreline survey conducted on 24-September-09 (see appendix D).

Salmon Lake and McGrath Pond. Boat launches are areas of significant nutrient loading potential because they provide an unobstructed path for runoff to enter the lake (Kallin, pers. comm.). Unpaved private boat launches (Figure 19a and b) are of particular concern because they are made of dirt or gravel, which can easily be washed into the lake. One drainage ditch was identified by the surveyors, and this is also a potential pathway for runoff. Additionally, riprap is present in 106 lots, but 13 lots were identified as needing riprap to stabilize the shoreline. All but one of the lots that need riprap are located along the shoreline of Salmon Lake.

Table 8. Lots within watershed containing characteristics that may impact water quality. Data were collected during the shoreline survey conducted by CEAT on 24-September-09 (see Appendix D).

Characteristic	Percent of Lots with Characteristic	Number of Lots with Characteristic
Dock	73%	197
Lawn	63%	172
Riprap	39%	106
Aquatic Macrophytes	34%	93
Bare Soil	34%	91
Boat Launch	9%	24
Beach	7%	19
Drainage Ditch	<1%	1

Septic Waste Disposal Systems

Introduction and Regulations

The communities in the Salmon Lake/McGrath Pond watershed do not have access to municipal wastewater treatment. Sewer systems in this region are inefficient and impractical for wastewater disposal because of the long distances that separate houses, low population densities and proximity to multiple water bodies. Instead, waste is treated through alternative methods of subsurface disposal: pit privies, septic systems, holding tanks and cesspools.

Pit privies are deep holes where human waste and paper can decompose (Johnson 2005). Because they are only designed for low-volume use and have low water content, pit privies are not a significant threat to water quality. Through proper construction and maintenance, they can be adequate methods of waste disposal. According to Maine Regulations, a pit privy falls under the category of a disposal field and can be used as waste treatment (MRSA Title 22, Section 706.1). Pit Privies can only be used for human wastes and must follow certain setback and construction regulations.

Holding tanks are concrete or plastic containers that collect waste from the residence (see Background: Watershed Land Use: Subsurface Wastewater Disposal Systems). Requiring routine pumping to prevent overflow, they act as a temporary storage unit for wastewater. If they are properly maintained and do not leach wastewater into the environment, holding tanks are positive methods of wastewater control. Maine Regulations state that holding tanks may only be installed when no other practical alternative exists (MRSA Title 22, Section 706.3). Holding tanks must be routinely inspected as well as follow specific construction and design regulations to prevent system failure (MRSA Title 22, Section 2000). In order to increase treatment efficiency, regulations prohibit first time holding tank use for flows exceeding 100 gallons per day or 500 gallons per week (MRSA Title 22, Section 2005). This ensures that holding tanks are not used to manage large volumes of effluent.

Cesspools are also present within the watershed. Cesspools are deep holes with stoned lined sides that collect all the wastewater from the residence via a drainage pipe. The effluent infiltrates into the soil directly. Because cesspools are less effective than septic systems and require more frequent pumping, they are uncommon and no longer permitted. Maine regulations prohibit large capacity cesspools and mandated any preexisting cesspools to be closed by April 5, 2005 (MRSA Title 22, Section 206.1).

Septic systems are the most common method of subsurface wastewater disposal in the Salmon/McGrath watershed. Septic systems are favored because of their efficient and natural process of wastewater treatment (EPA 2005). Microorganisms remove harmful bacteria from the effluent, and nutrients are absorbed by the surrounding soil before effluent can reach groundwater or surface water. A septic system consists of two main components: the septic tank and the drainage field.

A septic tank is commonly made from concrete or plastic (Miller 2007). Acting as a storage unit, all wastes produced by the home are collected in the septic tank. There, the waste separates into sludge, effluent and scum (see Background: Watershed Land Use: Subsurface Wastewater Disposal Systems). The scum and sludge remain in the tank and are pumped out on a regular basis. The effluent leaves the tank and enters the drainage field for further treatment.

A series of perforated pipes moves the effluent throughout the drainage field. The bacteria found in the soil treats the effluent, and nutrients are absorbed. Certain types of soil treat wastewater more effectively than others. Soils that are composed of sand and loam are ideal because they are permeable but do not allow rapid infiltration. When the surrounding soil is not ideal, proper soil, or synthetic fill, can be brought to the site to mitigate this deficiency (Miller 2007). Proper filtration of wastewater also requires specific depth between the bottom of the drainage field, the bedrock and the water table. If the surrounding land does not provide ideal conditions, a mound system can be built to add necessary depth. Similar to the previously mentioned systems of waste disposal, septic tanks must be periodically pumped, to ensure complete separation of sludge, scum and effluent (EPA 2005).

When construction or maintenance of a septic system is not done properly, failure of the treatment process can occur. Warning signs of failure include strong odors, bright green grass over the drainage field and flooding of the surrounding land (Hoover 1994). When failure occurs, wastewater is no longer being treated properly. Anaerobic organisms that function to remove bacteria die and nutrients are unable to be absorbed by the saturated soil. This leads to an overload of nutrients entering the water supply and the potential for contamination of ground and surface water (EPA 2005).

To minimize the risk of malfunctioning septic systems, the State of Maine passed a septic regulation policy in 1974.Septic systems may only be installed after a plumbing inspector evaluates the proposed construction site. Maine requires a minimum of 100 ft between the drainage field and the high water mark of a water body, as well as 100-300 ft between the drainage field and neighboring wells, depending on size and use of well, and design flow of septic system (MRSA Title 22, Section 701). In addition, septic systems must be located on suitable soils, as determined through tests and site evaluations. There must be at least 12 in of soil between the drainage field and water table, or hydraulically restrictive horizon, and bedrock (MRSA Title 22, Section 400.4). This depth increases to 15 in when a septic system is within the shoreland zone or any major water body. These, along with construction and location restrictions, ensure effective waste treatment and prevent system failure. Unfortunately, these regulations do not apply to grandfathered properties, which had septic systems installed before regulations were established. Because of their age and minimal construction standards, these older septic systems potentially provide a significant source of phosphorus loading.

Methods

The examination of wastewater disposal systems in the Salmon/McGrath watershed was conducted in several phases. In September 2009, a house count was conducted during the shoreline survey and road survey. By observing structural features of the houses, age and occupation patterns were estimated. This information was used to estimate the age of the septic system for each residence. Interviews with the Municipal Code Enforcement Officers of Belgrade and Oakland, Gary Fuller and Bob Ellis, the McGrath Pond/Salmon Lake Association President, Rick Swanson, as well as the executive director of the Belgrade Regional Conservation Alliance, Peter Kallin, were conducted to supplement the data collected. These interviews were also used as an opportunity to gather information regarding problems with septic systems in the watershed. Tax records were used to confirm ages of residential properties and their septic systems. However, some septic systems may have been replaced since house construction. Houses that were located within 250 ft of the water were considered shoreline homes and were given special consideration due to their increased potential for impacting the lake.

The youth camps in the watershed were contacted for information, and their septic system construction permits were obtained from Town Offices. These camps include Camp Tracy in Oakland and Camp Modin and the Maine Golf and Tennis Academy in Belgrade. The information regarding the design of these systems is particularly important because the large number of campers and staff produce a high volume of waste. Youth camps are considered separately in the phosphorus model because of the large volume of effluent that needs to be processed by their septic systems.

Results and Discussion

With a total of 611 houses in the Salmon/McGrath watershed, 275 were determined to be shoreline residences. In addition, the Maine Golf and Tennis Academy, Camp Modin, Camp Tracy and Whisperwood Cottages are all located along the shoreline. The potential for further shoreline development is decreased because of minimum lot size and the extent of the pre-existing development. Both the Lake Association President and the Code Enforcement Officers commented on the lack of requests for construction permits, and both agreed that any major building proposals are unlikely in the near future (Ellis, pers. comm.; Fuller, pers. comm.). When subdivisions are approved, septic systems must be installed on each lot, before sale of the lot and construction (Ellis, pers. comm.). This guarantees installation of proper septic systems.

Although new house construction is occurring slowly, there is a notable trend to convert seasonal homes into year-round residences (Kallin, pers. comm.). Out of the 275 shoreline homes, 165 were determined to be seasonal. There were no seasonal, non-shoreline homes. Seasonal homes require septic systems that can handle three months, the estimated stay of seasonal residents, worth of wastewater instead of twelve months (Kallin, pers. comm.). The conversion of a seasonal home to a year-round home requires the installation of a year-round septic system as well as related permits for construction (Ellis, pers. comm.). This regulation does not apply to grandfathered houses, which are houses converted before 1974. These houses that were converted before the change in regulations only need to replace their septic systems once the old systems fail.

Gary Fuller, the Code Enforcement Officer of Belgrade, noted the general lack of information regarding the septic systems in the watershed. He estimated 50% of the residences had new or replaced septic systems. However, this estimate was rough due to a lack of precise information (Fuller, pers. comm.). In Oakland, Bob Ellis stated that the number of new or replaced septic systems was much lower than this estimate. He estimated that of the 3000 septic systems in the entire Town of Oakland, 1/20 were replaced or new. Between 2000 and 2009, there have only been 22 new septic systems installed for residential properties in the Oakland part of the Salmon/McGrath watershed (Ellis, pers. comm.).

There were no concerns expressed over particular areas or specific potential problem sites by the Code Enforcement Officers. When problems are discovered, Ellis explained, investigation of the issue starts immediately and residents with septic system problems are given ten days, or more in special circumstances, to fix the malfunction (Ellis, pers. comm.). The commitment to proper maintenance is evident in the community. Both Code Enforcement Officers noted a positive community response to efforts to improve lake water quality through compliance with septic system codes. In both towns, citizens work hard to alert Code Enforcement Officers when problems occur.

However, Peter Kallin expressed concern over the lack of effective septic ordinances for houses, as well as an absence of a database, which would catalogue all septic systems in the watershed. In addition, the lack of required routine maintenance and inspection left room for worry. Maine requires 12-24 in of soil between the drainage field and the water table. Kallin explained that in many states, 4 ft is required, suggesting Maine standards could be more stringent (Kallin, pers. comm.).

The dam at the southern end of Salmon Lake on the outlet stream was mentioned as a concern for the septic systems closest to the shoreline. When the dam was installed, the water table in the watershed rose (Kallin, pers. comm.). Many of the older houses along the shoreline are in fact closer to the water than when originally built. Septic systems could also be even closer to the water table, making the threat of nutrient loading greater.

In the watershed, there are four holding tanks, three of which are located at Whisperwood Cottages, and three cesspools. This information was obtained through examination of tax cards filed by each residential property in the watershed. Both Code Enforcement Officers did not know the exact number of holding tanks and cesspools in the watershed but agreed that these numbers seemed correct (Ellis, pers. comm.; Fuller, pers. comm.). Holding tanks are only used when there is no other viable option due to soil or slope conditions and have potential to be damaging to the water quality if they are not properly maintained and pumped regularly (Kallin, pers. comm.). According to state regulation, some effluent is permitted to leach from a holding tank and still pass inspection, leading to direct transfer of waste from the residence into the environment (Kallin, pers. comm.). This allows for untreated effluent, loaded with nitrogen, phosphorus and bacteria, to enter the lake. Pit privies were not of concern in the watershed. A few outhouses were seen during the shoreline survey, but their purpose seemed ornamental. It is unlikely that any pit privy in the watershed is used as a main method of wastewater control because each property had an alternative method of control, such as septic system.

In addition to the surveys, the permits for septic system construction were examined for Camp Tracy, Camp Modin and the Maine Golf and Tennis Academy. These youth camps have had new septic systems installed to accommodate increased camp size, as well as replacement of older, inefficient systems. Code Enforcement Officers agreed that the camps were compliant to all regulations and worked to improve the water quality of the lake.

Camp Tracy had permits for construction of septic tanks and drainage fields approved in 2005, 2006 and 2008. The project in 2005 was notable because of its size. Filed as a replacement system, Camp Tracy planned for two additional septic tanks, with a total capacity of 4,500 gallons, and a drainage field composed of 108 concrete chambers. This design was created to accommodate a new bathhouse. The bathhouse was designed to accommodate 150 full-time campers, 130 day campers and 30 staff. Other septic construction projects were completed to accommodate additional campers and cabins.

Camp Modin had permits for construction of septic tanks and drainage fields approved in 1995, 1997, 1998 and 1999. In 1995, Camp Modin replaced old septic systems and installed two large septic tanks in addition to their pre-existing tank. Additional drainage fields were created to accommodate new cabins and an increase in system use. The Maine Golf and Tennis Academy had permits for construction of septic tanks and drain fields approved in 2004, 2006 and 2008. In 2004 and 2006, the camp replaced trench septic systems with new septic tanks and drainage fields. They added a new drainage field in 2008 to accommodate increased use.

Up-to-date septic systems in the Salmon/McGrath watershed are well maintained and do not cause great concern for water quality. However, older systems are less effective at treating wastewater, and replacement of these systems would likely result in an improvement of water quality. It is important to encourage proper maintenance of septic systems in the watershed to minimize negative impacts on water quality and reduce the chance of system failure. Complete records of all septic systems would help maintain knowledge and awareness of septic issues in the watershed. Belgrade and Oakland residents in the Salmon/McGrath watershed should continue to show diligent cooperation in their management strategies to prevent water quality degradation from improper waste disposal in the Salmon/McGrath watershed.

Septic Suitability Model

Introduction

When not maintained properly, septic systems, the predominant method of wastewater treatment in the watershed, can contribute a significant amount of phosphorus, nitrate and other nutrient inputs to nearby bodies of water (Canter and Knox 1986, D'Itri and Wolfson 1988). Effective septic systems rely on properly functioning leach fields for effluent from the septic tank to be filtered further through the soil. Ideally, wastewater is treated completely and all excess nutrients and microbes are removed (EPA 2005). Soil type and slope of the leach field both have a considerable impact on the rate and distance at which effluent moves through the soil (Canter and Knox 1986).

Porous soils with high percentages of sand may allow effluent to leach too quickly and may not remove all contaminants. Soils that are densely compacted may not allow effluent to move through at all, causing increased runoff or flooding. Either situation can cause incomplete filtration of the effluent and potential contamination of the lake (Canter and Knox 1986). Saturated hydraulic conductivity (Ksat) is used to measure the rate at which water moves through saturated soils, such as those found in a leach field. This measurement is used in part to determine how suitable a given soil type is for installation of a septic system (NRCS 2009a).

Depth to bedrock and water table are also important factors in determining the suitability of an area for a septic system. In areas in which depth to bedrock is shallow, there may not be enough depth for effluent to percolate through the soil before reaching the impermeable bedrock. This situation could lead to flooding or runoff of nutrient and bacteria-rich effluent directly into the lake (KCSWCD 1990).

In hydrologic terms, the water table is the upper level of the groundwater, which rises and falls throughout the year as precipitation levels change the amount of groundwater in an area. If the water table of an area is close to the soil surface, it may come into direct contact with the leach field during times of high rainfall or snowmelt. This could cause mixing between incompletely filtered wastewater and groundwater, leading to groundwater contamination. Direct interaction with the water table can also overwhelm the leach field, causing flooding and runoff of effluent directly into lakes and streams (Canter and Knox 1986).

The slope of the area where the leach field is situated is especially important to the rate at which effluent moves through a leach field. Effluent will quickly leach through any septic systems built on steep areas, which may cause incomplete treatment. The erosion potential of steep areas is also much higher than that of more moderately sloped areas, meaning that erosion from a leach field built on a steep area is likely to be especially high. A slope greater than 20% will generally cause effluent to filter through a leach field too quickly and not allow the soil to remove all contaminants. Fast-moving effluents can also cause erosion under the soil surface, bringing more nutrients and contamination from wastewater into nearby water bodies (Canter and Knox 1985).

In some areas, water forms standing puddles or ponds from which water is only removed by percolation into the soil or evaporation. These areas would be highly susceptible to leach field flooding in the spring and other times of the year when water is likely to gather.

Ponding is a measure of how likely water is to form these pools, in terms of the number of times per year where pools are likely to accumulate in an area (NRCS 2009a).

Methods

A GIS model was created to assess septic suitability within the Salmon/McGrath watershed. Previous septic suitability models created by CEAT have relied heavily on Kennebec County Soil and Water Conservation District (KCSWCD) soil septic potential ratings. Soil types are rated as *not limited*, *somewhat limited* or *very limited* for septic potential. These ratings are based on permeability, mean depth to bedrock, erodibility (K-factor), nutrient absorption capacity and slope of a soil area to evaluate septic potential (KCSWCD 1990). All soil types in the Salmon/McGrath watershed have a *very limited* soil septic potential. Because the map created from this model shows a relative scale of septic suitability, the use of this factor in the model would not have any effect on the outcome. However, the *very limited* rating is useful when comparing septic suitability of the Salmon/McGrath watershed to that of other watersheds.

Slope data were obtained from the Maine Office of GIS (MGIS 2009). Soil type and depth to bedrock data were obtained from the Natural Resource Conservation Service (MDEP 1998B).

Distance to bedrock and water table data were put into ArcGIS® maps and reclassified on a 1-9 scale. Ponding was given a value of zero if ponding was considered unlikely or nine if it was likely. Values for saturated hydraulic conductivity (Ksat) ranged from 0-705 meters/day, with the majority of values falling between 1 and 10. These values were also reclassified on a scale from 1-9. Slope was classified on a continuous one to nine scale as well.

After obtaining data, CEAT used ArcGIS® to evaluate the septic suitability of the land area of the Salmon/McGrath watershed. Soil characteristics and slope were each given a 50% weight in the model; the soil characteristics category was then divided into four sections: saturated hydraulic conductivity, distance to bedrock and distance to water table were given equal ratings of 15% each; ponding was weighted at 5%.

Results and Discussion

The map created from the septic suitability model for the Salmon/McGrath watershed shows a range of septic suitability ratings (Figure 20). Because KCSWCD rated the entire watershed as having a "very limited" septic potential, all septic systems in the area require careful installation and monitoring. Further development must be done carefully to prevent leaching or other forms of contamination of the lakes. Homeowners with septic systems and those looking to install them must be familiar with the regulation authorities to ensure proper installation and maintenance of septic systems (see Watershed Development Patterns: Residential Development: Residential Zoning).

Areas in red have the lowest levels of septic suitability and areas in green are higher. The septic suitability map can be compared with the buffer quality map, which shows the location of houses along the shoreline of Salmon Lake and McGrath Pond (Figure 15, Figure 16). As most houses along the shoreline have septic systems, the comparison can be used to assess the septic suitability of existing houses and septic systems. A majority of houses along the lake are built in areas where septic suitability is relatively good in comparison to the rest of the watershed. However, it is important to remember that a relatively good rating for this watershed still has *very limited* septic suitability. All septic system owners in the watershed, and especially those in areas designated in red, must monitor their septic systems carefully to ensure that the systems are functioning properly. Owners of lots in areas with exceptionally low septic suitability may benefit from evaluating other possibilities for wastewater management systems. Holding tanks and pit privies are alternatives mentioned in the background to this report that may be more suitable for certain areas. However, these alternatives must be considered carefully, as specific soil and use conditions must be met for these systems to function properly (see Watershed Land Use: Subsurface Wastewater Disposal).

To differentiate septic suitability levels throughout the watershed, which is rated *very limited* for septic suitability, this model included factors not used by CEAT in previous models. The map produced for this model cannot be directly compared to previous septic suitability maps without an understanding of the different methods used to create each model.

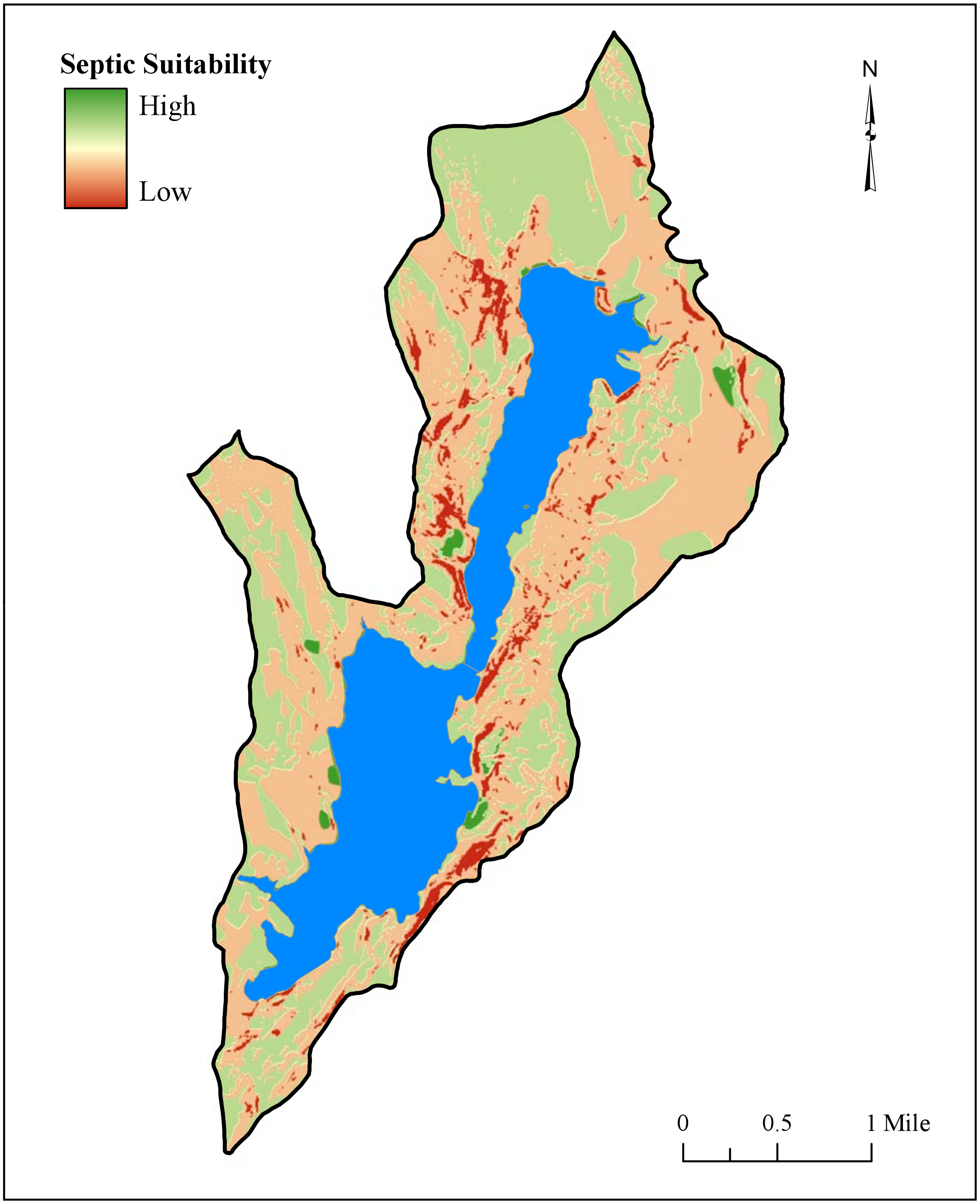

Figure 20. The Septic Suitability Model of the Salmon/McGrath watershed indicates areas of septic suitability based on slope (50%) and soil characteristics including saturated hydraulic conductivity (a measure of permeability) (15%), distance to restrictive feature (a measure of soil depth) (15%), distance to water table (15%) and ponding (the ability of an area to form pools of water) (5%). Red areas represent lower suitability and green areas represent higher suitability.

Roads

Introduction

Road conditions within the Salmon/McGrath watershed are influential in determining lake water quality. Most roads close to the lake shore are camp roads, and these roads can be a major source of nutrient loading into the lake because of their close proximity to the shoreline (KCSWCD 2000). Camp roads change natural storm water drainage patterns and increase the potential for erosion by removing protective vegetative cover and creating a highly erodible pathway of exposed soils in the watershed. Up to 85% of all erosion and sedimentation problems in lake watersheds originate from improper construction and maintenance of camp roads. Sediments that enter the lake can turn the water brown, cause sedimentation, irritate fish gills, increase phosphorus loading and the potential for algal blooms and decrease property values (KCSWCD 2000).

Roads within the watershed can be classified into three categories: state roads, town roads and camp/dirt roads. State and town roads are maintained regularly by state and local governments and are typically kept in good condition. Camp roads, however, are generally privately owned and maintained by residents living on each road. Many camp roads fall into disrepair because residents lack the funding, organization or knowledge of road repair to keep the road well maintained (KCSWCD 2000). However, it is estimated that $1 spent on routine maintenance will save $15 in capital repairs because costs increase as problems worsen (YCSWCD 2009). Road maintenance is not only good for maintaining water quality but is also cost-effective.

Regulations

There are three major laws in the State of Maine that affect camp road maintenance and construction. The Erosion and Sedimentation Control Law (Title 38, Chapter 3, Section 420-C) requires that erosion control devices be installed before any activity begins that will disturb the soil, and the devices must be maintained until the site is permanently stabilized (KCSWCD 2000). The Erosion and Sedimentation Control Law must be followed during road maintenance or construction. The Natural Resources Protection Act (Title 38, Chapter 3, Section 480-B) requires a permit from the Maine Department of Environmental Protection before beginning any activity in, on, over or within 75 ft of lakes, ponds, rivers, streams, brooks and wetlands. Regulated activities include filling, disturbing the soil, building permanent structures, removing or displacing vegetation, dredging or draining. The Mandatory Shoreland Zoning Act (Title 38, Chapter 3, Section 435-449) regulates development within 250 ft of lakes, rivers, tidal areas and wetlands, and within 75 ft of streams. Maintenance activity on existing camp roads generally does not require a permit under the Mandatory Shoreland Zoning Act. A permit may be required if the maintenance involves filling or widening the road (KCSWCD 2000).

Road associations are an effective means of developing successful camp road maintenance programs because they provide a way for road users to maintain their roads in a cost-effective manner (YCSWCD 2009). Establishing a road association can open communication among residents, improve planning and implementation of road maintenance, create an efficient means of dividing maintenance costs among residents and allow possible use of town funds and equipment for road repair. Road associations are also eligible to receive state grants for road repair (YCSWCD 2009). The McGrath Pond/Salmon Lake Association is currently collecting data about road associations within the Salmon/McGrath watershed (Borman, pers. comm.). The lake association is trying to learn how many road associations exist in the watershed and whether or not these road associations have an organized maintenance plan. Members of the lake association are designing a newsletter that will inform residents of the attempt to collect information about existing road associations. If the newsletter does not generate many responses, they will contact residents from each road directly to ask if a road association exists for that road. This process is in the initial stages, so information regarding road associations in the Salmon/McGrath watershed is still unknown (Borman, pers. comm.).

Methods

On 5-October-09, the Colby Environmental Assessment Team (CEAT) performed road surveys on most of the roads within the Salmon/McGrath watershed. Additional survey work was performed on 22-October-09 and 29-October-09. The watershed was divided into six areas and analyzed by groups of three to four surveyors for each area. The length and width of state and town roads were measured to determine their areas within the watershed, but no quality ratings were assigned to these roads because they fall under state and town jurisdiction. The road lengths were measured with odometers, and GPS points were taken at the ends of each road for use in GIS models. GIS was used to find lengths of roads for which the length was not recorded during the 5-October-09 road survey. The width of each road was measured using a distance wheel. The survey of camp roads included measurement of length and width; the roads were also assessed qualitatively based on road material, surface condition, crown height, ditch and culvert presence and condition, water diversion presence and condition and evidence of erosion (see Background: Roads; Appendix E).

After evaluating these characteristics, groups assigned each road a quality rating of good, acceptable, fair or poor (Figure 21). A good road has a sufficient crown, ditching and culverts where necessary, good road surface conditions and little to no evidence of erosion. An acceptable road has a few minor problems, such as an insufficient crown or a lack of ditching. In general, roads were rated as acceptable if there were no significant signs of erosion at the time of the survey, but these roads may lack characteristics that help divert water away from the road and could have erosion problems in the future. If water diversion structures already exist, maintenance is needed for proper functioning. Fair roads have more substantial problems, such as some signs of erosion, ditches or culverts in need of maintenance or an insufficient crown. Poor roads have major problems, such as large areas of erosion, poor road surface condition or damaged or blocked culverts. Repair priority should be given to roads in the poor category to prevent further damage. Surveyors addressed road problems by recording a description of the problem and suggesting possible remediation techniques (see Appendix F).

Results and Discussion

The CEAT road survey revealed that there are 66 camp roads, 3 state roads and 12 town roads in the Salmon/McGrath watershed. There are 17.8 mi of camp roads and 17.3 mi of state and town roads. The mean camp road width is 15.8 ft, and the mean width for state and town roads is 29.4 ft. Because roads have narrow widths, their total area within the watershed is small. Camp roads cover 13.2 ha, and state and town roads cover 27.7 ha. CEAT focused on camp roads because of their increased potential for phosphorus loading and their close proximity to the lake. Of the 66 camp roads in the watershed, 1

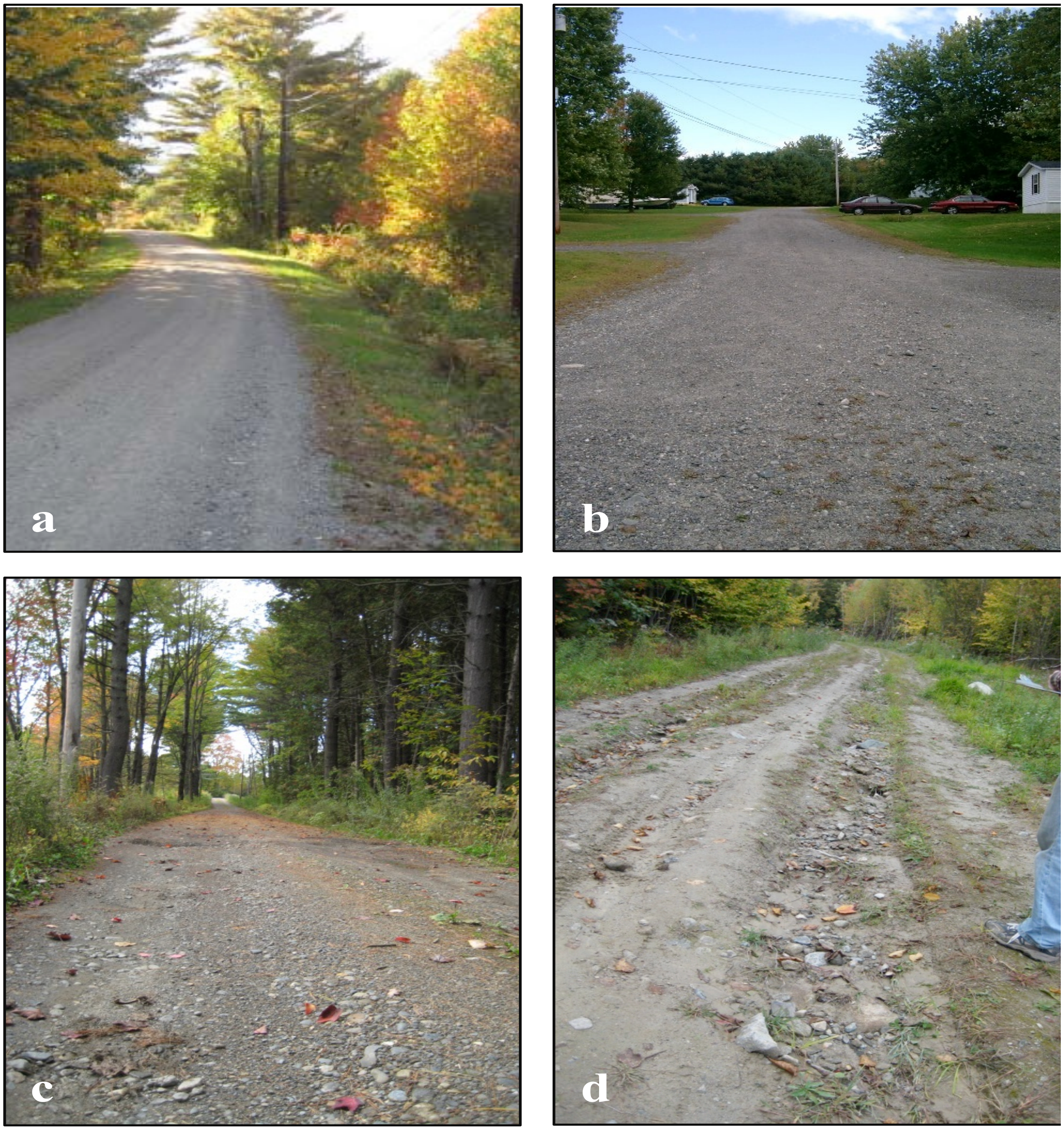

Figure 21. Examples of road qualiting ratings in the Salmon/McGrath watershed. (a) A road rated good - has a visible crown and natural ditching, and the surface is in good condition. (b) Acceptable - no evident erosion problems, but lacks a crown and culverts are in need of maintenance. (c) Fair - lacks ditching and proper crowning and has evident potholes. (d) Poor - tire ruts and extensive signs of erosion.

10 roads (15%) were rated as good, 18 (27%) were rated as acceptable, 23 (35%) were rated as fair, and 15 (23%) were rated as poor. Of the 17.8 mi of camp roads, 2.8 mi (15%) were rated as good, 5.9 mi (33%) were rated as acceptable, 5.5 mi (31%) were rated as fair, and

3.7 mi (21%) were rated as poor. Roads of all quality ratings were dispersed evenly throughout the watershed (Figure 22).

CEAT found problems on 40 of the 66 camp roads in the watershed. Common problems included culverts in poor condition, potholes, tire ruts, major signs of erosion along the road and poor maintenance of water diversion structures (Figure 23). The road problems identified during the survey are listed in Appendix F and are accompanied by suggested remediation techniques. In order to protect water quality most effectively, roads rated as poor should be repaired immediately. Roads rated as fair should be addressed second. Once the major road problems are repaired, some acceptable roads could be enhanced by adding water diversion structures at appropriate locations. All roads should be maintained regularly after repair.

The Belgrade Lakes Region has programs that residents in the Salmon/McGrath watershed can utilize to improve camp road quality. The Belgrade Regional Conservation Alliance (BRCA) is an organization dedicated to reducing sources of nutrient loading into the Belgrade Lakes (BRCA 2009). The BRCA Youth Conservation Corps has completed more than 494 erosion-control projects in the Belgrade Lakes watershed. Some of these projects have improved camp roads by lining eroding ditches with stones and building water bars and turnouts on roads. Landowners in the Belgrade Lakes watershed can report an area that needs erosion control to the BRCA, and the Youth Conservation Corps will provide free labor to improve the area. Landowners would only pay for the materials and any permit fees (BRCA 2009). The Youth Conservation Corps has already completed many projects to improve camp road quality in the Belgrade Lakes Region. Residents in the Salmon/McGrath watershed can use this program to repair some road problem areas identified in the CEAT road survey and to reduce the costs of road repair.

The Maine Department of Environmental Protection (MDEP) is also working to reduce non-point sources of nutrient loading in the Belgrade Lakes Region (MDEP 1998c). The MDEP administers the Non-point Source Grants Program to provide financial assistance for projects that prevent, control or abate water pollution by non-point sources. Maine public

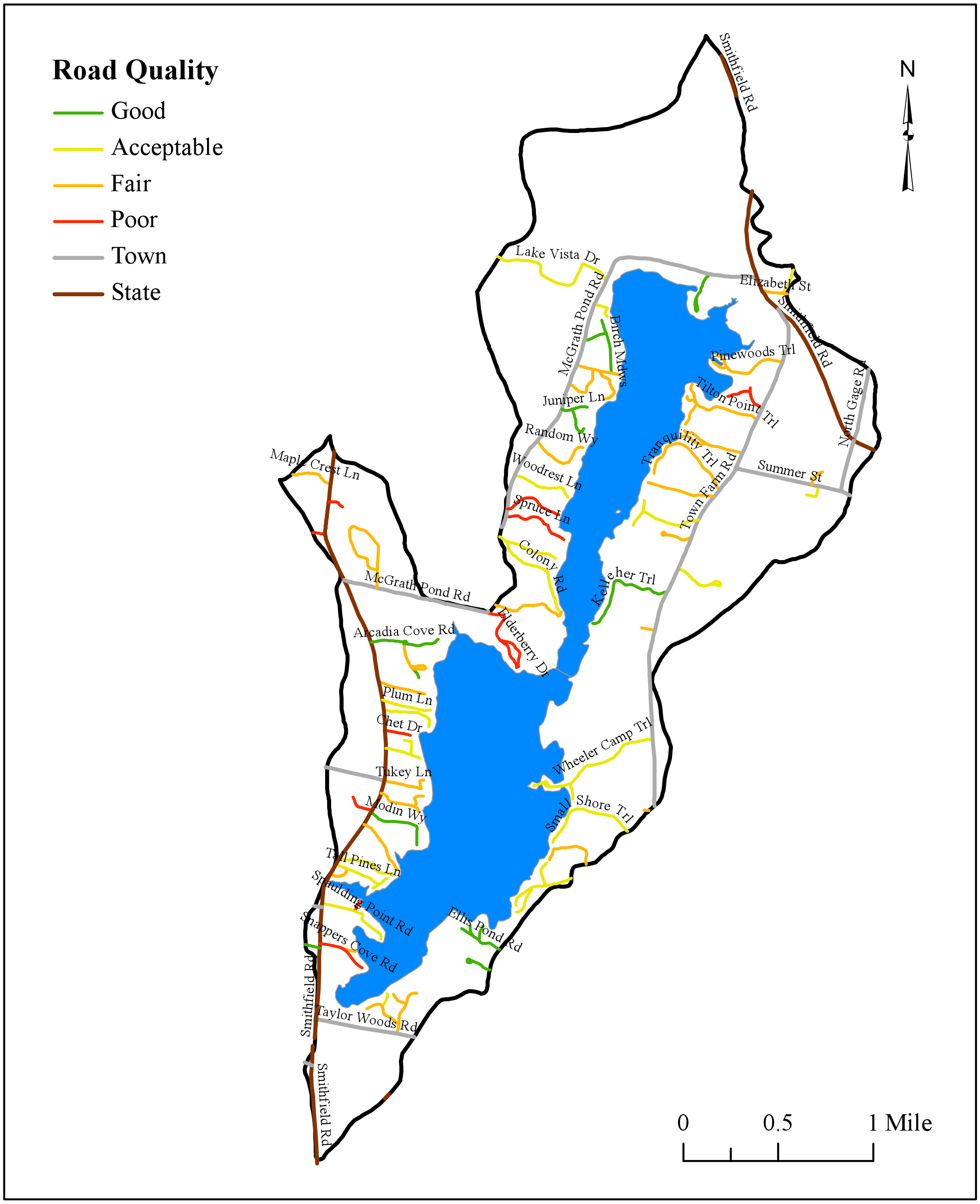

Figure 22. Road quality ratings of the camp roads in the Salmon/McGrath watershed (see Watershed Development Patterns: Roads). Town and state roads are also present in this map for reference, but were not given quality ratings. Data for this map were gathered by CEAT surveys in September and October 2009.

Figure 23. Examples of road problems in the Salmon/McGrath watershed. (a) A road with deep potholes. The road should be regraded to eliminate the potholes and improve crowning. (b) A culvert that is crushed and overtaken by grass. The culvert is also rusting. This culvert needs maintenance or replacement. (c) Rubber bars in disrepair. These rubber bars will not divert water properly and should be replaced. (d) A road with extensive erosion. Structures should be added to improve the removal of runoff from the road surface, such as rubber bars or ditches.

organizations such as state agencies, soil and water conservation districts, regional planning agencies, watershed districts, municipalities and nonprofit organizations are eligible to receive non-point source grants. The MDEP also conducted a survey of the Salmon/McGrath watershed in the spring and summer of 1998 to identify and document potential sources of non-point source pollution. During the survey, 131 sites were determined to have an impact on water quality. Each site was given a ranking based on technical level to install, impact, cost of remediation, and priority. The sites were categorized by land use, and remediation techniques were suggested for each site. Private roads comprised 27% of the sites and town and state roads accounted for 8%. Over half (55%) of the sites were residential and driveway sites. The MDEP published these finding in a report and included steps that the McGrath Pond/Salmon Lake Association and the BRCA can take to reduce non-point sources of nutrient loading. These suggestions included working with the Youth Conservation Corps to address problems found in the 1998 survey, working with road associations or landowners to improve camp road maintenance and developing vegetated buffer demonstrations (MDEP 1998c). These actions will improve water quality in Salmon Lake and McGrath Pond by reducing non-point sources of nutrient loading in the Salmon/McGrath watershed.

Soils

Soil properties (see Background: Watershed Land Use: Soil Types) are important in evaluating how land use and development within a watershed can affect erosion, nutrient loading and eutrophication of a lake (Barnes, Zac et al. 1998). Soils are generally classified by particle composition and depth. Particle composition is a function of particle size and texture and is a measure of the proportions of sand, silt and clay in the soil. Particle size strongly influences soil permeability, which affects the rate of effluent flow through the soil. As more water flows through the soil, the likelihood of nutrients and sediments being flushed into the water table and into the lakes is increased. Soil depth refers to the distance between the ground surface and the water table or restrictive feature such as bedrock. Sand, silt and clay particles hold water at different capacities. Sand is the largest soil component in size and its surface area to volume ratio is low, so sand particles have difficulty adhering to each other and obstructing the flow of water, resulting in relatively fast drainage. In contrast, clay particles compact more easily and have a higher surface area to volume ratio, which restricts drainage and instead of absorbing nutrients and sediments, allows them to flow into the lakes as surface runoff. Silt is a relatively small soil particle without the same cohesive properties as clay and can be easily transported as surface runoff to the lakes if exposed or eroded (Barnes, Zac et al. 1998).

Soil data were obtained from two separate sources. A shapefile of soil types was downloaded from the Maine Office of Geographic Information Systems (MGIS 2007). Soils in the Salmon/McGrath watershed were then extracted to create a layer specifically for the watershed. Additional soil attributes, including saturated hydraulic conductivity, distance to restrictive feature, distance to bedrock, ponding and k-factor were obtained from the Natural

Resources Conservation Service (NRCS) Soil Data Viewer (NRSC 2009b). There were eleven soil series identified in the watershed, including Hinckley, Hollis, Leicester, Limerick, Lyman, Madawaska, Made land, Melrose, Paxton, Peat and Muck and Peru (Figure 24). As a result of glaciations, all of these soil series are different varieties of loams, which is the result of mixing of soil particles of varying sizes. The proportions of different sized particles, soil depth and texture in the soil determine how the soil is categorized. In the Salmon/McGrath watershed, there exist stony, sandy and silty loams, which were respectively described based on the relatively high proportions of rocks (not considered soil particles), sand and silt present in the soil (NRSC 2009b). The proportions of different sized particles influence soil permeability and runoff potential that can increase the rate of eutrophication of Salmon Lake and McGrath Pond. Made land is an exceptional, miscellaneous category of which exact soil characteristics are unknown (USDA 1978). Made land generally refers to land where new soils are introduced or existing soils are altered from their natural state in preparation for construction of homes, businesses or agriculture (Commonwealth of Pennsylvania 1990).

The eleven soil series in the Salmon/McGrath watershed occur to varying extents in a patchy distribution. Much of McGrath Pond is surrounded by Leicester, a very stony, deep, and poorly drained loam. Salmon Lake is surrounded by several soil types. The southern lakeshore and portion of the watershed are surrounded by Peru loam, a deep and well-drained soil that formed from dense glacial till. Much of the eastern shore of Salmon Lake is characterized by peat and muck, a compact soil with low erodibility. The western shore is characterized primarily by the Paxton series, a well-drained and very deep soil. Finally, the northern shore is surrounded by Limerick, Lyman, Made land, Melrose and Peat and muck series, all with varying depths, erodibility and drainage abilities (NRSC 2009b). In areas such as this, developers should pay close attention to soil characteristics because erosion potential and septic suitability can vary significantly over short distances due to different soil types.

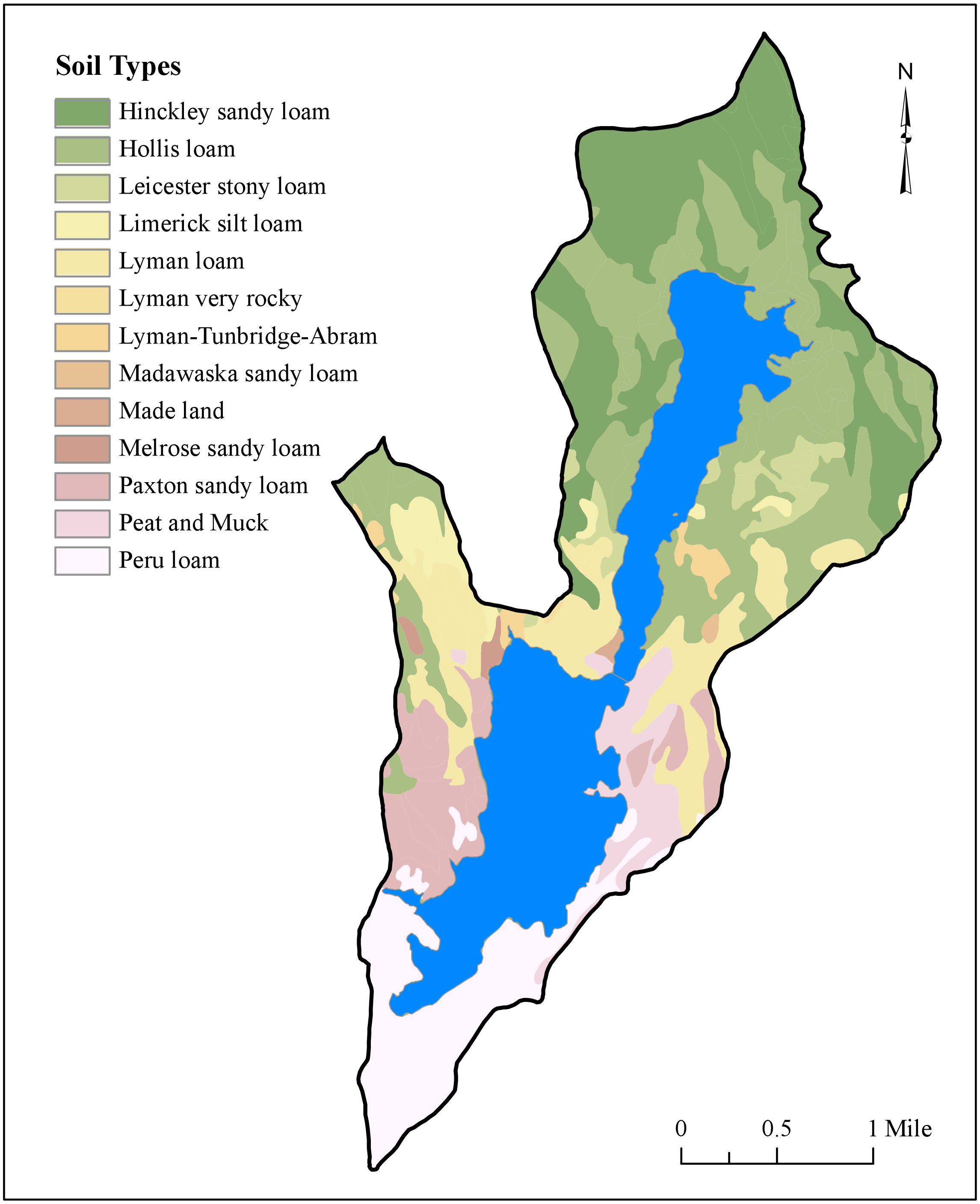

Figure 24. Soil types in the Salmon/McGrath watershed. Made land indicates land areas where new soils have been introduced, so exact soil characteristics are unknown. Soil data were obtained from the Maine Office of GIS.

Erosion Potential Model

Introduction

Erosion is a naturally occurring process accelerated by running water and sloped surfaces, which moves solid material away from its original location. Although some soil erosion is natural, in many places the activities of humans may accelerate this process beyond the natural ability of the environment to replenish soil, which causes harmful consequences for the health of the ecosystem (Morgan 1980). Eroded soils are ultimately washed into nearby water bodies, causing sedimentation, increased turbidity of water and higher concentrations of pollutants such as phosphorus, bacteria, oil and fertilizer that cling to soil particles (MDEP 2005a). The phosphorus level of a lake is delicately balanced so that small inputs above what occurs naturally can have damaging effects on water quality, organisms that depend on the lake and humans who use the lake for recreation. Levels of phosphorus above 12-15 ppb have been found to cause algal blooms and diminish the health of lakes in Maine (Williams 2008). In Maine, soil erosion is the most significant factor contributing to nutrient loading in surface water (MDEP 2005a). Accelerated soil erosion is caused by a number of factors, but most importantly by changing land use patterns (see Land Use Types: Trends). The Erosion Potential Model for the Salmon/McGrath watershed was constructed to show the susceptibility of erosion in different areas of the watershed.

The amount of erosion in a particular area is predominantly affected by the degree of slope in that location, soil type and land use practices (see Watershed Land Use: Soil Types). Both degree of slope and slope length are important in determining erosion potential (Figure 25; Morgan 1986). As slope increases, the potential of erosion in that location also increases because gravity is more easily able to pull loose stones and sediments downward, and running water accelerates and pulls apart soil. As the slope length increases, there is more space for running water to gain momentum and erode soil. The amounts of both wind and precipitation also influence the amount of erosion in an area (MDEP 2005a). Strong winds can pull sediments apart and move larger bits of sediment that would normally stay in one place. Frequent or intense precipitation washes away land where sediments are loosely held together.

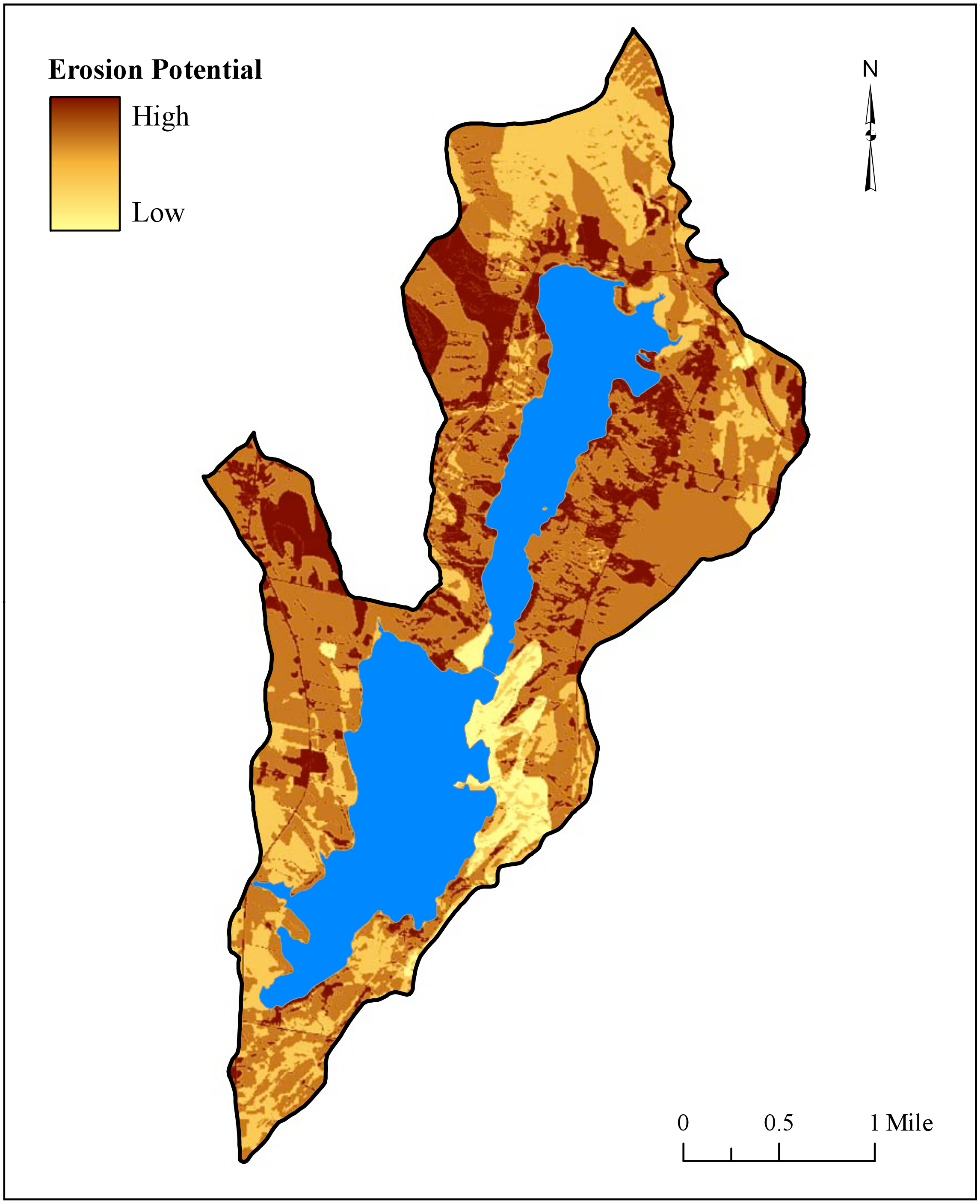

Figure 25. The Erosion Potential Model indicates the susceptibility to erosion of specific areas in the Salmon/McGrath watershed. Dark areas represent high erosion potential and light areas represent low erosion potential. Erosion potential is a function of slope (30%), soil k-factor (40%) and land use type (30%).

Soil type is very important in determining the potential amount of erosion in a certain area (see Watershed Development Patterns: Soils). Soil texture, soil stability, infiltration capacity and proportional content of organic matter all affect how susceptible a soil is to erosion (Morgan 1986). Generally, soils that have high infiltration rates, significant proportions of organic matter and well-defined soil structures are most resistant to erosion (MDEP 2005a). Large soil particles, like gravel and small pebbles are resistant to erosion because more energy is required to transport these particles. However, small clay particles are also resistant to erosion because of their high surface area to volume ratio, which makes them adhere to one another. Soils that contain lots of sand and silt are most easily eroded because the particles are small enough to be transported by running water but also large enough that they do not stick together as much as clay particles do (Morgan 2005). Soils with less than 45% sand and more than 27% clay are considered less erodible. These soils include mostly clayey loams and silty loams (Morgan 1986).

Land use types also play an important role in determining the erosion potential of an area. Land that has a high ratio of impervious surfaces increases the erosion potential of a location because water cannot percolate and instead creates runoff. Additionally, cultivated land involves plowing, which redistributes soil within a specific area, breaks down the soil structure and reduces the organic matter and nutrients present. These types of changes make the soil more susceptible to erosion (Morgan 2005). Cropland soils also often contain fertilizers and pesticides, which can be washed away by runoff. Vegetation cover is useful to prevent erosion, and its effectiveness depends on the density of cover and root growth. It lessens the impact and reduces the splash of raindrops, slows the movement of surface runoff and allows for infiltration of water into the ground (Morgan 1986). Construction activities also increase erosion potential because soils are disrupted and vegetation cover is often removed.

Methods

To construct the Erosion Potential Model (Figure 26), three different factors that affect the potential erosion of soil in the Salmon/McGrath watershed were considered. These factors included slope, land use patterns and soil type. To incorporate the slope into the model, elevation data were downloaded from the Maine Office of GIS. Digital Elevation

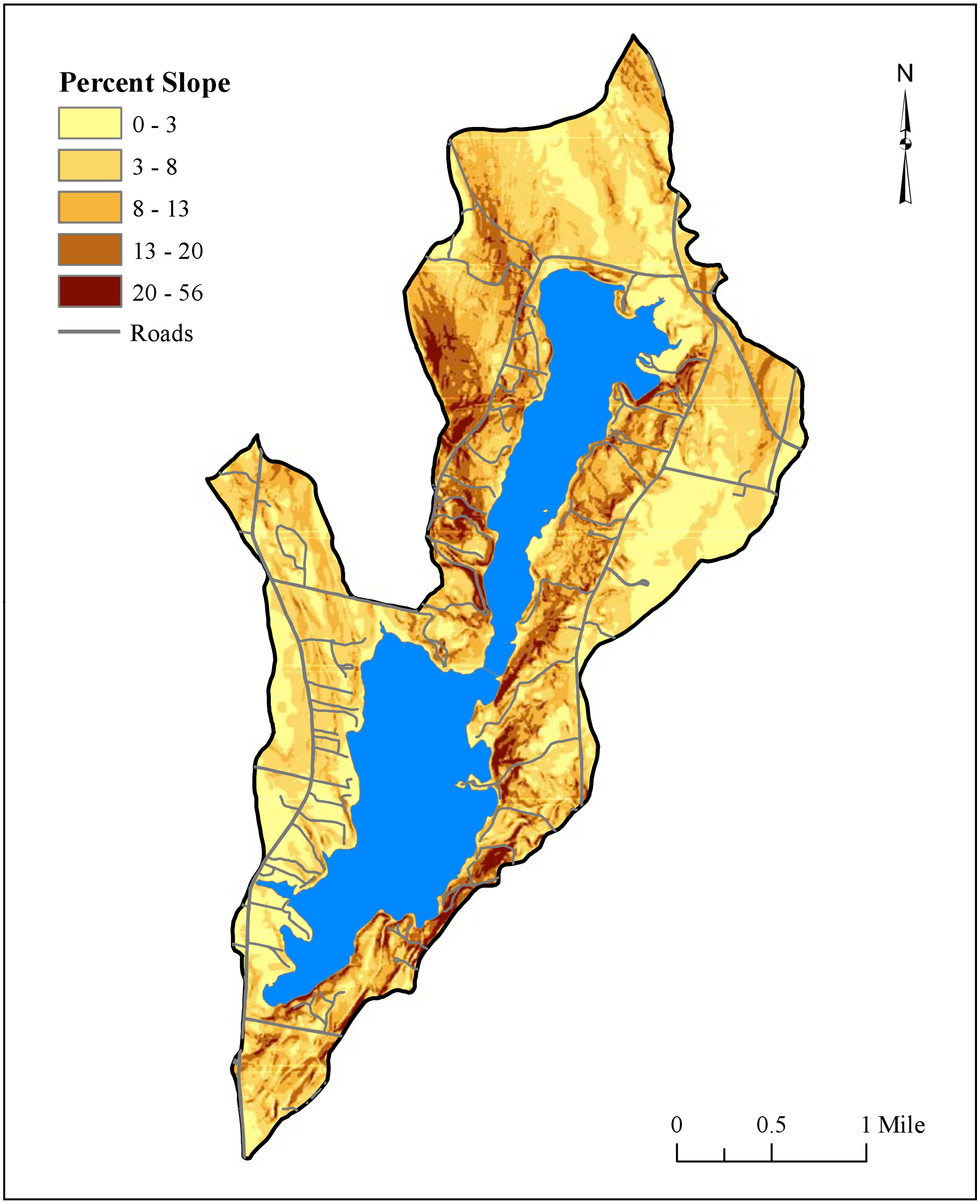

Figure 26. Map of percent slope of land in the Salmon/McGrath watershed based on Digital Elevation Models (DEM) provided by the Maine Office of GIS and analyzed with ArcGIS™. Major roads have been added to the map for reference.

Models (DEM) of the area with 10x10 m resolution were used and were then cropped to fit the Salmon/McGrath watershed boundary. The resulting raster values were then converted to slope percentages using Spatial Analyst. These percentages were reclassified on a scale of integers from 1-9 with 9 representing the steepest slope percentages in the dataset and the highest erosion potential. Slopes rated 1 were not steep, so they had the lowest erosion potential.

Soil information, including soil k-factor (susceptibility to erosion), was downloaded from the Soil Survey Geographic Database (SSURGO), a component of the Maine Natural Resource Conservation Service (NRCS 2009). All soil types occurring within the Salmon/McGrath watershed were mapped using data from Kennebec County. Reports of physical soil properties were electronically generated and downloaded to provide k-factor values (NRCS 2009). K-factor values in the Salmon/McGrath watershed ranged from 0.00-0.32. Surrounding Salmon Lake and to the north of McGrath Pond, the soil k-factor is lowest in the watershed, at 0.24. Parts of the watershed to the north of Salmon Lake and most of the land surrounding McGrath Pond have k-factor values of 0.28, which is moderate for the soils in this watershed. Within the areas that have a 0.28 k-factor, there are a few small pockets where the soil has the highest k-factor of 0.32, corresponding to the presence of the Limerick soil series, which has the highest susceptibility to erosion. The k-factor is 0 in wetland areas, where the soil is unlikely to erode, and in made land, where the k-factor is unknown because exact soil characteristics are unknown. Because the watershed has fairly homogenous soil types in terms of k-factor, each of the four different k-factors was assigned a value from 1-9 based on their relative erosion potential (Table 9). K-factors of 0 received the lowest erosion potential value of 1, and k-factors of 0.32 received the highest erosion potential rating of 9. The scaled k-factor attribute was then converted to a raster for use in the model.

Table 9. Erosion Potential ratings for different soil type k-factors in the Salmon/McGrath watershed (NRCS 2009).

K-factor	Erosion Potential Rating	Soil Types
0	0	Peat and Muck, Made Land
0.24	5	Hinckley, Paxton, Peru
0.28	7	Hollis, Lyman, Leicester, Madawaska, Melrose
0.32	9	Limerick

To determine the effect of land use type on erosion potential, the Land Use Types dataset (see Land Use Types) was used. Each land use type was assigned an erosion potential rating on a scale of integers from 1-9 (Table 10), with 9 representing the highest susceptibility to erosion (CEAT 2009). For example, roads of all types were given the highest rating, 9, because their impervious surfaces provide little opportunity for infiltration of rain water and increase runoff, leading to higher potential erosion. In contrast, wetlands were given a rating of 1 because they absorb rainwater and filter out many harmful nutrients before they can enter the lake. The lake itself was given a rating of 0. This data layer was then converted to a raster image to be used in the model.

To create the Erosion Potential Model, slope, soil type and land use were each given a relative weight depending on their respective influence on erosion potential. Soil type was given a weight of 40% because it more likely contributes more to erosion potential than either slope or land use, which were both given a rating of 30%. Soil type has a greater effect on erosion potential than either slope or land use type because soil type fundamentally determines how susceptible an area is to erosion through particle size and composition, regardless of the land use type or slope. The Erosion Potential Model was produced in Spatial Analyst using the combination of these three weighted overlays.

Table 10. Erosion Potential ratings for different land use types in the Salmon/McGrath watershed (CEAT 2008, CEAT 2009).

Land Use Type	Erosion Potential Rating
State Road, Municipal Road, Dirt Road	9
Horse Farm, Sawmill	8
Commercial	7
Camp, Park	6
Cleared Land, Golf Course, Non-shoreline Residence, Shoreline Residence	5
Cropland, Logged Area, Municipal, Open Field	4
Regenerating Land, Reverting Land	3
Coniferous Forest, Deciduous Forest, Mixed Forest, Transitional Forest	2
Wetland	1

Results and Discussion

Areas of the map with a darker color represent areas with high erosion potential (Figure 26). These areas are more concentrated around the shoreline of McGrath Pond where residences are fairly concentrated, and especially on its northwest corner where considerable logging is being practiced. Both the northeast corner of the watershed and the eastern shore of Salmon Lake have fairly low erosion potentials because there are many wetlands those two locations, which dampen susceptibility to erosion despite the fairly steep slope on the eastern side of Salmon Lake. The area to the west of McGrath Pond is a logging area located on a fairly steep slope, so much of the land has little vegetation, which makes this area particularly susceptible to erosion (Figure 26). Areas with especially low erosion potential include forested areas at the northern and southern regions of the watershed. Aside from the dark areas concentrated around residences on McGrath Pond and the logged area, the majority of the watershed has a fairly moderate to low erosion potential.

Erosion Impact Model

Introduction

The Erosion Impact Model is similar to the Erosion Potential Model (Figure 26) with the main difference being the consideration of the proximity of potential areas of erosion to Salmon Lake and McGrath Pond and their tributaries. The principal assumption of this model is that the impact of erosion on lake water quality is higher in areas closer to the lakes than in areas farther from the lakes. For example, although an area of land near the lakes or tributaries has only moderate erosion potential based on soil type, land use and slope, erosion from this area may have a higher impact on lake water quality than would erosion from a highly erodible area farther from the lake.

Methods

The Erosion Impact model consisted of a weighted overlay of three datasets: the existing Erosion Potential Model (see Watershed Development Patterns: Erosion Potential Model), lake proximity and stream proximity. A weighted overlay is a model type in which values from different datasets are weighted according to importance and added together to form a composite dataset (ESRI 2009). The lake proximity dataset was prepared by creating a 250 ft buffer around the lakes. This distance was chosen because 250 ft is the legal boundary between shoreline and non-shoreline development under Maine state and town regulations (see Watershed Development Patterns: Residential Development Patterns; Town of Belgrade 1991; Town of Oakland 1995). The buffered area was assigned an erosion impact rating of nine, indicating its high erosion potential and closeness to the lake. The remaining area in the watershed was then divided into eight rings of equal widths and assigned values of 1-8, with one representing the outermost area in the watershed where eroded sediments and nutrients are least likely to reach the water body. The resulting buffer layer was then converted to raster with pixel values assigned based on the distance from the lakes for use in the model.

The stream proximity dataset was prepared in similar fashion. The stream layer was given a buffer of 75 ft because this is the distance from the streambed designated as Resource Protection under Belgrade and Oakland Shoreland Zoning, consistent with Maine state law (Town of Belgrade 1991, Town of Oakland 1995). Development in this area is not allowed without a permit to maintain natural vegetative buffers and reduce potential nutrient loading into streams. The area within the buffer was assigned a value of eight, representing the high potential for streams to transport eroded nutrients and sediments into the lakes. The value of eight was chosen to account for the indirectness of erosion input to the lake through streams contrasted with the direct erosion input area of 250 ft around the lakes. Land outside the buffered area was given a rating of zero because the impact of erosion in these areas was already accounted for in the lake proximity dataset (CEAT 2009). The resulting buffer layer was then converted to raster based on distance from streams for use in the model.

The weighted overlay incorporated all three datasets with the following weights: Erosion Potential Model, 50%, lake proximity, 40% and stream proximity, 10%. Erosion potential is a very important factor and makes the determination of erosion impact possible, so it was given the highest weight of 50%. Lake proximity is also a very important factor since the severity of erosion impact can be a function of distance from the lakeshore, so it was also given a high weight of 40%. Stream proximity was weighted only 10% because sediments and nutrients can settle out or be absorbed by plants while traveling downstream.

In addition, some streams do not flow consistently throughout the year and their flow rates are determined by fluctuations in precipitation.

The output map is a raster image with a 10 x 10 pixel cell resolution that uses a color gradient to display areas of varying erosion impact. Green areas represent areas of relatively low erosion impact and red areas represent areas of relatively high erosion impact. The stream layer was included for spatial reference.

Results and Discussion

In the Salmon/McGrath watershed, the resulting erosion impact (Figure 27) ranged from low to high. Areas immediately adjacent to the lakes pose a higher threat of erosion impact, though an exception is the northeast shore of Salmon Lake near the connection to McGrath Pond. The land at this location is undeveloped and characterized by wetlands which have very low erosion potential. In general, areas surrounding streams exhibited higher erosion impact, though the impact of streams is reduced further from the lakes as the distance eroded sediments must travel increases. Streams are an important mode of transport for nutrients and eroded sediments, especially after periods of heavy rainfall when the rate of stream flow is increased. Some streams flow into wetlands (see Background: Watershed Land Use: Wetlands), however, which contain aquatic macrophytes that have some capacity to act as nutrient filters (Washington State Department of Ecology 1998). Nonetheless, erosion near streams is best kept to a minimum to decrease the total amount of nutrients entering streams. State and municipal regulations regarding development along streams should continue to be followed and enforced to maintain natural vegetative buffers and reduce erosion and nutrient loads.

The results of the Erosion Impact Model can be applied to responsible future development planning. Development increases the area of exposed soils and reduces the extent of vegetative buffers. Development in areas of high erosion impact should take special concern to maintain natural buffer strips and reduce the amount of exposed soils to prevent additional erosion. Another important consideration in development planning is the suitability of the area for a septic system (Figure 20; see Watershed Development Patterns: Septic Waste Disposal Systems). An area with low erosion impact seemingly suitable for development might also have low septic suitability, so development in this area is less

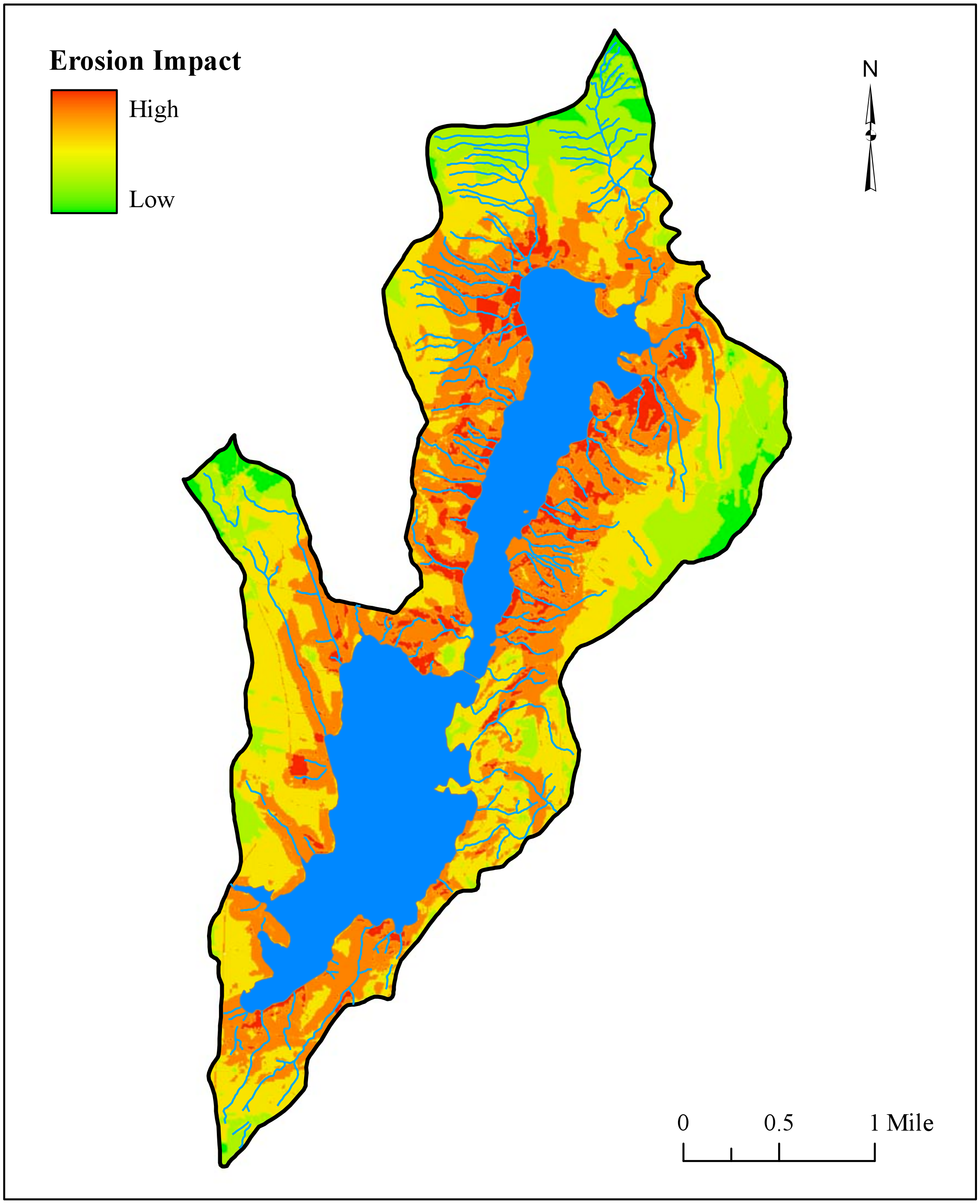

Figure 27. The Erosion Impact Model of the Salmon/McGrath watershed indicates areas where erosion is most likely to affect lake water quality. Red represents areas of high erosion impact and green represents areas of low erosion impact. Erosion impact is a weighted function of the Erosion Potential Model (50%) (Figure 25) and proximity to lakes (40%) and proximity to streams (10%).

desirable than in an area with low erosion impact and high septic suitability where the impact of development on lake water quality would be lower.

It is also important to consider that the Salmon/McGrath watershed, compared to the other watersheds in the Belgrade Lakes Region, has a relatively high lake surface to land area ratio. There are few areas in the watershed located more than a mile from the lakeshore, so the short distance runoff must travel to enter the lakes can increase the impact of erosion on lake water quality throughout the watershed. The most recent erosion impact assessments in the Belgrade Lakes Region conducted by CEAT were of the North and South basins of Long Pond (CEAT 2007, 2008). Erosion impact in Long Pond North is relatively high in most of the watershed (CEAT 2007) because the lake surface to land area ratio is high. In the South basin, however, erosion impact is low in most areas not immediately surrounding the lake (CEAT 2008) because the watershed is much larger and contains a considerable amount of land relatively far from the water body.

WATER QUALITY ASSESSMENT

WATER QUALITY STUDY SITES

Bathymetry

To provide an enhanced understanding of the basin shape of Salmon Lake and McGrath Pond, a bathymetry map (Figure 28) of the lakes was produced using three data sources. A powerboat was equipped with a Lowrance, an instrument outfitted with both Sonar and a Global Positioning System (GPS). The Lowrance recorded depth and GPS points everywhere the powerboat traveled and 39,180 points were collected. Data were also obtained manually during the Colby Environmental Assessment Team (CEAT) shoreline survey with one depth point taken directly offshore from each shoreline residence for a total of 339 points. A third dataset was introduced because a few sections of the lake were not thoroughly covered by the powerboat or the shoreline survey. This information came from bathymetry maps obtained online from Maine PEARL, an online environmental database associated with the University of Maine. Ten selected points from the PEARL maps covering under-surveyed areas of the lakes were manually added to a composite layer in ArcGIS 9.3 containing depth points from all three data sources.

The bathymetry map was produced using the kriging method of interpolation (ESRI 2009). Interpolation is a way of mathematically predicting values of areas based on the values of surrounding areas. Kriging is one of several interpolation methods, but is considered the most accurate and useful when dealing with large datasets such as this one (ESRI 2009). Due to the locations of the data points taken, the lakes were divided into three separate areas, interpolated individually and then recombined to form a composite bathymetry profile. The reason for this was that taken data points were not evenly distributed throughout the lakes, so areas with high densities of data points would receive a disproportionately high weight in the interpolation if the lake had not been split into three sections. In each section, the angle and direction of the search radius for neighboring points was manipulated to smooth the resulting values. The output map was displayed with a cell resolution of 1 x 1 pixels to maximize smoothness and visual variability. Some accuracy was sacrificed when data were smoothed and interpolated because known values were

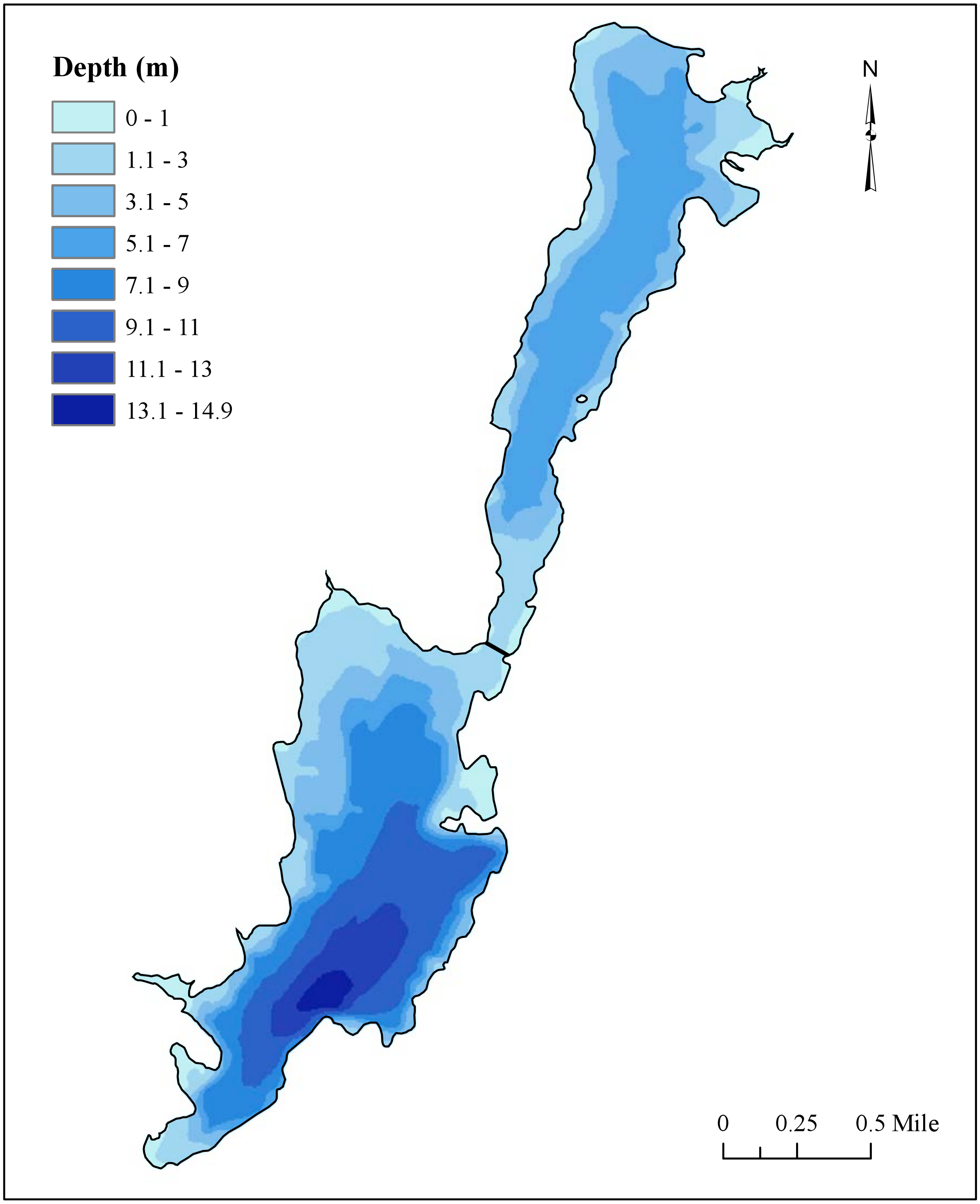

Figure 28. Bathymetry map of Salmon Lake and McGrath Pond, based on a kriging interpolation in ArcGIS 9.3.1 of over 40,000 depth points surveyed by CEAT in the summer and fall of 2009. Points were obtained from three sources: (1) Lowrance, an instrument with a combined Sonar and Global Positioning System (GPS), (2) manual measurements along the shoreline and (3) depth maps obtained from the PEARL website (PEARL 2009e, 2009f).

recalculated based on surrounding values, but the high volume of data points and the separate interpolations were used to balance accuracy and useful visual representation.

Salmon Lake and McGrath Pond have a total surface area of 458.1 hectares (ha) and a mean depth of 5.5 m (n=39,180) based on the areas surveyed. In general, Salmon Lake is considerably deeper than McGrath Pond. The deepest recorded area was 14.9 m in the southeast portion of Salmon Lake, which was shallower than the 15.9 m indicated by the PEARL map (PEARL 2009b). The deepest area of McGrath Pond recorded was 7.0 m, which was shallower than the 8.2 m recorded on the map (PEARL 2009a). The depth of McGrath Pond is fairly uniform in the central part of the basin, generally ranging 6-7 m. Salmon Lake is more variable, with the eastern section of the lake over 9 m deep in areas close to the shore. The northwest section, however, is consistently shallow with depths below 3 m relatively far offshore.

In the Belgrade Lakes Region, Salmon Lake is a moderately deep lake and McGrath Pond is relatively shallow. Messalonskee Lake and Long Pond South are the deepest lakes in the Belgrade chain, reaching depths of 34 and 28 m, respectively (CEAT 1998, 2008). The basin shapes of Messalonskee Lake and Long Pond South are elongated and relatively steep, conditions that tend to produce deeper lakes because steep inclines on land generally continue underwater (Davis, Bailey et al. 1978). Salmon Lake has a somewhat rounded basin and a relatively flat western shore, so it would be expected that Salmon Lake would be shallower than Messalonskee Lake and Long Pond South, especially in the western portion of the lake. The eastern shore of Salmon Lake, however, is considerably steeper, which could help explain the deeper water in the eastern section of the lake. North Pond is the shallowest lake in the Belgrade chain, reaching a maximum depth of 6 m (CEAT 1997). McGrath Pond is surrounded by gently sloping land similar to the land around North Pond, which could explain the shallower characteristics of McGrath Pond. The deepest part of the lake is the elongated central portion, though the northern section is shallow and rounded in shape like North Pond (CEAT 1997).

The bathymetry of a lake is closely related to its trophic status because deeper lakes tend to contain fewer nutrients and more dissolved oxygen (see Background: Lake Characteristics: Trophic Status). The deepest areas, however, do not mix during the summer and can become anoxic, which can lead to the release of phosphorus into the water column from bottom sediments. Anoxia was detected in Salmon Lake at Site 1 on 18-August-09 and 17-September-09 (see Salmon/McGrath Water Quality: Dissolved Oxygen and Temperature). Shallower areas have higher productivity and are at a higher risk for establishment of invasive plants such as Eurasian watermilfoil (see Water Quality Assessment: Invasive Plants) because light can penetrate through the water column to the lake bottom (Chapman 1992). The risk of the colonization of Eurasian watermilfoil, due to the public boat access and extensive shallow areas especially along the western shore of Salmon Lake, is of particularly high concern and will continue to be monitored closely in the near future by Maine DEP.

Sampling Methods

There were a total of 14 lake sample sites chosen to assess the water quality of Salmon Lake and McGrath Pond and these sites were chosen as either Characterization or Spot sites. Two Characterization Sites were selected in Salmon Lake and two in McGrath Pond; all tests were performed at these sites to characterize a variety of chemical parameters for the two water bodies and to determine the overall health of the lake system. Spot Sites were selected at various points throughout the two water bodies and were chosen based on their proximity to wetlands or developed lands to examine the impact of watershed land use on the water bodies. The sampling for all sites in 2009 was completed on 3-June, 17-June, 25-June, 09-July, 15-July, 28-July, 04-August, 10-August, 18-August, 17-September or 24-September and was done by the Colby Environmental Assessment Team (CEAT). A variety of sampling techniques were used at the lake sites including surface, mid-depth and bottom grabs, as well as epicore samples. Each of these four techniques was used at the deepest sites in Salmon Lake (Site 1) and McGrath Pond (Site 3). At the remaining two Characterization Sites (Sites 2 and 10) surface, mid-depth and bottom grabs were performed. At the Spot Sites, only surface grabs were used due to inadequate depths for the other methods.

There were a total of seven Tributary Sites, labeled A-G, selected from the Salmon/McGrath watershed, however; only six tributaries were sampled because Site C was found to be dry. The different tributaries were selected based on their inflow or outflow contribution to Salmon Lake and McGrath Pond. These sites were also chosen based on their proximity to different land use types to examine the impact of watershed land use on the lake. The sampling for all the Tributary Sites was done on 17-September-09 and all samples were surface grabs.. At the six Tributary Sites only surface grabs were used, again because they were too shallow for additional methods. For more detailed information on water quality sampling and analytical procedures, see Appendices K and L. See Figure 29 for a map of site locations.

Salmon Lake and McGrath Pond

Descriptions of Characterization and Spot Sites in Salmon Lake and McGrath Pond are provided below.

Site 1: Salmon Lake Characterization Site

Northing: 4930132 Easting: 0437734 Depth: 14.5 m

This site is located in the south-central region of Salmon Lake approximately 0.5 miles east of the cove leading to Great Pond. It was chosen because it is approximately the deepest point in the entire lake system. CEAT performed a variety of tests at this site throughout the summer and the Maine Department of Environmental Protection (Maine DEP) has performed various tests here in years past, beginning in the 1970s.

Site 2: McGrath Pond Characterization Site

Northing: 4934071 Easting: 0439280 Depth: 7.2 m

This site is located in the central region of McGrath Pond in the middle of the lake offshore from Camp Tracy and was chosen due to its high depth. CEAT performed a variety of tests at this site throughout the summer of 2009 and Maine DEP has performed various tests here in years past.

Site 3: McGrath Pond Characterization Site

Northing: 4934704 Easting: 0439377 Depth: 6.8 m

This site is located in the north-central region of McGrath Pond just outside of Mutton Hill Cove and was chosen due to the fact that it is relatively deep. CEAT performed a variety of tests at this site throughout the summer and Maine DEP has performed various tests here in years past.

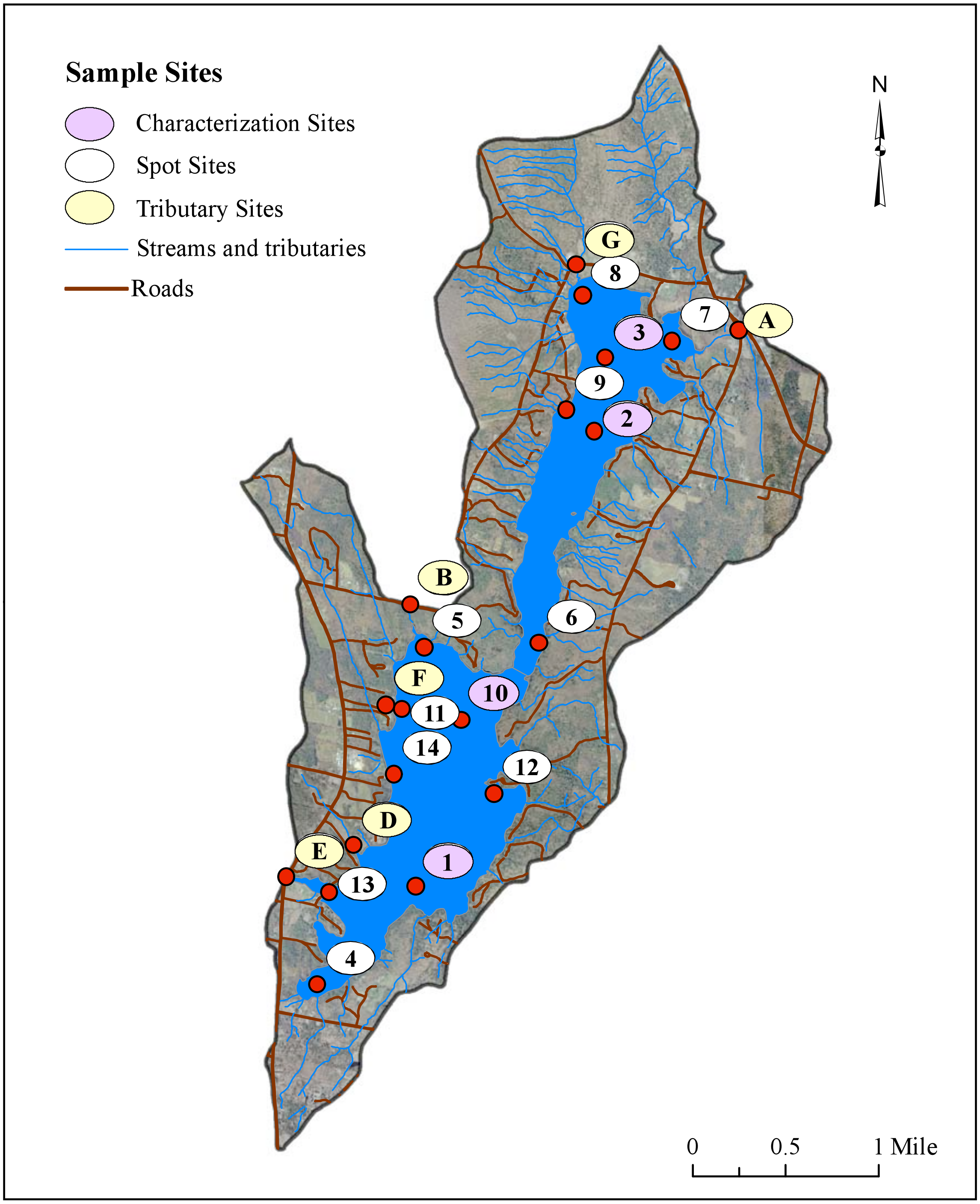

Figure 29. The locations of the sample sites used for water quality testing in the Salmon/McGrath watershed. The sites are classified into tributary sites, (yellow), to determine the quality of water entering the lake trhough tribuatries, characterization sites (purple), to determine the overall water quality of the lake and spot sites (white), to determine the effects of specific land use types in the watershed on water quality.

Site 4: Salmon Lake Spot Site

Northing: 4929280 Easting: 0436888 Depth: 2.6 m

This site is located in the southernmost tip of Salmon Lake and was chosen due to its proximity to wetlands to determine if they are a source or a sink for nutrients or pollutants and to characterize the southern cove of the lake. Tests were performed at this site by CEAT throughout the summer.

Site 5: Salmon Lake Spot Site

Northing: 4932202 Easting: 0437808 Depth: 0.8 m

This site is located in the northwestern cove of Salmon Lake and was chosen based on its proximity to wetlands to determine if they are a source or a sink for nutrients or pollutants, to characterize the northwestern cove of the lake and to examine the effect of the Cold Brook inflow.

Site 6: McGrath Pond Spot Site

Northing: 4932234 Easting: 0438798 Depth: 2.0 m

This site is located in the channel between Salmon Lake and McGrath Pond and was chosen to determine the quality of water flowing between the two water bodies. Tests were performed at this site by CEAT throughout the summer.

Site 7: McGrath Pond Spot Site

Northing: 4934852 Easting: 0439952 Depth: 1.7 m

This site is located in Northeast Bay of McGrath Pond and was chosen due to its proximity to wetlands, to characterize the northeastern cove of McGrath Pond and to examine the effect of inflow from various nearby tributaries. Tests were performed at this site by CEAT throughout the summer.

Site 8: McGrath Pond Spot Site

Northing: 4935246 Easting: 0439177 Depth: 1.6 m

This site is located in Mutton Hill Cove in the northwestern region of McGrath Pond and was chosen to characterize this area of the pond, to examine the effect of inflow from different land use types and to determine the impact of various tributaries draining into this area.

Site 9: McGrath Pond Spot Site

Northing: 4934257 Easting: 0439040 Depth: 2.0 m

This site is located along the western shore of McGrath Pond approximately 75 m offshore from Camp Tracy's beach. It was chosen due to its proximity to Camp Tracy to examine the youth camp's potential effect on water quality.

Site 10: Salmon Lake Characterization Site

Northing: 4931567 Easting: 0438127 Depth: 8.1 m

This site is located in the north central region of Salmon Lake just outside of the northwestern cove. It was chosen as a second characterization site for the lake because it is relatively deep.

Site 11: Salmon Lake Spot Site

Northing: 4931662 Easting: 0437617 Depth: 2.6 m

This site is located along the approximately 50 m off the western shore of Salmon Lake just outside of the northwestern cove. It was chosen due to its close proximity to a dense shoreline residential area.

Site 12: Salmon Lake Spot Site

Northing: 4930935 Easting: 0438413 Depth: 9.2 m

This site is located approximately 50 m off the southern shore of Birch Point on the eastern shore of Salmon Lake and was chosen due to its close proximity to a dense residential area.

Site 13: Salmon Lake Spot Site

Northing: 4930077 Easting: 0436988 Depth: 1.7 m

This site is located directly outside of the cove on the western shore of Salmon Lake. It was chosen to determine the quality of the water flowing toward Great Pond via Hatchery Brook.

Site 14: Salmon Lake Spot Site

Northing: 4931104 Easting: 0437549 Depth: 3.8 m

This site is located on the western shore of Salmon Lake approximately 75 m offshore from the sawmill. This site was chosen to examine the potential effect of the sawmill on water quality.

Tributaries

Descriptions of Tributary Sites are provided below.

Site A: McGrath Pond Tributary Site
Northing: 4934409 Easting: 0440534
This site is located in Northeast Bay Stream, which enters the pond between Sites 2 and 7. It was chosen to examine the quality of water entering the lake system from the eastern part of the watershed.

Site B: Salmon Lake Tributary Site
Northing: 4932569 Easting: 0437691
This site is located in Cold Brook, which enters the lake near Site 5 and was chosen to characterize the water quality of the major tributary flowing into Salmon Lake before reaching the wetland area.

Site D: Salmon Lake Tributary Site
Northing: 4930488 Easting: 0437199
This site is located in a tributary just south of Camp Modin and was chosen to examine the potential effect of the youth camp on the water quality and the effect of the nearby road. It is important to note that the water at this site was stagnant when sampling occurred.

Site E: Salmon Lake Tributary Site
Northing: 4929205 Easting: 0436808
This site is located in Hatchery Brook (downstream from the dam), which flows from Salmon Lake into Great Pond. It was chosen to determine the overall quality of water as it left the Salmon/McGrath watershed.

Site F: Salmon Lake Tributary Site
Northing: 4930487 Easting: 0437197

This site is located in a tributary on the western side of Salmon Lake and was chosen to investigate the effects of multiple road crossings on the water quality.

Site G: McGrath Pond Tributary Site
Northing: 4935509 Easting: 0439124

This site is located in Mutton Hill Road Stream just north of Mutton Hill Cove in McGrath Pond. It was chosen to determine the effect of outflow from surrounding land use types on lake health.

SALMON/ McGRATH WATER QUALITY

Physical Measurements

Dissolved Oxygen and Temperature

Introduction

Dissolved oxygen (DO) and temperature are important indicators of lake water quality. DO measures the amount of oxygen (O_2) dissolved in water, reported in parts per million (ppm) and temperature represents the amount of heat held in the water, measured in degrees Celsius (°C). In lakes, DO is removed from the water when organisms respire and from the decomposition of dead organic matter (Brönmark and Hansson 2005). Oxygen is added to the lake through photosynthesis and by diffusion from the atmosphere.

The dissolved oxygen concentration in lakes is influenced by water temperature and density, a property that creates a significant relationship within lakes. Generally, DO is negatively correlated with water temperature; as water temperature increases, dissolved oxygen levels decrease (PEARL 2009g). Additionally, the density of water increases as temperature decreases; warmer, less-dense water floats at the top of a lake while colder, more-dense water sinks to the bottom. This creates distinct layers of different temperatures in a lake, known as thermal stratification. Lakes tend to stratify during the summer months into three layers: the epilimnion, metalimnion and hypolimnion (see Background: Annual Lake Cycles). As a result of thermal stratification, colder water sits at the bottom of a lake whereas warmer water floats at the surface. This prevents the mixing of well-oxygenated water at the surface with oxygen-deprived water at depth, which can lead to a severe depletion of oxygen near the bottom resulting in anoxic conditions (DO level of less than l ppm).

Low oxygen levels can have significant impacts on aquatic organisms and natural processes. Most aquatic organisms require dissolved oxygen concentrations above 5-6 ppm. When concentrations fall below this level, organisms become stressed and can die (Boyd 2005). Low dissolved oxygen concentrations can have particularly adverse affects on fish populations because they require dissolved oxygen at certain levels, above 5-6 ppm, in order for oxygen to diffuse through their gills and into their blood. Furthermore, under anoxic conditions, phosphorus trapped in sediments as part of ferric compounds breakdown and is re-released back into the water column (See Background: Phosphorus and Nitrogen Cycles). Salmon Lake and McGrath Pond are dimictic lakes, meaning the water column mixes twice a year in the spring and fall (See Background: Annual Lake Cycles). When the water column mixes, temperature and dissolved oxygen are redistributed uniformly. However, mixing also brings nutrient rich sediments containing phosphorus from the bottom making them available at the surface, which can lead to algal blooms. This has adverse affects on lake health since algal blooms further reduce DO in lake water when dead algae sink to the bottom depths and are decomposed (PEARL 2009g).

Methods

A YSI 650 MDS Sonde was used to make profile measurements of Sites 1-3, which were sampled throughout the summer from 3-June-09 to 18-August-09 and again on 17-September-09 (except Site 2). Sites 4-7 were also sampled on the surface throughout the summer. On 17-September-09, Site 10 was sampled with the Sonde and Sites 4-9, 11-13 were sampled on the surface with a YSI dissolved oxygen probe. Dissolved oxygen and temperature readings were also taken at all tributary sites with a YSI dissolved oxygen probe on 17-September-09, except Site C, which had dried up. For more detailed methods see Appendices J and K.

Results and Discussion

Lakes

Dissolved oxygen at Site 1, in Salmon Lake, ranged throughout the summer from 10.42 ppm at the surface to 0.04 ppm at a depth of 13 m. DO was highest in the first 5 m of the water column and was between 7 and 10 ppm throughout the summer. Overall, oxygen concentrations were highest during the month of July and decreased over the summer months with levels reaching the lowest concentrations in August and September (Figure 30). June had low dissolved oxygen at bottom depths but concentrations increased in July, possibly due to mixing by the storms of June and early July. However, by mid-August the dissolved oxygen in the water dropped below 5-6 ppm at depths below 6 m and was anoxic at depths below 8 m. These results are similar to DO measurements collected by Maine DEP in the past three years, in which concentrations fell below 5 ppm at depths of 7-9 m and below 1 ppm at depths of 7-12 m during some point of the summer months. The observed decrease in DO below 6 m in this study was due to thermal stratification, which limits the replenishment of dissolved oxygen in the hypolimnion.

Site 1 exhibited strong thermal stratification throughout the summer. The temperature was highest in the epilimion and ranged from 17-25 °C. Below the epilimnion temperatures dropped quickly and towards the bottom ranged from 11-12.5 °C (Figure 31). Site 1 displayed stratification on 3-June-09 with temperature readings indicating a thermocline between 6 m and 10 m (Figure 32). Thermal stratification became more pronounced in August and DO levels decreased drastically below the thermocline and were anoxic below 8 m (Figure 32).

At Site 2, the water never became anoxic and DO ranged from 11.5ppm at the surface to 2.7 ppm near the bottom at 6 m. DO levels did not decrease or vary as much with depth compared to Site 1 (Figure 30). Additionally, DO varied randomly over the course of the summer, showing no trend of decreasing or increasing. These findings are most likely due to the shallowness of the site and mixing of the water column, particularly with the frequent rainstorms in June and early July.

Site 2 exhibited weak thermal stratification. Temperature in the epilimnion ranged from 17-28 °C, reaching the highest temperatures in late August. Temperatures decreased with depth, ranging from 15-22 °C at the bottom (Figure 31). Site 2 never exhibited distinct thermal stratification and no thermocline was present (Figure 32). These findings suggest that water was well mixed at this site, possibly due to the stormy weather of June and July which may explain the varying DO concentrations that were observed.

As discussed above, DO and temperature across Salmon Lake and McGrath Pond showed distinct differences. Salmon Lake exhibited well-defined thermal stratification,

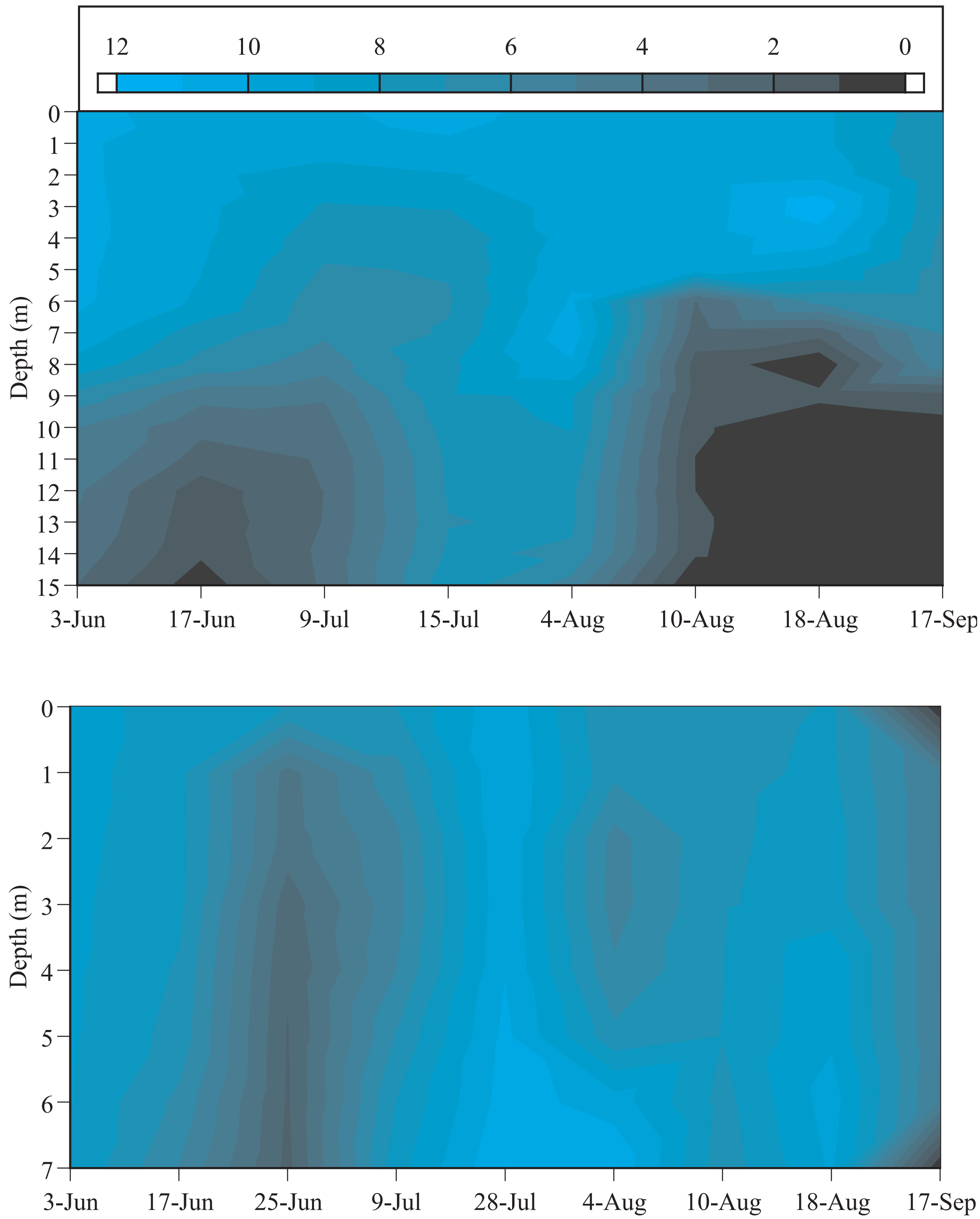

Figure 30. Dissolved oxygen profile (mg/L) of Site 1 in Salmon Lake (top) and Site 3 in McGrath Pond (bottom) for summer 2009. Data collected by CEAT from June to September. See Figure 29 for site locations.

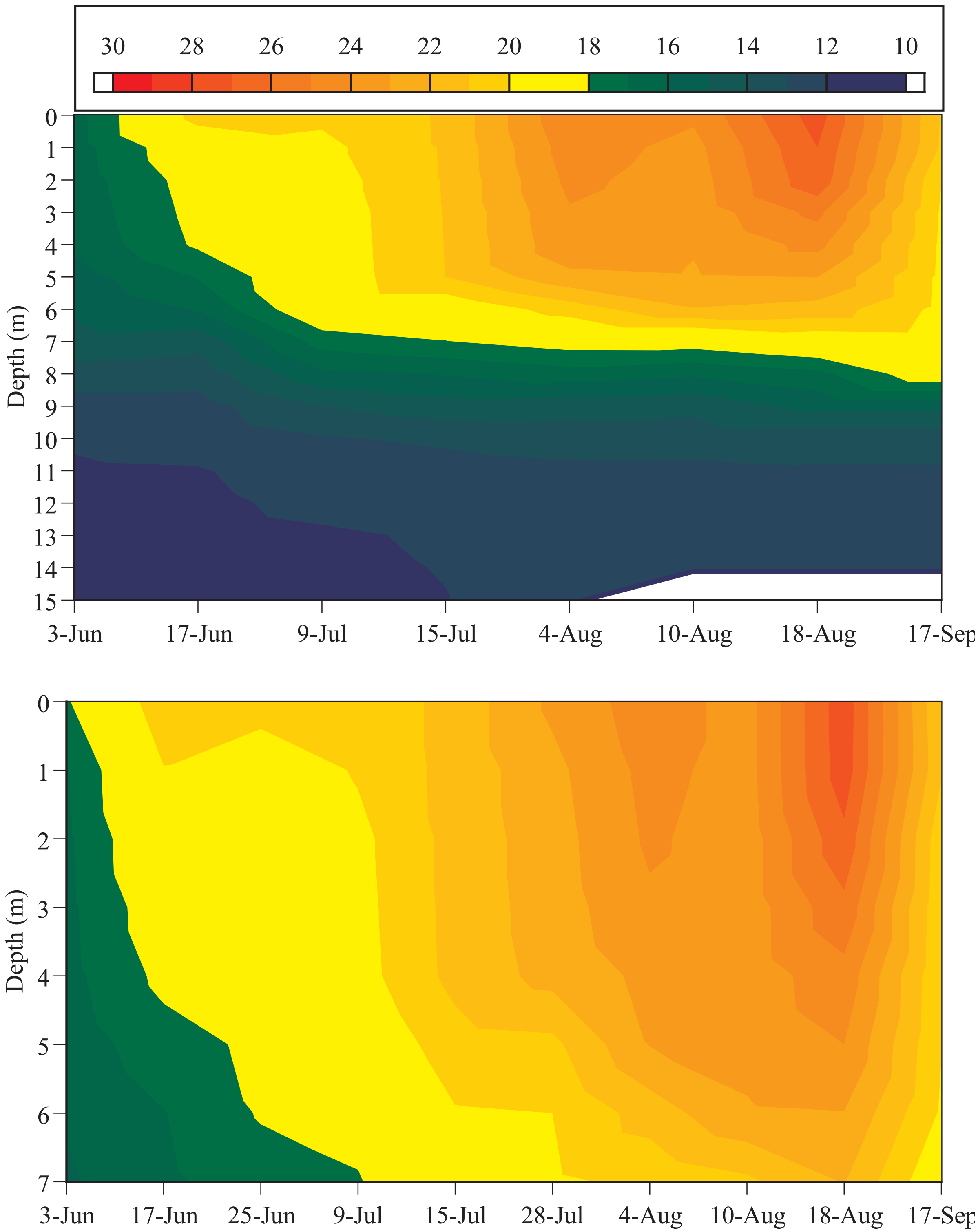

Figure 31. Temperature profile (°C) of Site 1 in Salmon Lake (top) and Site 3 in McGrath Pond (bottom) for summer 2009. Data collected by CEAT from June to September. See Figure 29 for site locations.

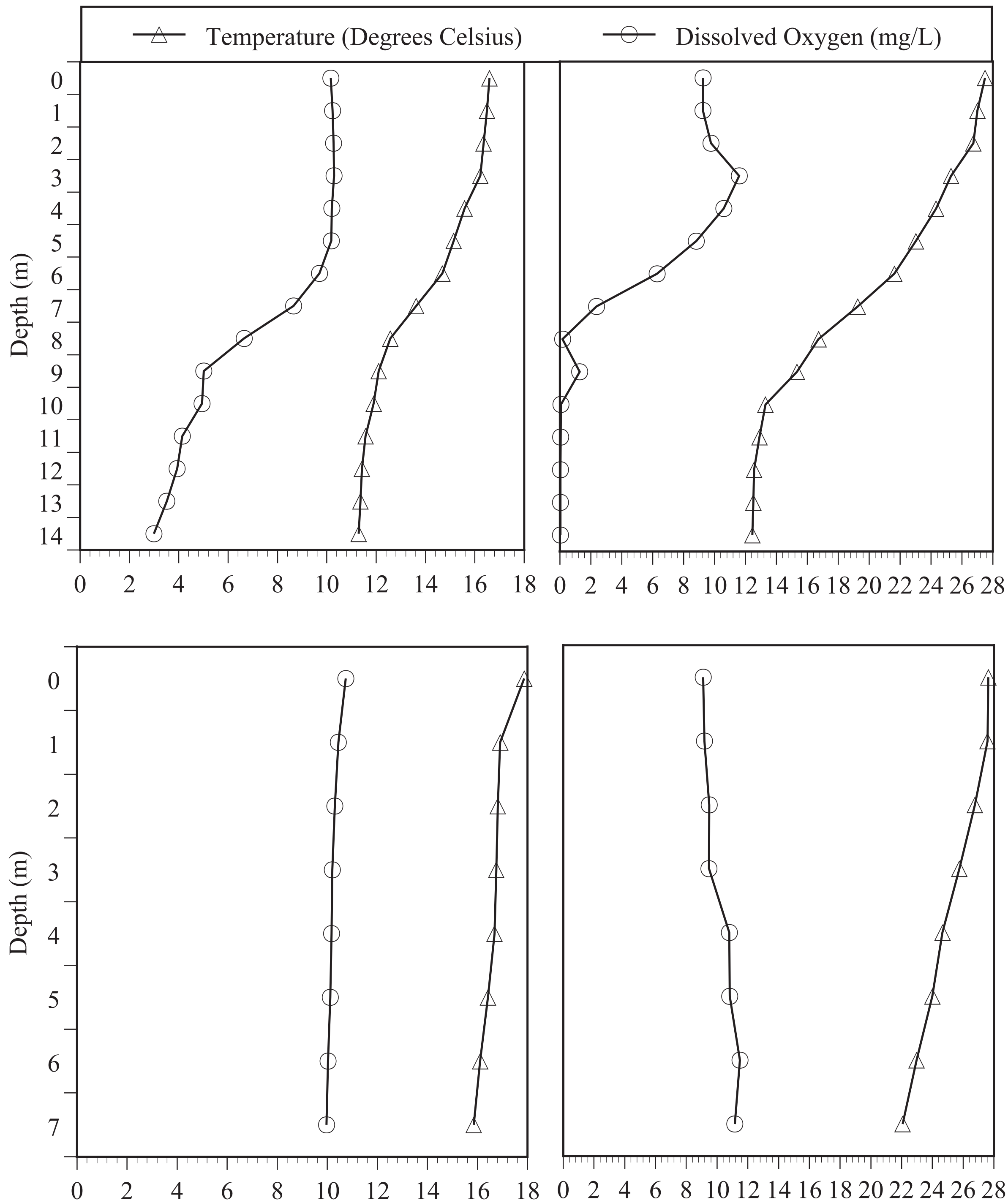

Figure 32. Dissolved oxygen and temperature profiles of Site 1 in Salmon Lake (top) and Site 3 in McGrath Pond (bottom) measured by CEAT on 3-June-09 (left) and 18-August-09 (right). See Figure 29 for site locations.

which severely limited DO concentrations at lower depths. In comparison, McGrath Pond showed a less stratified water column and more uniform DO concentrations throughout. These factors have influenced the extent of potential anoxic water in each water body (Figure 33). A large area of Salmon Lake, particularly in the southern portion, has the potential for anoxic conditions below 8 m while McGrath Pond has no anoxic areas. These findings suggest that efforts should be made to improve dissolved oxygen concentrations, particularly in Salmon Lake and DO should continue to be monitored in both water bodies.

Tributaries

Dissolved oxygen varied across tributary sites with a range of 10.25 ppm at Site A and 6.64 ppm at Site D (Figure 34). The tributary at Site D had a dirt road across it, which restricted water flow and the low DO concentration could be the result of bacterial activity on dead organic matter that had accumulated in the stagnant water. Sites B and E-G all had DO values between 8.24 and 9.16 ppm. These are considered healthy concentration levels and there is no cause for concern.

Transparency

Introduction

Transparency is a measure of water clarity that is determined by how far light can penetrate into the water column. It is also an indirect measurement of algal density and lake productivity. Transparency is influenced by the amount of suspended particles within the water column originating from algae, phytoplankton and soil erosion (PEARL 2009h). The ability of light to penetrate into the water column decreases with depth, because light is absorbed and scattered by dissolved and suspended matter in water. A high transparency reading indicates clear water, greater light penetration and lower lake productivity. The measurement of transparency is important because it denotes the photic zone, which is the area of the lake where algae and aquatic plants are able to photosynthesize (Brönmark and Hansson 2005). The photic zone is important to the lake ecosystem because algae and aquatic plants form the base of the food chain and provide much of the dissolved oxygen in the lake (Brönmark and Hansson 2005).

Transparency values vary widely in Maine lakes, ranging from approximately 0.5-20 m with a mean of 4 m (PEARL 2009h). Generally, a transparency of 2 m or less indicates that

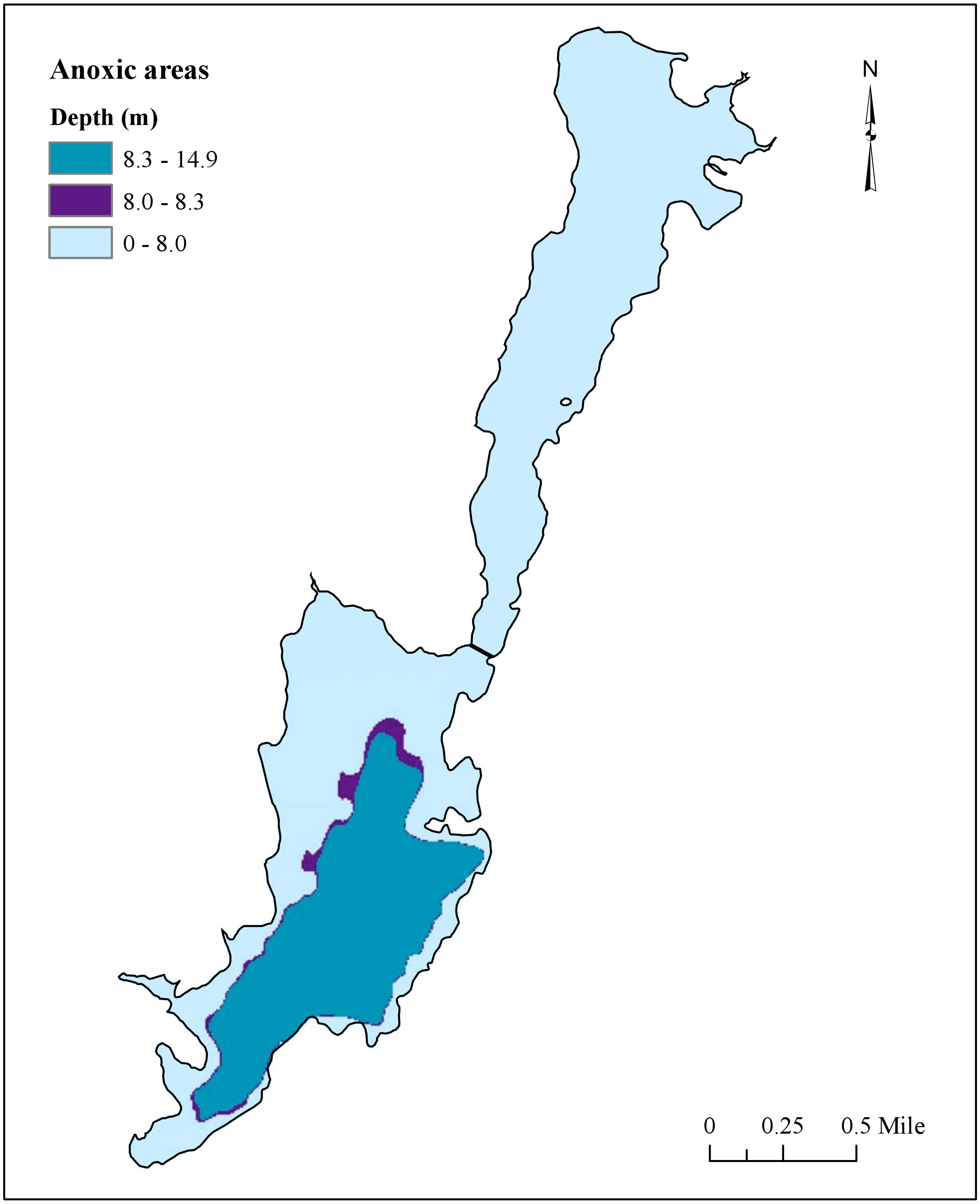

Figure 33. Map of potentially anoxic areas in Salmon Lake and McGrath Pond. Anoxia (DO < 1 ppm) was detected at Site 1 (Figure 29) on 18-August-09 at 8.3 m and deeper and on 17-September-09 at 8.0 m and deeper. Teal (August) and purple (September) represent areas of the lakes on these respective dates at which anoxia could occur based on depth and DO measurements at Site 1. Depth areas were obtained from the bathymetry map (Figure 28).

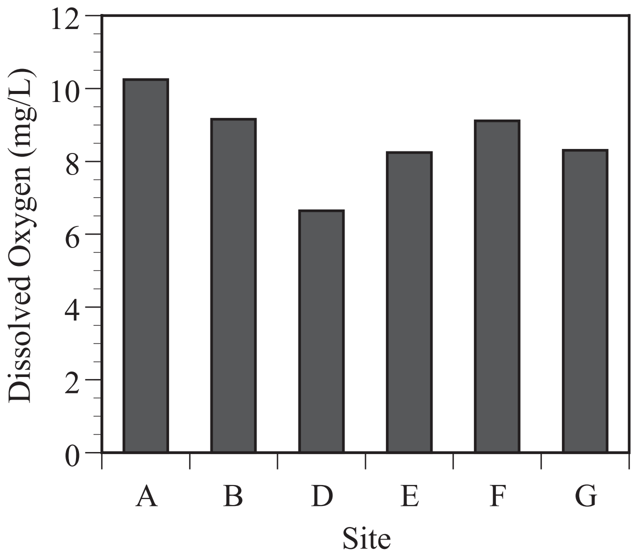

Figure 34. Dissolved oxygen measurements of tributaries in the Salmon/McGrath watershed measured by CEAT on 17-September-09. See Figure 29 for site locations.

there may be a water quality problem stemming from elevated productivity, such as an algal bloom.

Methods

Transparency was measured using a Secchi disk, an 8 in-diameter black and white disk, and an Aqua Scope. The Secchi disk is lowered into the water, while someone is viewing the water column with the Aqua Scope, until the disk is no longer visible and a reading is taken. The disk is then raised until it reappears and a second reading is recorded. This is repeated three times to obtain a mean depth. Transparency was measured on a near weekly basis from 3-June-09 to 18-August-09 for Sites 1 and 2. Site 3 was measured from 9-July-09 through 18-August-09. Site 3 and 10 were also measured on 17-September-09. For more detailed methods see Appendices J and K.

Results and Discussion

Lakes

Over the summer of 2009, transparency at Site 1 in Salmon Lake ranged from 3.45-5.65 m with an overall mean (± SE) of 5.10 ± 0.41 m (n=8). The site experienced a significant decrease in transparency as summer progressed (Figure 35), indicating a decrease in water clarity due to algal growth, which often increases as the summer progresses. At Site 2, in McGrath Pond, transparency ranged from 5.5-7.2 m with an overall mean (± SE) of 6.44 ± 0.17 m (n=9). The mean Secchi depth for Site 2 remained level throughout the summer with a slight increase in August (Figure 35). However, it is important to note that the Secchi depth never fell below 2 m for either of these sites, indicating that no algal blooms occurred in either Salmon Lake or McGrath Pond.

The historic transparencies of Salmon Lake and McGrath Pond confirm the summer findings. Historically, water clarity in both water bodies has improved since the mid-1970's

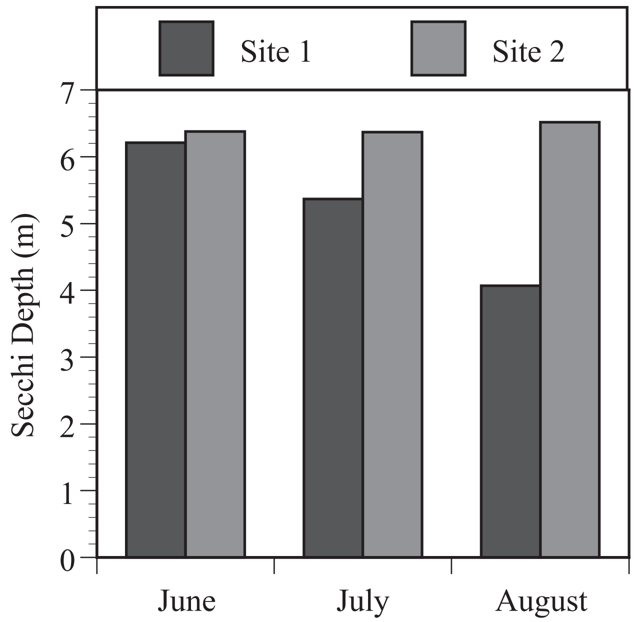

Figure 35. Mean Secchi depth (m) for Sites 1 and 2 of Salmon Lake and McGrath Pond in summer 2009. See Figure 29 for site locations.

but in varying amounts (MDEP 2009a). Salmon Lake has a historical mean transparency of 5.0 ± 0.2 m (n=34), but exhibits great year-to-year variability (Figure 36). Mean transparency in 2003 was 3.6 m and at one point fell below 2 m (MDEP 2009a). In contrast, McGrath Pond has experienced a greater increase in transparency since 1975 with a historical mean (± SE) of 5.7 ± 0.1 m (n=33). The difference in observed transparency between the two lakes is mostly likely due to different productivity levels within the lakes; Salmon Lake is more productive than McGrath Pond. However, these findings are comparable to other lakes in the Belgrade Region such as Great Pond and Long Pond, which have mean transparencies of 6.6 m and 6.0 m, respectively (CEAT 1999, CEAT 2008). Transparency within these two water bodies are at healthy levels, but should be monitored into the future.

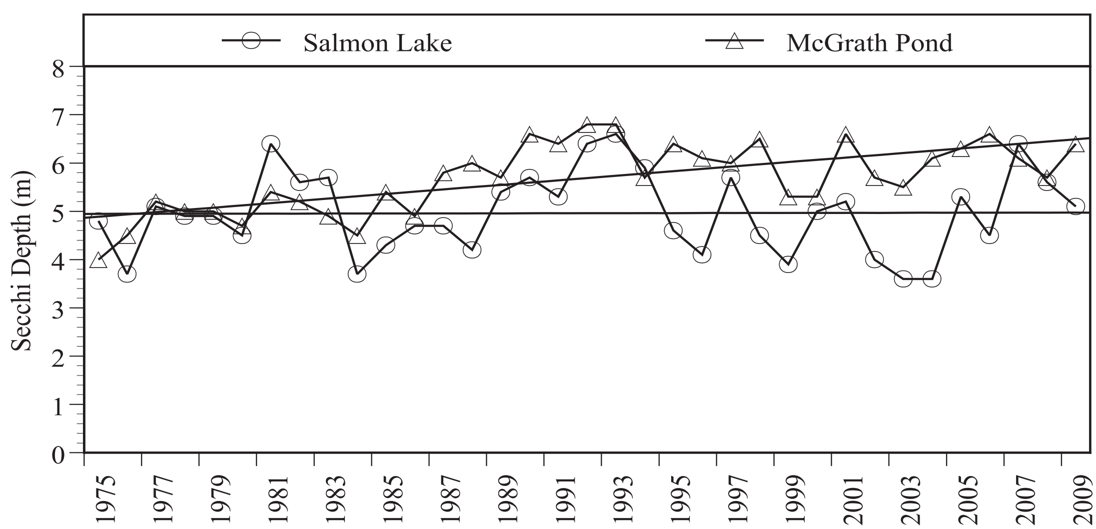

Figure 36. Historical mean transparency from 1975 to 2009 for Salmon Lake (Site 1) and McGrath Pond (Site 3) (Pearl 2009e, Pearl 2009f). Lines indicate trend of mean transparency depth for Salmon Lake and McGrath Pond. See Figure 29 for site locations.

Turbidity

Introduction

Turbidity is a measurement of water clarity by function of total suspended solids in water. Particles that are too large to dissolve into solution but small enough to remain suspended in water contribute to turbidity (Boyd 2005). These particulates scatter the light striking them into different directions; the more suspended particles in water, the higher the measured turbidity. Particulates can be both organic and inorganic, originating from living organisms, detritus and soil particles. Primary sources of these particulates in lakes are soil erosion, waste discharge, phytoplankton, resuspended sediments from the lake bottom, algae and urban runoff (Lake Access 2009).

The concentration of suspended particles in water can have significant impacts on lake health and function. High turbidity restricts light penetration, which has negative impacts on macrophyte productivity, which in turn affects organisms dependent on them for food, cover and the generation of oxygen (Lake Access 2008). Additionally, high levels of suspended solids, along with high sedimentation rates, can lead to shallow lake areas filling in, smothering benthic habitats and killing benthic organisms and fish eggs (Boyd 2005). Turbidity in water also detracts from the value of the lake for recreational purposes and makes it less aesthetically pleasing.

Methods

Water samples were taken from the surface, mid- and bottom depths of Sites 1-3 and from the surface at Sites 4-7, which were too shallow for collection at other depths. Samples were collected on a near weekly basis from 3-June-09 to 18-August-09. Surface samples were also taken for Sites 1-3 and 8-13 on 17-September-09. Additionally, water samples were taken at all the Tributary Sites on 17-September-09, except Site C, which had dried up. A HACH™ 2100P Turbidimeter was used to measure turbidity in Nephelometric Turbidity Units (NTU). The instrument measures turbidity by sending a beam of light through a sample of water and measuring the amount of scattered light caused by suspended particles. For more detailed methods see Appendices J and K.

Results and Discussion

Lakes

Throughout the summer, the surface turbidity reading for Site 1, in Salmon Lake, ranged from 0.49-4.25 NTU with a mean (± SE) of 1.53 ± 0.35 NTU (n=13). Surface turbidity remained level for most of the summer but rose drastically in August, a function of increased algal growth over the course of summer (Figure 37). At Site 3, in McGrath Pond, surface turbidity ranged from 0.44-1.25 NTU with a mean (± SE) of 0.73 ± 0.07 NTU. (n=13) The measured surface turbidity remained relatively level throughout the summer (Figure 38), suggesting that there was no significant increase in particulates contributing to turbidity throughout the summer.

Bottom turbidity readings for Sites 1 and 3, throughout most of the summer, were higher than at the surface and at the middle. At Site 1, readings ranged from 1.00-5.56 NTU with a mean (± SE) of 2.65 ± 0.52 (n=9). Site 3 readings ranged from 0.42-1.00 NTU with a mean (± SE) of 0.74 ± 0.06 (n=9). The high observed bottom turbidity readings are due to dead organisms falling through the water column into the hypolimnion and accumulating near the bottom of the lake. Also, currents mixing fine bottom sediments into the bottom of

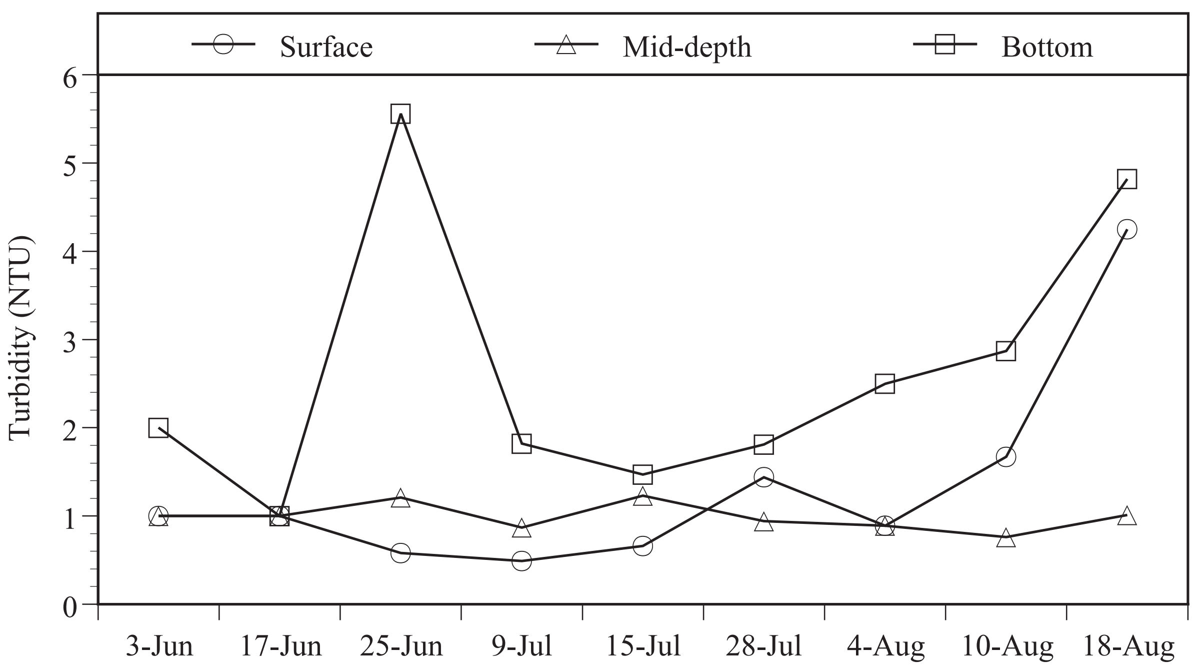

Figure 37. Surface, mid-depth and bottom turbidity (NTU) for Site 1 of Salmon Lake. Water samples collected by CEAT throughout the summer months of 2009. See Figure 29 for site locations.

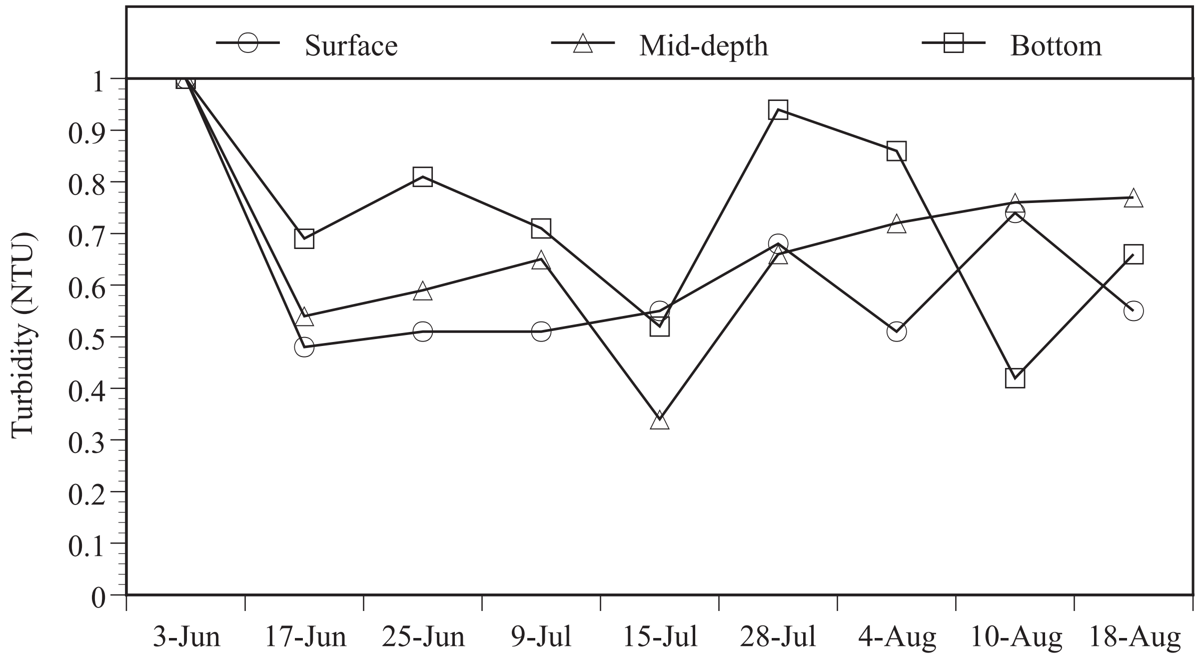

Figure 38. Surface, mid-depth and bottom turbidity (NTU) for Site 3 of McGrath Pond. Water samples collected by CEAT throughout the summer months of 2009. See Figure 29 for site locations.

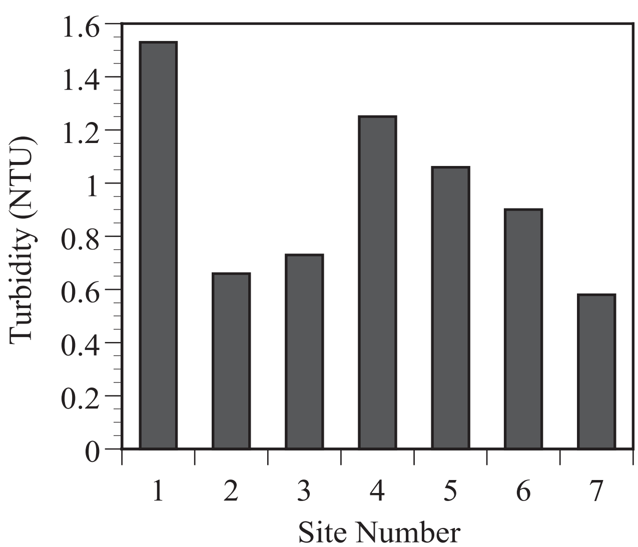

Figure 39. Mean surface turbidity (NTU) for selected sites in Salmon Lake and McGrath Pond. Data collected by CEAT from June to September, 2009. See Figure 29 for site locations.

the water column could have contributed to the increased turbidity.

Overall, surface turbidity varied greatly across sites but was correlated with the individual lakes (Figure 39). Sites 2, 3 and 7, located in McGrath Pond, had the lowest measured surface turbidity with a total mean (± SE) of 0.71 ± 0.04 NTU (n=28). In comparison, Sites 1, 4-6 located within Salmon Lake, had higher turbidity readings and a total mean (± SE) of 1.28 ± 0.13 NTU (n=38). This suggests that inputs or natural process may be affecting turbidity in Salmon Lake and not in McGrath Pond. However, these findings are similar to mean turbidity measured in Long Pond (0.9 NTU) and Great Pond (2.52 NTU) (CEAT 1999, CEAT 2008). Turbidity does not appear to be negatively impacting water quality in Salmon Lake nor McGrath Pond and is not a major concern.

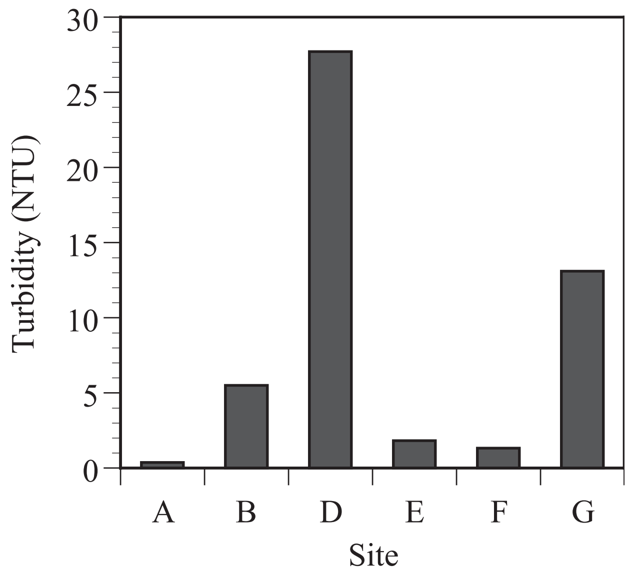

Figure 40. Turbidity measurements of tributaries in Salmon/McGrath watershed. Collected by CEAT on 17-September-09. See Figure 29 for site locations.

Tributaries

Turbidity values of the tributaries of the surrounding watershed ranged from 0.4-27.7 NTU (Figure 40). The sites with the highest values were Sites D, G, and B with 27.7, 13.3 and 5.5 NTU, respectively. Sites D and G had relatively stagnant water with high amounts of organic materials which is reflected in the high measured turbidity. These two tributaries should be of great interest due to their high turbidity values. The largest tributary within the watershed, Site B, should also be closely monitored due to its relatively high turbidity and amount of outflow going into the lake. The rest of the Tributary Sites had low turbidity, with values below 1.5 NTU.

True Color

Introduction

Color is a measurement of the concentration of suspended and dissolved organic particles in the water (PEARL 2009b). It is measured in Platinum-Cobalt Units (Pt-Co), with a range of 1-250 Pt-Co units. The tea color often associated with colored lakes is due to the presence of tannins and lignins in the water. Plant decomposition is the primary source for tannins and lignins, which increase the levels of dissolved particles in the water. There are two different ways to measure the color of a lake: apparent and true color. Apparent color includes suspended and dissolved particles in the water column and is not filtered prior to testing. True color is measured after the suspended particles have been removed through filtration. Suspended particles enter the water column through soil erosion, plant decomposition and substrate weathering (PEARL 2009b). The different particles entering the water result from the surrounding land use patterns and soil types. During certain seasons, wetlands can contribute a significant amount of dissolved particulate matter into the water due to their high rate of plant decomposition (see Background: Wetlands).

A lake with a color concentration greater than 30 Pt-Co units is considered colored (PEARL 2009b). On average, Maine lakes are non-colored, with a mean concentration of 28 Pt-Co units. Colored lakes often have reduced transparency readings and increased phosphorus levels, but color values do not indicate productivity. Rather, they interfere with the performance of the tests (MVLMP 2009a).

Methods

True color was measured at Sites 1-3 approximately every two weeks from 17-June-09 through 10-August-09. This fall, surface samples were taken at Sites 1-4, 14, E and G. All sites were sampled on 17-September-09, except for Site 14, which was sampled on 24-September-09. The samples were kept on ice, until returning to the laboratory and analyzed within 24 hours of collection. To determine the true color of each sample, a 47 mm, 0.45-micron membrane filter was rinsed with E-pure water, and then used to filter the lake water once it had returned to room temperature. Using a HACH 4000 DR Spectrophotometer, the samples were analyzed to obtain true color readings in Pt-Co. The spectrophotometer produced the readings by analyzing the absorbance of wavelengths within the visual light spectrum of the sample. For more detailed methods, see Appendices J and K.

Results and Discussion

Lakes

The results of the true color tests performed from June-September 2009 revealed a range of 7-51 Pt-Co units within the water bodies (Figure 41). The mean (± SE) true color value for the lake sites was 21 ± 3.8 Pt-Co units (n=12), suggesting that both Salmon Lake and McGrath Pond are not considered colored and are below the mean of 28 Pt-Co units for Maine lakes. Individually, Salmon Lake had a mean (± SE) true color of 19 ± 5.5 Pt-Co units (n=7), while McGrath Pond had a mean (± SE) true color of 23 ± 5.4 Pt-Co units (n=5).

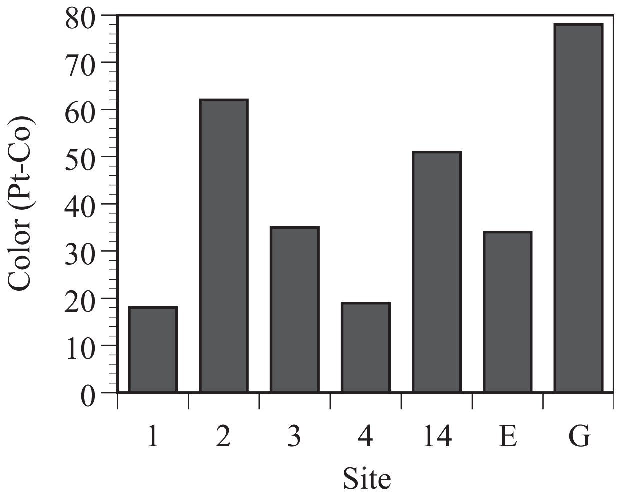

Figure 41. True color of Salmon Lake and McGrath Pond at Sites 1-4, 14, E and G. All samples were collected on 17-September-09 except for Site 14, which was collected on 24-September-09 and analyzed by CEAT. See Figure 29 for site locations.

A study of Salmon Lake and McGrath Pond in 1994 reported mean color values of 16 Pt-Co units and 11 Pt-Co units, respectively (CEAT 1994). The mean color for other Belgrade lakes, not including Great Pond was 20 ± 7.6 Pt-Co units (CEAT 1999). Compared to the results from the 1994 study, our color values were slightly higher, but they remain consistent with similar lakes in the Belgrade Lakes Region.

Site 2 had the highest true color value of 62 Pt-Co units, however this value was not included into the calculation of the mean for the combined water body or McGrath Pond. A sampling or analysis error may have accounted for the unreasonably high value. Excluding Site 2, Site 14 had the highest mean color value of 51 Pt-Co units, which may be due to its proximity to the sawmill. The sawmill has the potential to contribute excess byproducts of the mill operation, containing tannins and lignins, into the lake. Although, Peter Kallin, who is the Executive Director of the Belgrade Region Conservation Alliance, has said there is no knowledge of any problems coming from the sawmill (Kallin, pers. comm.). It is possible that other factors are contributing to the high color at Site 14 and a closer analysis of the area is recommended to verify the cause.

Historically, both Salmon Lake and McGrath Pond have been considered non-colored lakes with mean apparent color concentrations of 15 and 16 Pt-Co units, respectively (PEARL 2009e, PEARL 2009f). Usually, apparent color values are higher than true color values because the water is not filtered prior to analysis (Bouchard, pers. comm.). Data from the 1970's have shown an increasing trend in color concentrations for Salmon Lake. McGrath Pond, on the other hand, has experienced relatively constant color concentrations over the same time period (Figure 42). The cause for the recent higher color concentrations at some sites in Salmon Lake and McGrath Pond may be the result of changing land use around the watershed, especially on the northwestern side of McGrath Pond. For instance, the areas of logged and developed land have seen significant increases since the historic land use from 1965/66 and the sawmill has expanded, perhaps accounting for the high color values (see Land Use Types: Trends).

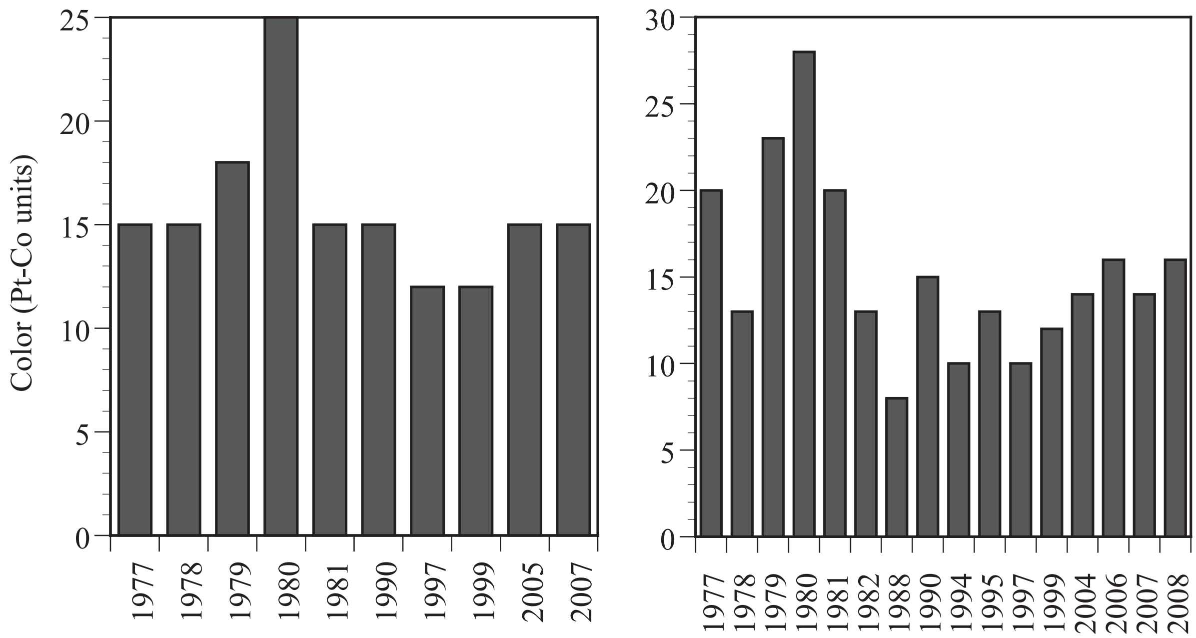

Figure 42. Historic mean color in Pt-Co units for selected years at Site 3 in McGrath Pond (left) and Site 1 in Salmon Lake (right) (PEARL 2009e). See Figure 29 for site locations.

Tributaries

The mean (± SE) true color for Sites E and G was 56 ± 22 (n=2) Pt-Co units (Figure 41). Higher values in the tributary sites are not uncommon because the smaller quantity of water in the stream has a higher concentration of particles relative to the lake water (Davis, Bailey et al. 1978). Site E had a true color value of 34 Pt-Co units, which was higher than the mean true color for the lake sites of 21 Pt-Co units. Its location on the western shore of Salmon Lake in Hatchery Brook, which flows from the Salmon/McGrath watershed to Great Pond, is important for determining the quality of water as it leaves Salmon Lake. The primary land use adjacent to the outlet is a dense collection of shoreline homes. Typically, residential land does not contribute an excess of plant material into the water, so a high color value would not be expected.

In contrast, Site G had a true color reading of 78 Pt-Co units, which was the highest of all of the sites tested. The large variability between the two values can be accounted for by the different surrounding land uses at Sites E and G. Site G is located on a tributary as it crosses a major road in the northern tip of McGrath Pond. The land use types around this site include cropland, pasture and a horse boarding business (see Figure 8). All of these land types have the potential to contribute plant material into the tributary, which then flows into McGrath Pond. This is a location where further monitoring is important to take steps to avoid increases in soil erosion or agricultural runoff from this area.

Conductivity

Introduction

Conductivity measures the ability of water to carry an electrical current and corresponds directly to the dissolved ions concentrated in the water (PEARL 2009l). It is measured in micro Siemens (μS) per centimeter for freshwater. The dissolved ions present in water include bicarbonate, calcium, sulfate, chloride, sodium, magnesium and potassium (ESAE 1998, Kegley and Andrews 1998). In wastewater, phosphate and nitrate ions are more abundant, contributing negatively to water quality. Agricultural runoff, septic systems and drainage from swimming pools containing chloride could cause the concentration of these ions to increase. Typically, the conductivity range for normal surface water is 30-400 μS/cm (PEARL 2009l). For Maine lakes, the mean conductivity is 47 μS/cm (MVLMP 2009a). Higher conductivity values are directly correlated to an increase in pollutants entering the lake.

Methods

Conductivity was measured from 17-June-09 to 18-August-09 for Sites 1-7, approximately once a week using the YSI 650 MDS Sonde. On 17-September-09, surface water samples were taken at lake Sites 1-3, 8-10, 12, 13 and A-G (Site C was dry). Site 14 was an additional site added a week later to investigate the water quality near the sawmill and sampled on 24-September-09. The water samples were put on ice and refrigerated until conductivity was measured on 15-October-09. For the surface samples, a YSI conductance bridge was used to measure conductivity. For more detailed methods, see Appendices J and K.

Results and Discussion

Lakes

Between June-August 2009, Salmon Lake had a mean conductivity of 79.5 ± 0.7 μS/cm (n=131) and McGrath Pond had a mean conductivity of 78.8 ± 0.8 μS/cm (n=106). The conductivity values were slightly greater than the historic conductivity values taken from the Maine Department of Environmental Protection (MDEP). From 1975-2009, the mean conductivity was 63 μS/cm for Salmon Lake and 76 μS/cm for McGrath Pond (PEARL 2009e, PEARL 2009f). Since 1975, conductivity has increased slightly more in Salmon Lake, but overall in the past 34 years there has not been a large change in either water body.

Conductivity ranged from 64-80 μS/cm for the lake sites sampled on 17-September-09. The mean (± SE) conductivity was 67.3 ± 2.1 μS/cm (n=6) for Salmon Lake and 76.8 ± 3.5 μS/cm (n=5) for McGrath Pond (Figure 43). These values show a slight decrease from the conductivity results this summer but are close to the historic mean conductivity of 63 μS/cm for Salmon Lake and 76 μS/cm for McGrath Pond.

Site 2 had the highest conductivity value based on the data from this fall and this may possibly be attributed to the nearby wetland, as well as the municipal dump. Higher conductivity readings also occurred at Sites 8 and 9 in McGrath Pond. Site 8 is situated in an area with high soil erosion potential, as well as agricultural land use types that could be contributing runoff. Similarly, Site 9 is located near Camp Tracy. Youth Camps are often a source of soil erosion coming into a lake because of the close proximity of beachfront areas to the shoreline and the large concentration of people using the campgrounds.

When a watershed analysis was last performed in 1994 on Salmon Lake and McGrath Pond, the conductivity values fell within a range of 50-60 μS/cm (CEAT 1994). This range was lower than the historic mean conductivity values, suggesting that in the years since there has possibly been a small increase in the amount of dissolved ions entering the Salmon/McGrath watershed. In comparison to other lakes in the Belgrade Lakes Region, both Salmon Lake and McGrath Pond had higher conductivity values. North Pond had a mean conductivity of 27.3 ± 1.8 μS/cm and Great Pond had a mean conductivity of 32.2 ± 1.0 μS/cm (CEAT 1997, CEAT 1999). Although the conductivity results for both water bodies are higher than the mean conductivity for Maine lakes of 47 μS/cm, this is not of serious concern because the historic conductivity values based on the MDEP data have also been high and our current results are within a similar range.

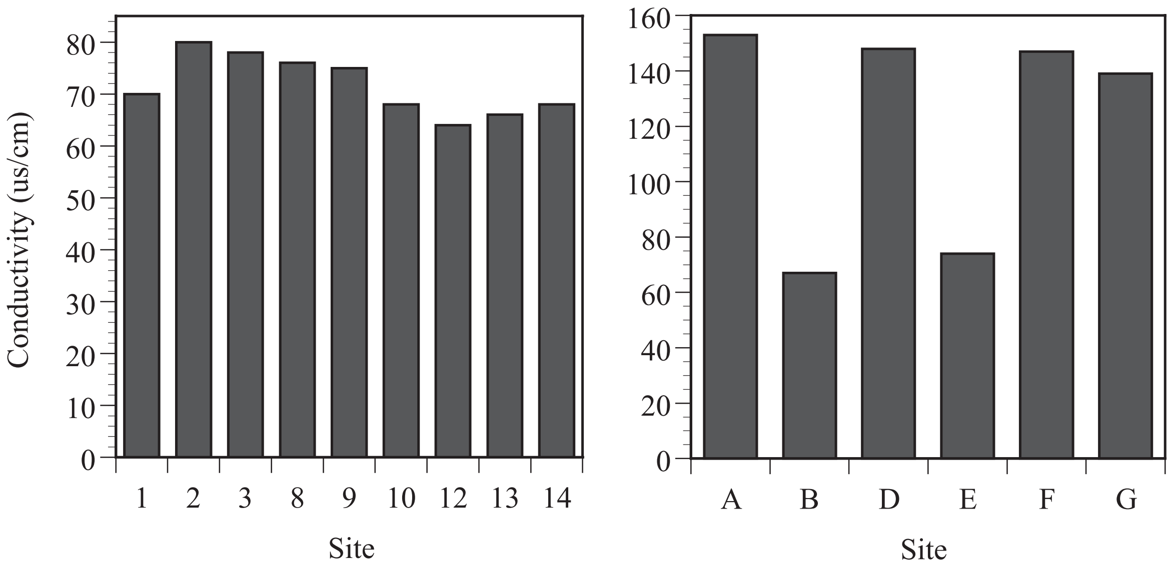

Figure 43. Conductivity at selected sites in Salmon Lake and McGrath Pond (left) and at Tributary Sites A, B and D-G (right). The samples were collected on 17-September-09 for all sites except Site 14, which was sampled on 24-September-09 and analyzed by CEAT. See Figure 29 for site locations.

Tributaries

The conductivity readings for Tributary Sites A, B and D-G ranged from 67-153 µS/cm, with a mean (± SE) of 121 ± 16 µS/cm (n=6) (Figure 43). This value was slightly less than three times the mean conductivity of 47 µS/cm for Maine lakes (MVLMP 2009a). However, the high conductivity values in the Tributary Sites are not an immediate cause for concern because tributaries typically have a greater concentration of dissolved ions compared to the lake itself, due to the large quantity of water in the lake diluting the ion concentration (Davis, Bailey et al. 1978). Sites A, D, F and G all had conductivity readings above 135 µS/cm. The highest conductivity reading of 153 µS/cm at Site A could be due to its proximity to a large wetland. Depending on the season, wetlands can either be a sink or source for nutrients and it is possible that as plant material died and decomposed this fall, nutrients and organic particles were released back into the water, causing higher conductivity values (MDEP 2009c). Site D was sampled when the water was stagnant, so in the absence of flowing water, ions can build up and are not released, creating conditions for high conductivity. Sites F and G are located near cropland and runoff from these areas could contain soil with pesticides and fertilizers made from many of the ions that have the ability to conduct electricity.

Chemical Measurements

Total Phosphorus

Introduction

Phosphorus is considered to be the most important limiting nutrient to phytoplankton growth (PEARL 2009i, PEARL 2009j). Plants require phosphorus to grow, providing evidence that it is directly correlated with algal blooms in freshwater systems. A slight increase in the phosphorus concentration of water (measured in ppb) can negatively affect water quality by leading to significant algal blooms.

Phosphorus is naturally present in freshwater systems, but in very small concentrations. However, human activities have greatly increased the phosphorus load coming into lakes (see Background: Nutrient Loading). The change in phosphorus concentrations can accelerate the natural aging process of lakes from a trophic state of oligotrophic to eutrophic and finally, to dystrophic. Oligotrophic lakes have annual mean total phosphorus concentrations of 4-10 ppb, and are characterized by high transparency, low dissolved solids and high oxygen levels. For eutrophic lakes, the typical phosphorus concentration ranges from 35-100 ppb (see Background: Trophic Status of Lakes). Phosphorus levels in the range of 12-15 ppb can cause algae blooms to occur, often seen in eutrophic lakes (PEARL 2009e). For this study, 13 ppb was chosen as the critical level of phosphorus concentrations in the lake (Firmage, pers. comm.). In extreme cases, these nuisance algal blooms can form mats across the surface of a lake, preventing oxygen from reaching the bottom sediments (MVLMP 2009a). When the algae die, aerobic decomposers break down the organic matter. These organisms respire, further depleting dissolved oxygen levels at the bottom of the water column. Lake stratification also affects dissolved oxygen levels in deep lakes, similar to Salmon Lake, and can have a significant impact on algal blooms (see Background: Annual Lake Cycles). Light is unable to penetrate down to the hypolimnion, preventing photosynthesis from occurring. Without a replenishment of the oxygen levels in the bottom of the lake, the water can become anoxic. At this level, fish kills often occur and the water quality deteriorates quickly (see Background: Trophic Status of Lakes).

Phosphorus typically comes from two different sources, either external or internal loading. External loading can be a significant source of phosphorus, primarily through runoff from the watershed. Phosphorus is considered to be a non-point source pollutant and there are many different factors that can cause an increase in its concentration. Some potential sources of phosphorus include agricultural runoff, camp roads, steep driveways, lawns stretching down to the shoreline and septic systems (see Background: Nutrient Loading). Multiple non-point sources render the control of external phosphorus loading a difficult process.

When lakes become anoxic, not only do fish species struggle to survive, but also algal populations continue to increase through a process known as internal loading (see Background: Phosphorus Cycle). In lake bottom sediments, iron exists in an oxidized form and under aerobic conditions, the iron can bind with phosphorus to form an insoluble complex, known as ferric phosphate. This complex has the ability to tie up excess phosphorus, making it unavailable to cause algal blooms. However, in anoxic conditions, iron undergoes a reduction and phosphorus is released back into the water column. Phosphorus can build up in the sediments, potentially providing a larger source of phosphorus than external inputs. On average, Maine lakes have a mean phosphorus concentration of 12 ppb (MVLMP 2009a).

Methods

Beginning 3-June-09 through 10-August-09, water samples were taken in triple acid rinsed 125 mL Erlenmeyer flasks approximately every ten days at Sites 1-7 in both Salmon Lake and McGrath Pond. Over the summer, at the Characterization Sites for Salmon Lake (Site 1) and McGrath Pond (Sites 2 and 3) surface, middle, bottom and epicore phosphorus samples were taken. For Sites 4-7, only surface water samples were taken due to their shallow depths. On 17-September-09, Sites 8-13 were added to test the phosphorus concentration at other locations in Salmon Lake and McGrath Pond. Sites A-G were added to test the water quality of the tributaries coming into both water bodies. Site 14 was tested on 24-September-09 to determine the water quality near the sawmill. During the fall sampling, at Sites 2 and 10, water samples were taken at the surface, mid-depth and bottom levels. For Sites 1 and 3, epicore samples were taken in addition to samples at the surface, middle and bottom levels (see Appendix J). At the remaining sites, only surface samples were taken.

After the samples were collected, they were put on ice until they were returned to the lab. For each sample, the water was split into two 50 mL samples and then refrigerated until they were ready to be digested. The ascorbic acid method was used to determine the total phosphorus concentration (ppb) of the water samples (see Appendix J). For the digestion phase, 1 mL of 1.75 N ammonium peroxydisulfate and 1 mL of 11 N sulfuric acid were added to each sample. These were then placed into an autoclave for 30 minutes at 15 lb/in^2 and 120° C. The purpose of the digestion phase was to convert the condensed, organic phosphorus into soluble orthophosphate that could be measured. Once the samples had finished digesting, they were allowed to cool and then placed in the refrigerator.

In the post-digestion phase, the samples were allowed to warm to room temperature, and then a phenolphthalein indicator was added to each of the samples. First, 1 mL of 11 N NaOH was added to return the samples to a pH of approximately 6. The 11 N NaOH was then added in a drop-wise fashion until the samples turned slightly pink. To discharge the light pink shade, 5 N H_2SO_4 was added drop-wise. Each of the samples then received 8 mL of a combined reagent, containing 5 N sulfuric acid, potassium antimonyltartrate, ammonium molybdate and ascorbic acid. The combined reagent reacted with the orthophosphate, producing a blue colorimetric reaction. Using a Milton Roy Thermospectronic Aquamate Spectrophotometer, the intensity of the blue shade was measured in cells with a path length of 10 cm. The final phosphorus concentration for each of the samples was recorded in parts per billion (ppb), based on a standard curve (see Appendix J). The results of the tests performed this fall were compared to historical phosphorus data obtained from the Maine Department of Environmental Protection (PEARL 2009e, PEARL 2009f).For more detailed methods, see Appendices J and K.

Results and Discussion

Lakes

Using data from this summer and fall collected by the Colby Environmental Assessment Team (CEAT), epicore samples at the Characterization Sites in Salmon Lake and McGrath Pond were used to describe the phosphorus loading in both water bodies. Epicore samples include a larger proportion of the water column in comparison to the surface grab samples, so they were used to find the mean phosphorus concentration. The value for each of the lakes was used to compare the accuracy of the Phosphorus Model produced by CEAT (see Background: Phosphorus Budget).

Site 1 in Salmon Lake had a mean (± SE) epicore phosphorus concentration of 13.0 ± 0.7 ppb (n=9) and Site 2 in McGrath Pond had a mean of 10.6 ± 1.8 ppb (n=10) for June-September 2009 (Figure 44). The trend for the epicore phosphorus concentrations showed that over the summer, the levels increased in both Salmon Lake and McGrath Pond. On average, the epicore phosphorus concentration for Salmon Lake of 13 ppb was at the critical level, providing evidence that algal blooms could occur. McGrath Pond is less likely to experience a bloom with a mean concentration of 10.6 ppb, which is below the critical level. Site 1 in Salmon Lake saw fairly constant readings of epicore phosphorus concentrations, while the readings at Site 2 in McGrath Pond saw greater fluctuation. This may have been due to the fact that the summer was unseasonably cool, with a significant amount of rainfall and wind, causing the water column to continuously mix in the shallower pond.

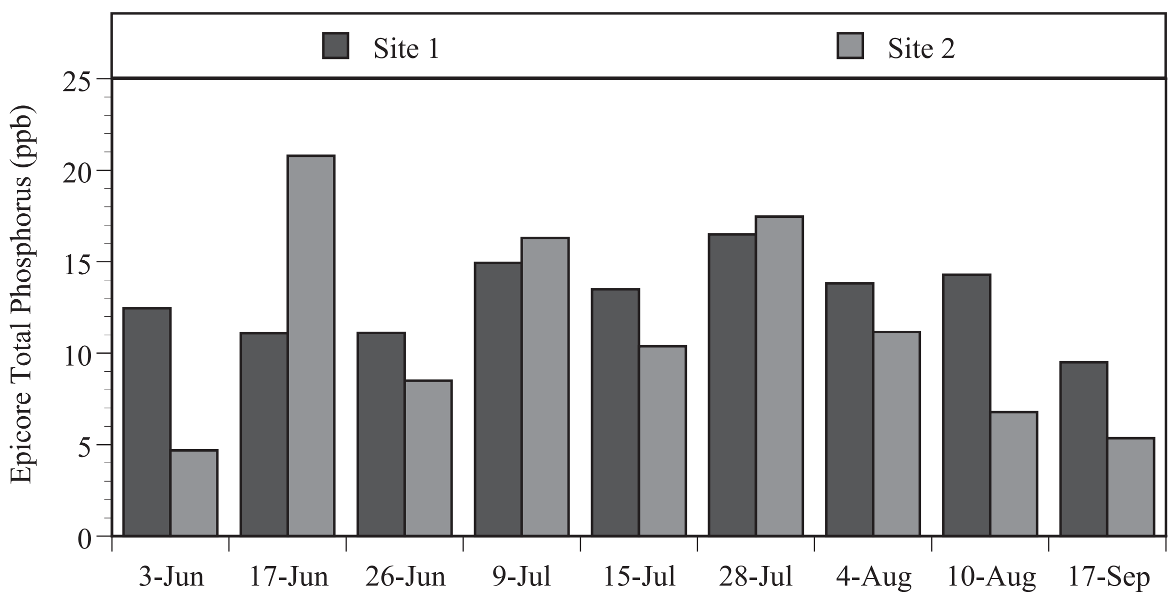

Figure 44. Epicore total phosphorus concentrations (ppb) for Site 1 and Site 2 from June-September 2009. Values for 28-July-09 and 17-September-09 were taken from Site 3 because samples were not available for Site 2. Samples were analyzed by CEAT. See Figure 29 for site locations.

The historic epicore phosphorus concentrations collected by MDEP from 1976-2009 reveal that the phosphorus concentration in Salmon Lake has been consistently above the critical level of 13 ppb for most of its sampling history (Figure 45).

Salmon Lake first bloomed in 1971 and as recently as 2003, but McGrath has never experienced an algal bloom (Nichols, Sowles et al. 1984, MDEP 2009a). McGrath Pond had its highest mean epicore phosphorus concentration of 14 ppb in 1979, but the concentration has declined in years since and continues to remain below the critical phosphorus level. In contrast, Salmon Lake saw a peak of 25 ppb in 1975, but phosphorus concentrations dropped until 1990 when they began to increase again. The decrease in phosphorus concentrations during the 1980's was largely due to an EPA sponsored lake restoration project working to help reduce the phosphorus input to the lakes from specific agricultural areas (Sowles 1987). A study of Salmon Lake and McGrath Pond performed in 1994 found mean surface phosphorus concentrations ranging from 8.3-16.2 ppb with most of the values below 15 ppb (CEAT 1994). In agreement with our current findings, the 1994 report found that on average McGrath Pond had lower phosphorus concentrations than Salmon Lake. It is also a positive sign to note that our mean epicore phosphorus concentrations were lower than levels in 1994,

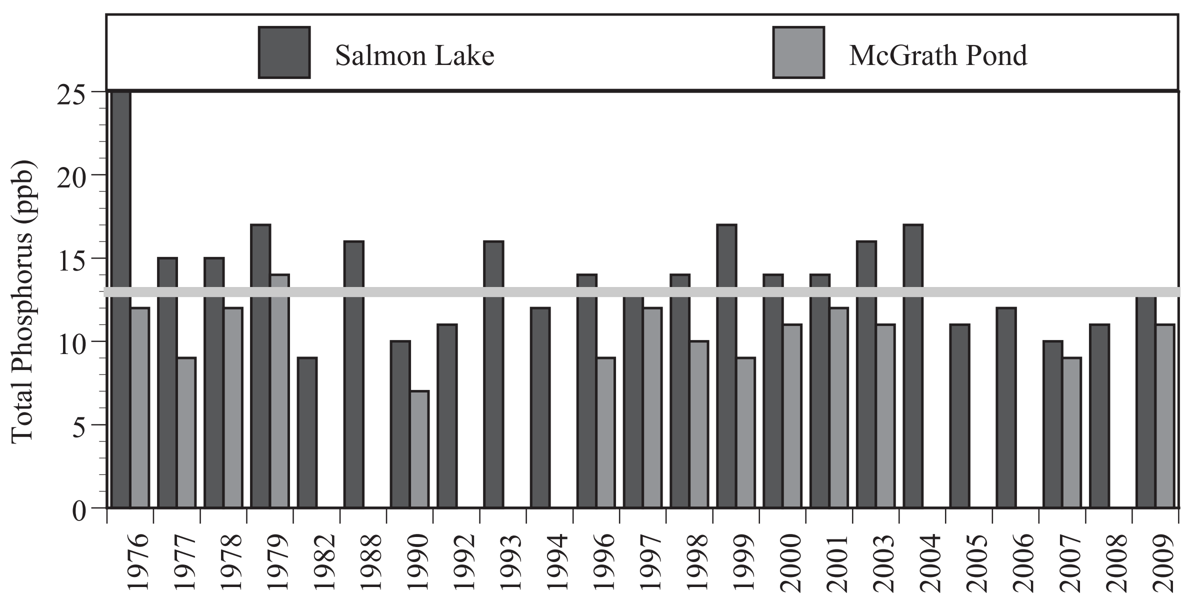

Figure 45. Historic epicore total phosphorus concentrations (ppb) of Salmon Lake and McGrath Pond from Maine DEP for 1976-2008 and from CEAT for 2009. The dotted line at 13 ppb indicates the critical level for total phosphorus that when sustained, causes algal blooms (PEARL 2009e).

suggesting that recent efforts to improve the water quality in the past few years have been successful but vigilant monitoring must continue in order to keep the phosphorus concentration below critical levels. Compared to North Pond, a similar lake in the Belgrade Lakes Region with a phosphorus concentration ranging from 8.9-11.6 ppb, the mean phosphorus concentration for Salmon Lake and McGrath Pond fell within a comparable range, which is encouraging for the Salmon/McGrath watershed (CEAT 1997).

The higher phosphorus readings in Salmon Lake compared to McGrath Pond may be due to a variety of factors. One potential explanation is that increased development around Salmon Lake is negatively affecting its water quality. The depth of Salmon Lake may also account for the difference in water quality compared to McGrath Pond. The anoxic conditions in the summer at the bottom of Salmon Lake led to an increase in the internal loading, which accelerates eutrophication (see Physical Measurements: Dissolved Oxygen and Temperature). The increasing concentration of phosphorus in the bottom layers decreases the water quality throughout the water column by mixing.

The results from the four Characterization Sites were used to provide a good assessment of the water quality at different trophic levels in both water bodies. A comparison of water samples taken at Sites 1, 2, 3 and 10 on 17-September-09 showed a wide range of phosphorus concentrations from 6-295 ppb at the surface, mid-depth and bottom depths (Figure 46). Sites 1 and 10 in Salmon Lake both showed evidence of stratification and internal phosphorus loading. The high phosphorus concentration of 295 ppb at the bottom in Site 1 was significantly higher than the bottom phosphorus concentrations at any of the other sites. Site 1 is located at the deepest spot in Salmon Lake and the

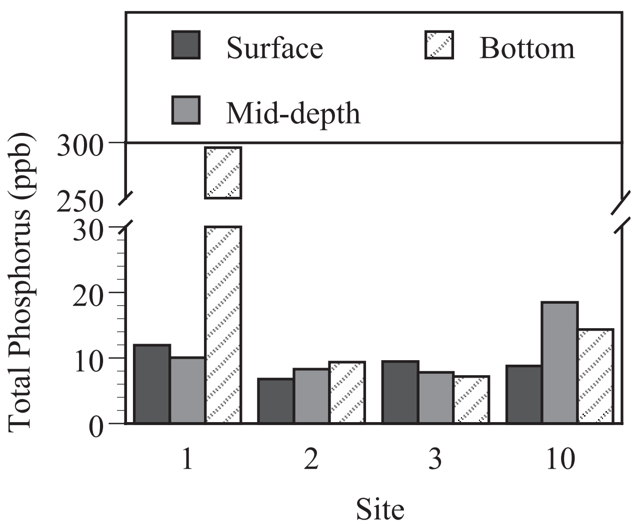

Figure 46. Surface, mid-depth and bottom phosphorus concentrations (ppb) sampled on 17-September-09 for Sites 1 and 10 in Salmon Lake and Sites 2 and 3 in McGrath Pond. See Figure 29 for site locations.

water at this site became anoxic near the end of the summer, causing internal loading to take place. Sites 2 and 3 in McGrath Pond had no anoxic areas because they were not deep enough to experience this phenomenon (see Physical Measurements: Dissolved Oxygen and Temperature). The consistent phosphorus concentrations at the different depth levels at Sites 2 and 3 are typical of a pond because it is too shallow to experience stratification and nutrient mixing, as well as oxygenation occurs throughout the summer, preventing a build-up of phosphorus in the bottom sediments (Nichols, Sowles et al. 1984).

Fourteen spot sites were sampled as an assessment of phosphorus concentrations at specific locations in Salmon Lake and McGrath Pond. For the lake sites sampled on 17-September-09, surface phosphorus concentrations ranged from 7-13 ppb (Figure 47). Salmon Lake had a mean (± SE) phosphorus concentration of 10.5 ± 0.4 ppb (n=10) and McGrath Pond had a mean of 8.4 ± 0.8 ppb (n=7). In general, both Salmon Lake and McGrath Pond had lower surface phosphorus concentrations than the epicore phosphorus concentrations. Typically, the phosphorus concentrations on the surface of the water are less than those deep in the water column because the algae on the surface use the phosphorus to grow. Also, sampling was performed later in the fall when cooler temperatures and mixing had already begun to occur.

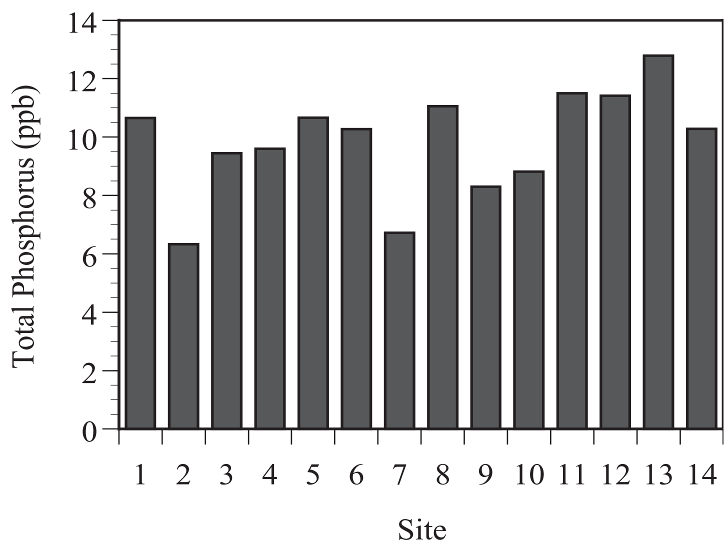

Figure 47. Surface total phosphorus concentrations (ppb) al all sites in Salmon Lake and McGrath Pond from September-09. Samples were collected and analyzed by CEAT. See Figure 29 for site locations.

Overall, the sites in Salmon Lake had a higher concentration of phosphorus compared to McGrath Pond. The difference in depth between the two water bodies may account for some of the variability, but the contrasting land use types around Salmon Lake and McGrath Pond also play an important role. Large areas of mixed forest, wetlands and fewer shoreline residences along the eastern shore characterize the land use of McGrath Pond. In contrast, Salmon Lake has considerably more development along the western shore of the lake, as well as cropland and multiple Youth Camps (see Land Use Types; Figure 8).

The adjacent land use at the different sites plays an important role when comparing the phosphorus samples from each of the spot sites sampled on 17-September-09. Sites 2 and 13 had noticeably high phosphorus concentrations and this may be attributed to their proximity to fairly dense residential areas with a large number of shoreline homes. A number of shoreline residences have septic systems that were installed before 1974, which contribute to external phosphorus loading (see Development: Septic Systems). There are also open field areas not far from the shoreline, so runoff could be entering the watershed near these sites. In comparison, Site 4 is located in the southern tip of Salmon Lake in a less populated area, surrounded primarily by mixed forest. Sites 5 and 7 had lower phosphorus concentrations in part perhaps due to their proximity to wetland areas without a lot of development. The wetland could be acting as a sink for phosphorus during some months of the year, taking up the excess nutrients and causing the concentration in the water to decrease.

The lower phosphorus concentrations in 2009 are a positive sign for McGrath Pond, and especially for Salmon Lake. It is evident that the lake associations and local residents have taken steps, such as the addition of buffer strips, to improve the surrounding land use of the watershed because phosphorus concentrations have decreased since 2003. However, Salmon Lake and McGrath Pond have low flushing rates, making both water bodies prone to water quality issues because the water does not turnover as quickly as some of the other lakes in the Belgrade chain (see Water Budget). In order to maintain the health of Salmon Lake and McGrath Pond, careful monitoring must continue to occur.

Tributaries

The mean (± SE) surface phosphorus concentration at all of the tributary sites was 46 ± 36 ppb (n=6), with values ranging from 1-261 ppb (Figure 48). Site D had a value of 261 ppb, which may be due to sampling when the water was stagnant. A lack of flowing water has the potential to create an unrealistically high phosphorus concentration. Without Site D included in the calculation of the mean for the Tributary Sites, the phosphorus concentration was 10.5 ± 3.5 ppb, which provides a more accurate depiction of phosphorus levels in the remaining sites.

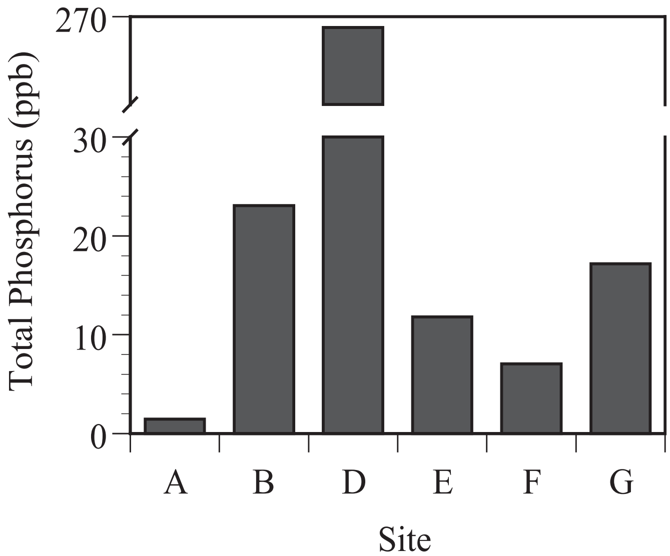

Figure 48. Total phosphorus concentrations (ppb) at Sites A, B and D-G in the Salmon/McGrath watershed for September-09. Samples were collected and analyzed by CEAT. See Figure 29 for site locations.

Site B had a phosphorus concentration above the critical level, with a reading of 23.1 ppb. The surrounding land use of Site B does not point to a specific cause for the high phosphorus concentration because the majority of the immediate land use is a wetland land area and reverting land. Wetlands can act as a source or a sink for phosphorus depending upon the season (MDEP 2009c). However, the tributary site was sampled before it reached the marsh, where the water may have been filtered or nutrients absorbed, explaining why the phosphorus concentration at Site 5 in Salmon Lake was not exceptionally high. A closer examination of Cold Brook, the major tributary flowing into Salmon Lake, would have to be conducted to determine the actual input of phosphorus from that source.

Site G also had a higher than average surface phosphorus concentration with a value of 17.2 ppb. This may be due to its proximity to the pasture and livestock area. Other sources of phosphorus could be coming from the roads or soil because the northern tip of the McGrath Pond watershed has high soil erosion potential due to the steep gradient coming into water (see Figure 25 and Figure 26). The large expanse of logged land could also be creating a significant amount of runoff.

Beginning in 1978, the area near the Mutton Hill Road Stream, which CEAT labeled as Site G, was a focal point of restoration plans undertaken as part of an EPA funded project, in which the Maine Department of Environmental Protection (MDEP) and the U.S. Geological Survey (USGS) constructed a nutrient budget for Salmon Lake (Nichols, Sowles et al. 1984). By 1980, a small family farm was identified as a significant controllable source of phosphorus. Under the Salmon Lake restoration project, steps were taken such as the placing of an earthen berm to divert clean water runoff around the farm and construction of a covered manure-stacking pad next to the barn to improve the water quality before it entered the water body (Sowles 1987). It appears that the restoration carried out in 1980 was mildly successful due to the subsequent drop in phosphorus concentrations in later years, but based on our current results, the phosphorus concentration at Site G is still high, so additional mitigation strategies may be necessary to reduce the nutrient loading in that area of the watershed.

The results from the surface phosphorus concentration tests point out that the Tributary Sites are contributing a significant amount of phosphorus into the lake. These point sources should undergo careful monitoring to determine the primary causes for the phosphorus loading. In the study performed by MDEP and USGS, they estimated that three tributaries together potentially represented 69% of the external load to Salmon Lake, yet drain only 22% of its watershed (Nichols, Sowles et al. 1984). In the two years after the restoration project began in 1980, there was no measurable improvement in lake water quality (Sowles 1987). However, the large diary farm, which was highlighted in the MDEP and USGS report as the largest source of nutrient loading, is no longer in existence (see Land Use Changes, Figure 12). Monitoring of all of the tributaries must continue to occur because the removal of excess phosphorus coming into the watershed through the tributaries could greatly improve the health of Salmon Lake and McGrath Pond.

Nitrates

Introduction

Nitrates are a measure of the nitrogen concentration present in the water. Along with phosphorus, it is considered to be one of the most important limiting factors to algal growth (Brönmark and Hansson 2005). However, there must be an excess of phosphorus, in the presence of adequate nitrogen, for eutrophication to occur (Pearsall 1993). The normal level for nitrate concentration in "natural waters" is 0.1 ppm and in lakes, levels greater than 0.2 ppm can stimulate algal growth. Nitrate levels greater than 5 ppm are indicative of contamination, primarily due to fecal matter from faulty septic systems or agricultural runoff (Chapman 1992).

Within the Salmon/McGrath watershed, potential sources of nitrates include agricultural operations and livestock areas. Fertilizers used on agricultural fields contain ammonium nitrate, potassium nitrate and ammonium dihydrogen phosphate (Kegley and Andrews 1998). Production and use of fertilizers containing nitrogen has increased dramatically from almost none in the 1940's to 80,000,000 metric tons in 1998 (ESAE 1998). When fertilizers runoff into the water without passing through an adequate buffer, the nitrate concentration in the water has the potential to increase significantly. One potential source of nitrogen is the horse boarding business and surrounding pasture located at the northern end of McGrath Pond, near Site G. There are also approximately five major areas of cropland distributed around both water bodies, although the percentage of these areas in the watershed has decreased significantly from the historic land use in 1965/66 (see Land Use Changes, Figure 12).

Old septic systems can also be a source of nitrates. Septic systems installed before 1974 are harmful to water quality and do not meet the current regulations for control of wastewater (see Development: Septic Systems). Overflowing septic tanks could also increase nitrate levels in both water bodies. The numerous shoreline residences around Salmon Lake and McGrath Pond have the potential to add nitrates into the water if proper treatment and management of wastewater does not occur (see Development: Residential).

With the release of new research, the role of nitrate levels causing algal growth in water bodies has come into question. In a study performed by Schindler, Findley et al. (2008), the researchers demonstrated that the biological production of lakes is more strongly correlated to phosphorus concentrations regardless of the nitrate concentrations. Their results concluded that phosphorus should be the focus for water quality management, rather than nitrates (Schindler 1974, Schindler, Findley et al. 2008).

Methods

A Nitrate Low Range Test (Calcium Reduction Method) was performed using the HACH DR 4000U Spectrophotometer (see Appendix J). Nitrates were measured in mg/L, which is equivalent to ppm. Surface samples were taken at Sites 1, 3, 4, 5, 7, 8, 11-14 and G. The samples were put on ice and then refrigerated upon returning to the lab. Collection and analysis of the samples occurred on 17-September-09 for all sites, except for Site 14, which was collected and analyzed on 24-September-09.For more detailed methods, see Appendices J and K.

Results and Discussion

Lakes

The mean (± SE) nitrate concentration for the sites in both Salmon Lake and McGrath Pond was 0.03 ± 0.002 ppm (n=11) (Figure 49). This mean is well below the normal nitrate concentration of 0.1 ppm. These results are comparable to nitrate tests performed in Salmon Lake and McGrath Pond in 1994, which had a nitrate concentration of 0.02 ppm (CEAT 1994). According to the watershed analysis report done in 1999 for Great Pond, the mean nitrate concentrations in the Belgrade Lakes was found to be 0.049 ± 0.010 ppm (CEAT 1999). Evident from the data analysis, nitrate concentrations within the lake are not a significant factor contributing to the water quality of either Salmon Lake or McGrath Pond and should not be a cause of concern.

Tributaries

Nitrate sampling was conducted at Site G on 17-September-09 (Figure 49). Site G had a nitrate concentration of 0.25 ppm, which was well above the normal level of 0.1 ppm. At that nitrate concentration, there is enough nitrogen in the water to react with excess phosphorus to cause an algal bloom. The surrounding land use and road quality of Mutton Hill Road near the tributary could be sources of nutrients entering the tributary. Further analysis of the water quality at the Mutton Hill Road Stream should be done to determine its effect on McGrath Pond.

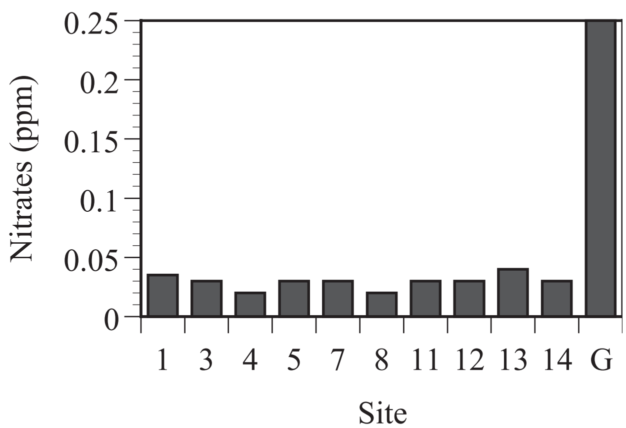

Figure 49. Nitrate concentrations (ppm) at selected lake sites and at Tributary Site G. Samples were collected on 17-September-09 for all sites except Site 14, which was collected on 24-September-09 and analyzed by CEAT. See Figure 29 for site locations.

pH

Introduction

pH is the measure of the concentration of hydrogen ions (H^+) and is used to determine the acid-base status of a solution; a higher pH represents a lower concentration of hydrogen ions. The pH scale is logarithmic and ranges from 0 to 14, with 0 being the most acidic, 7representing a neutral solution and 14 as the most alkaline (Chapman 1992). pH is measured on a logarithmic scale and a change of one pH unit is equal to a factor of ten change in hydrogen ion concentration. Maine lakes range from a pH of 4.45-9.35, with a mean of 6.7 (PEARL 2009d).

pH levels are affected by a variety of factors including photosynthesis, respiration and depth. Photosynthesis causes an uptake of hydrogen ions, increasing the pH of the water. However, during respiration, carbon dioxide is produced to form carbonic acid, releasing hydrogen ions and ultimately lowering the pH. There are daily and seasonal fluctuations of pH based on the amount of photosynthesis occurring (PEARL 2009d). Depth also plays an important role in pH because further down in the water column, less light is able to penetrate. In lower levels of light, less photosynthesis occurs, causing the pH to decrease with an increase in depth. However, respiration and decomposition (both of which decrease pH), are able to occur at any point throughout the water column and further contribute to lower pH levels at greater depths (PEARL 2009d). pH is an important parameter in determining water quality because it influences the flora and fauna that are able to survive in the lake, because different species have different pH tolerances (MVLMP 2009a).

Methods

Surface measurements of pH were taken at Sites 1-7 from June to August 2009 using an YSI 650 MDS Sonde. Additional pH measurements were taken at Sites 2, 4-9, 11-13, and A-G (excluding C) on 17-September-09 and at Site 14 on 24-September-09 using an EXTECH ExStick pH meter. Measurements were taken at varying depths at Sites 1, 3 and 10 on 17-September-09 using an YSI 650 MDS Sonde. Both instruments were calibrated prior to testing. For more detailed methods see Appendices J and K.

Results and Discussion

Lakes

Surface pH measurements taken from Salmon Lake and McGrath Pond on 17-September-09 ranged from 6.28-7.89 with a mean (± SE) of 7.36 ± 0.05 (n=40), which is slightly more basic than the average Maine lake (pH=6.7). Readings taken at varying depths generally showed that pH decreased with an increase in depth (see Appendix L), suggesting there is a higher concentration of hydrogen ions at the bottom of the lake than at the surface. In deeper waters, less light is available for photosynthesis, resulting in less carbon dioxide being removed from the water column and a lower pH. Additionally, respiration and decomposition, both of which decrease pH, can continue to occur at any depth in the water column, resulting in lower pH levels at higher depths (PEARL 2009d).

Typically, the difference in pH between shallow and deep water diminishes as the summer continues into fall, as turnover occurs. The most acidic measurements recorded in both Salmon Lake and McGrath Pond occurred in the middle of the summer, and the results indicate that at this time, the pH was relatively uniform throughout the water column **(**Figure 50). This suggests that the lake might have mixed in the middle of the summer, bringing the more acidic waters up from the bottom and decreasing the overall pH of the water. This may be due to the fact that the weather was unseasonably cold and stormy during the June and early July 2009, possibly causing the water to mix prematurely. The acidity could also be due to the fact that bad weather (less sunlight) would mean lower levels of photosynthesis occurring at the surface, and ultimately a lower pH. However, the August and early September saw a re-stratification of the water column. This was a result of the warmer and sunnier weather that was present during this time, causing an increase in pH levels near the surface where more photosynthesis was occurring. The water at greater depths continued to stay relatively acidic due to the continued absence of photosynthesis, regardless of the weather. This stratification is more evident in Salmon Lake because it is deeper than McGrath Pond.

The pH of Salmon Lake rose from 7.2 in 1940 to 7.8 in 2006 and similarly, the pH of McGrath Pond rose from 7.1 in 1940 to 7.7 in 2004, a trend that tends to occur in lakes as they become more eutrophic (CEAT 2005). This slight increase in pH may be due to increased nutrient levels over the years, causing an increase in the growth of macrophytes and algae in the water. Higher levels of plant growth are a signal that more photosynthesis is occurring and the pH begins to rise. Although the pH has not increased drastically, it is still an important trend to watch. For example, the mean (± SE) pH from 1940-2006 was 7.23 ± 0.08 (n=21), however as previously mentioned, the mean pH for Maine lakes is only 6.7, suggesting that Salmon Lake and McGrath Pond are slightly more alkaline than what is typical for lakes in this area.

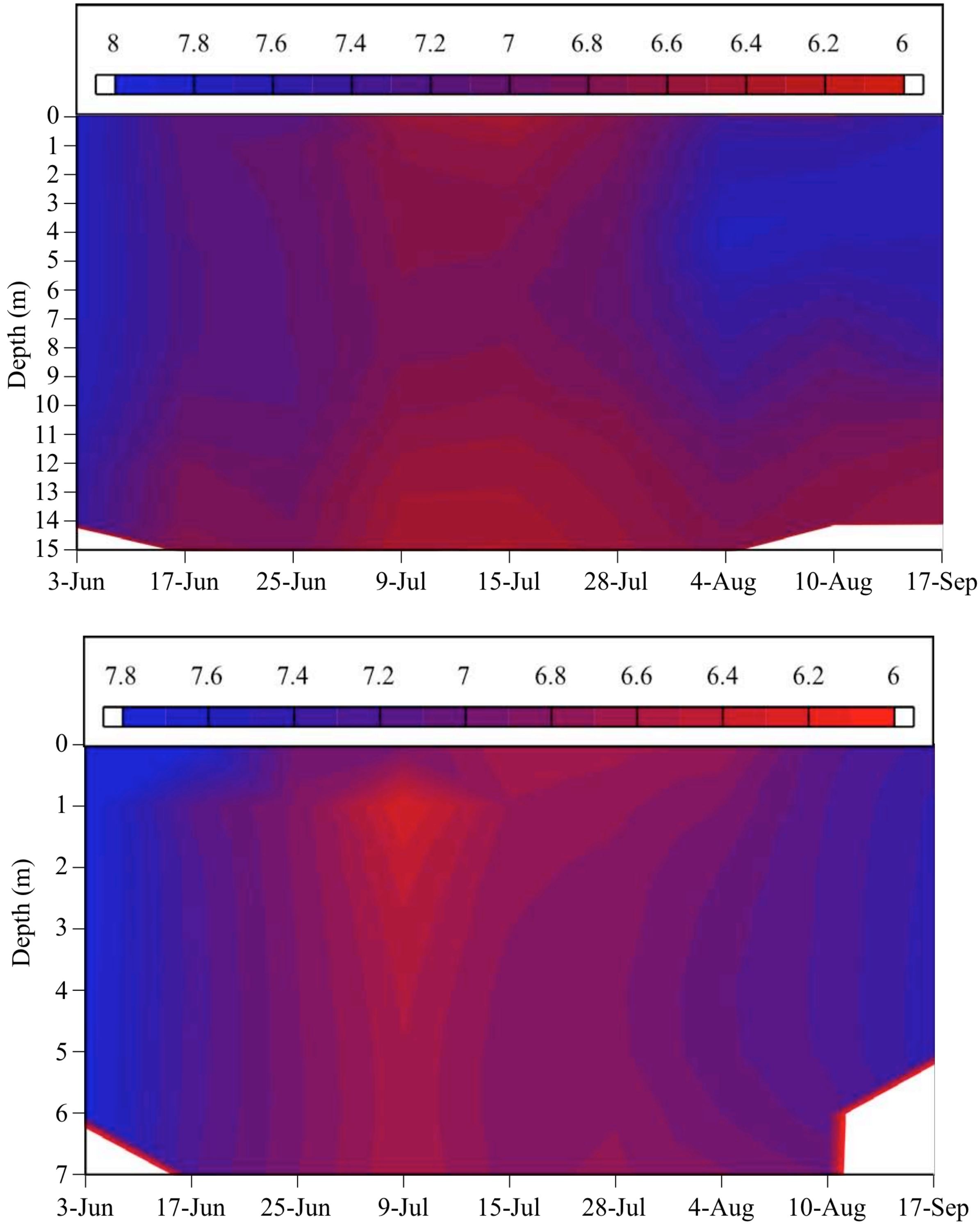

Figure 50. pH depth profile for Site 1 (top) in Salmon Lake and Site 2 (bottom) in McGrath Pond from June-September 2009. See Figure 29 for site locations.

Alkalinity

Introduction

Alkalinity is a measure of buffering capacity for a body of water and is largely determined by the geology of the rocks and soil surrounding the lake system (Chapman 1992). These rocks contain carbonate, bicarbonate and hydroxide compounds, which are the predominant buffers in freshwater lakes (PEARL 2009d). Certain types of rock, such as limestone, are high in carbonate, and others, like granite, have lower levels of carbonate. Lakes with a granite bedrock have a lower alkalinity than those that are composed of a predominantly limestone bedrock. pH and wastewater also play an important role in determining the buffering capacity of a water body. Household cleaning products often contain high levels of carbonates, which can cause an increase in alkalinity. However, these products (and wastewater in general) also contain other unwanted nutrients that can be transported into lakes, indicating that high alkalinity is not always an accurate indicator of lake health (CEAT 2006).

Methods

An alkalinity surface sample was taken at Sites 1 and 3 from June to August 2009 and an additional sample was collected from Site 3 on 17-September-09 by CEAT. The samples were placed on ice, and then returned to the laboratory for analysis. They were then titrated with a 0.02 N sulfuric acid (H_2SO_4) solution to achieve a pH between 4.3-4.7 and then were further titrated to reduce the pH by 0.3. The formula was used to calculate alkalinity in milligrams of $CaCO_3$ per liter.

$$\text{Total Alkalinity} = \frac{(2B-C) \times N \times 50{,}000}{\text{mL of sample}}$$

where: N=normality of standard acid

B=mL titrant to first recorded pH

C=total mL titrant to reach final pH

For more detailed methods see Appendices J and K.

Results and Discussion

Lakes

The mean (± SE) alkalinity for Salmon Lake and McGrath Pond from July to September 2009 was 15.16 ± 2.85 mg/L (n=6) and ranged from 9.5-24.1 mg/L. These results are typical of Maine lakes and fall within or close to the mean range of 4-20 ppm (ppm can be directly related to mg $CaCO_3$/L), suggesting that Salmon Lake and McGrath Pond are not in immediate danger of acidification. Salmon Lake and McGrath Pond have similar alkalinity levels compared to nearby water bodies such as Togus Pond and China Lake, which have mean alkalinities of 18.25 ± 1.35 and 19.60 ± 1.61 ppm, respectively (CEAT 2005, CEAT 2006).

Higher levels of alkalinity in McGrath Pond compared to Salmon Lake (see Appendix L) suggest that McGrath Pond has a better buffering capacity, but the reason for this difference in uncertain. When examining alkalinity in Salmon Lake and McGrath Pond over time, there appears to be a notable increase from 1977-2007 (Figure 51), suggesting that neither water body is in immediate danger of acidification. However, as previously mentioned, alkalinity is not necessarily an accurate indicator of lake health. This increase in alkalinity may be due to increased levels of wastewater that contain carbonates and unwanted nutrients that are harmful to the water, offsetting the positive result of a higher buffering capacity (CEAT 2006). It is important to continue to observe alkalinity levels in both Salmon Lake and McGrath Pond over time to monitor their status.

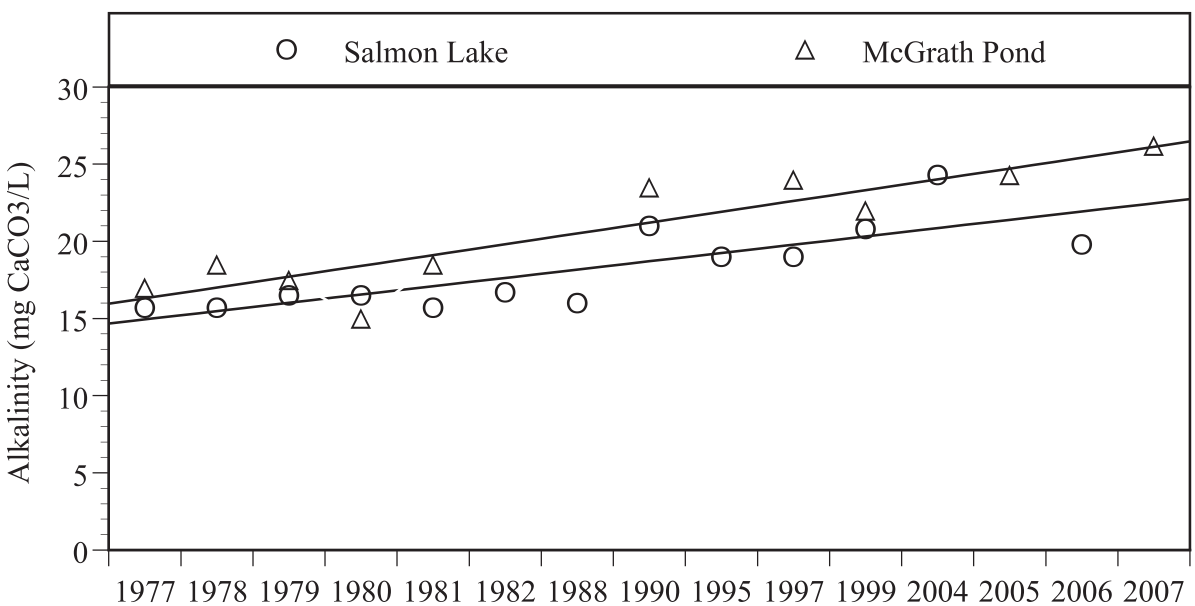

Figure 51. Alkalinity levels (mg CaCO3/L) for Salmon Lake (Site 1) and McGrath Pond (Sites 2 and 3) from 1977-2007 (MDEP 2009). See Figure 29 for site locations.

Hardness

Introduction

Hardness is the measure of the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions and is recorded as the sum of the two in milligrams per liter (mg/L) (Eaton 2005). These ions are present due to the weathering of various types of rock, predominately limestone (Chapman 1992). Soft water is defined by the USGS as 0-60 mg/L and is more prone to algal blooms. Calcium ions have the ability to tie up phosphorus in the water and because soft water has lower levels of these ions, less phosphorus is tied up, and thus more is free to be available in the water column, causing algal blooms. Hard water ranges from 121-180 mg/L and is less likely to bloom due to higher Ca^{2+} concentrations (Pearsall 1993, USGS 2009a).

Methods

Hardness sampling was conducted at Sites 1 and 3 from June to August 2009 and again on 17-September-09 by CEAT. Concentrated nitric acid (HNO_3) was added to the samples in the field for preservation. They were then placed on ice and returned to the laboratory for analysis. The samples were tested within 28 days of collection according to the HACH titration method. For more detailed methods see Appendices J and K.

Results and Discussion

Lakes

The mean (± SE) hardness from July to September 2009 was 2.29 ± 0.24 mg/L (n=9), which is considered soft water by USGS standards (USGS 2009a). The fact that algal blooms have occurred in Salmon Lake in the past supports the idea that softer water is more prone to algal blooms. Additionally, McGrath Pond appears to have slightly harder water than Salmon Lake at means of 2.4 and 1.8 mg/L, respectively (see Appendix L).

Salmon Lake and McGrath Pond were found to have softer water than some of the nearby water bodies such as Pattee, Togus and Threemile Ponds, which had mean hardness measurements of 6.13, 20.6 and 4.04 mg/L, respectively. These comparisons suggest that Salmon Lake and McGrath Pond may be slightly more susceptible to algal blooms than some of the nearby lake systems if water quality is not maintained.

Biological Analysis

Chlorophyll-*a*

Introduction

Chlorophyll is a pigment that is present in photosynthesizing organisms and is used to determine the amount of algal growth in a water body. There are three types of chlorophyll (*a*, *b*, and *c*), however chlorophyll-*a* is the easiest to measure, and is most commonly used to estimate phytoplankton biomass (Brönmark and Hansson 2005). Measuring chlorophyll is also an indirect way to estimate the trophic status and productivity level of a lake or pond (Chapman 1992). Higher levels of chlorophyll suggest a more eutrophic lake and similarly, higher chlorophyll represents higher productivity levels. The growth of algae is influenced by light, temperature and nutrient levels, with the result that chlorophyll-*a* levels fluctuate daily, seasonally and with depth (Chapman 1992).

Methods

Measurements were taken at Sites 1-3 and 10 on 17-September-09 at varying depths using an YSI 650 MDS Sonde that had been previously calibrated to a 0 standard using deionized water. The Sonde measures the amount of florescence from the chlorophyll when it is hit by the light from the probe (Firmage, pers. comm.). For more detailed methods see Appendices J and K.

Results and Discussion

Lakes

Measurements from the 17-Septmber-09 sampling show that at the surface, Salmon Lake has more chlorophyll-*a* than McGrath Pond (Figure 52). High levels at the surface indicate the presence of large amounts of live phytoplankton. The difference between the two water bodies may be due to the fact that there are more nutrients present in Salmon Lake, allowing for the lake to support higher levels of phytoplankton. McGrath Pond flows into Salmon Lake, with the result that Salmon Lake can have higher nutrient levels without McGrath Pond being affected. Observations that Salmon Lake has relatively frequent algal blooms (as recently as 2003) support these results (MVLMP 2009a).

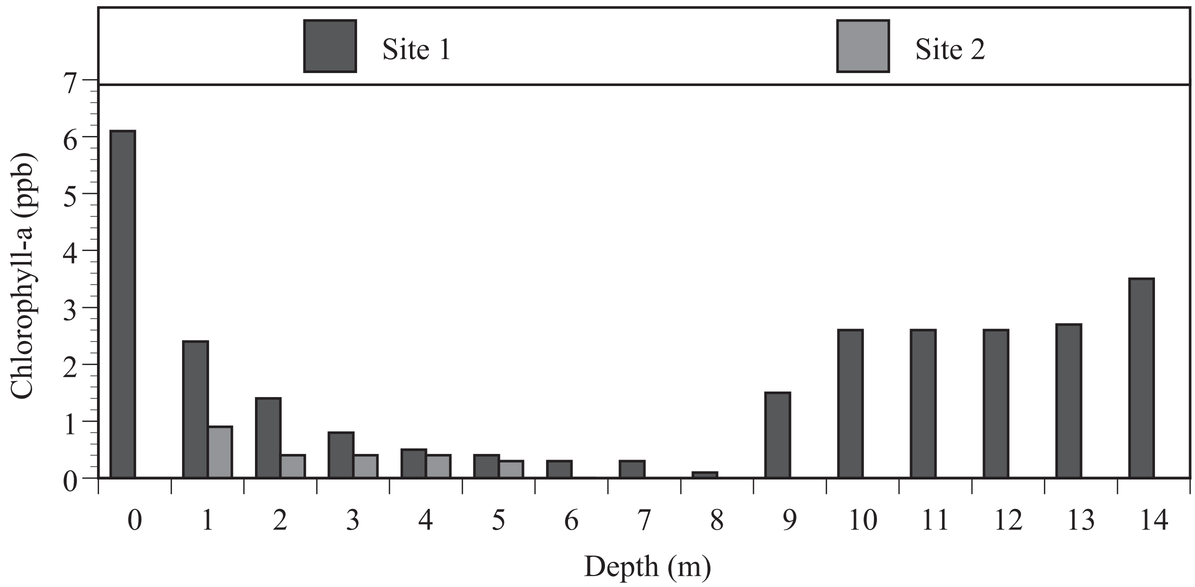

Figure 52. Chlorophyll-*a* concentrations (ppb) for Site 1 in Salmon Lake and Site 2 in McGrath Pond sampled on 17-September-09. Data for Site 2 at a depth of 0 m is not available. See Figure 29 for site locations.

As expected, chlorophyll-*a* levels initially decrease with an increase in depth in Salmon Lake, however after approximately nine meters, levels begin to increase. The increase of chlorophyll-*a* in deeper waters is likely due to the accumulation of dead phytoplankton, which can still be measured because chlorophyll in these organisms continue to fluoresce for a period of time after death. This increase is more evident in Salmon Lake than McGrath Pond because the measurements were taken in a deep hole in Salmon Lake, which is not present in McGrath. The water in deep holes is not as susceptible to wind, explaining the settling of dead phytoplankton in Salmon Lake.

WATER BUDGET

Introduction

A water budget is a set of calculations that summarizes all inputs and outputs of water in a lake. The water budget is used to generate the flushing rate for the lake, which represents the number of times the lake volume is replaced in one year. The flushing rate can provide valuable information about the vulnerability of a lake to the accumulation of nutrients and pollutants (Chapman 1992). Lakes with high flushing rates have a higher turnover rate, making them less susceptible to the buildup of pollutants and nutrients that can cause water quality issues. A high flushing rate does not prevent a lake from having water quality problems, but it does reduce the effect of the buildup of nutrients, such as phosphorus, that may occur in lakes with low flushing rates. Lakes with high flushing rates also respond to remediation techniques more quickly (George, Hurley et al. 2007). The water budget yields the percent of each input into the lake and indicates the relative impact of each source.

Methods

The water budget for Salmon Lake and McGrath Pond was calculated jointly and includes all inputs from runoff and precipitation and deducts the water lost due to evaporation to determine the net input (I_{net}) for the lakes. Salmon Lake and McGrath Pond do not have any major point sources of water inputs such as an inlet from another lake. The input value from runoff includes all direct water runoff into the lake as well as runoff that flows into streams within the Salmon/McGrath watershed, which then flow into the lake. Net input was measured in cubic meters per year. This value was then divided by the lake volume to determine the flushing rate. The following formulae were used to calculate I_{net} and the flushing rate for Salmon Lake and McGrath Pond.

I_{net}= (Runoff x Watershed Land Area) + (Precipitation x Lake Area) -(Evaporation x Lake Area)

Flushing Rate = (I_{net} Salmon Lake and McGrath Pond) / (mean depth x Salmon Lake and McGrath Pond surface area)

Although water levels in the lake constantly change due to storm events and management policies for the dam at the outlet to Great Pond, this study assumes that the amount of water entering the lake is equal to the amount leaving the lake over the course of the year because the lake is not increasing or decreasing in size over time (see Appendix G).

The value used for runoff (0.622 m/yr) and the value used for evaporation (0.560 m/yr) are from a study of the Lower Kennebec Basin (Prescott 1969). The precipitation value is the mean precipitation over a ten-year period measured by the National Oceanic and

Atmospheric Administration (NOAA 2009) from a recording station at the Augusta, ME airport from January 1999 through December 2008. Mean depth for each lake was determined using bathymetry measurements taken during the summer and fall of 2009 by the Colby Environmental Assessment Team (CEAT) along with PEARL (2009e and 2009f) depth data and multiplied by lake surface area to determine the total lake volume.

Results and Discussion

Runoff is the greatest contributor of water (66%) into Salmon Lake and McGrath Pond with precipitation contributing 34%. Using the value of these inputs and subtracting the evaporation multiplied by the lake surface area, the I_{net} was calculated at 12,185,357.75 m^3. This value was used to calculate the flushing rate for Salmon Lake and McGrath Pond of 0.47 flushes/year. This means that approximately 47% of the water in the lake is replaced each year. Salmon Lake and McGrath Pond have a flushing rate similar to the flushing rate of several other area lakes (Table 11), although it is lower than the mean flushing rate for Maine lakes, which is 1-1.5 flushes/year (MDEP 1996). Consequently, Salmon Lake and McGrath Pond are vulnerable to nutrient loading and accumulation of pollutants. Salmon Lake is currently on the list generated by the Maine DEP of lakes with water quality issues, although it has not reported an algal bloom since 2003 (MDEP 2009a). It is important to reduce nutrient inputs because they will tend to accumulate because of the low flushing rate. Salmon Lake and McGrath Pond are part of the chain of Belgrade lakes that ultimately drains into the Kennebec River, so it is important to maintain the water quality of these lakes so that other connected lakes are not negatively affected.

Table 11. Watershed areas, volumes and flushing rates for area lakes including Salmon Lake and McGrath Pond.

Lake	Watershed Area (m^2)	Volume (m^3)	Flushes/year
Great Pond[d]	214,710,014	209,160,000	0.52
Long Pond, South Basin[a]	39,190,184	46,191,231	3.61
North Pond[e]	30,920,000	37,148,856	1.36
Long Pond, North Basin[b]	23,126,300	34,922,160	3.79
Salmon Lake and McGrath Pond	15,727,343	25,727,841	0.47
East Pond[c]	10,598,777	33,848,120	0.29

[a]CEAT 2008, [b]CEAT 2007, [c]CEAT 2000, [d]CEAT 1999, [e]CEAT 1997

PHOSPHORUS BUDGET

Introduction

By estimating the relative contribution of a variety of land use types, in addition to atmospheric, septic system and bottom sediment inputs, a phosphorus budget can be constructed and used to predict the annual loading of phosphorus into the water body from the surrounding watershed. Furthermore, mathematical modeling of the relationship between inputs and outputs (via settling out of the water column and the flow of water out of the lake) can be used to predict the concentration of phosphorus in the water body. Estimating the relative contributions of a variety of land use categories to the total phosphorus load can highlight external factors most responsible for lake health. Finally the model can apply projections for future land use to predict the impact of future development on the trophic status of the lake (see Future Projections: Phosphorus Model Predictions).

Methods

The phosphorus budget for Salmon Lake and McGrath Pond was developed from studies by Reckhow and Chapra (1983), previous Colby Environmental Assessment Teams (2007), and from Total Maximum Daily Load Studies conducted by the Maine Department of Environmental Protection on Maine Lakes including East Pond (2001a), China Lake (2001b), Webber Pond (2002), Togus Pond (2005a), Long Lake (2005b), Wilson Pond (2007) and Long Pond (2008). The Salmon/McGrath watershed was investigated using land use characteristics (see Land Use GIS: Methods). To estimate the contribution of each land use category to overall phosphorus loading in the watershed, export coefficients (E_c) were assigned.

Export coefficients provide an estimate of phosphorus runoff per unit area of a specified land use in a given time interval and are expressed in units of kg/ha/yr. Coefficient values obtained by studies done on land use categories in one region can be applied to similar locales. Uncertainty inherent in the application of studies across different watersheds, however, mandates the application of a range of values (Reckhow and Chapra, 1983). Coefficients representing the high, low and best estimates of phosphorus contributions for each land use type were obtained from the aforementioned studies by Reckhow and Chapra, CEAT, and MDEP (see Appendix H). The phosphorus budget for Salmon Lake and

McGrath Pond included coefficients for the following land-use categories: mixed forest (Ec_{mf}), coniferous forest (Ec_{cf}), deciduous forest (Ec_{df}), regenerating land (Ec_{rl}), pasture (Ec_{pa}), cropland (Ec_{cr}), logged areas (Ec_{lg}), wetlands (Ec_{w}), cleared land (Ec_{c}), commercial land (Ec_{cm}), municipal land (Ec_{mu}), camp roads (Ec_{cr}), state roads (Ec_{sr}), parks (Ec_{pk}), shoreline development (Ec_{s}), non-shoreline development (Ec_{n}), golf course (Ec_{gc}), shoreline septic systems (Ec_{ss}) non-shoreline septic systems (Ec_{ns}) and youth camp septic systems (Ec_{yc}). The model also included coefficients for atmospheric (Ec_{a}) and bottom sediment (Sd_{cs}) inputs.

An estimate of the total phosphorus contribution of a specific land use for a given time interval can be obtained by multiplying its loading coefficient by the area (ha) of the category represented in the watershed. Estimating the phosphorus contribution of septic systems mandates consideration of the number of people contributing to each system, the time scale on which those contributions occur and the ability of the soil to retain waste-borne phosphorus, preventing it from reaching the water column (Reckhow and Chapra 1983). The total phosphorus contribution for shoreline septic systems (W_{ss}) is calculated as follows:

$$W_{ss} = Ec_{ss} \text{ x } (\text{\# capita years}) \text{ x } (1 - SR)$$

The "capita years" term accounts for the mean number of people and duration of use for septic systems in the watershed. The soil retention coefficient (SR) rates the ability of the substrate to prevent septic system phosphorus from percolating into the water body on a scale of 0-1, and is a function of phosphorus adsorption capacity, permeability, drainage and slope (Reckhow and Chapra 1983). Substrates with high soil retention coefficients are effective at preventing phosphorus from entering the water body. Finally, phosphorus contributions of atmospheric and sediment inputs are obtained by multiplying their respective coefficients by the total hectares of lake surface area. Summation of these values produces an estimate (W) of the total mass of phosphorus entering Salmon Lake and McGrath Pond in kg/yr:

$$W = (Ec_{mf} \text{ x } Area_{mf}) + (Ec_{cf} \text{ x } Area_{cf}) + (Ec_{df} \text{ x } Area_{df}) + (Ec_{w} \text{ x } Area_{w}) + (Ec_{rl} \text{ x } Area_{rl}) + (Ec_{pa} \text{ x } Area_{pa}) + (Ec_{cr} \text{ x } Area_{cr}) + (Ec_{lg} \text{ x } Area_{lg}) + (Ec_{c} \text{ x } Area_{c}) + (Ec_{cm} \text{ x } Area_{cm}) + (Ec_{mu} \text{ x } Area_{mu}) + (Ec_{sr} \text{ x } Area_{sr}) + (Ec_{pk} \text{ x } area_{pk}) + (Ec_{s} \text{ x } Area_{s}) + (Ec_{gc} \text{ x } Area_{gc}) + (Ec_{n} \text{ x } Area_{n}) + (Ec_{ss} \text{ x capita-yrs x } (1-SR_{1})) + (Ec_{ns} \text{ x capita-yrs x } (1-SR_{2})) + (Ec_{yc} \text{ x capita-yrs x } (1-SR_{3})) + (Ec_{a} \text{ x Lake } area_{s}) + (Sd_{cs} \text{ x Lake } area_{cs})$$

Total phosphorus concentration within the lake was calculated from an equation derived by Reckhow and Chapra (1983):

$[P]$ (in ppb) = $L / (11.6 + 1.2q_s)$ where $L = W/A_s$ and $q_s = Q_{total}/A_s$

Areal phosphorus loading (L) refers to the total mass loading of phosphorus per unit surface area of the lake, and was calculated by dividing the total phosphorus-loading estimate (kg/yr) by the surface area of the lake (m^2), yielding units of $kg/m^2/yr$. Q_s refers to the total volume of water entering the lake in a given time per unit surface area. Q_s was calculated by dividing the total annual water loading of the lake (m^3/yr) by the surface area of the lake, yielding units of m/yr (see Water Budget: Methods). The term $11.6 + 1.2q_s$ relates the settling velocity of phosphorus to annual water loading. Plugging the values obtained in the model into the above equation yields a prediction of the total phosphorus concentration (in ppb), which is a function of the composition of land use categories within the watershed and of climatic trends which affect the total water loading (see Water Budget: Methods).

Results and Discussion

Watershed loading estimates ranged from 345.5-1228.4 kg/yr of phosphorus, with a best estimate of 596.27 kg/yr (see Appendix I). Inclusion of sediment inputs predicted a range of 391.3-1594.9 kg/yr and a best estimate of 871.2 kg/yr phosphorus. Based on these loading estimates, the phosphorus model predicted a best estimate of 12.3 ppb of phosphorus in the combined water body of Salmon Lake and McGrath Pond, with low and high estimates of 5.5 and 22.5 ppb, respectively (see Appendix I). Coefficients were adjusted such that the output of the model matched that of field data for phosphorus in the water body following late-spring remixing of the water column. Analysis of an epicore sample taken from Site 1 on 3-Jun-09 yielded a phosphorus concentration of 12.5 ppb. That this value falls within the range predicted by our model and within 1 ppb of the best estimate phosphorus concentration supports the accuracy of the model.

Phosphorus inputs into Salmon Lake and McGrath Pond come exclusively from non-point sources and sediment release. Because no permanent water bodies in the surrounding area feed into the lake, point source inputs were not included in the model. Numerous tributary streams feeding into the lake were treated as inputs of runoff from surrounding land, and were not counted as individual point sources. The model predicted that sediment loading accounts for 31.6% of the total phosphorus load, while non-point inputs including runoff and atmospheric deposition account for the remaining 68.4%. Studies of other lakes in the Belgrade region indicated that sediment release contributed to total phosphorus loading in varying proportions. Pattie Pond received 18.7% of its phosphorus from sediment release (CEAT 2009), possibly reflecting its shallower mean and maximum depth and reduced frequency and duration of anoxic episodes. Sediment release contributed 16.2% of the total load into the north basin of Long Pond (CEAT 2007) despite having a greater mean depth (10 m) than that of Salmon Lake (5.5 m, see Salmon Lake and McGrath Pond Characteristics: Watershed Information). Deeper water would be expected to release phosphorus at a higher rate due to a higher frequency of anoxic episodes (see Background: Phosphorus and Nitrogen Cycles). A possible explanation is that the presence of three youth camps, extensive shoreline development and poor septic suitability (see Watershed Development Patterns: Septic Suitability Model) around Salmon Lake and McGrath Pond augment the external load while sediment release remains constant, resulting in a smaller relative contribution.

Despite a low export coefficient of 0.17 kg/ha/yr (see Appendix H), atmospheric inputs contributed 13.1% of the watershed phosphorus load based on the model (Table 12). Atmospheric deposition occurs when particulate phosphorus, released into the atmosphere by wood burning and industrial production, is returned to Earth's surface via precipitation, often far away from its original source (Reckhow and Chapra, 1983). The high contribution of atmospheric deposition can be attributed to the fact that Salmon Lake and McGrath Pond have a large combined surface area relative to that of the watershed. The total surface area of Salmon Lake and McGrath Pond comprises 30% of its total watershed area. Other lakes in the Belgrade region vary in surface area relative to their respective watersheds. East Pond, has the largest surface area to watershed ratio (38%) among the Belgrade Lakes, and receives 26% of its phosphorus from atmospheric deposition (MDEP 2001). Conversely, Messalonskee Lake comprises only 3% of its watershed, and has been estimated to receive between 2.9% and 4.1% of its phosphorus load from atmospheric deposition (CEAT 1998). While much of the particulate phosphorus that precipitates on land is absorbed by vegetation, that which precipitates onto the surface of the lake itself goes directly into the water body. The large combined surface area of Salmon Lake and McGrath Pond causes atmospheric deposition to contribute a larger portion to the overall phosphorus load than it would if the surface of the water body accounted for a smaller percentage of the total watershed area.

Table 12. Low, best and high estimates of the percent contribution of each land use category to the total phosphorus load in the Salmon/McGrath watershed. Percentages are expressed as the amount of phosphorus contributed by each category relative to the total phosphorus-loading estimate generated by the model. Land use categories are ranked by the size of the best estimate of their percent contribution to the overall phosphorus load.

Land Use Type	Low Estimate (%)	Best Estimate (%)	High Estimate (%)
Shoreline septic systems	8.50	14.94	24.86
Atmos. input	19.89	13.06	7.83
Cropland	15.33	11.11	6.69
Shoreline development	8.73	10.12	7.81
Non-shoreline development	9.78	9.07	11.00
Logged areas	7.47	8.66	6.31
Youth Camp Septic	9.01	8.60	5.81
Camp roads	3.65	6.05	8.81
Mixed Forest	6.78	5.89	4.45
State roads	2.43	3.02	3.91
Non-shoreline septic	0.00	2.09	5.08
Golf Course	2.14	1.28	1.75
Cleared land	1.09	1.27	1.64
Coniferous Forest	1.04	1.21	1.03
Municipal	1.36	0.92	0.83
Pasture	1.02	0.74	0.47
Deciduous Forest	0.61	0.59	0.40
Park	0.27	0.50	0.30
Commercial land	0.62	0.41	0.50
Regenerating Land	0.26	0.30	0.44
Wetlands	<0.01	0.17	0.08

Among the remaining non-point sources, youth camp septic systems, shoreline septic systems, cropland, shoreline and non-shoreline residential development and logged areas were large contributors of phosphorus (Table 12). Shoreline septic systems contributed a best estimate of 89.1 kg/yr of phosphorus. Although septic systems were assigned a lower export coefficient than several other land uses including cropland and shoreline residential lots (see Appendix H), a poor soil retention coefficient for shoreline systems (0.7%) reflected poor septic suitability of the soil, high proportion of systems built before 1974 ordinances on septic system quality (see Watershed Development Patterns: Septic Waste Disposal Systems) and close proximity to the shoreline. These factors combine to increase the likelihood of phosphorus-laden leakages reaching the water body. By contrast, non-shoreline systems were buffered from the water body by distance, minimizing the chances of wastewater percolation.

Cropland accounted for 11.1% of the external phosphorus load in the model, despite representing only 2.9% of the total watershed area (Figure 53). Cropland contributes particularly large amounts of phosphorus due in part to the application of fertilizers (see Background: Agriculture and Livestock). Phosphorus-containing fertilizers, including manure, that are not absorbed by crops are transported down-slope by runoff from precipitation and irrigation. The arrangement of crops in rows confounds this problem by providing open spaces between plants, reducing the likelihood of incorporation into crop biomass, and allowing runoff to flow at a more rapid rate than if the space between rows was vegetated or cultivated with a cover crop (Green et al., 1996).

Logged areas contributed 8.7% of the total phosphorus load. Logged areas pose similar nutrient loading problems to cropland in that they involve the clearing of paths through natural vegetation for transport of harvested timber (see Background: Forestry). These paths, in addition to the inherent thinning of the forest as trees are harvested, reduce the absorptive capacity of the land with regard to nutrients in runoff. The absence of fertilizers and persistence of forest vegetation implies that logged areas contribute substantially less phosphorus per unit surface area than cropland. This distinction is reflected by a lower export coefficient of 0.4 kg/ha/yr (see Appendix H). Because logged areas comprise a greater proportion of the watershed area than cropland, they still contribute a large proportion of the overall phosphorus load.

Shoreline and non-shoreline residential development contributed 10.1% and 9.1% of the total phosphorus load, respectively. Residential development often involves the clearing of large areas of forested or naturally vegetated land for foundations, lawns and driveways. Lawns have considerably less plant biomass than do canopied forests and absorb less phosphorus from runoff. Driveways and roofs are impermeable surfaces that have no nutrient absorption capacity and accelerate the flow of runoff toward the water body. Though the impacts of shoreline development on water quality can be mitigated through vegetated buffers, buffers along the Salmon/McGrath shoreline range in consistency and quality (see Watershed Development Patterns). The impact of camp roads constructed for access to residential lots, especially those along the shore, was considered separately from

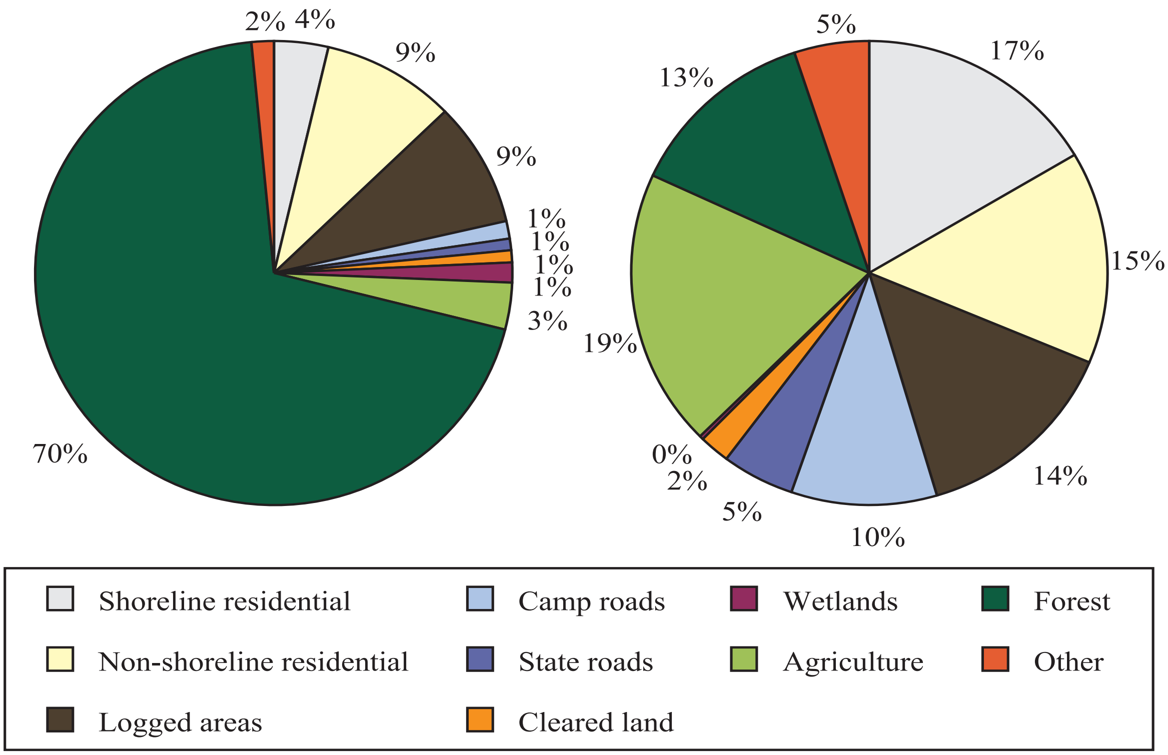

Figure 53. Land use composition and percent contribution of land use types to the overall phosphorus load into Salmon Lake and McGrath Pond. Illustrated on the left are areas of each land use type represented as percentages of the total watershed land area. Illustrated on the left are areas of each land use type represented as percentages of each land use type to the total external phosphorus load. Values are expressed as percentages of the total phosphorus load. "Agriculture" includes cropland and pasture, "Forest" includes regenerating land, deciduous, coniferous and mixed forest and "Other" includes parks, golf courses, commercial and municipal lands.

the residential lots themselves. Though camp roads represented a smaller portion (6.1%) of the total phosphorus load than the land uses examined thus far, their contribution was disproportionately greater than their relatively small area (7.4 ha) represented in the watershed (Figure 53). Camp roads facilitate nutrient loading by increasing the flow of surface water runoff, particularly when they slope steeply to the waterfront. The impact of camp roads can be reduced through construction of ditches, diversions and proper crowning to divert runoff into more thickly vegetated areas on either side (see Background: Roads).

INVASIVE SPECIES

Monitoring

Invasive aquatic macrophytes are threatening to the health of a lake because they can compete with native aquatic macrophytes and eventually take their place in the ecosystem. Invasive aquatic macrophytes generally have no natural predators in the ecosystem because they are not native to that environment. They are most commonly spread among different water bodies by catching on boats or other equipment that are used in the water and traveling with those boats to different locations (MVLMP 2009b). Many aquatic invasives can grow from plant fragments, so roots do not need to be present for infestation to occur, which makes it fairly easy for these plants to begin growing in a new place (MDEP 2005b). Once invasive aquatic plants have established themselves in a water body, it is nearly impossible to eradicate them, so the most effective method to combat invasive aquatics is to prevent their introduction to unaffected water bodies (MVLMP 2009b). The Maine Volunteer Lake Monitoring Program is one of the largest and most well established citizen based lake monitoring corps in the country. They provide training workshops for volunteers and also perform courtesy boat inspections before boats enter a water body to help prevent spread of invasive aquatic plant fragments that may catch on boats (MVLMP 2009b).

Of particular importance to our study is the aquatic invasive Eurasian watermilfoil (*Myriophyllumspicatum)*, which was found on 1-August-08 in the outlet of Salmon Lake where water leaving the lake flows into Great Pond. The infestation was estimated to be only a year or two old at that time, so its fairly early discovery is beneficial to the removal process (MDEP 2005b). Eurasian watermilfoil has been found in only one other location in Maine; a privately owned gravel pit in Scarborough (Calder 2008). Eurasian watermilfoil is an invasive aquatic macrophyte native to Asia, North Africa and Europe and is considered more aggressive than its relative, the variable leafed watermilfoil (MVLMP 2009b). Eurasian watermilfoil was introduced to the United States sometime in the 1950's-1980's and has since become a significant problem in water bodies across the United States. Presently, Eurasian watermilfoil is growing in nearly every state. However, of the 5700 lakes in Maine, only 29 contain invasive aquatic species (Calder 2008).

Since Eurasian watermilfoil was discovered in Salmon Lake, mechanical and later chemical measures have been taken to stop its growth and eradicate it from the water body. The stems of Eurasian watermilfoil can grow up to three meters long and its bipinnate leaves are arranged in whorls with many thin leaflets (MVLMP 2009b; see Appendix A). It roots in the bottom of the lake and grows quickly into thick canopies that both crowd out native plants and interfere with recreational activity. Eurasian watermilfoil generally grows at depths of 1-4 m but can grow as deep as 9-10 m, depending on the abundance of sunlight at those depths (Smith and Barko 1990; Figure 54).

Regulations

The Maine Volunteer Lake Monitoring Program has compiled a list of the eleven most unwanted invasive plant species in Maine. These plants include: Brazilian Elodea (*Egeriadensa)*, Curly leaved pondweed (*Potamogetoncrispus*), Eurasian watermilfoil (*Myriophyllumspicatum*), European naiad (*Najas minor*), Fanwort (*Cabombacarolinia*), Frogbit (*Hydrocharismorsus-ranae*), Hydrilla (*Hydrillaverticulata*), Parrot feather (*Myriophyllumaquaticum*), Variable leaf watermilfoil (*Myriophyllumheterophyllum*), Yellow floating heart (*Nymphoidespelata*) and Water chestnut (*Trapanatans*) (see Appendix A). Since 2000, it has been illegal to sell, propagate or introduce any of these eleven plants to Maine waters (MVLMP 2009b). Currently, only four of these eleven invasive aquatics are present in Maine: Variable leafed watermilfoil, Eurasian watermilfoil, Curly leafed pondweed and Hydrilla. In 2001, the Interagency Task Force on Invasive Aquatic Plants and Nuisance Species was established to advise the Land and Water Resources Council in the areas of researching, controlling and eradicating invasive aquatic plants and nuisance species (MVLMP 2009b). This group created an action plan for an early detection system to avoid invasive aquatic infestation. The goal of this Early Detection System is to educate people how to recognize invasive aquatic plants and train volunteers for courtesy boat inspections. This system was developed with the theory that prevention is the best method to avoid invasive aquatic infestations.

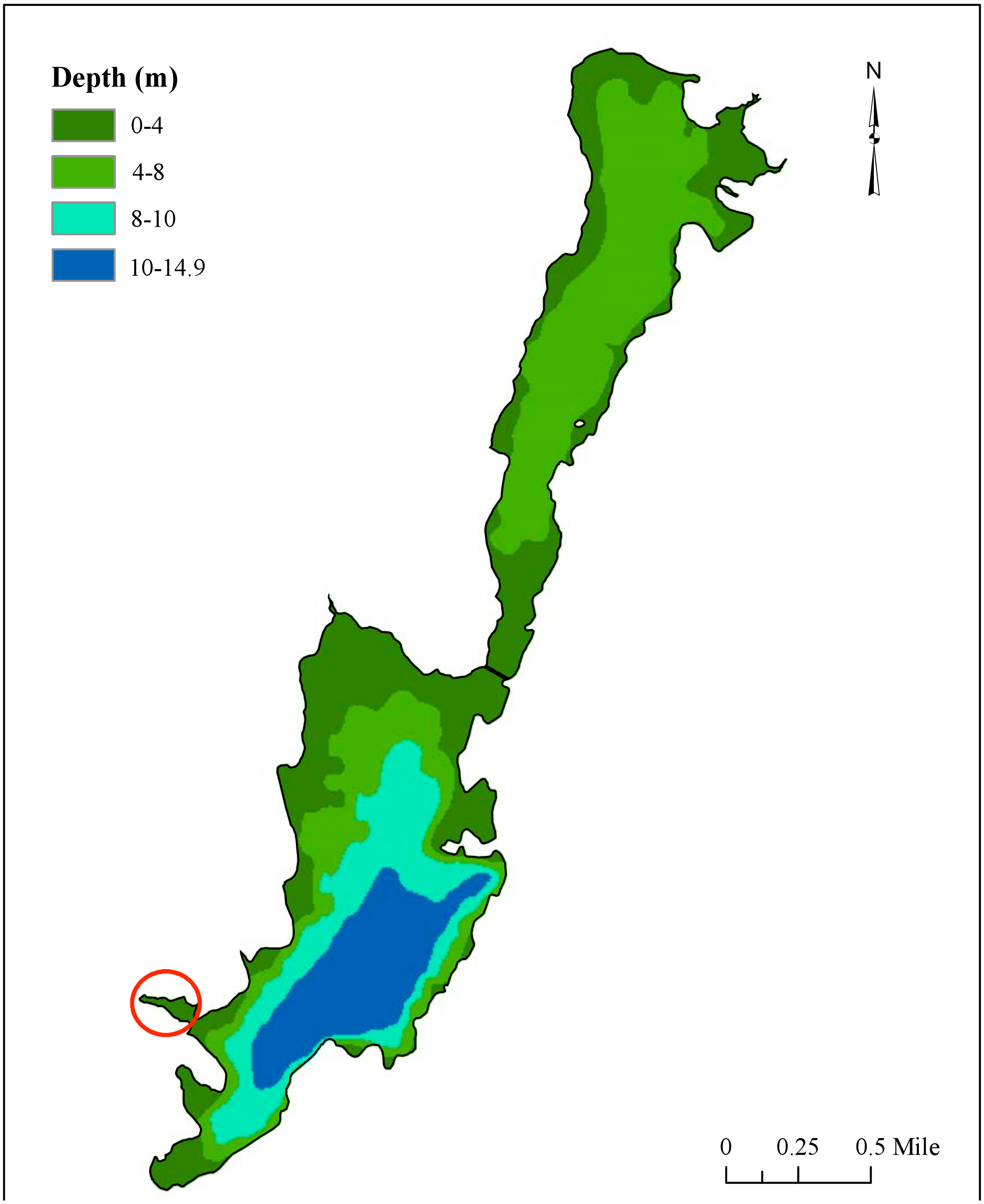

Figure 54: Extent to which Eurasian watermilfoil establishment is possible in Salmon Lake and McGrath Pond. Areas in dark green indicate depth of 0-4 m, where Eurasian watermilfoil commonly grows. Depths between 0-8 m, light green, are possible areas in which Eurasian watermilfoil could establish a population. Areas in turquise (8-10 m) are less likely to become infested, but a milfoil invasion is still possible. Areas in blues (deeper than 10 m) are sufficiently deep to make the establishment of the plant unlikely. The red circle denotes the cove in which watermilfoil is currently found.

Removal Theories and Strategies

Removal techniques for invasive species vary greatly depending on the extent of the infestation and the specific water body involved. Generally, the first step is to identify where in the water body the infestation has happened and to mark those places with buoys to prevent further boat or human traffic from entering the area and spreading the problem to other areas via fragmentation (McPhedron 2002). The first method of control mandated by the Department of Environmental Protection (DEP) is hand removal of the plant. However, this is often unsuccessful in larger infestations because fragments inevitably break off and smaller plants are sometimes missed. If this method proves ineffective, other methods such as mechanical control may be considered. Herbicide treatment is another, but infrequently used, option (MDEP 2005b). The DEP has the authority to determine whether herbicides should be applied, but they are generally avoided because of potential negative environmental impact and the possibility of creating herbicide resistant species. Application of an herbicide also requires a period of review and comment from municipalities adjoining the lake as well as from property owners on the affected water body (McPhedron 2002).

The potential Eurasian watermilfoil growth map was developed based on both depths at which Eurasian watermilfoil commonly grows and light attenuation depths in Salmon Lake and McGrath Pond (Figure 54). The 0-4 m depth range is where Eurasian watermilfoil could easily grow if an infestation were to occur; the 4-8 m depth range could also support growth of the plant, but it is somewhat less likely, and depends on abundance of sunlight at those depths. The 8-10 m depth range indicates where it is unlikely but still possible for the plant to establish itself, and depends mostly on the amount of sunlight penetration (Smith and Barko 1990). At depths greater than 10 m, it is very unlikely for the plant to grow because sufficient sunlight does not reach these depths. The presence of Eurasian watermilfoil in Salmon Lake is of particular concern because Salmon Lake is a part of the Belgrade Lakes chain, and because all of the lakes in the chain are interconnected, the infestation could travel to shallow regions of Great Pond and potentially on to other lakes in the chain.

After the discovery of Eurasian watermilfoil in Salmon Lake, boat access in the cove was restricted to residents of the cove only and small “clamshell" benthic barrier mats were placed on the lake bottom to restrict sunlight penetration and stop plant growth. Because the bottom of the cove has many rocks and tree trunks, mats could not be placed everywhere so divers were hired to pull out plants that were not covered by the benthic barriers (Karen Hahnel, pers. comm.). Nets were put in the cove entrance to prevent plant fragments from floating to other parts of the lake and potentially spreading the infestation to other regions of the lake (Crosby 2009). During the summer of 2009, divers removed 325 plants in the six-acre cove, more than twice the amount removed in 2008, but this method was not completely successful in eradicating the plant (Crosby 2009). In July 2009, the Maine DEP applied for a permit to use 2,4-Dichlorophenoxyacetic acid (2,4-D) to control growth of the plant. The herbicide was applied in the infested cove on 10-September-09. Since the application of the herbicide, water tests in late September 2009 revealed very low concentrations of the herbicide (5.7 ppb) in areas of Salmon Pond outside of the cove, and no herbicide in Great Pond (Crosby 2009). The effect of this herbicide treatment on Eurasian watermilfoil growth and on non-target organisms will not be entirely clear until spring of 2010, when plant growth resumes.

FUTURE PROJECTIONS

POPULATION TRENDS

Historical Population Trends

Census data show that in Belgrade the population has been steadily increasing since 1960, when the population was 1,102 residents (KVCOG 2009). The greatest decennial increase was between 1970 and 1980 when the population increased 56.9%. The most recent estimate stated that in 2008 the population was 3,213 residents (U.S Census Bureau 2009). Additionally, the median age has increased from 31 years of age in 1980 to 40 years of age in 2000 (KVCOG 2009). This indicates that those who choose to raise a family in Belgrade tend to remain there later into their lives, as well as the addition of retirees making Belgrade their home. Although the number of residents 18 years of age and younger is increasing, the rate per decade is decreasing, as is the number of college graduates. Additionally, the percent of elderly citizens is increasing and the rate of high school graduates is remaining the same over these years.

In Oakland, the population has risen from 3,075 people in 1960 to the 2007 estimate of 6,184 residents (U.S. Census Bureau 2009). Similar to Belgrade, the largest rise was 46.0% from 1970 to 1980 (KVCOG 2009). Unlike Belgrade, the rate of population increase has shown signs of leveling off in the past few decades. The number of residents under the age of 18 has remained constant for the past 20 years, while the numbers of those over the age of 65 have steadily increased. The median age has increased from 29 years of age in 1980 to 37 years of age in 2000. There is a steady rise in the number of high school graduates from the past two decades.

Population Predictions

In Belgrade, the estimated population for the year 2020 is 4,100 residents (KVCOG 2009). It is not surprising to note a continued decrease in the rate of younger residents and an increase in elderly citizens. Most likely the median age will continue to rise into the future.

In Oakland, the estimated 2020 population is 7,500 residents. Although this is significantly larger than the population estimate for Belgrade, it is a link in the chain of a predicted population leveling. This means that over the past few decades, the rate of population growth in Oakland is diminishing and should continue to do so in the future. Oakland should expect to see an increase in residents under the age of 18 but not at the same rate as Belgrade. The median age should continue to rise as both Belgrade and Oakland move towards a community comprised predominately of adults.

Economic Predictions

With the increase in retired residents in Oakland and Belgrade, the economy has been moving towards a bedroom community, which means that there will be less commercial development in this region as residents tend to live in these two towns but commute to larger cities such as Augusta and Waterville to work. This pattern should continue as we proceed into the future. More and more businesses will be transferring to in-home properties, which correlates with the future population predictions. Rick Swanson, president of the McGrath Pond/Salmon Lake Association, discussed the progression of residents in the watershed. He said that recent trends showed that seasonal residents were shifting to year-round (Swanson, pers. comm.). He indicated that these people were more often older, retired citizens.

DEVELOPMENT TRENDS

Historical

Human development has impacted the Belgrade Lakes Region for over 200 years. Colonists from New Hampshire and Massachusetts settled the area that is now Oakland in the late 1700's (Town of Oakland 2009). In 1771, the area was incorporated as Winslow, then in 1872 the land west of the Kennebec was incorporated as Waterville. In 1883, Oakland broke away from Waterville and incorporated. Settlers looking for new hunting grounds came to Belgrade in 1774 and by 1790, the population was 159 (Town of Belgrade 2009). The Town of Belgrade incorporated in 1796 with a population of 250 people. Development centered around farming, logging and grist and lumber mills. In the late 1990's, the number of farms, mills and jobs declined and the Belgrade Lakes region became a "bedroom community," where residents live in Belgrade and commute to another town for work. Belgrade provides a rural quality of life to residents and nearby Augusta and Waterville provide jobs (Town of Belgrade 2009). This development trend in Belgrade and Oakland is consistent with similar trends across central Maine. The Brookings Report found that in 1970, almost 45% of Central Maine's population resided in regional hubs, including Waterville and Augusta (Brookings 2006). Today, only 33% of this population lives in cities, and residents are choosing to live in more rural locales, including the Belgrade Lakes Region. Rural land is being converted to higher-density suburban land and second homes. In 1994, the Colby Environmental Assessment Team found that 70% of the Salmon/McGrath Watershed was developed. From 1970 to 2000, the total number of houses has increased in Oakland and Belgrade (KVCOG 2009). Belgrade and Oakland attract tourists and second homeowners because of their proximity to lakes. In 2000, 38.6% of houses in Belgrade were seasonal homes and 11.1% of houses were seasonal homes in Oakland (KVCOG 2009). From 1970 to 2000, the percent of seasonal homes has decreased in both Oakland and Belgrade. In 2006, 16% of all dwellings in Maine were designated as second homes (Brookings 2006).

Current

Since 2007, there has been a decline in residential and commercial development in Belgrade and Oakland (Ellis, pers. comm.; Rushton, pers. comm.). All construction projects with an estimated cost of $1,500 or more must apply to the town for a permit (Town of Belgrade 2009, Town of Oakland 2009). The number of permits issued is a measurement of construction development in the area. Between 1-January-08 and 31-December-08, Oakland issued building permits for 33 new dwelling units, 59 residential additions and renovations, 24 new garages and 14 new commercial constructions (Town of Oakland 2008). The total estimated project costs were $5,798,085 (Town of Oakland 2008). In the beginning of 2008, the planning board reviewed several sub-division permit applications for Oakland, however by winter of 2008, sub-division development had slowed (Town of Oakland 2008).

Belgrade saw a decline in subdivision and commercial permits. Beginning in 2007, there has been a decline in building permit applications for single-family dwellings and a decline in the total number of building permit applications for the shoreland zone (Town of Belgrade 2008). In 2007, Belgrade issued 128 total building permits. In 2008, they only issued 93. In 2007, Belgrade issued 22 building permits for single-family dwellings. In 2008, they only issued 9. This decline in development has continued into 2009.

In 2009, new building continued to decline in the towns of Belgrade and Oakland (Ellis, pers. comm., Rushton, pers. comm.). Robert Ellis, Code Enforcement Officer for the Town of Belgrade, reported that the Oakland Planning Board canceled six meetings between January and October of 2009 because they had no permit applications to discuss (Ellis, pers. comm.). From January to November of 2009, 25 new homes have been built, compared to 33 in 2008. Peter Rushton, a member of the Belgrade Planning Committee, reports that Belgrade has not received a large number of building permit applications for 2009 (Rushton, pers. comm.). This is probably a reflection of the economic downturn. The Planning Committee is using meeting time to collaborate with the Long Range Planning Committee to write a Comprehensive Plan for the Town of Belgrade. Oakland started to write a comprehensive plan in 1991 and again in 2001 (Ellis, pers. comm.). The town did not complete or approve either plan and has no current plans to write another comprehensive plan.

In the Salmon/McGrath watershed, development in 2008 and 2009 included the paving of McGrath Pond Road (Town of Belgrade 2008, 2009). Belgrade began updating McGrath Pond Road in 2008. They replaced culverts, added ditching to the entire road and cut trees to improve snow plow access. In the summer of 2009, Belgrade completed construction and repaved the road surface.

The Salmon/McGrath watershed has two subdivision plans with approved permits that remain unconstructed. Oakland approved the development of Mutton Hill Road (now called Lake Vista Drive) and ten residential lots in 1985 (Ellis, pers. comm.). At present, only one house has been built and the remaining nine lots are unsold and undeveloped with no town notification of development plans for the near future. The second subdivision is the Belgrade Estates Retirement Community (Kallin, pers. comm.). The subdivision plan includes two phases of development (Belgrade Estates 2009). The first phase is the construction of 10 cottage homes. The second phase is the construction of a main lodge with 14 luxury assisted living apartments, a fitness center and wellness clinic and four additional cottage homes. An office on McGrath Pond Road has been built but no homes have been constructed.

Future

The Belgrade Planning Board and Long Range Planning Committee is updating the 1998 Belgrade Comprehensive Plan for growth and development (Rushton, pers. comm.). The planning board is reviewing the current state of the town to write a comprehensive plan that the town can implement. This includes: understanding town history and culture; identifying critical natural resources; investigating water quality trends; interviewing local business owners; assessing location and condition of roads and analyzing municipal services and infrastructure. The Planning Board will "evaluate the town's capability to provide for the environmental and economic welfare of its residents" (Town of Belgrade 2008). The Belgrade Planning Board is studying the feasibility of coordinating watershed management, code enforcement and planned development with neighboring towns (Rushton, pers. comm.).

The Belgrade Planning Board predicts that commercial and residential development of the Belgrade Lakes Region will continue to grow at a slow rate. The current population growth rate for Belgrade is 1.5% of the population per year and 6.5% per year for Oakland (KVCOG 2009). High quality of life and the natural beauty of the area continue to attract residents and second homeowners to the Belgrade Lakes Region (Rushton, pers. comm.). The Belgrade Planning Board does not foresee large-scale business or development coming to Belgrade and Oakland. They predict that the towns will remain bedroom communities with residents continuing to commute to Waterville and Augusta (Rushton, pers. comm.).

The reason the Planning Board predicts the Belgrade Lakes Region will remain a bedroom community is because there are constraints to large-scale development (Rushton, pers. comm.). Belgrade lacks a municipal waste water line and treatment center, which limits development. Oakland has a municipal sewer system, but it does not serve the entire town limits. Every house outside of the wastewater sewer line must build its own septic system or holding tank. A second constraint is the lack of municipal water line for Belgrade and part of Oakland, meaning that each new house will have to put in its own well to have access to water. The third constraint is the topography of the area. The location of the lakes does not allow for the building of major thru roads or large-scale subdivisions. Residential development in the area has taken place on dead-end residential roads (Rushton, pers. comm.). Minimum lot sizes prevent the building of large subdivisions, especially in the shoreland zone. The area may continue to see conversions of seasonal homes to year-round homes on existing lots due to enforced minimum lot sizes in the shoreland zone (Rushton, pers. comm.). The Shoreland Zoning Ordinances require that each residential lot contain at least 200 feet of shore frontage and at least 40,000 square feet of lot area (Town of Belgrade 1991, Town of Oakland 1995). The amount of land and shoreland frontage will limit the number of houses built on the shore. In areas where there is no more room for development, residents may remodel an existing structure, instead of building a new one (Rushton, pers. comm.).

Land conservation will continue to be part of future plans for the development of the Salmon/McGrath watershed (Kallin, pers. comm.). The Belgrade Regional Conservation Alliance (BRCA) is working to conserve land and water resources in the Belgrade Lakes Region. BRCA has 49 acres of conserved land within the Salmon/McGrath watershed on the east side of the Narrows, the channel between McGrath Pond and Salmon Lake. Currently, BRCA is working to increase this land to a total of 200 acres that will be open to the public (Kallin, pers. comm.).

PHOSPOROUS MODEL PREDICTIONS

Introduction

The future health of Salmon Lake and McGrath Pond depends upon changing land use patterns in the surrounding watershed. Given that different land use categories contribute unequally to the overall phosphorus load entering the lakes, conversion of low-exporting land into land uses with higher phosphorus exportation rates can be expected to increase the total concentration of phosphorus within the lake and negatively impact the health of the aquatic ecosystem. Incorporating projections of future land use patterns into the phosphorus model can quantify the potential impact of these changes on the nutrient levels in the lakes, and can help inform development policies aimed at keeping phosphorus concentrations below the threshold range of 12-15 ppb likely to stimulate algal blooms.

Methods

Land use projections for the Salmon/McGrath watershed were based on residential development spurred by population growth in the watershed, and on the expected conversion of reverting lands to forest as those lands undergo succession. The model focuses on residential development because of the characterization of Belgrade as a "bedroom community" with low levels of commercial activity inhabited predominantly by residents who work elsewhere (see Future Projections: Development Trends). Residential land use projections for 2020 were based on a population growth model developed by the Kennebec Valley Council of Governments (see Future Projections: Population trends, KVCOG 2009). Future population predictions and estimated mean household occupancy were used to estimate the number of new houses that would be built to accommodate a population increase.

To account for the fact that much of Oakland and Belgrade fall outside the Salmon/McGrath watershed, an estimate of the current watershed population was obtained by multiplying the number of houses in the watershed by the mean number of people occupying each household. This estimate was extrapolated to 2020 according to the projected mean population growth rate of Belgrade and Oakland during that time. Dividing this figure by the mean number of 2.6 inhabitants per household (KVCOG 2009) yielded the projected number of new residential developments by 2020. The predicted number of new houses was divided among shoreline and non-shoreline categories according to the current ratio of shoreline to non-shoreline residential lots in the watershed. Additionally, a portion of regenerating land was re-designated as mixed forest to account for succession operating on old fields.

Results and Discussion

Land Use and Development

Current population figures were obtained from a 2008 survey, which yielded a population of 3,213 for Belgrade and 6,184 for Oakland (U.S. Census Bureau 2009). The population of Belgrade is predicted to increase to 4,100 inhabitants by 2020 and that of Oakland is expected to increase to 7,500 (see Future Projections: Population Trends; KVCOG 2009). Shoreline and residential surveys yielded a total of 611 houses in the Salmon/McGrath watershed (see Watershed Development Patterns: House Count). Based on the mean occupancy estimate of 2.6 people per household (KVCOG 2009), 1588 people are currently estimated to reside within the Salmon/McGrath watershed. Multiplying this value by the mean projected growth rate of 22.5% for Belgrade and Oakland between 2009 and

2020 yields a predicted total watershed population of 1,946 inhabitants in 2020. Considering the mean occupancy of 2.6 people/household, 137 new homes are estimated to be constructed by 2020, increasing the total for the watershed to 748. Applying the current proportion of 45% shoreline development (see Watershed Development Patterns: House Count) to residential composition in 2020, we estimate that 62 new shoreline and 83 new non-shoreline houses will be built. Minimum lot sizes for residential development, coupled with zoning restrictions prohibiting development near streams, wetlands or on heavily sloped land (see Watershed Development Patterns: Residential Zoning), restrict the number of buildable shoreline lots to 13 for Salmon Lake and six for McGrath Pond. 18 vacant lots along both lakeshores were designated as unbuildable due to their failure to meet minimum requirements for lot size or shore frontage, or because the lots were located on ground with more than a 20% slope. Assuming that development will continue away from shore as waterfront space is used up, 19 shoreline and 118 non-shoreline homes are predicted to be constructed in the Salmon/McGrath watershed by 2020.

This study assumes that new housing developments obtain land by clearing mixed forest, the predominant land use type within the watershed. Mean area estimates of 0.4 ha for non-shoreline and 0.2 ha for shoreline residential lots (see Watershed Development Patterns: House Count) predict that the projected 137 new homes in the Salmon/McGrath watershed will take up a total of 51.0 ha of land previously occupied by mixed forest. These changes in land use area were accounted for in the phosphorus model predictions for 2020. This study also assumed that a portion of regenerating land should undergo succession and convert to mixed forest by 2020. Succession rates were adapted from a comparison of satellite photos of the nearby Long Pond watershed from 1966 and 2007, which predicted that five percent of all regenerating land would be converted to mixed forest by 2020 (CEAT 2008). This succession rate indicates a loss of 0.3 ha of regenerating land by 2020, concurrent with a gain of 0.3 ha of mixed forest.

b. Phosphorus Budget Projections

Modeling of future land use in relation to phosphorus loading in the Salmon/McGrath watershed indicates that residential development associated with population growth will result in increased mean phosphorus concentrations in the water body by 2020. Incorporating projections for future housing development, conversion of mixed forest, and succession of regenerating land, the model predicted a concentration range of 5.8-24.8 ppb phosphorus, with a best estimate of 15.3 ppb, for the combined water body of Salmon Lake and McGrath Pond in 2020. These values indicate a 3% increase in the mean phosphorus concentration of the water body from the 12.5 ppb observed at the spring overturn in 2009 (see Phosphorus Budget: Results and Discussion). Although the best estimate prediction of 12.9 ppb phosphorus falls below the 15 ppb threshold above which a lake is considered to be highly susceptible to algal blooms (Firmage, pers. comm.), the high estimate of 24.79 ppb greatly exceeds this threshold. Shoreline development regulations and continued water quality monitoring are crucial to ensuring that total phosphorus for Salmon Lake and McGrath Pond remain below 15 ppb. A mitigating factor might be that new homes would have to be built at least 100 feet from the shoreline and the septic systems added would comply with the current regulations.

Predicted increases in phosphorus loading can be attributed to unique characteristics of residential development regarding erosion and runoff. Driveways and roofs associated with houses are impervious to rain water and can accelerate the rate of surface runoff flow (see Background: Shoreline Residential Areas). These impervious surfaces lack the capacity to absorb and incorporate excess phosphorus present in runoff. Construction of additional septic systems to accommodate new homes increases the likelihood that surrounding soils will be contaminated with excess phosphorus from wastewater, which may ultimately percolate into the water body (see Background: Subsurface Wastewater Disposal Systems). Finally, clearing of canopied forest vegetation for lawns or gardens reduces the quantity of plant biomass per unit area of land and restricts the capacity for vegetation to absorb, incorporate and transpire phosphorus from the soil and surface runoff (Chapin and Slack 1979). The export coefficient range for residential development reflects a range of house distances from shore and relative buffer quality revealed by shoreline surveys of Salmon Lake and McGrath Pond (see Appendix I). Compliance with residential zoning codes limiting the proximity of new houses to the waterfront (see Watershed Development Patterns: Residential Zoning) and construction of proper vegetated buffers (see Watershed Development Patterns: Buffer Strips) are critical to minimizing the impact of projected development on water quality and maintaining phosphorus concentrations below the 15 ppb threshold necessary for severe algal blooms.

RECOMMENDATIONS

The study conducted by the Colby Environmental Assessment Team (CEAT) suggests that Salmon Lake and McGrath Pond have potentially impaired water quality. The quality of the water bodies appears acceptable now, but phosphorus concentrations are at a tipping point. Additional phosphorus loading into the lakes could result in algal blooms. In addition, the discovery of Eurasian watermilfoil in Kozy Cove in Salmon Lake represents a serious threat to these lakes, to Great Pond and to other lakes in the area. CEAT believes that it is important to take the proper steps now to prevent deterioration of the water quality of these lakes. Below is a list of recommendations offered by CEAT for stakeholders to consider.

WATERSHED MANAGEMENT

Buffer Strips, Erosion and Boat Ramps

Effective shoreline buffer strips are a key strategy for mitigating nutrient loading from different land uses within the Salmon/McGrath watershed. Although land uses close to the lakes have a higher probability of causing nutrient loading, nutrients from more distant locations can also be carried into the lake by tributaries or runoff from roads and driveways. Potential nutrient loading can be reduced by:

- Constructing a buffer that covers the entire lot shoreline, consists of a variety of different native vegetation types and extends back into the lot as far as possible. Native vegetation is best suited to filter out nutrients and is adapted to local climate and soil conditions.
- Creating shoreline access paths that are narrow and winding to reduce direct flows along the path and into the lake.
- Minimizing exposed soil near the lake shoreline to decrease susceptibility to erosion.
- Installing riprap where needed to help mitigate shoreline erosion from wave action.
- Abandoning private boat ramps in favor of using a public ramp. This action would eliminate nutrient-loading happening at these sites. It would also make boat inspections for invasive species easier.

- Monitoring public boat ramps closely to make repairs or changes that prevent erosion leading to nutrient loading.

Septic Systems

In 1974, Maine passed regulations to improve the design and efficiency of septic systems. These regulations addressed the proper procedures for installation and maintenance of septic systems to have the least impact on the water body. CEAT estimates that 385 out of the 611 residences in the watershed were constructed before 1974 and are exempt (i.e., grandfathered) from these new regulations. Improperly functioning septic systems are a leading source of phosphorus loading into lakes. Old and inefficient septic systems should be brought up to date as quickly as possible. CEAT recommends the following actions:

- All septic systems be registered with the town so accurate monitoring can occur.
- Older systems should be replaced before failure.
- Septic systems should be installed as far back from the shoreline as feasible. This placement will facilitate nutrient absorbance by the soil before they enter the water body.

Roads

Roads are an essential component of any developed area to provide for transportation access. Poorly maintained roads, especially camp roads, can lead to high nutrient loading into nearby water bodies. Road recommendations include:

- Inspect and repair all roads regularly, especially camp roads. In the long run, the cost of regular maintenance on the road is significantly cheaper than infrequent full-scale repairs.
- Maintain proper ditching and crowning of camp roads to help create roads with little runoff and erosion.
- Inspect and replace broken or obstructed culverts.
- Install water diversions wherever necessary (e.g., channels and rubber strips) to help move water away from the road into natural habitats where it can be absorbed.

- Design driveways to be winding and not lead directly to the water body to prevent runoff into the lake. Also, prevent runoff on camp roads from flowing down driveways and into the lake.
- Correct existing problems as soon as possible to help prevent further nutrient loading. CEAT has identified specific problems for repair consideration.

Land Use

Land uses will continue to change over the ensuing years both in negative and positive ways in relation to potential for nutrient loading into these lakes. While we understand development will occur, CEAT offers some recommendations that can help protect water quality:

- Land uses closer to the lake likely have a higher impact on the water quality. Extra steps should be taken to mitigate nutrient or chemical loading from shoreline residences, youth camps or commercial businesses located close to the shoreline.
- CEAT estimates that there are 19 undeveloped and buildable lots on the shoreline of these lakes. Caution should be used in developing these lots to mitigate possible nutrient loading. Ideally, leaving these lots as native vegetation would have the least impact on water quality.
- If development does occur in the watershed, building near existing roads would help minimize lake impacts.

In-Lake Management

Water Quality

Salmon Lake and McGrath Pond have experienced recent improvements in water quality. However, the history of both water bodies has shown an oscillating trend of improvements in water quality followed by a decline. The Salmon/McGrath watershed is near a tipping point for algal blooms, and small increases in lake phosphorus concentration could cause algal blooms to reappear. For Salmon Lake and McGrath Pond to remain categorized as mesotrophic lakes, deterioration in the water quality must be avoided. CEAT recommends the following actions:

- Maintaining the water quality of McGrath Pond and Salmon Lake through continued vigilant monitoring at the lake characterization sites for changing trends in phosphorus concentrations.
- Monitoring of Cold Brook and the Mutton Hill Road Stream, as well as other tributaries for evidence of possible nutrient loading. Year-round monitoring of tributaries as well as lakes by the McGrath Pond/Salmon Lake Association should be considered.

Invasive Species

The exclusion of invasive aquatic macrophyte species is an important priority for maintaining ecologically healthy lakes. CEAT recommends the following actions:

- Encouraging residents to take advantage of training programs and informational literature to learn how to recognize and prevent further infestations of invasive aquatic macrophytes.
- Continuing boat inspections to help prevent future introductions of invasive aquatic macrophyte species into these water bodies.
- Restricting boat launches to the public boat lunch would facilitate boat inspections and reduce the chances of another accidental introduction into these lakes.
- Continuing efforts to eradicate the Eurasian watermilfoil population in Kozy Cove.

Community Awareness and Education

There are many educational programs that raise stakeholder awareness that have and will continue to play an important role in watershed care and maintenance. Although the McGrath Pond/Salmon Lake Association and the Belgrade Regional Conservation Alliance have been successful in educating and raising awareness regarding important lake issues, it is important to continue to build upon these efforts.

The McGrath Pond/Salmon Lake Association

The McGrath Pond/Salmon Lake Association has performed water quality tests since the 1970's. These tests are extremely useful in monitoring changes in water quality. Educational programs as well as boat launch inspections are also important in preventing invasive species infiltration. These programs are commendable but must be continued to ensure water body protection.

Maine Volunteer Lakes Monitoring Program (MVLMP)

The MVLMP is a successful program that helps maintain water quality through monitoring efforts and educating the public on topics such as the danger of invasive species. These efforts should continue.

Maine Department of Environmental Protection (MDEP)

In addition to the MDEP monitoring program, MDEP sponsors a successful program called *Lake Smart*, which recognizes homeowner efforts to protect lake water quality. Innovative programs such as *Lake Smart* should be continued to help educate stakeholders regarding best management practices. MDEP should continue efforts to extirpate Eurasian watermilfoil from Kozy Cove.

Belgrade Regional Conservation Alliance (BRCA)

The Youth Conservation Corps, established by BRCA, has performed over 500 projects in the Belgrade lakes area. This program has proven to be very effective in reducing nutrient loading from residential areas including roads and driveways and should be continued.

BRCA has also purchased land throughout the Belgrade Lakes Region including 49 acres in the Salmon/McGrath watershed for conservation purposes. Preserving this and other lands will have positive effects on the quality of these lakes for all their users to enjoy.

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Roy Bouchard	Maine Department of Environmental Protection
Karen Hahnel	Maine Department of Environmental Protection
Gary Fuller	Code Enforcement Officer, Town of Belgrade
Robert Ellis	Code Enforcement Officer, Town of Oakland
Peter Kallin	Belgrade Regional Conservation Alliance, Executive Director
David Halliwell	Maine Department of Environmental Protection
Rick Swanson	McGrath Pond Salmon Lake Association, President
Cheryl Cook	Belgrade Town Office
Don Borman	McGrath Pond Salmon Lake Association, Former President
Peter Rushton	Belgrade Planning Committee, member
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Tracey Greenwood	Colby College, Department of Biology, Lab Instructor
Manuel Gimond	Colby College, GIS & Quantitative Analysis Specialist
Ian McCullough	Colby College, Department of Biology Research Assistant
Kimberly Bittler	Colby College, Department of Biology Research Assistant
Caitlin Peavey	Colby College, Department of Biology Research Assistant
Andrew Young	Colby College, Department of Biology Research Assistant
Michael Ambrogi	Colby College, Department of Biology Research Assistant

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PERSONAL COMUNICATIONS

Name	Affiliation
Borman, Don	Former President, McGrath Pond/Salmon Lake Association
Bouchard, Roy	Lake Assessment Biologist, Maine Department of Environmental Protection
Carter, Chuck	Director, Camp Tracy
Cole, F. Russell	Professor, Department of Biology, Colby College
Ellis, Robert	Code Enforcement Officer, Town of Oakland
Firmage, David	Professor, Department of Biology, Colby College
Fuller, Gary	Code Enforcement Officer, Town of Belgrade
Halliwell, David	Lake Assessment Biologists, Maine Department of Environmental Protection
Hahnel, Karen	Environmental Science Specialist, Maine Department of Environmental Protection
Kallin, Peter	Executive Director, Belgrade Region Conservation Alliance
Lavenson, Joel	Director, The Maine Golf and Tennis Camp
Rushton, Peter	Member, Belgrade Planning Committee
Swanson, Rick	President, McGrath Pond/Salmon Lake Association

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APPENDICES

APPENDIX A. ELEVEN MOST UNWANTED INVASIVE AQUATIC PLANTS GUIDE

A field guide including pictures and descriptions of the eleven most unwanted invasive aquatic plants in Maine. Pictures were extracted from Maine VLMP (2004), and photo credits are listed underneath each respective species name. This guide was created in order to provide information about invasive aquatic plant identification for residents. An asterisk (*) indicates a plant species that has been discovered in a Maine water body (MDEP 2005).

Brazilian elodea (*Egeria densa*)

http://ipm.ppws.vt.edu/scott/weed_id/eldde.htm

Brazilian elodea is a rooted, submersed perennial with bright green leaves, densely arranged in whorls of 4 to 6 leaves on slender, brittle stems. (Note: the lower leaves may be opposite or in whorls of 3 leaves.) The leaves are finely toothed, strap-shaped with a pointed tip, 1 to 3 cm long, and up to 5 mm wide. (Having more than 3 leaves per whorl, and leaves more than 1 cm in length help to distinguish this plant from Maine's native waterweeds.) Branches form irregularly along the stems in areas where two whorls appear to be joined (known as "double nodes"). The small flowers (averaging 2 cm in diameter) have three white petals and a yellow center, and emerge just above or at the surface on slender stalks projecting from leaf axils near the stem tips. The slender roots are pale and un-branched. Unlike hydrilla, Brazilian elodea does not produce tubers.

*Curly-leaf pondweed (*Potamogeton crispus*)

http://www.lakehubert.org/curlyleaf.html

Curly-leaf pondweed is a submersed aquatic perennial with submersed leaves only. The slightly flattened stems emerge from slender rhizomes and sprouting turions, often branching profusely as they grow, giving the plants a busy appearance. Mature stems average 0.4 to 0.8 m in length. Stipules when visible (they disintegrate early) are slightly joined to the stem at the base and 4 to 10 mm long. Flower spikes appear above the surface of the water from June through September. The small flowers are arranged in a terminal spike on a curved stalk measuring about 7 cm in length. The fruits (seeds) have a prominent cone shaped beak and a bumpy ridge along the "crown." Turions form in the leaf axils during the growing season. The turions, resembling small ruffled pinecones, are hard (like stiff plastic) and typically 1 to 2 cm long.

*Eurasian watermilfoil (*Myriophyllum spicatum*)

http://www.aqua-fish.net/show.php?h=myriophyllumspicatum

Eurasian watermilfoil is a submersed aquatic plant with feather-like finely divided leaves, typically with 12 to 24 pairs of thread-like leaflets on each leaf. The leaves are arranged in whorls (3 to 6 leaves per whorl). The whorls are openly spaced along the stem, with 1 to 3 cm between whorls. Flowers occur in the axils of the bracts, arranged in whorls around a slender spike that emerges generally upright from the surface of the water. The bracts have smooth margins and the flowers are generally larger than the bracts. Eurasian watermilfoil does not form winter buds.

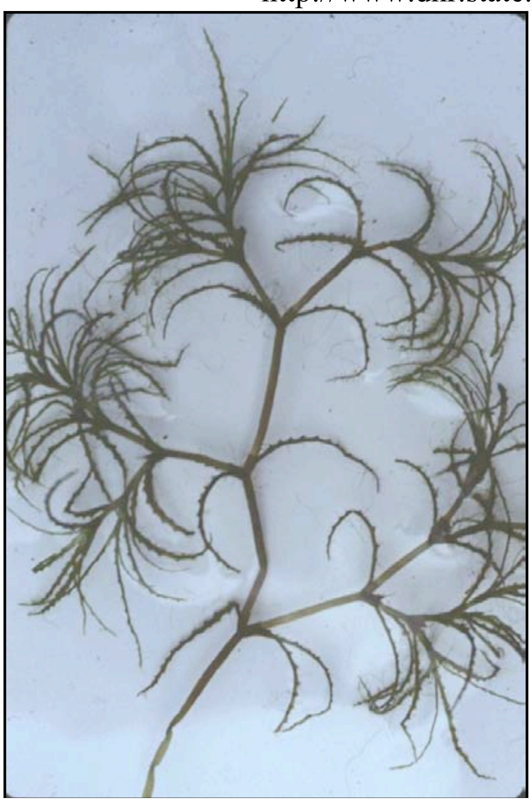
European frogbit (*Hydrocharis morsus-ranae*)

http://flickr.com/photos/28113115@N00/2809337443/

European frog-bit is a small free-floating aquatic plant. Its small kidney or heart shaped water lily like leaves (1.3 – 6.3 cm long) are not anchored to the bottom substrate. The floating leaves have elongate stalks, 4-6 cm long, and form a rosette from the short submerged stem. Simple unbranched root-like tendrils (resembling slender bottle brushes) dangle below. The flowers of European frog-bit have three white petals with a yellow center.

European naiad (*Najas minor*)

http://www.dnr.state.md.us/bay/sav/key/najas3.html



Seedlings grow from slender roots; developing stems up to 2.5 m long that often branch profusely near the top. Leaves may appear to be opposite, sub-opposite, in whorls or clumps. The leaves are small (rarely more than 3.5 cm long) and very slender (0.3 – 0.5 mm wide), strap-shaped, pointed and serrated. The leaf serrations of European naiad, though tiny, can usually be observed without magnification (separating it from native naiads). A second characteristic that distinguishes European naiad from two of Maine's three native naiad species is the abruptly protruding blocky or fan-shaped leaf base. The upper margin of the leaf base is finely toothed or "fringed" in appearance. Like all naiads, the flowers are small, inconspicuous, and borne in the leaf axils. The seeds are purplish, 1.5 to 3.0 mm long, spindle shaped and slightly curved, with rectangular indentations arranged in distinct longitudinal rows.

Fanwort (*Cabomba caroliniana*)

http://aquarium-journal.com/2007/05/carolina-fanwort-cabomba-caroliniana.html

Fanwort is a submersed perennial with stems emerging at intervals along horizontal rhizomes. The plant has two distinct leaf types. The submersed leaves are finely divided, widely branched, and held apart from the stem on slender petioles, resembling tiny fans with handles. The leaves are arranged in opposite pairs along the main stem. The orderly formation of leaves and stems gives the plant a "tubular" appearance underwater. Plants range in color from grass green to olive green to reddish. Floating leaves, when present, are inconspicuous (1 cm long), elongate and elliptical. They are arranged alternately on slender petioles attached to center of each leaf. Small white flowers (1 cm in diameter) develop among the floating leaves.

*Hydrilla (*Hydrilla verticillata*)

http://weeds.hotmeal.net/weeds/List_A.html

Hydrilla is a perennial submersed aquatic plant with long slender, branching stems emerging from horizontal underground rhizomes and above ground stolons. The leaves are strap-like and pointed with claw-like serrations along the outer margins. The leaves are typically arranged in whorls of 4 to 8. Small white flowers rise to the surface on slender stalks from the upper leaf axils. Hydrilla produces two types of over-wintering structures. Spiny green turions (5 to 8 mm long) are produced in the leaf axils. Small, somewhat crescent-shaped tubers (5 – 10 mm long), form along the rhizomes and stolons. The tubers have a scaly appearance under magnification and are pale cream to brownish in color.

Parrot feather (*Myriophyllum aquaticum*)

http://www.waterwereld.nu/vederkruideng.php

Parrot feather has both emergent and submersed leaves. The bright green emergent leaves are 2.5 cm to 5 cm long, and are the plant's most distinctive characteristic, growing like a dense stand of miniature fir trees to a height of one foot above the surface of the water. The feather-like finely divided leaves have 10 to 18 pairs of thread-like leaflets and are arranged in whorls of 4 to 6 around the stem. The submersed leaves are less vibrant, on tough, often thickly entangled cord-like stems. Small white flowers are inconspicuous and borne in the axils of the emergent leaves.

*Variable watermilfoil (*Myriophyllum heterophyllum*)

http://www.missouriplants.com/Others/Myriophyllum_heterophyllum_page.html

Variable watermilfoil is a submersed, aquatic plant that is often characterized by a dense "bottle brush" appearance and thick, robust reddish stems. Feather-like divided leaves are arranged in densely packed whorls. There are generally 4 to 6 leaves per whorl and 5 to 14 pairs of thread like leaflets on each leaf. The plant produces spike-like flowers that emerge above the surface of the water from mid to late summer. The bracts and flowers are whorled. Minute white flowers develop in the axils of the bracts. The bracts are typically deeply toothed, blade-shaped and more than twice the length of the tiny flowers. The flower spikes are often essential to confirming species identification.

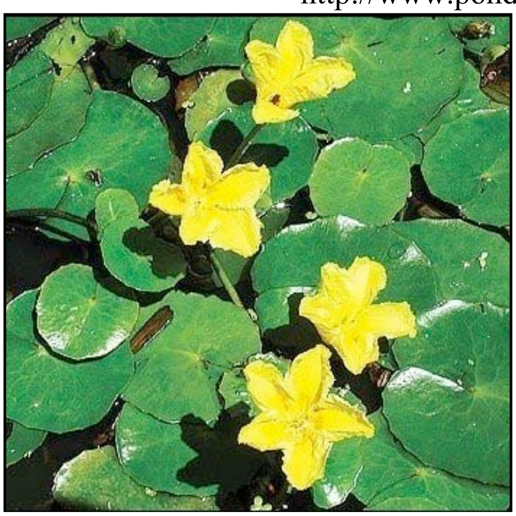
Water chestnut (*Trapa natans*)

http://www.thebeatnews.org/Issues/Invasives/Invasive%20species.html

Water chestnut has two distinct leaf types. The floating leaves are four-sided but somewhat triangular (or fan shaped) with conspicuously toothed margins along the outside edges. The upper surface of the leaf is glossy; the undersides are covered with soft hairs. The leaves are arranged in a radiating pattern or rosette and joined to the submersed stem by long petioles (up to 15 cm long). The rosettes are anchored to the sediments on slender stems reaching lengths of up to 5 m. White flowers appear above the rosettes in mid to late July, each emerging from its own stalk from the axils of the floating leaves. When the fruits form they submerse and dangle beneath the rosette. The fruits are woody and nut-like, typically with four sharp barbs.

Yellow floating heart (*Nymphoides peltata*)

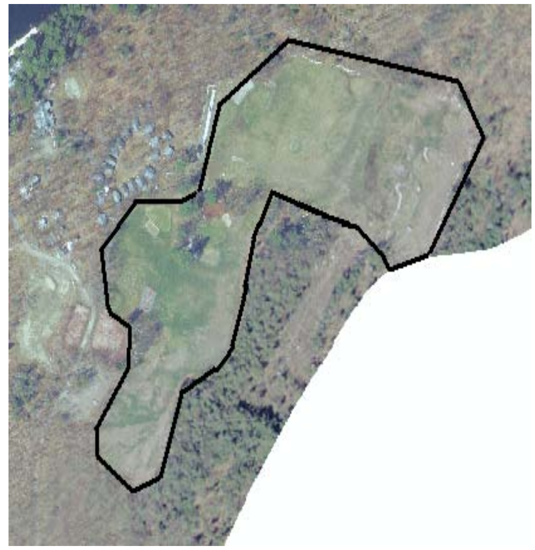
http://www.pondplantgirl.com/ebay/heart.htm



Yellow floating heart is a bottom-rooted perennial that produces branched stolons just below the water surface. Each rooted stem supports a loosely branched group of several leaves. The leaves are nearly round to heart-shaped. (Note that all heart-shaped floating leaved plants that are native to Maine produce only one leaf per rooted stem.) The leaves are typically wavy (shallowly scalloped) along the outer edges and have purplish undersides. Leaves average 3 to 10 cm in diameter. The flowers are showy (3 to 4 cm in diameter), bright yellow with five distinctly fringed petals. They are held above the water surface on long stalks with 1 to 5 flowers per stalk. The seeds are oval and flat (about 3.5 mm long) and hairy along their outer edges.

APPENDIX B. LAND USE PICTORIAL DEFINITIONS

Youth Camp



Golf Course

Park

Commercial


Municipal

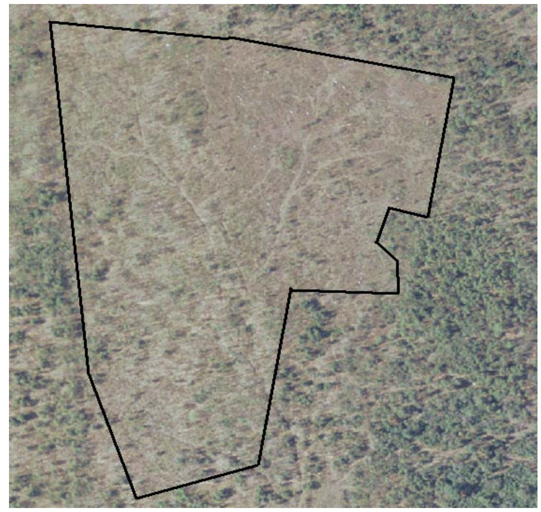

Pasture


Sawmill


Livestock


Cropland

Deciduous Forest



Transitional Forest

Coniferous Forest

Successional Forest

Mixed Forest

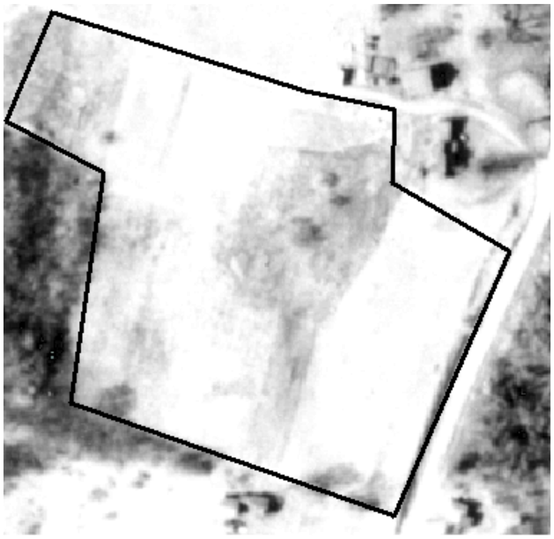
Logged Land

Grass Field

Non-shoreline Residential

Open Field

Shoreline Residential



Historical Fields (1965/1966)
Black = Open Land

Current Fields (2007)
Black = Grass Field
Grey = Open Field

These two images depict the same location in the Salmon/McGrath watershed.

APPENDIX C. RESIDENTIAL AND COMMERCIAL SURVEY FORM

Residential Property Characteristics								
Surveyors Names:							Date:	
Camera #:								
Road Name	**Septic?**	**Driveway?**	**Other?**	**Point Name**	**Northing**	**Easting**	**Pic #**	**Comments**

Commercial Land Use

Surveyors Names: Date:

Camera #:

Road Name	**What is it?**	**Point Name**	**Northing**	**Easting**	**Pic #**	**Comments**

APPENDIX D. SHORELINE SURVEY FORM

GPS Coordinates: _______________ _______________
Depth:____________________

House #:	Pre-1974 or Post-1974			Seasonal or Year Round		
	0-10	**10-25**	**25-50**	**50-75**	**>75**	**Score**
House Distance (ft.)	*4*	*3*	*2*	*1*	*0*	
Buffer depth (ft.)	*4*	*3*	*2*	*1*	*0*	
	0	**1-25**	**26-50**	**51-75**	**>75**	
Buffer % along shore	*5*	*4*	*3*	*2*	*1*	
	0-5°	**6-15°**	**16-25°**	**>25°**		
Slope	*0*	*1*	*2*	*3*		
	None	**Some**	**Moderate**	**Severe**		
Shoreline Erosion	*0*	*1*	*2*	*3*		
Add values from 'Score' column above to obtain "Total" value					**Total**	
Shore Length (ft)	**<60**	**60-120**	**120-180**	**>180**		
Circle if applicable: *Beach* *Dock* *Lawn* *Boat* *Launch* *Bare Soil on Lot* *Drainage Ditch* *Aquatic Macrophytes*					*RipRap/Retaining Wall: Present Needed*	
Overall Rating of Buffer: (Best) 1 2 3 4 5 (Worst)						
Comments:						

APPENDIX E. ROAD SURVEY FORM

Road Survey: Non-Camp Road in Watershed

Date:_______ GPS Unit #:______ Camera #:______
Surveyors:________________________

Road name:	Road Type:	state	other:
GPS at start of road:	**Waypoint name:**		
GPS at end of road:	**Waypoint name:**		
Road length (miles)			
Average width (feet, include shoulders):			

Road name:	Road Type:	state	other:
GPS at start of road:	**Waypoint name:**		
GPS at end of road:	**Waypoint name:**		
Road length (miles)			
Average width (feet, include shoulders):			

Road name:	Road Type:	state	other:
GPS at start of road:	**Waypoint name:**		
GPS at end of road:	**Waypoint name:**		
Road length (miles)			
Average width (feet, include shoulders):			

Road name:	Road Type:	state	other:
GPS at start of road:	**Waypoint name:**		
GPS at end of road:	**Waypoint name:**		
Road length (miles)			
Average width (feet, include shoulders):			

Road name:	Road Type:	state	other:
GPS at start of road:	**Waypoint name:**		
GPS at end of road:	**Waypoint name:**		
Road length (miles)			
Average width (feet, include shoulders):			

Road Survey: Camp Road in watershed

Date:______ GPS Unit #:______ Camera #:______
Surveyors:_________________________

Road name:

GPS at start of road: **Waypoint name:**
GPS at end of road: **Waypoint name:**
Road length (miles):
Average width (feet, include shoulders):
Slope (general):
Steep Moderately Steep Small Incline Flat
Slope (lake approach):
Steep Moderately Steep Small Incline Flat
Talley # inaccessible lakefront driveways:
DESCRIBE CROWN:
Measurement: 0-2 in 2-4 in 4-6 in 6-8 in
DESCRIBE DITCH CONDITION:

Shape: U-Shape V-Shape

Material: Vegetation Stone-lined Gravel/Dirt Dirt

Clear of Debris: Yes No
DESCRIBE CULVERT CONDITION:

Proper diameter: Yes No

Cleared of debris: Yes No

Material in good condition: Yes No
DESCRIBE ROAD SURFACE CONDITIONS:

Material: Pavement Packed gravel Loose gravel Dirt

Age: New Old

Road use: Year-round Seasonal

Overall condition: Good Acceptable Fair Poor

Comments:

Picture # and description (if any taken):

Road Survey: Problem Areas

Date:_________ GPS Unit #:______ Camera #:______ Surveyors:________________________

Please indicate any problems from the following categories:

Problems with the crown:	Height, berms, tire marks
Problems with the ditches:	Depth and width, vegetation, sediments, shape
Problems with diversions:	Are they needed? Where does the runoff go?
Problems with culverts:	Wear (erosion, crushed), diameter, debris inside

Road name: Road type: state camp other:
GPS reading: Waypoint name:
Location on road (miles): Picture #:
Problem area: crown ditch diversion culvert other
Summary of problem:

What needs to be done:

Road name: Road type: state camp other:
GPS reading: Waypoint name:
Location on road (miles): Picture #:
Problem area: crown ditch diversion culvert other
Summary of problem:

What needs to be done:

Road name: Road type: state camp other:
GPS reading: Waypoint name:
Location on road (miles): Picture #:
Problem area: crown ditch diversion culvert other
Summary of problem:

What needs to be done:

APPENDIX F. ROAD PROBLEM AREAS

Poor Rating

Chet Drive
Problem(s): Evidence of erosion, potholes
Remediation: Consider regrading the road, add water diversion structures

Cottonwood Drive
Problem(s): Poor road drainage, berms, culverts needed for drainage
Remediation: Add water diversion structures, consider regrading the road, install culverts where needed

Elderberry Drive
Problems(s): Road has negative crown, deep tire ruts, large rocks in road surface
Remediation: Consider regrading the road, add water diversion structures

Horseshoe Lane
Problem(s): Major erosion, potholes
Remediation: Consider regrading the road, add water diversion structures

Kennebec Lodge Lane
Problems(s): Road has negative crown, deep tire ruts, large rocks in road surface
Remediation: Consider regrading the road, add water diversion structures

Lake Vista Drive (bottom half)
Problem(s): Exposed culvert, major erosion, berms
Remediation: Consider regrading the road, add water diversion structures, perform culvert repair

Perry Trail
Problem(s): Very poor crown, major erosion problems at the end of the road
Remediation: Consider regrading the road, add water diversion structures

Rainbow Road
Problem(s): Major erosion, culvert beginning to rust
Remediation: Consider regrading the road, add water diversions structures, perform culvert maintenance

Unknown: under construction off McGrath Pond Road
Problem(s): Major erosion, drainage problems
Remediation: Install (better) erosion-preventing devices during construction period

Unknown (off Ellis Cove Lane)
Problem(s): Very steep road that runs right to lake, tire ruts
Remediation: Consider regrading the road, add water diversion structures

Snappers Cove Road

Problem(s): Puddles and berms, poor crown

Remediation: Consider regrading the road, add water diversion structures

Spruce Lane

Problem(s): Major erosion and tire ruts

Remediation: Consider regrading the road, add water diversion structures to remove water from the road surface

Fair Rating

Alexander Place

Problem(s): Evidence of erosion, water bars in disrepair, culverts beginning to rust

Remediation: Add water diversion structures, perform culvert and water bar maintenance

Denwood Point Lane

Problem(s): 3 rubber bars in poor condition, culverts filled with debris

Remediation: Repair/replace rubber bars, perform culvert maintenance

Elizabeth Street

Problem(s): Erosion on side of road

Remediation: Consider regrading the road, add water diversion structures

Ellis Cove Lane

Problem(s): Water goes over road and into lake, rusty culvert

Remediation: Install culverts where needed, maintain existing culverts

Fowler Drive

Problem(s): Poor crown

Remediation: Consider regrading the road

Golf Academy Road

Problem(s): Significant erosion in loop at the end of the road

Remediation: Consider regrading the road, add water diversion structures

Olivia Ave

Problem(s): Most culverts in poor condition, erosion in cul-de-sac

Remediation: Perform culvert maintenance, add water diversion structures, consider regrading the road if necessary

Prince Terrace

Problem(s): Evidence of erosion

Remediation: Consider regrading the road, add water diversion structures

Savage Trail

Problem(s): Tire ruts
Remediation: Consider regrading the road, add water diversion structures

Small Shore Trail (200-400)

Problem(s): Berms, evidence of erosion
Remediation: Consider regrading the road to remove berms, add water diversion structures

Sawdust Trail

Problem(s): Evidence of erosion (but not in watershed), poor crown
Remediation: Consider regrading the road, add water diversion structures

Tranquility Trail

Problem(s): Not enough space between top of culvert and road surface
Remediation: Repair culverts

Turkey Road

Problem(s): Some signs of erosion, potholes, ditches very shallow
Remediation: Consider regrading the road, add water diversion structures, increase ditch depth

Watts Trail

Problem(s): Berms, poor crown
Remediation: Consider regrading the road

Wendell Lane

Problem(s): Tire ruts, potholes, berms
Remediation: Consider regrading the road

Acceptable Rating

Bickford Place

Problems(s): Evidence of erosion, potholes over culvert
Remediation: Consider regrading the road, add water diversion structures, try to create 1 foot of distance between the road surface and the top of the culvert (if possible through regrading) or perform culvert repair

Colony Road

Problem(s): Very steep road running in direction of lake, all trees cut on slope
Remediation: Plant vegetation, add water diversion structures

East Side Trail (150-199)

Problem(s): Culvert filled with debris
Remediation: Perform culvert maintenance

East Side Trail (200-300)
Problem(s): Culvert filled with debris
Remediation: Perform culvert maintenance

Jessica Lane
Problem(s): Culvert in poor condition, not enough space between top of culvert and road surface
Remediation: Perform culvert maintenance, consider regrading the road to establish crown over culvert or perform culvert repair

Paul's Acres Lane
Problem(s): Ditches filled with debris
Remediation: Perform ditch maintenance

Plum Lane
Problem(s): Debris in culverts, ditches very shallow
Remediation: Perform culvert maintenance, increase ditch depth

Sachem Lane
Problem(s): No ditching to carry water away from road
Remediation: Install ditches

Serenity Cove Lane
Problem(s): Some erosion at top of road
Remediation: Add water diversion structures, consider regrading the road if necessary

Small Shore Trail (100-199)
Problem(s): Culvert in poor condition (plastic, crushed)
Remediation: Perform culvert maintenance or replace culvert

Spaulding Point Road
Problem(s): First half of the road in acceptable condition, gets worse as it goes along
Remediation: 2nd half of road needs general maintenance

Good Rating

Birch Meadows
Problem(s): Debris in culverts
Remediation: Perform culvert maintenance

Juniper
Problem(s): Road has very steep lake approach
Remediation: Add water diversion structures to prevent water from reaching the lake

APPENDIX G. WATER BUDGET VALUES AND CALCULATIONS

The Water Budget calculates the sources and losses of water to Salmon Lake and McGrath Pond and the flushing rate of the lake.

Physical Parameters used in the Salmon Lake and McGrath Pond Water Budget:

Parameter	Value	Unit
Runoff Rate (**NKRPC unpublished**)	0.622	meters / year
Precipitation Rate (**NOAA 2009**)	1.071	meters / year
Evaporation Rate (**Prescott 1969**)	0.560	meters / year
Salmon Lake and McGrath Pond Watershed Area	20,429,790	square meters
Salmon Lake and McGrath Pond Surface Area	4,702,447	square meters
Salmon Lake and McGrath Pond Volume	25,727,841	cubic meters

1. Calculating the Net Input (I_{net}) of Salmon Lake and McGrath Pond and its inputs:

I_{net} Salmon Lake and McGrath Pond = (runoff × watershed land area) + (precipitation rate × lake area) – (evaporation × lake area)

I_{net} Salmon Lake and McGrath Pond = 12,185,358 m^3

2. Calculating the Total Input (Q) of water to Salmon Lake and McGrath Pond used in the Phosphorus Budget:

Q = (Salmon Lake and McGrath Pond I_{net} + [evaporation × lake area]

Q = 14,818,728 m^3 / year

3. Calculating the Flushing Rate of Salmon Lake and McGrath Pond:

Flushing Rate = (I_{net} Salmon Lake and McGrath Pond) / Salmon Lake and McGrath Pond Volume

Flushing Rate = 0.47 flushes / year

APPENDIX H. PHOSPHORUS MODEL EQUATION

To estimate the rate at which different land use types contributed phosphorus to the water body, this study adapted export coefficients from studies on nearby lakes. Studies included those performed by the Maine Department of Environmental Protection to determine Total Maximum Daily Loads (TMDL) of phosphorus necessary to prevent algal blooms and eutrophication. Coefficients were selected based on similarities between lakes covered in the TMDL studies to Salmon Lake and McGrath Pond. Some coefficients were adjusted to account for unique characteristics of Salmon Lake and McGrath Pond such that the model outputs matched phosphorus concentrations obtained from chemical analysis of field samples. The phosphorous loading estimate (W) for the Salmon McGrath Watershed was obtained using the following equation and export coefficients:

$$W = (Ec_{mf} \times Area_{mf}) + (Ec_{cf} \times Area_{cf}) + (Ec_{df} \times Area_{df}) + (Ec_{w} \times Area_{w}) + (Ec_{rl} \times Area_{rl}) + (Ec_{pa} \times Area_{pa}) + (Ec_{cr} \times Area_{cr}) + (Ec_{lg} \times Area_{lg}) + (Ec_{c} \times Area_{c}) + (Ec_{cm} \times Area_{cm}) + (Ec_{mu} \times Area_{mu}) + (Ec_{sr} \times Area_{sr}) + (Ec_{pk} \times area_{pk}) + (Ec_{s} \times Area_{cs}) + (Ec_{gc} \times Area_{gc}) + (Ec_{n} \times Area_{n}) + (Ec_{ss} \times \text{capita-yrs} \times (1\text{-}SR)) + (Ec_{ns} \times \text{capita-yrs} \times (1\text{-}SR)) + (Ec_{a} \times \text{Lake area}_{s}) + (Sd_{cs} \times \text{Lake area}_{cs})$$

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

Estimated Range = 0.15–0.21 Best Estimate = 0.17

Reckhow and Chapra (1983) estimated an export coefficient range of 0.15–0.16. A recent study on Long Pond, located in the same county as Salmon Lake and McGrath Pond, used a lower range of 0.11–0.21 (MDEP 2008). The distance of Salmon Lake and McGrath Pond from large-scale industrial or urban development implies that air particulate concentrations of phosphorus are relatively low. This study adopted the range derived from the Long Pond study, but adjusted it upward to account for the larger surface area of Salmon Lake and McGrath Pond relative to its watershed area.

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

Estimated Range = 0.02–0.07 Best Estimate = 0.04

Coniferous forests export less phosphorus due to the reduced leaf litter associated with coniferous trees. The coefficient range for mixed forests is similar to a recent study on Togus Pond (MDEP 2005)

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

Estimated Range = 0.02–0.09 Best Estimate = 0.05

Deciduous forests export more phosphorus than coniferous or mixed forests because deciduous trees produce more leaf litter than coniferous trees. For this reason, the best estimate is higher than that for coniferous forest. The coefficient range was derived from a recent study on Togus Pond (MDEP 2005).

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

Estimated Range = 0.03–0.07 Best Estimate = 0.05

This range is derived from a recent study on Togus Pond (MDEP 2005). The presence of deciduous trees interspersed with coniferous trees produces more leaf litter than a homogenous forest of conifers, but less than a forest comprised entirely of deciduous trees. The best estimate is higher than that for coniferous forest, but the high estimate is lower to account for the moderating effect of conifer presence on the total leaf litter produced.

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

Estimated Range = 0.30–1.60 Best Estimate = 0.60

Cleared land is defined as land cleared of all vegetation except grass and can apply to bare dirt or gravel surfaces as well. Coefficients were based on a recent study on Togus Pond (MDEP 2005), which estimated a range of 0.25–1.75, with a best estimate of 0.50 for low-density residential areas. Low-density residential areas were defined in the study as cleared land with minimal houses. Coefficients were adjusted slightly upward to account for the inclusion of bare dirt surfaces in the definition of cleared land, as the lack of vegetation promotes erosion and facilitates nutrient runoff.

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

Estimated Range = 0.15—0.90 Best Estimate = 0.30

Regenerating land consists of land that has been cleared in the past, but is currently into the early to mid-successional stages of revegetation. The lack of a full canopy renders the land less proficient at re-absorbing phosphorus from runoff. This study applied a range based on a recent study on Long Pond (CEAT 2007), with a best estimate selected to fall between midway between those for cleared land and mixed forest due to the assumption of a partial canopy.

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

Estimated Range = 1.20–1.86 Best Estimate = 1.50

The coefficient range for cropland derives from a study by Reckhow and Chapra (1983) on Higgins Lake in Michigan, which is surrounded by intensive agriculture. High and best estimate coefficients were adjusted downward based on a recent study on Webber Pond (MDEP 2002), which is located in the same county as Salmon Lake and McGrath Pond and is surrounded by less intensive agriculture than Higgins Lake. The low estimate was adjusted upward to account from the distinction in this study between row crops and other agricultural practices, such as hay land and pasture, that have less of an impact on nutrient loading.

Ec_{pa} = export coefficient for pasture (kg/ha/yr)

Estimated Range = 0.80–1.30 Best Estimate = 1.00

Pasture includes grass fields and buildings for livestock grazing and housing. The estimate range is based on a study on China Lake (MDEP, 2001), with a range and best estimate coefficient lower than that of cropland to account for the absence of cleared rows between crops and for less intensive fertilization and irrigation.

Ec_{lg} = export coefficient for logged areas (kg/ha/yr)

Estimated Range = 0.20–0.60 Best Estimate = 0.40

High, low and best estimate coefficients for logged areas were obtained from a study on Webber Pond (MDEP 2002). The range and best estimate are higher than those for mixed forest due to the decreased capacity of paths cleared for timber transport to slow runoff and absorb phosphorus.

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

Estimated Range = 0.00–0.05 Best Estimate = 0.05

Coefficient values were obtained from a past study on Togus Pond (MDEP 2005), which estimated a range of 0.00–0.05. The low values account for the tendency of wetlands to act as a phosphorus sink during the summer months, absorbing excess phosphorus and preventing it from entering the water body (CEAT 2007).

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

Estimated Range = 0.35–1.00 Best Estimate = 0.40

Though no major town centers fall within the Salmon/McGrath watershed, commercial summer camps and sports facilities are associated with a large quantity of impervious surfaces and export more phosphorus than undeveloped land. Export coefficients for commercial land were obtained from a recent study on Togus Pond (MDEP 2005)

Ec_{mu} = export coefficient for municipal land (kg/ha/yr)

Estimated Range = 0.50–1.30 Best Estimate = 0.70

Municipal land consists of land used for government or town purposes. Municipal land is associated with high levels of impervious surfaces, in addition to cleared land and landfilling. Coefficients are based on a recent study on Long Lake, which estimated the phosphorus export of public utilities, landfills, and boat ramps (MDEP 2005). This study combined these land uses and their coefficients to obtain export estimates for the municipal category

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

Estimated Range = 0.70–6.00 Best Estimate = 2.00

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

Estimated Range = 0.70–4.00 Best Estimate = 1.50

Coefficients for state and private camp roads are adapted from a recent study on Togus Pond (MDEP 2005). The greater high and best estimate coefficients used for camp roads reflect their close proximity to the water body and lack of pavement. Because they are often in poor condition relative to state roads and because many in the Salmon/McGrath watershed slope steeply as they approach the shoreline, camp roads pose a greater potential for erosion and nutrient runoff than do state roads (see Development: Roads).

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

Estimated Range = 0.25–0.98 Best Estimate = 0.80

Coefficients for parks are adapted from a recent study on Wilson Pond (MDEP 2007). Parks consist of land cleared of vegetation except grass for recreational purposes. Parks are predicted to export more phosphorus than normal cleared land due to the application of fertilizers and pesticides and to the presence of impervious surfaces such as roads, parking lots, and small structures (see Land Use Types).

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

Estimated Range = 0.55–1.75 Best Estimate = 1.10

A study on Higgins Lake in Michigan (Reckhow and Chapra 1983) assigned a coefficient range of 0.35–2.70 to shoreline development to reflect the fact that most development was residential. Recent studies on Webber Pond (MDEP 2002) and Long Pond (MDEP 2008) applied similar ranges. Both studies used a best estimate of 1.00. This study adopted the coefficients from the Long Pond report but increased the low and best estimate to account for the large proportion of houses built before the 1974 ordinance mandating that lots be set back from the shoreline (see Watershed Development Patterns: House Count). The above procedure produced coefficients that matched those of the "medium impact" residential classification in the Togus Pond Study.

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

Estimated Range = 0.25–1.00 Best Estimate = 0.40

Coefficient values are adapted from studies on Wilson Pond (MDEP 2007) and Long Pond (MDEP 2008). Non-shoreline residential land contributes less phosphorus to the total watershed load than shoreline development because they are buffered from the water body by at least 250 feet of land (see Land Use Types: Residential).

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

Estimated Range = 1.55–4.50 Best Estimate = 1.60

A study on Webber Pond (MDEP 2002) assigned export coefficients for three different sub-uses comprising golf courses: trees and greens, fairways and other areas. Trees and greens were assigned a best estimate coefficient of 4.50 to reflect extensive application of fertilizers to greens and their characteristic lack of obstacles that would help slow runoff and absorb phosphorus. Fairways and other areas were assigned a best estimate of 0.70, reflecting less intensive mowing, fertilization and irrigation relative to greens. Our study assumed that fairways and other areas would comprise the majority of the golf course by area and assigned a best estimate coefficient of 1.50 that fell between the MDEP best estimates for each category, but closer to that for fairways and other areas than to that for greens.

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

Estimated Range = 0.50–1.30 Best Estimate = 0.65

A study on Long Pond yielded a coefficient range of 0.4–1.2 (MDEP 2008). These coefficients were increased by 0.1 to reflect the large proportion of houses built before 1974 along the shoreline of Salmon Lake and McGrath Pond. Older septic systems are expected to contribute more phosphorus to surrounding soil than new systems (see Residential Development: Septic Waste Disposal Systems).

SR_1 = shoreline soil retention coefficient

Estimated Range = 0.40–0.85 Best Estimate = 0.65

Soil retention refers to the capacity of a particular soil type to filter phosphorus from groundwater, preventing it from reaching the water body. Reckhow and Chapra

(1983) quantified soil retention on a scale from 0–1, where excellent nutrient filters are designated closer to 1 and poor filters closer to 0. Retention coefficients are adapted from a study on Togus Pond (MDEP 2005), which is characterized by moderately coarse-textured soil particles that drain well and increase the likelihood of percolation into the water column.

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

Estimated Range = 0.40–1.00 Best Estimate = 0.50

Coefficients for non-shoreline septic systems were adapted from a study by Reckhow and Chapra (1983). Coefficients were adjusted upward slightly because many of the houses in the watershed were built before 1974 ordinances on septic system quality. Non-shoreline septic systems contribute less phosphorus than shoreline septic systems because they are buffered from the water body by more than 250 ft of soil.

SR_2 = non-shoreline soil retention coefficient

Estimated Range = 0.75–1.00 Best Estimate = 0.90

See shoreline soil retention coefficient. Non-shoreline coefficients were adapted from the same study on Togus Pond (MDEP 2005). Non-shoreline septic systems are situated further from the water body from shoreline systems, and water must travel a longer distance through soil, increasing the likelihood of nutrient filtration and adsorption.

I = combined export coefficient and number of capita years for youth camp septic (kg/yr)

Estimated Range = 155.60-357.00 Best Estimate = 256.30

This value was determined using an EPA estimated wastewater output range for institutional facilities of 199.87–401.25 L/camper/day. A best estimate of 300.56 was assigned by calculating the mean of the high and low values. Wastewater output values were multiplied by the EPA-estimated phosphorus content of 23.1 ppm for camp wastewater to obtain a range and best estimate of the mass contribution of phosphorus per camper, per day. These values were converted from mg to kg then multiplied by the total number of campers inhabiting each camp and the combined number of operating days per year for each camp (capita years) to obtain an estimate of the total phosphorus contribution of youth camps (kg/yr).

SR_3 = soil retention coefficient for youth camp septic

Estimated Range = 0.60-0.90 Best Estimate = 0.80

Although the three youth camps are located along the waterfront of Salmon Lake and McGrath Pond, recent renovations have improved the condition of septic systems and relocated them farther from the shore (see Watershed Development Patterns: Septic Waste Disposal Systems). These factors were accounted for by an upward adjustment of the coefficient range from shoreline soil retention.

SD_{cs} = sediment release coefficient

Estimated Range = 0.10-0.80 Best Estimate = 0.60

Coefficients for sediment release were adapted from a study by Reckhow and Chapra (1983). Sediment release rates vary depending on the frequency of anoxic episodes in the hypolimnion (see Background: Phosphorus and Nitrogen Cycles), and are difficult to predict within a specific watershed. This study adjusted the best estimate such that the phosphorus model output matched phosphorus concentrations observed in epilimnion core field sample taken shortly after spring overturn in the lake (see Phosphorus Budget: Results and Discussion).

APPENDIX I. PHOSPHORUS MODEL PREDICTIONS FOR ANNUAL MASS RATE OF PHOSPHORUS INFLOW

Total annual phosphorus inflow (L) refers to the total annual quantity of phosphorus entering the water body per unit surface area of the lake. L was calculated by dividing the annual inflow of phosphorus (W) by the surface area of the lake (A_s) (Reckhow and Chapra 1983).

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

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

Dividing the total volume of water flowing into the lake per year (Q_{total}) (see Appendix H) by the surface area of the lake (A_s) yielded the total annual atmospheric water loading (q_s) (Reckhow and Chapra 1983).

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

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

Dividing areal phosphorus loading by a term relating the settling rate of phosphorus to the areal water loading of the lake yields an estimate of the total phosphorus concentration in the lake (Reckhow and Chapra 1983).

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

P = total phosphorus concentration (ppb)

Constants for high, low and best estimates for Salmon Lake and McGrath Pond:

A_s = 4581300.0 m^2
Q_{total} = 14818728 m^3
q_s = 3.23 m/yr

Low Estimate	**Without Sediment Release**	**With Sediment Release**
W =	345.5 kg/yr	391.3 kg/yr
L =	0.8 kg/ha/yr	0.9 kg/ha/yr
P =	4.9 ppb	5.5 ppb

Best Estimate	**Without Sediment Release**	**With Sediment Release**
W =	596.2 kg/yr	871.2 kg/yr
L =	1.3 kg/ha/yr	1.9 kg/ha/yr
P =	8.4 ppb	12.3 ppb

High Estimate	**Without Sediment Release**	**With Sediment Release**
W =	1228.4 kg/yr	1594.9 kg/yr
L =	2.7 kg/ha/yr	3.5 kg/ha/yr
P =	17.3 ppb	22.5 ppb

APPENDIX J. QUALITY ASSURANCE

The Salmon Lake and McGrath Pond study followed a quality assurance plan developed by CEAT to standardize the water sampling and analysis procedures used. The following document was modified from CEAT (2009).

<u>Bottle Preparation:</u>

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

<u>Approaching site and sampling:</u>

1. When approaching the test site, speed up first, then kill the engine and coast to the sampling site.
2. Always sample from the bow of the boat facing the wind.
3. When surface sampling, hold the bottle upside down, draw water into the bottle by pushing horizontally away from the boat to 0.5 m down. Then lift the bottle out of the water and cap.
4. Hands should never touch sampled water. Use gloves.
5. Bottle lids should not touch the bottom of the boat. Rinse the lids with distilled water, if they are dropped.

<u>Surface Grab:</u>

1. Remove the cap from the sample bottle being careful not to touch either the cap or bottle.
2. Invert the sample bottle and place in the water.
3. Turn the sample bottle sideways moving the bottle through the water away from the boat, finally tilt the bottle upright and remove the bottle from the water.
4. Place bottle in cooler.

<u>Secchi Disk:</u>

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

<u>Depth Finder:</u>

1. Put vertically in water column.
2. Push black/yellow button down for a few seconds. Release.
3. Pull up and read depth. Repeat two times.

Turbidimeter:

1. Use the HACH 2100 Portable Turbidimeter (HACH 1999), making sure cleaned sample cells were included with the portable turbidimeter.
2. Conduct analysis in the field using the calibrated instrument (calibrated with three standards). Follow surface sampling procedure.
3. Read samples on site.

YSI 6820 MDS (Multiparameter Display System) Sonde:

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

pH meter:

A. Calibration: Before any test is performed, the probe of the 6820 MDS Sonde must be calibrated using a 2-point calibration method at pH 4 and pH 10. This should be done once during the testing day, provided the calibration entered into the meter is not accidentally deleted.
    1. Press the POWER button. The pH meter automatically enters the measurement.
    2. Press CALIBRATE and ISEI pH. Then press 2 POINT.
    3. Enter the Sonde standard pH value and insert probe into pH 4 solution. Go to Sonde menu.
    4. After calibration, rinse the sensor thoroughly with E-pure water.
    5. Repeat calibration for pH 10.
    6. Be sure to rinse the probe with distilled water prior to and following each measurement.

B. Measurement.
    1. Immerse the Sonde 0.5 m to 1.0 m below the surface.
    2. Go to SONDE RUN in the 6820 main menu. Wait for the probe to stabilize.
    3. Highlight "Log One Sample" and press the ENTER arrow at one meter intervals.

Dissolved Oxygen:

1. Calibrate the probe of the 6820 MDS Sonde in the saturated air chamber after the proper warm-up time.
2. Lower the Sonde into the water, shaking it gently to make sure there are not bubbles around the probe.
3. Immerse the probe until covered. Record measurements as described above.
4. On the tenth depth profile make three random duplicate readings.
5. Duplicate readings should not vary more than ± 0.2 ppm.
6. If readings vary more than 0.5 ppm repair of the membrane or meter is advised.

7. The electrode must be in a flow of water.
8. Record a DO measure immediately, and if the reading is decreasing, keep the electrode moving in the water.

Grab Sampler:

1. Open and secure two flaps as demonstrated in class.
2. Lower tube into water, counting meters as lowered (demarcated by black lines on rope). Lower to 1 meter above bottom (depth taken with depth finder).
3. Take sample by throwing weight down rope.
4. Raise tube, open blue valves, and pour water into appropriate sample bottles.
5. Repeat for mid-depth sample.

Epicore Samples:

1. Rinse the collection tube three times by lowering it down into the lake water and pulling it back out.
2. For sites with sufficient depth for a thermocline to form, lower the tube 1 m below the epilimnion into 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 on the tube indicate one meter.
5. Crimp the tubing just above the water (best done by bending it tightly, twisting, and then holding it in one hand).
6. Pull the tubing up, making sure that the excess tubing goes into the water and not the boat. Be careful not to touch the end through which the water comes out.
7. Allow the water to drain into the labeled epicore mixing bottle, being careful not to touch the inside of the tube, the cap, or the end of the tube.
8. Be sure to keep the non-pouring end of the tube up, so the water does not drain out of it, and so that it does not take up surface water.
9. Hold up the crimped area and undo the crimp. Continue to raise the tubing and move towards the draining end.
10. Repeat the process three times, draining all of the water into the 1 L epicore mixing bottle.
11. Pour about 125 mL each of this water into two PPM flasks (fill to just below the neck). Be careful not to contaminate the samples by touching the inside of the bottles or the inside of the caps.
12. Discard the remaining water from the mixing bottle and rinse it with E-pure water. Place all samples into the cooler on ice.

Quality Control Sampling:

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

4. Run one control with each set of samples analyzed.

Total Phosphorus:

1. Collect and make splits and duplicates for every ten samples.
2. Make standard solutions of known concentrations with each testing to ensure lab precision.
3. Use reagent blanks to make a standard curve to determine the concentration of phosphorus studied. The standard curve should have a minimum of six points.
4. The accuracy of the Absorbic Acid method used for total phosphorus analysis has a detection limit of 2 ppb.
5. Preserve water samples for analysis by digesting with sulfuric acid and ammonium peroxydisulfate, and then autoclave at 15 psi for 30 minutes.
6. Conduct analysis within 28 days of sampling date.

APPENDIX K. WATER QUALITY MEASUREMENTS AND TEST

Physical, chemical, and biological tests performed in the summer of 2009 at Salmon Lake and McGrath Pond (see Figure –IIIA2-WS-KRL for site locations)

Sample Date	Temp/ DO	Secchi Disk	Turbidity	Color	Conductivity	Total Phosph.	Nitrates	pH	Alkalinity	Hardness	Chlorophyll-a
3-Jun	1-3	1,2	1-7	-	1-3	-	-	1-3	-	-	1-3
								1-3			
17-Jun	1-3,5,6	1,2	1-7	2	1-3.5,6	-	-	5,6	-	-	1-3,5,6
25-Jun	1-4,5,7	1,2	1-7	-	1-7	-	-	1-7	-	-	1-3,5,7
9-Jul	1-7	1-3	1-7	-	1-7	-	-	1-7	3	3	1-4,7
15-Jul	1-7	1-3	1-7	3	1-7	-	-	1-7	1	-	1-3,5-7
28-Jul	1-7	1-3	1-7	1	1-7	-	-	1-7	1	1	1-4,7
4-Aug	1-7	1-3	1-7	1	1-7	-	-	1-7	1	1	1-4,7
10-Aug	1,2,4,5 ,6	1-3	1-7	1	1,2,4-6	-	-	1-6	1	-	1,2,4
18-Aug	6	1,2	1-7	6	-	-	-	6	-	-	-
17-Sep	1,3,10, A-G	3,10	1-3,8-14, A-E	1-4, E, G	1-3,8-13,A-G	1-13, A-G	3-5, 11-13	1-13 A,G	1,3	-	1,3,10
24-Sep	-	-	-	14	14	14	1,14	-	-	-	-

APPENDIX L. WATER QUALITY TESTS FOR SALMON LAKE AND MCGRATH POND

Physical Tests: Temperature (° C) and dissolved oxygen (ppm) at Site 1. Data were collected by CEAT June–September 2009.

	03-Jun-09		17-Jun-09		09-Jul-09		15-Jul-09		04-Aug-09		10-Aug-09		18-Aug-09		17-Sep-09	
Depth (m)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	16.6	10.2	20.5	9.8	20.2	9.8	21.1	10.4	24.9	9.5	24.2	9.2	27.5	9.3	20.9	7.3
1	16.6	10.2	19.0	9.1	19.7	9.6	21.1	9.9	24.5	9.2	23.7	9.3	27.0	9.3	20.9	7.0
2	16.5	10.2	18.5	9.2	19.5	8.6	21.1	8.9	24.3	9.2	23.5	9.3	26.7	9.8	20.0	7.1
3	16.4	10.3	18.4	9.2	19.3	7.9	21.1	8.1	23.9	9.4	23.4	9.4	25.3	11.6	19.9	7.0
4	16.2	10.3	18.2	9.2	19.3	7.5	21.0	7.3	23.8	9.4	23.1	9.5	24.3	10.6	19.8	6.8
5	15.6	10.2	17.1	9.0	19.2	6.9	21.0	7.1	22.7	9.7	22.9	9.5	23.0	8.8	19.8	6.6
6	15.1	10.2	16.1	8.9	19.1	6.4	19.1	6.9	20.5	10.1	21.9	3.0	21.6	6.3	19.7	6.5
7	14.7	9.7	14.3	7.5	17.4	6.2	18.0	7.1	18.5	10.6	18.6	2.6	19.3	2.4	19.4	6.1
8	13.6	8.7	13.5	6.7	15.8	5.5	16.1	7.8	16.6	9.9	16.2	1.6	16.7	0.2	18.9	5.6
9	12.6	6.7	12.6	4.3	14.0	4.1	14.6	7.9	14.4	8.1	14.2	1.7	15.3	1.3	15.3	1.6
10	12.1	5.0	12.3	3.3	12.9	3.6	13.2	7.5	13.4	8.1	13.5	1.2	13.3	0.1	13.4	0.6
11	11.9	4.9	12.0	2.6	12.4	3.1	12.7	7.2	12.8	7.6	12.8	1.0	12.9	0.1	12.9	0.5
12	11.6	4.1	11.9	1.5	12.2	3.0	12.3	7.1	12.5	7.2	12.6	1.0	12.6	0.0	12.7	0.4
13	11.4	3.9	11.8	1.3	11.9	3.0	12.1	7.0	12.4	7.1	12.5	1.2	12.5	0.0	12.6	0.4
14	11.4	3.5	11.6	1.2	11.8	3.2	12.0	7.1	12.4	6.9	12.5	1.1	12.5	0.0	12.5	0.4
15	11.3	3.0	11.5	0.4	11.7	3.1	-	-	12.4	5.6	-	-	-	-	-	-

APPENDIX L (continued)

Physical Tests: Temperature (° C) and dissolved oxygen (ppm) at Site 2. Data were collected by CEAT June–July 2009.

	03-Jun-09		17-Jun-09		25-Jun-09		09-Jul-09		15-Jul-09		28-Jul-09	
Depth (m)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	17.6	10.5	20.7	9.0	20.3	2.5	20.5	9.1	21.4	32.0	23.1	19.9
1	17.4	10.2	19.3	9.2	19.9	2.5	20.1	9.1	21.4	33.5	22.7	17.9
2	17.3	10.2	19.1	9.2	19.0	2.5	19.8	8.7	21.4	33.4	22.4	18.2
3	17.1	10.2	18.6	9.2	18.6	2.4	19.7	8.6	21.4	33.2	22.3	18.3
4	16.5	10.2	18.3	9.1	18.3	2.3	19.6	8.5	21.3	32.8	22.0	18.3
5	16.3	10.1	17.6	8.7	18.2	2.1	19.5	8.6	20.5	33.1	21.7	18.6
6	15.9	10.1	17.0	8.1	18.2	2.0	18.9	8.4	19.6	33.7	20.5	17.7
7	15.6	9.8	16.6	6.7	17.7	1.9	18.0	8.3	19.4	34.5	19.7	18.3

Physical Tests: Temperature (° C) and dissolved oxygen (ppm) at Site 2. Data were collected by CEAT in August 2009.

	04-Aug-09		10-Aug-09		18-Aug-09	
Depth (m)	Temp	DO	Temp	DO	Temp	DO
0	24.9	12.4	23.5	6.0	27.1	10.6
1	24.4	15.4	23.4	8.2	26.9	8.6
2	24.2	17.2	23.4	8.8	26.9	9.0
3	24.1	17.0	23.4	8.7	25.5	9.6
4	23.5	17.5	23.3	8.8	24.5	10.0
5	22.6	17.9	23.2	9.2	24.0	10.1
6	20.8	18.6	22.5	9.3	22.6	10.9
7	20.2	18.8	21.0	9.8	21.8	11.4

APPENDIX L (continued)
Physical Tests: Temperature (° C) and dissolved oxygen (ppm) at Sites 3-7. Data were collected by CEAT June-July 2009.

	03-Jun-09		17-Jun-09		25-Jun-09		09-Jul-09		15-Jul-09		28-July-09	
Depth (m)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
Site 3												
0	17.9	10.7	20.7	9.2	20.6	9.0	20.2	9.0	-	-	23.2	11.8
1	16.9	10.4	20.0	9.3	19.1	4.6	20.1	7.7	-	-	22.7	12.0
2	16.8	10.3	19.3	9.3	18.8	4.5	19.7	6.8	-	-	22.6	11.9
3	16.8	10.2	18.7	9.3	18.5	3.5	19.6	6.6	-	-	22.5	11.8
4	16.7	10.2	18.3	8.9	18.4	3.1	19.6	7.0	-	-	22.4	12.0
5	16.4	10.1	17.6	8.6	18.2	2.9	19.0	8.1	-	-	20.7	12.3
6	16.1	10.0	17.0	7.7	18.1	2.9	18.4	9.0	-	-	20.0	12.5
7	15.9	10.0	16.8	7.0	17.6	2.7	17.9	9.6	-	-	19.8	13.0
Site 4												
0	-	-	-	-	19.1	15.9	21.5	14.0	20.9	12.1	22.5	30.7
Site 5												
0	-	-	21.1	9.3	21.0	13.9	20.7	10.2	20.9	21.4	23.4	24.8
Site 6												
0	-	-	19.6	9.3	-	-	20.2	10.9	21.5	44.3	23.2	19.1
Site 7												
0	-	-	21.3	8.9	20.8	8.6	20.1	10.2	20.3	17.3	23.2	10.2

APPENDIX L (continued)

Physical Tests: Temperature (° C) and dissolved oxygen (ppm) at Site 2. Data were collected by CEAT June–July 2009.

	03-Jun-09		17-Jun-09		25-Jun-09		09-Jul-09		15-Jul-09		28-Jul-09	
Depth (m)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0	17.6	10.5	20.7	9.0	20.3	2.5	20.5	9.1	21.4	32.0	23.1	19.9
1	17.4	10.2	19.3	9.2	19.9	2.5	20.1	9.1	21.4	33.5	22.7	17.9
2	17.3	10.2	19.1	9.2	19.0	2.5	19.8	8.7	21.4	33.4	22.4	18.2
3	17.1	10.2	18.6	9.2	18.6	2.4	19.7	8.6	21.4	33.2	22.3	18.3
4	16.5	10.2	18.3	9.1	18.3	2.3	19.6	8.5	21.3	32.8	22.0	18.3
5	16.3	10.1	17.6	8.7	18.2	2.1	19.5	8.6	20.5	33.1	21.7	18.6
6	15.9	10.1	17.0	8.1	18.2	2.0	18.9	8.4	19.6	33.7	20.5	17.7
7	15.6	9.8	16.6	6.7	17.7	1.9	18.0	8.3	19.4	34.5	19.7	18.3

Physical Tests: Temperature (° C) and dissolved oxygen (ppm) at Site 2. Data were collected by CEAT in August 2009.

	04-Aug-09		10-Aug-09		18-Aug-09	
Depth (m)	Temp	DO	Temp	DO	Temp	DO
0	24.9	12.4	23.5	6.0	27.1	10.6
1	24.4	15.4	23.4	8.2	26.9	8.6
2	24.2	17.2	23.4	8.8	26.9	9.0
3	24.1	17.0	23.4	8.7	25.5	9.6
4	23.5	17.5	23.3	8.8	24.5	10.0
5	22.6	17.9	23.2	9.2	24.0	10.1
6	20.8	18.6	22.5	9.3	22.6	10.9
7	20.2	18.8	21.0	9.8	21.8	11.4

APPENDIX L (continued)

Physical Tests: Secchi Depth measurements at Sites 1-3 and 10. Data were collected by CEAT June-September 2009.

Site	3-Jun-09	17-Jun-09	25-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	18-Aug-09	17-Sep-09
1	5.3	7.2	-	5.4	5.7	5.1	5	3.8	3.5	-
2	5.6	7.2	6.6	6.6	6	6.5	6.5	6	7	-
3	-	-	-	6.3	6.4	6.5	5.9	6.5	-	6.3
10	-	-	-	-	-	-	-	-	-	3.9

Physical Tests: Surface, middle, bottom turbidity (NTU) measurements at Sites 1-3 and 10 (epicore values were also given for Sites 3 and 10) Data were collected by CEAT June-September 2009.

	17-Jun-09	25-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	18-Aug-09	17-Sep-09
Site 1									
Surface	1.0	0.6	0.5	0.7	1.4	0.9	1.7	4.3	1.73
Middle	1.0	1.2	0.9	1.2	0.9	0.9	0.8	1.0	2.25
Bottom	1.0	5.6	1.8	1.5	1.8	2.5	2.9	4.8	1.91
Site 2									
Surface	0.6	0.5	0.4	0.5	0.7	0.5	0.7	0.6	0.63
Middle	0.6	0.6	0.7	0.5	0.67	0.6	0.8	0.8	0.84
Bottom	0.7	0.8	0.8	0.8	0.85	1.3	1.1	0.8	0.94
Site 3									
Surface	0.5	0.5	0.5	0.55	0.68	0.51	0.74	0.55	0.65
Middle	0.5	0.6	0.7	0.34	0.66	0.72	0.76	0.77	1.25
Bottom	0.7	0.8	0.7	0.52	0.94	0.86	0.42	0.66	1
Epicore	-	-	-	-	-	-	-	-	1.08
Site 10									
Surface	-	-	-	-	-	-	-	-	2.58
Middle	-	-	-	-	-	-	-	-	2.14
Bottom	-	-	-	-	-	-	-	-	2.56
Epicore	-	-	-	-	-	-	-	-	2.57

APPENDIX L (continued)

Physical Tests: Temperature (° C) and dissolved oxygen (ppm) at Sites 3-7, 10-13, A, B and D-G. Data were collected by CEAT June–September 2009.

	04-Aug-09		10-Aug-09		18-Aug-09		17-Sep-09	
Depth (m)	Temp	DO	Temp	DO	Temp	DO	Temp	DO
Site 3								
0	24.5	8.0	23.6	8.3	27.6	9.1	-	-
1	24.3	8.2	23.6	8.8	27.6	9.2	21.1	5.9
2	24.2	6.7	23.5	8.8	26.8	9.5	20.3	5.9
3	23.8	6.6	23.4	8.9	25.8	9.5	20.2	6.0
4	23.2	7.2	23.4	9.0	24.7	10.8	20.1	5.9
5	23.0	8.3	23.3	9.0	24.0	10.8	20.0	6.0
6	21.5	11.5	22.9	8.6	23.0	11.5	19.9	5.8
7	20.2	12.9	20.8	8.4	22.1	11.2	-	-
Site 4								
0	24.9	11.8	24.2	9.6	-	-	19.9	5.8
Site 5								
0	25.1	26.0	23.9	9.3	-	-	21.0	8.1
Site 6								
0	24.1	31.4	22.9	8.6	27.6	8.8	20.3	8.4
1	-	-	-	-	-	-	20.0	8.3
2	-	-	-	-	-	-	18.7	9.4
Site 7								
0	24.6	12.1	23.5	9.4	27.4	9.6	20.1	10.2
1	-	-	-	-	26.9	8.6	-	-
2	-	-	-	-	26.9	9.0	-	-
3	-	-	-	-	25.5	9.6	-	-
4	-	-	-	-	24.5	10.0	-	-
5	-	-	-	-	24.0	10.1	-	-
6	-	-	-	-	22.6	10.9	-	-
7	-	-	-	-	27.8	11.2	-	-

	17-Sep-09	
Depth (m)	Temp	DO
Site 10		
0	20.8	6.5
1	20.6	6.5
2	20.0	6.5
3	19.8	6.5
4	19.8	6.4
5	19.7	6.4
6	19.7	6.4
7	19.4	6.4
8	19.3	6.5
Site 11		
0	20.9	8.1
Site 12		
0	20.9	8.3
Site 13		
0	20.5	8.7
Site A	11.5	10.3
Site B	13.1	9.2
Site D	13.5	6.6
Site E	18.8	8.2
Site F	13.0	9.1
Site G	14.3	8.3

APPENDIX L (continued)

Physical Tests: Conductivity measurements at Sites 1-3 and 10. Data were collected by CEAT June-September 2009.

Depth (m)	17-Jun-09	25-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	18-Aug-09	17-Sep-09
Site 1									
0	74.4	74.6	74.6	74.9	75.1	75.3	75.3	75.7	76.2
1	45.0	73.8	74.5	75.1	75.0	75.1	75.2	75.6	76.2
2	73.8	73.6	74.4	75.1	74.9	75.1	74.9	75.7	76.0
3	73.7	73.4	74.3	75.1	74.8	74.8	74.8	76	75.9
4	73.7	73.3	74.3	75.1	74.7	74.6	74.6	75.7	75.9
5	73.8	73.5	74.3	74.6	74.7	75.0	74.5	74.1	75.8
6	73.3	73.4	74.8	74.7	75.1	76.7	74.1	73.8	75.9
7	73.5	72.5	75.4	76.0	76.6	79.4	74.9	74.4	76.1
8	74.0	74.6	77.2	77.4	78.5	80.2	76.4	76	76.5
9	74.4	75.6	78.5	80.7	84.8	87.2	79.5	76.2	88.7
10	75.2	76.7	82.1	83.6	86.5	89.8	87.6	90.1	99.6
11	75.9	77.2	84.2	86.3	88.2	89.8	91.1	92.9	102.5
12	76.5	79.5	87.9	88.5	90.5	89.8	92.1	94.5	104.3
13	77.3	80.3	88.7	88.6	91.3	91.3	92.6	94.7	105.1
14	85.3	85.9	93.8	89.1	91.9	92.0	92.9	95.1	106.9
15	-	-	94.1	-	92.3	92.4	-	75.7	107.1
Site 2									
0	86.9	85.2	86.7	86.9	87.5	87.5	87.1	87.4	-
1	86.4	84.8	86.6	87.1	87.2	87.4	87.1	87.2	-
2	86.6	84.7	86.4	87.1	87.2	87.3	87.1	87.2	-
3	86.0	84.4	86.4	87.2	87.2	87.3	87.1	86.5	-
4	86.0	84.5	86.3	87.2	87.4	87.2	87.1	86.4	-
5	86.4	84.3	86.3	87.0	87.1	88.1	87.1	86.2	-
6	86.6	84.5	87.7	87.4	88.0	88.8	87.8	87.4	-
7	87.2	84.2	89.2	87.5	89.2	89.8	89.1	89.5	-

APPENDIX L (continued)

Physical Tests: Surface turbidity (NTU) measurements at Sites 4-13, A, B and D-G. Data were collected by CEAT June-September 2009.

Site	17-Jun-09	25-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	18-Aug-09	17-Sep-09
4	1.0	0.8	0.5	0.8	0.9	1.2	1.1	3.0	-
5	1.2	0.5	0.5	0.7	0.8	1.5	1.4	1.9	-
6	1.0	0.6	0.6	0.8	0.8	0.8	1.2	1.4	-
7	0.5	0.3	0.6	0.6	0.6	0.4	0.4	0.7	-
8	-	-	-	-	-	-	-	-	0.8
9	-	-	-	-	-	-	-	-	0.6
11	-	-	-	-	-	-	-	-	2.2
12	-	-	-	-	-	-	-	-	2.5
13	-	-	-	-	-	-	-	-	2.5
A	-	-	-	-	-	-	-	-	0.4
B	-	-	-	-	-	-	-	-	5.5
D	-	-	-	-	-	-	-	-	27.7
E	-	-	-	-	-	-	-	-	1.8
F	-	-	-	-	-	-	-	-	1.3
G	-	-	-	-	-	-	-	-	13.1

Physical Tests: Surface color (Pt-Co units) measurements at Sites 1-4, 14, E and G. Data were collected by CEAT June-September 2009.

Site	17-Jun-09	01-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	17-Sep-09	24-Sep-09
1	-	12	-	17	12	7	18	-
2	16.5	-	-	-	-	-	62	-
3	-	-	11	-	-	-	35	-
4	-	-	-	-	-	-	19	-
14	-	-	-	-	-	-	-	51
E	-	-	-	-	-	-	34	-
G	-	-	-	-	-	-	78	-

APPENDIX L (continued)

Chemical Tests: Surface, middle, bottom phosphorus (ppb) concentrations at Sites 1-3 and 10 (epicore values were also given for Sites 1, 2 and 3). Data were collected by CEAT for June-September 2009.

	3-Jun-09	17-Jun-09	26-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	17-Sep-09
Site 1									
Surface	6.8	12.1	7.7	11.7	11.8	9.3	11.8	8.3	10.6
Middle	6.1	13.3	10.8	15.7	17.9	11.8	13.7	11.2	10.1
Bottom	16.6	27.0	51.3	63.1	73.2	80.8	98.4	130.5	295.3
Epicore	12.4	11.1	11.1	14.9	13.5	16.5	13.5	14.3	9.5
Site 2									
Surface	3.8	9.4	8.5	11.7	6.5	7.6	9.9	9.5	6.3
Middle	5.3	9.5	7.9	14.6	9.4	8.8	10.4	9.0	8.3
Bottom	7.4	9.7	8.5	12.8	11.4	12.9	11.3	8.9	7.2
Epicore	4.7	20.8	8.5	16.3	10.4	-	11.2	6.8	-
Site 3									
Surface	5.2	8.3	7.4	13.5	8.2	12.0	9.1	7.8	9.4
Middle	10.1	18.6	11.0	14.6	10.2	14.8	15.0	6.9	7.8
Bottom	4.9	14.3	13.7	14.5	13.1	13.2	10.5	6.5	7.2
Epicore	1.7	-	-	-	-	17.5	-	-	5.2
Site 10									
Surface	-	-	-	-	-	-	-	-	8.8
Middle	-	-	-	-	-	-	-	-	8.9
Bottom	-	-	-	-	-	-	-	-	18.5

APPENDIX L (continued)

Physical Tests: Conductivity measurements at Sites 1-3 and 10. Data were collected by CEAT June-September 2009.

Depth (m)	17-Jun-09	25-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	18-Aug-09	17-Sep-09
Site 3									
0	86.8	85.7	86.3	87.2	87.3	87.6	87.4	87.8	-
1	86.5	85.2	86.3	87.2	87.2	87.6	87.6	87.7	91.8
2	86.2	85.3	87.0	87.3	87.1	87.5	87.3	86.9	91.3
3	85.7	85.2	86.8	87.2	87.1	87.7	87.3	86.6	91.1
4	85.6	84.9	87.1	87.2	87.0	87.7	87.3	86.5	91
5	86.5	84.8	87.2	87.3	87.7	88.2	87.4	86.3	90.8
6	86.5	84.7	88.3	87.4	88.9	88.3	87.8	86.7	90.8
7	87.0	85.4	89.6	87.6	88.9	90.1	91.2	88.4	91.8
Site 10									
0	-	-	-	-	-	-	-	-	75.9
1	-	-	-	-	-	-	-	-	76.2
2	-	-	-	-	-	-	-	-	76
3	-	-	-	-	-	-	-	-	76.1
4	-	-	-	-	-	-	-	-	76
5	-	-	-	-	-	-	-	-	76.1
6	-	-	-	-	-	-	-	-	76.1
7	-	-	-	-	-	-	-	-	76.2
8	-	-	-	-	-	-	-	-	76.3

APPENDIX L (continued)

Chemical Tests: pH measurements at Site 1. Data were collected by CEAT June-September 2009.

Depth (m)	03-Jun-09	17-Jun-09	25-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	17-Sep-09
0	7.8	7.1	7.2	6.6	6.4	6.8	7.4	7.3	7.6
1	7.7	7.2	7.0	6.7	6.6	6.9	7.5	7.5	7.6
2	7.7	7.2	7.1	6.7	6.7	6.9	7.6	7.6	7.7
3	7.8	7.2	7.1	6.7	6.7	7.0	7.7	7.7	7.6
4	7.7	7.2	7.1	6.8	6.8	7.0	7.7	7.6	7.6
5	7.7	7.2	7.1	6.8	6.8	7.0	7.7	7.5	7.6
6	7.7	7.2	7.1	6.8	6.9	7.0	7.7	7.4	7.5
7	7.7	7.2	7.1	6.8	6.8	7.0	7.5	7.3	7.5
8	7.7	7.2	7.1	6.8	6.8	7.0	7.5	7.2	7.4
9	7.7	7.1	7.1	6.8	6.8	6.9	7.4	7.1	7.2
10	7.7	7.1	7.1	6.7	6.7	6.8	7.2	7.0	7.0
11	-	7.0	7.1	6.6	6.6	6.7	7.1	6.9	6.8
12	7.6	6.9	7.0	6.6	6.5	6.7	7.0	6.8	6.7
13	7.5	6.8	6.9	6.5	6.5	6.6	6.9	6.7	6.6
14	7.5	6.8	6.9	6.5	6.4	6.6	6.8	6.7	6.6
15	7.5	6.7	6.9	6.4	-	6.6	6.7	-	-

APPENDIX L (continued)
Physical Tests: Surface conductivity measurements at Site 12-14, A, B and D-G. Data were collected by CEAT.

Site	17-Sep-09
12	64
13	66
14	68
A	153
B	67
D	148
E	74
F	147
G	139

Chemical Tests: Nitrate measurements (mg/L) at Site 1. Data were collected by CEAT in September 2009.

Site	17-Sep-09	24-Sep-09
1	-	0.04
3	0.03	-
4	0.02	-
5	0.03	-
7	0.03	-
8	0.02	-
11	0.03	-
12	0.03	-
13	0.04	-
14	-	0.03
G	0.25	-

APPENDIX L (continued)

Chemical Tests: pH measurements at Sites 4-12. Data were collected by CEAT June-September 2009.

Depth (m)	03-Jun-09	17-Jun-09	25-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	17-Sep-09
Site 4									
0	-	-	7.1	6.9	6.5	6.8	7.7	7.2	-
Site 5									
0	-	7.0	7.1	6.6	6.6	6.8	7.4	7.6	-
Site 6									
0	-	7.1	-	6.8	6.7	6.9	6.9	6.9	7.3
Site 7									
0	-	-	7.0	6.2	6.6	6.8	7.1	-	7.4
Site 8									
0	-	-	-	-	-	-	-	-	7.1
Site 9									
0	-	-	-	-	-	-	-	-	7.9
Site 10									
0	-	-	-	-	-	-	-	-	7.5
1	-	-	-	-	-	-	-	-	7.5
2	-	-	-	-	-	-	-	-	7.5
3	-	-	-	-	-	-	-	-	7.5
4	-	-	-	-	-	-	-	-	7.5
5	-	-	-	-	-	-	-	-	7.5
6	-	-	-	-	-	-	-	-	7.5
7	-	-	-	-	-	-	-	-	7.5
8	-	-	-	-	-	-	-	-	7.5
Site 11									
0	-	-	-	-	-	-	-	-	7.6
Site 12									
0	-	-	-	-	-	-	-	-	7.2

APPENDIX L (continued)

Chemical Tests: pH measurements at Sites 2 and 3. Data were collected by CEAT June-September 2009.

Depth (m)	03-Jun-09	17-Jun-09	25-Jun-09	09-Jul-09	15-Jul-09	28-Jul-09	04-Aug-09	10-Aug-09	17-Sep-09
Site 2									
0	7.8	7.1	7.0	6.9	6.7	6.7	6.9	-	7.1
1	7.8	7.1	7.1	7.0	6.8	6.7	6.9	7.1	-
2	7.8	7.2	7.2	7.0	6.8	6.8	7.0	7.1	-
3	7.8	7.2	7.2	7.0	6.9	6.8	7.0	7.1	-
4	7.8	7.2	7.2	7.0	6.9	6.8	7.1	7.1	-
5	7.8	7.2	7.2	7.0	6.9	6.8	7.1	7.1	-
6	7.8	7.2	-	7.1	6.9	6.9	7.0	7.0	-
7	7.7	7.2	-	7.1	6.9	6.8	7.0	6.9	-
Site 3									
0	7.8	7.2	6.9	6.3	6.6	6.7	7.2	-	-
1	7.8	7.2	6.9	6.5	6.7	6.8	7.2	-	7.3
2	7.8	7.3	6.9	6.5	6.8	6.9	7.2	-	7.4
3	7.8	7.3	6.9	6.6	6.8	6.9	7.1	-	7.4
4	7.8	7.3	6.9	6.6	6.8	6.9	7.2	-	7.5
5	7.7	7.3	6.9	6.6	6.9	6.9	7.1	-	7.5
6	7.7	7.2	6.9	6.6	6.9	6.8	7.1	-	7.5
7	-	7.5	6.9	6.6	6.8	6.8	6.9	-	-

APPENDIX L (continued)
Biological Tests: Chlorophyll-*a* measurements at Sites 1 and 2. Data were collected by CEAT on 17-September-09.

Depth (m)	17-Sep-09	Depth (m)	17-Sep-09
Site 1		**Site 2**	
0	6.1	0	-
1	2.4	1	0.9
2	1.4	2	0.4
3	0.8	3	0.4
4	0.5	4	0.4
5	0.4	5	0.3
6	0.3	6	0.0
7	0.3	7	0.9
8	0.1	-	-
9	1.5	-	-
10	2.6	-	-
11	2.6	-	-
12	2.6	-	-
13	2.7	-	-
14	3.5	-	-

APPENDIX L (continued)

Chemical Tests: Alkalinity measurements (mg $CaCO_3$/L) at Site 1. Data were collected by CEAT July-September 2009.

Site	01-July-09	15-Jul-09	18-Jul-09	04-Aug-09	10-Aug-09	17-Sep-09
1	11.8	-	-	11.1	10.3	
3	-	24.1	-	-	-	24.1

Chemical Tests: Hardness measurements (mg/L) at Site 1. Data were collected by CEAT July-September 2009.

	03-Jul-09	16-Jul-09	29-Jul-09	11-Aug-09	17-Sep-09
Site 1					
Mg	1.5	-	2.1	2.5	2.6
Ca	0.3	-	0.1	0.1	-
Total	1.8	-	2.2	2.6	-
Site 3					
Mg	-	0.3	-	-	2.3
Ca	-	0.04	-	-	0.2
Total	-	0.3	-	-	2.5