WATER BUDGET

INTRODUCTION

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

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

METHODS

In calculating a water budget the following formulas were used:

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

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

The water level in China Lake is not static throughout the year. In fact, it is adjusted seasonally and controlled at the dam in Vassalboro (see Historical Trends). Rainfall and runoff are not consistent throughout the year, but over the course of many years, a mean approximates what is typical during a given year. I_{net} is the net increase in water in the lake each year contributed from direct precipitation into the lake as well as the watershed runoff. It is based on rainfall average that was taken as a 10-year mean calculated using NOAA rainfall data collected at the Augusta airport from June 1995 through May 2005 (NOAA 2005). The other factors used in calculating I_{net}, runoff and evaporation rates, were obtained from the North Kennebec Regional Planning Commission (NKRPC unpublished data) and a U.S.G.S. study of the Lower Kennebec River Basin, respectively (Prescott 1969). Runoff is the mean rate of water flow off land, and the evaporation is a mean of water evaporating from the surface of the water.

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

RESULTS AND DISCUSSION

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

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

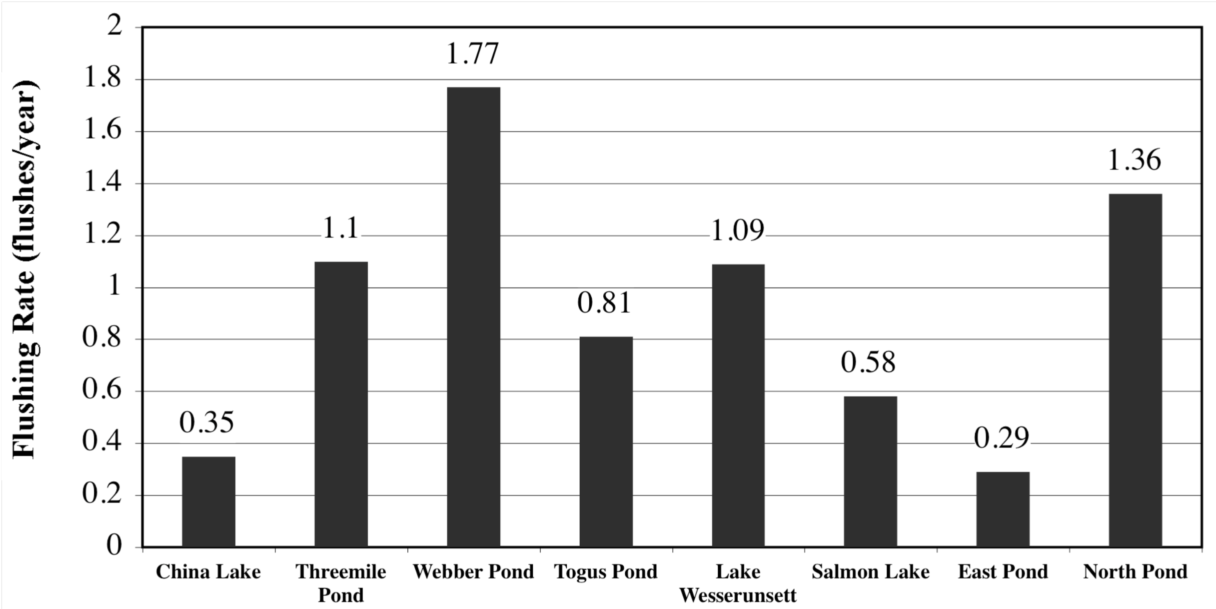

Figure 54. Flushing rate of China Lake and seven other lakes in the Kennebec Valley. All but China Lake were taken from previous Colby Environmental Assessment Team studies (CEAT 1997, 2000, 2001, 2003, 2004).

PHOSPHORUS BUDGET

INTRODUCTION

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

METHODS

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

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

W represents the total mass of phosphorus entering China Lake in kg/year. The Ec terms represent the export coefficients for the various land use types, measured in kg/ha/year. The export coefficient indicates the degree to which that land use type typically contributes phosphorus to the lake through runoff (see Appendix E). Phosphorus inputs included in this model are: atmosphere (a), mature forest (mf), cropland (cp), pasture (p), grassland (g), wetland (w), reverting land (rl), commercial and municipal land (cm), camp roads (cr), state and municipal roads (sr), shoreline development (s), non-shoreline development (n), shoreline septic system (ss), and non-shoreline septic system (ns). I_A, I_B, and I_C represent the amount of phosphorus released by institutions within the watershed (see Appendix E). I_A corresponds to China Primary and Middle Schools collectively, I_B corresponds to Erskine Academy, and I_C corresponds to Friends Camp, a residential summer camp. SR_1 and SR_2 indicate the soil retention capacity for phosphorus of shoreline and non-shoreline soils, respectively. SR_{3A}, SR_{3B}, and SR_{3B} indicate the soil retention capacity at the location of the three institutions. A_s represents the surface area of China Lake. This area, as well as areas for the various land use types, was obtained using DOQs of the China Lake watershed and ArcGIS® 9 (see Watershed Land Use Patterns: Methodology). Sd represents the amount of phosphorus released from sediments at the bottom of China Lake, and A_b represents the surface area of the lake bottom.

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

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

RESULTS AND DISCUSSION

The phosphorus loading model predicted a range of 1210 kg/yr to 5716 kg/yr of phosphorus entering the lake from external sources, with our best estimate being 2597 kg/yr. When sediment release (an internal source of phosphorus) was accounted for, the model predicted a range of 2814 kg/yr to 8283 kg/yr of phosphorus entering the lake from both external and internal sources, with our best estimate being 4843 kg/yr. The best estimate for total phosphorus concentration was calculated to be 18.8 ppb, with a range of 10.9 ppb to 32.2 ppb. These calculated phosphorus concentrations include phosphorus released from the sediments, which contributed greatly to the total phosphorus concentration of China Lake. Our best estimate of the phosphorus concentration from the model corresponds with the mean phosphorus concentration determined for surface, middle, and epicore samples for summer and fall 2005 (mean ± SE; 18.8 ± 1.0 ppb, n = 62). Our high estimate corresponds with the mean phosphorus concentration for surface, middle, epicore, and bottom samples for the summer and fall (30.0 ± 3.8 ppb, n = 84). Since the phosphorus concentration on the bottom of the lake (summer and fall 2005 mean ± SE; 61.8 ± 11.8 ppb, n = 22) was much higher than the concentration at all other levels, we felt that the lower estimate (our best estimate) most accurately represented the total phosphorus concentration of the majority of the water in China Lake.

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

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

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

Mature forest is the largest land use type within the watershed, accounting for 62% of the total land area. Mature forest exports very little phosphorus per area because the full canopy slows the velocity of rain, reducing the impact of rain on the underlying soil, and the roots help to hold soil in place and take up nutrients (see Appendix E). Although the phosphorus export coefficient for mature forest is very low, its large area makes mature forest the second largest contributor of phosphorus from an external source, contributing 431 kg/yr, or 16.6%, according to our best estimate (Table 8).

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

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

[a] Includes China Primary School and China Middle School

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

Atmospheric deposition of phosphorus into the lake accounted for 9.2% (241 kg/yr) of the total phosphorus entering China Lake from external sources (Table 8). Phosphorus is a byproduct of industrial production and wood-burning stoves among other things. Once released into the atmosphere, the phosphorus can be deposited into the lake through precipitation (Reckhow and Chapra 1983). The high contribution of phosphorus from atmospheric deposition reflects the large surface area of the lake, as well as the ability of phosphorus particles in the atmosphere to travel long distances before deposition (Reckhow and Chapra 1983).

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

LAKE REMEDIATION TECHNIQUES

INTRODUCTION

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

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

COMMONLY USED REMEDIATION TECHNIQUES

Physical Treatments

Water Removal Techniques

Hypolimnetic Withdrawal

The water in the hypolimnion of stratified lakes has the least amount of dissolved oxygen, and as a result, is the most susceptible to the release of phosphorus, toxic metals, and hydrogen sulfide from the sediment (Cooke et al. 1993). To combat this tendency, it is possible in some lakes to draw water out of the hypolimnion to let some of the most nutrient-rich water to escape from the lake. A 1994 analysis of China Lake claimed that three times as much phosphorus was contributed by the sediments than from external loading (Walker 1994). This does not agree with our findings (see Phosphorus Budget), however, it is clear that to stop algal blooms, reducing external phosphorus loading will not be sufficient. Reducing the amount of phosphorus in the hypolimnion will usually lead to a reduction in the amount of phosphorus in the epilimnion as well. Hypolimnetic withdrawal can be an effective long-term remediation technique for slowing the eutrophication process of a lake, and may retard or possibly eliminate algal blooms.

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

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

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

Dilution and Flushing

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

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

Drawdown

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

Dredging

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

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

Hypolimnetic Aeration

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

There are several types of aeration systems, including mechanical agitation, injection of pure oxygen, and injection of air using an air-lift design (Cooke et al. 1993). Air-lift carries the oxygen deficient hypolimnetic water to the surface, where it is aerated and then pumped back to the hypolimnion. In 1971, an aeration system was installed in Togus Pond (Anderson 1972). The results did not indicate any significant improvement to water quality except increased volume of the aerobic zone. Togus Pond continues to have algal blooms, and because of the costs associated with this type of aeration, it has not been done in any of the lakes in the Kennebec Valley since (CEAT 2005).

Chemical Treatments

Alum Treatment

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

The best time to treat a lake with alum is directly after ice-out in the spring because it catches the suspended phosphorus before the spring algal bloom (Cooke et al. 1993). However, there are certain conditions in the early spring which may not be ideal for the treatment. For instance, there are often strong winds that mix the water and can disrupt the distribution of the floc blanket, leading to thin spots, where the phosphorus-absorbing layer will not persist. It is important to time the alum treatment carefully taking into account weather patterns and the turnover schedule of the lake. To determine the ideal dosage of alum, laboratory tests are conducted in which lake samples are treated with increasing doses of alum until the desired amount of phosphorus is removed. The dose for the entire lake is then calculated based on mean depth, mean annual period of anoxia, and the results of the laboratory tests. Only those parts of the lake which are more than three meters (ten feet) deep are treated, because shallower water leaves the floc layer on the sediment vulnerable to disruption from winds, waves, and human activity (Walker 1994).

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

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

Even within Maine, the success of this type of treatment can vary widely. Annabessacook Lake, in Winthrop, ME had experienced algal blooms since the 1940's, largely due to non point-source agricultural nutrient loading, primarily from sewage effluent (Welch and Cooke 1999). After massive efforts, 80% of the municipal and agricultural wastewater was being diverted elsewhere by 1972, but the lake still experienced algal blooms despite the fact that external loading was greatly reduced. An alum treatment was carried out in 1978 and the lake had no blooms until 1991 (Welch and Cooke 1999). The alum treatment of Annabessacook was able to stop algal blooms for 13 years, but the treatment is not always as successful; the treatment of Threemile Pond failed after just three summers.

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

Calcium Additives

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

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

The effectiveness of this treatment is limited by its requirements, it has not been done on a large number of lakes, and cost estimates are widely variable. One example of this treatment comes from the hard, eutrophic Frisken Lake in British Columbia (Cooke et al. 1993). In the summer of 1983 and spring of 1984, the lake was treated with slaked lime, $Ca(OH)_2$. This treatment greatly increased Secchi disk transparency and phosphorus precipitation was significant. Prior treatments of the lake used the algicide copper sulfate, which caused damage to the epilimnotic biota and caused concerns over toxic buildup of copper (Welch and Cooke 1999). In these respects, the calcium treatment was more effective, as it achieved the same results as the copper sulfate had, without the toxicity. However, the precipitate that formed to bind the phosphorus dissolved the next season, meaning that the treatment would have to be done annually.

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

Ferrous

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

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

Algicides

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

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

Biological Treatments

Aquatic Plant Harvesting

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

The choice of which species to use for this is critical. In some lakes, exotic plant species including water hyacinth are brought in, with the hope that the plant will die during the harsh winter away from its natural tropical habitat (Cooke et al. 1993). Death during the winter is crucial, because it is impossible to harvest all of the vegetation and the introduction of an exotic species can have dire consequences (see Exotic Species).

Biological Control

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

Fish Stock Manipulations

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

In East Pond, MDEP is currently conducting a pilot study using biomanipulation under the assumption that the algae blooms are exacerbated by White Perch, which eat the plankton that normally eat the algae (Van-Riper, pers. comm.). Reducing the biomass of the dominant fish species that consume zooplankton may result in improved water clarity in impaired lakes (MDEP 2005e). It has been suggested that removal of the whole trophic level of the White Perch would result in less severe algal blooms. However, manipulating the trophic levels will not change the actual phosphorus levels in the water column or in the sediments, it only increases herbivory of the algae creating the blooms. No such manipulations have been suggested for China Lake.

APPLICATIONS OF REMEDIATION TECHNIQUES TO CHINA LAKE

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

Physical Treatments

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

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

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

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

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

Dredging is a great way to actually eliminate the problem of internal phosphorus loading, but it works best in small and/or shallow lakes. It is not feasible to dredge China Lake due to the vast costs associated with dredging such a large and deep area and storing so much phosphorus-rich sediment (Peterson 1979). In 1989, costs for dredging half a meter of China Lake's sediment were estimated by MDEP and found to be far too expensive to even entertain the idea.

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

Chemical Treatments

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

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

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

Biological Treatments

Aquatic Plant Harvesting

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

Biological Control

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

Fish Stock Manipulations

Currently, CEAT does not recommend fish stock manipulation as a method of remediation for China Lake. Once the MDEP pilot study on East Pond is completed, more information will be available regarding the success of fish stock manipulations, and perhaps this option can be explored further at that time.

FUTURE PROJECTIONS

POPULATION TRENDS

HISTORIC

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

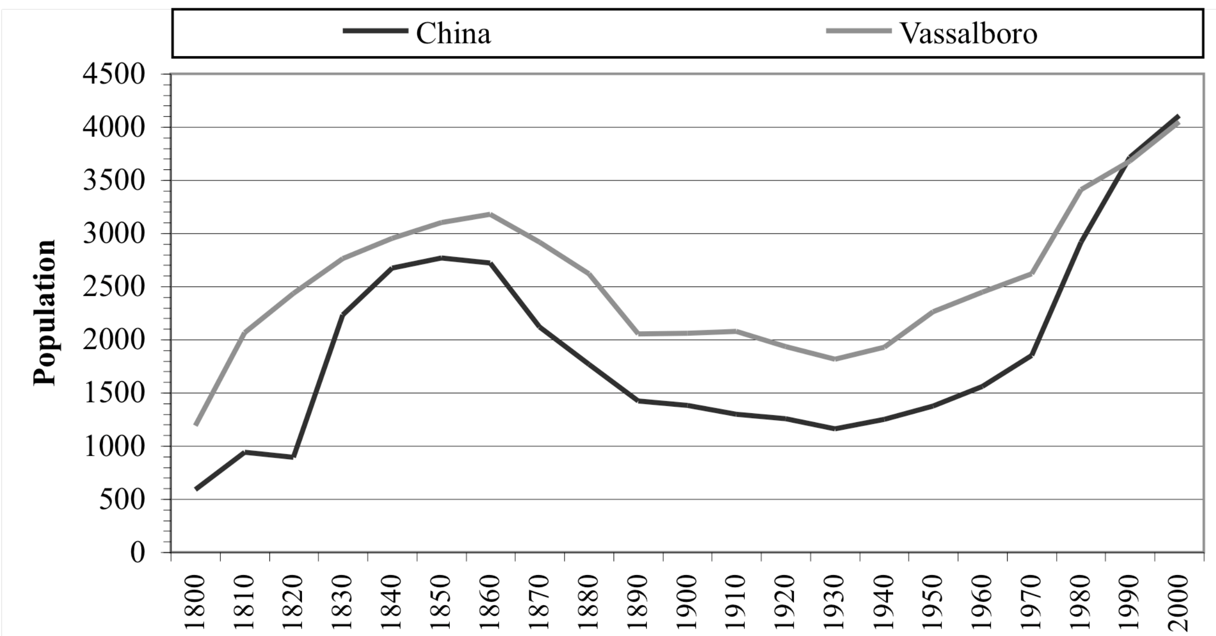

Figure 55. Population trend for the towns of China and Vassalboro from 1810 to 2000. Data obtained from Maine census data- population totals (Fogler Library 2002).

Between 1980 and 2000, the population of China increased at an annual rate of 1.7% per year (China Comprehensive Plan Committee 2005). A similar rate of population growth has occurred in Vassalboro. The period of growth between 1980 and 2000 has been the fastest long-term growth rate either town has experienced since the 1830s (Figure 55). In the 2000 US Census, 4,047 people lived in Vassalboro and 4,106 people lived in China (Fogler Library 2002). The populations of Vassalboro and China increased by 10% over the ten-year period of 1990 to 2000 (China Comprehensive Plan Committee 2005).

FUTURE

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

GENERAL DEVELOPMENT

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

Along with a rising population, there are an increasing number of people living alone in their homes, meaning that there may be more homes in proportion to population in the future (China Comprehensive Plan Committee 2005). Additions are built onto existing houses at an annual rate of 20 or more per year. The increase in size of individual houses increases the amount of nutrients each house contributes to the watershed. Residential growth can have negative effects on the watershed by increasing the number of septic systems and subsurface wastewater disposal systems, expanding impervious surfaces such as rooftops and driveways, and increasing the number and use of roads that can result in higher nutrient loading in the lake.

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

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

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

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

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

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

PHOSPHORUS BUDGET PREDICTIONS

METHODS

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

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

RESULTS AND DISCUSSION

Land Use and Development Projections

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

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

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

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

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

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

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

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

Phosphorus Budget Projections

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

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

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

[a] Includes China Primary School and China Middle School

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

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

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

RECOMMENDATIONS

WATERSHED LAND USE MANAGEMENT

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

<u>REDUCING EXTERNAL LOAD</u>

Development and Roads

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

Subsurface Waste Water Disposal Systems

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

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

Buffer Strips

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

Pasture and Agricultural Land

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

IN-LAKE MANAGEMENT

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

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

MONITORING AND REGULATIONS

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

COMMUNITY AWARENESS AND EDUCATION

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

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

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

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John Van Bourg	Kennebec Valley Water District, Vassalboro, ME.
Bobby Van-Riper	Maine Department of Inland Fish and Wildlife, Augusta, ME.