ANALYTICAL PROCEDURES AND RESULTS

WATER QUALITY STUDY SITES

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

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

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

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

**Site 1:** Northing: 4920148  Easting: 0454862  Depth: 27.5 m
Site located in the West Basin.

**Site 2:** Northing: 4918933  Easting: 0455432  Depth: 8.7 m
Site located at the south end of the East Basin, just north of the entrance to the West Basin.

**Site 3:** Northing: 4924273  Easting: 0459109  Depth: 16.0 m
Site located at the north end of the East Basin.

SPOT SITES

**Site 4:** Northing: 4921730  Easting: 0451831  Depth: 1.0 m
Site located at the dam where water drains from the West Basin. Samples were taken from the lakeside of the dam to characterize the water leaving the lake.

**Site 5:** Northing: 4921539  Easting: 0455255  Depth: 1.0 m
Site located on the north shore of the West Basin. Samples were collected where Ward Brook enters China Lake. Ward Brook is a tributary that runs from an agricultural area, through a buffer zone and into the lake. Samples from this site were used to determine the impact of agricultural land on local water quality.

**Site 6:** Northing: 4916232  Easting: 0454237  Depth: 1.5 m
Site located at the southern most end of the East Basin. Samples from this site were used to determine the impact of a public boat launch on local water quality.

**Site 7:** Northing: 4921476  Easting: 0456753  Depth: 1.5 m
Site located on the west bank of the East Basin, near the base of the farms. Samples from this site were used to determine the impact of agricultural land on local water quality.

**Site 8:** Northing: 4921609  Easting: 0457072
Site located on the west bank of the East Basin, just south of Green and Taconnet Islands. Samples were collected in front of a cluster of older houses to determine their potential impact on water quality.
TRIBUTARIES

Site 9: Northing: 4925513 Easting: 0459224
Site located at the major inlet on the north end of China Lake. Samples were taken from the streamside of the Route 201 bridge.

Site 10: Northing: 4917971 Easting: 0455555
Site located in Starkey Brook, which enters the lake from the east side of the East Basin, across from the entrance to the West Basin. Samples were taken from the stream, close to where it enters the lake.

Site 11: Northing: 4915720 Easting: 0454085
Site located in Jones Brook, which enters the East Basin at the southern end. Samples were taken from the brook, close to where it enters the lake.
**WATER QUALITY**

**PHYSICAL PARAMETERS**

**Dissolved Oxygen and Temperature**

*Introduction*

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

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

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

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

Results and Discussion

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

![Dissolved Oxygen Profile](image-url)

**Figure 13.** Dissolved oxygen profile at Site 1 of China Lake during the summer of 2005. See Figure 12 for site location.
At Site 2, DO levels ranged from 10.21 ppm at 3 m to 8.04 ppm at 16 m on 7-Jun-05 (Figure 13). Benthic DO levels decreased through the end of the monitoring, to 0.07 ppm on 19-Sept-05. Site 2 at China Lake first turned anoxic on 16-Aug-05 at a depth of 11 m. Stratification between the epilimnion and the hypolimnion occurred at a depth of 6 to 8 m.

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

In 1982, the lake water never turned anoxic (Figure 14). Historical data were from Site 1. However, similar to the observations made by CEAT, in September of 1987, 1992, and 1997, the lake became anoxic below the thermocline. In 1997, DO levels remained above 1.0 ppm into deeper water (17 m) than in 1992 (10 m), indicating that a smaller volume of the lake became anoxic in 1997. The anoxic conditions observed at depth indicate that internal phosphorus loading could be an important factor in China Lake. From the months of June to September 2005, temperature ranged from 24.8° C at the surface to 9.8° C at 27 m at Site 1 (Figure 15). In early June, temperature profiles indicate weak stratification, which increased as the summer progressed.
Figure 14. Historic dissolved oxygen profiles at Site 1 of China Lake (MDEP 2005c). See Figure 12 for site location.

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

*Introduction*

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

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

*Methods*

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

*Results and Discussion*

CEAT observed decreasing transparency from June to August. Mean (± SE) transparency for China Lake over all of the sampling dates was 2.90 ± 0.40 m, which is similar to that recorded at Threemile Pond (Table 4). The transparency was below 2 m on both sampling dates in August (Figure 16). This transparency corresponds with algal blooms, with transparency decreasing as the severity of the bloom increased in the late summer. Transparency in China Lakes...
Lake varied from 6.10 m at Site 1 at the beginning of the summer to 1.20 in late August, indicating the occurrence of an algal bloom at this time.


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

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

**Turbidity**

**Introduction**

Suspended matter in the water column affects turbidity readings. Turbidity results from the scattering and absorption of light, and changes daily similar to transparency. Spring runoff and rain can affect turbidity. Turbidity is lower when suspended organic and/or inorganic matter, silt, clay, or plankton is present in the water column. Low turbidity indicates that there is low light penetration resulting in low rates of photosynthetic activity in a lake (Chapman 1996).
Figure 16. Mean Secchi depth transparency at Site 1, 2, and 3 of China Lake during the summer of 2005. Minimum transparency below a depth of 2 meters (dotted line) indicates the occurrence of an algal bloom. See Figure 12 for site locations.

Figure 17. Mean, minimum, and maximum transparency of China Lake measured at Site 1 from 1971-2004 with Secchi disk (MDEP 2005c). Minimum transparency below a depth of 2 meters (dotted line) indicates the occurrence of an algal bloom. See Figure 12 for site location.
Methods

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

Results and Discussion

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

Color

Introduction

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

Methods

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

**Results and Discussion**

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

![Figure 18. Historic mean (± SE) color for selected years at Site 1 of China Lake (MDEP 2005c). See Figure 12 for site location.](image-url)
Conductivity

Introduction

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

Methods

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

Results and Discussion

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

On 19-Sep-05, surface conductivity ranged from 50 µMHOs/cm at Site 2 to 142.9 µMHOs/cm at Site 11. Results for conductivity at Sites 1, 2, and 3 obtained using the Conductivity Bridge were about 25-30 µMHOs/cm lower than results obtained using the Sonde for those same sites. Samples were stored on ice and transported to the lab, but were not returned to room temperature before testing. Since conductivity is temperature dependent, the data collected in the lab using the Conductance Bridge is only comparable to other data obtained
using the same methods on the same day. Sites 4 and 9 had a conductivity of 76.9 μMHOs/cm and Sites 10 and 11 had conductivities greater than 100 μMHOs/cm. The remaining sites all had conductivities between 50 and 58.8 μMHOs/cm. The mean (± SE) conductivity for all sites on 19-Sep-05, using the Conductivity Bridge method, was 72 ± 8.90 μMHOs/cm (Table 4). Historical conductivity means ranged from 63 μMHOs/cm in 1984 to a peak of 161.44 ± 0.25 μMHOs/cm in 2000 (Figure 19).

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

CHEMICAL PARAMETERS

**pH**

**Introduction**

The concentration of hydrogen ions (H⁺) in water is measured by pH. Values range from less than 1 (extremely acidic) to 14 (extremely basic) with pH of 7 indicating neutral acidity (Kalff 2002). pH is measured on a logarithmic scale - a change of 1 unit indicates a change of H⁺ concentration by a factor of ten. Lake water pH fluctuates naturally with the level primary productivity and unnaturally as a result of pollutants, such as acid rain. The degree of change of pH as a result of acid rain is influenced by alkalinity (see Water Quality: Alkalinity). However,
pH also changes as a result of photosynthesis. As plants use carbon dioxide during photosynthesis, pH increases. High pH can indicate an algal bloom. pH is an important parameter in lake water quality because it influences which plant and animal species are able to live in the lake; different organisms have specific pH ranges in which they can survive (MDEP 1996). In addition, the pH level of China Lake is important because most processes involved in mitigating water quality problems (such as chemical coagulation, disinfection, softening, and corrosion control) are pH dependent (Tomar 1999).

Methods

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

Results and Discussion

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

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

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

pH can fluctuate with depth and season for a variety of reasons. The most likely cause of pH change in China Lake, are the seasonal algal blooms. The removal of CO₂ from the water due to photosynthesis causes an increase in pH. The photosynthetic rate during an algal bloom rises dramatically, so the spike in pH in the late summer is due primarily to the increased algae content.


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

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

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

**Alkalinity**

*Introduction*

Alkalinity is the acid neutralizing capacity of a body of water (Kalff 2002) or the ability of a lake to sustain the addition of acid without causing a change in the overall pH (Novotny 2003). It is the measure of calcium carbonate (CaCO₃) in a body of water. Alkalinity in Maine lakes varies from 0.3 milligrams per liter (mg/L) to 150.3 mg/L, with an average of 12.2 mg/L (MDEP 1996). The most important factors in determining alkalinity are land composition, changes in pH, and wastewater (Murphy 2002). Of these, land composition has the greatest bearing on alkalinity in lakes. The soil and rock composition of the watershed determines the natural quantity of calcium carbonate in the water. For example, limestone and sedimentary rocks are high in carbonate, while granite is low in carbonate. pH and alkalinity are closely related (see Water Quality: pH) so changes in pH can cause changes in alkalinity.
Wastewater from residential land often has elevated levels of carbonate due to home cleaning agents and food waste (Murphy 2002). Maine lakes have a relatively high alkalinity and substantial buffering capacity and are relatively resistant to changes in pH.

**Methods**

Surface water samples were collected on 22-Sep-05 from each comprehensive site (Sites 1, 2, 3), each spot site (Sites 4, 5, 6, 7, 8), and two tributary sites (Sites 9, 11) to measure alkalinity. Tributary Site 10 (Starky Brook) was not sampled because the stream flow was prohibitively high. See Figure 12 for site locations. The samples were placed on ice and taken back to CEAC for analysis. Alkalinity values were measured in milligrams of CaCO$_3$ by titration with 0.02 N sulfuric acid (see Appendix B). Finally, mean alkalinity was compared to other local lakes to put China Lake in geographic context. Threemile Pond, Webber Pond, and East Pond, are of similar trophic status as China Lake, Great Pond is showing signs of eutrophication and Long Pond, North Basin is an example of a local lake in good condition.

![Figure 21. Historic mean pH for selected years at Site 1 of China Lake (MDEP 2005c). See Figure 12 for site location.](image)
Results and Discussion

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

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

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

Nitrate

Introduction

Nitrate is an essential nutrient for plant growth. Nitrogen undergoes a series of redox reactions depending on the presence or absence of oxygen to produce various derivatives such as ammonia, nitrites, and nitrates (Tomar 1999). In fresh water, nitrate (NO$_3^-$) is the most common form of nitrogen. Nitrate concentrations in the lake can be increased by development within the
watershed, specifically from municipal and industrial wastewaters, waste disposal sites, sanitary landfills, and inorganic nitrate fertilizers are potential sources of excess nitrogen (Chapman 1996).

**Methods**

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

**Results and Discussion**

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

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

The surface nitrate concentrations measured in the field with the Sonde and in the laboratory yielded similar trends. It is important to avoid value comparison between the two sets of data, because different analytical procedures were used. Nitrate profiles were measured at the three comprehensive sites on 22-Jun-05, 3-Aug-05, 16-Aug-05, and 19-Sep-05. The nitrate concentrations were highest during the late summer at the surface of the lake. Figure 24
illustrates the nitrate profile at Site 1, which is representative of the other two sites as they all expressed similar profiles (see Appendix C).

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

## Total Phosphorus

### Introduction

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

Elevated levels of phosphorus in freshwater lakes increase phytoplankton abundance causing deleterious consequences, such as reduced water clarity from algal blooms (see China Lake Characteristics: Algal Blooms) and reduced dissolved oxygen. Phosphorus is the key nutrient driving algal production, making lake water phosphorus concentration the most important factor in causing the algal bloom in a lake.
Phosphorus occurs naturally in sediments, decomposing leaf litter and other organic materials, so some phosphorus in the ecosystem is inevitable. However, human land-uses, recreational activities, and runoff contribute to the excess phosphorus loading of lakes (Novotny 2003). The Maine Department of Environmental Protection describes lakes with phosphorus concentrations of 12 – 15 parts per billion (ppb) as at risk for algal blooms (Bouchard, pers. comm.; see Background: Phosphorus and Nitrogen Cycles).

**Methods**

CEAT measured total phosphorus concentration on 07-Jun-05, 22-Jun-05, 03-Aug-05, 16-Aug-05, and 19-Sep-05 (see Appendix C). Comprehensive Site 2 was remeasured on 6-Oct-05 due to incorrect location of the first sample on 19-Sep-05. See Figure 12 for site location.

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

**Methods**

CEAT measured total phosphorus concentration on 07-Jun-05, 22-Jun-05, 03-Aug-05, 16-Aug-05, and 19-Sep-05 (see Appendix C). Comprehensive Site 2 was remeasured on 6-Oct-05 due to incorrect location of the first sample on 19-Sep-05. See Figure 12 for site locations. At the comprehensive sites (Sites 1, 2, and 3), samples were taken from the surface, mid-depth, epicore, and bottom of the lake. Surface samples were taken at all spot sites and tributary sites. After collection, all samples were placed on ice and taken back to CEAC for analysis (see Appendix B). CEAT also measured the phosphorus contribution of two of the tributary sites (Sites 9 and 11) after a storm. A Global Water Stormwater Sampler SS201, placed in the two sites, was programmed to begin sampling after 0.5 inches of rain fell during a storm. One hose collected water from the tributary and filled the sample bottle completely (4 liters) as soon as 0.5 inches of rain fell; this sample was referred to as the continuous sample. The other hose collected water from the tributary every 10 minutes, until the sample bottle filled completely (4 L); this sample is referred to as the staggered sample.
All samples were digested using 1.0 mL of 1.75 N ammonium peroxysulfate and 1.0 mL 11 N sulfuric acid (per 50 mL sample) in an autoclave at 15 lbs/in² and 120° C for 30 minutes. The digestion process converts all organic phosphorus bound with phytoplankton, algae, or other organisms into its inorganic form. Post-digestion, samples were brought to pH 6 and a combined reagent was added for analysis (see Appendix B). The color produced by the combined reagent reacting with the phosphorus was measured using a Milton Roy Thermospectronic Aquamate Spectrometer and converted to phosphorus concentration measured in parts per billion (see Appendix B). Finally, mean total phosphorus concentration was compared to other local lakes to put China Lake in geographic context. Threemile Pond, Webber Pond, and East Pond, are of similar trophic status as China Lake, Great Pond is showing signs of eutrophication and Long Pond, North Basin is an example of a local lake in good condition.

Results and Discussion

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

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

The results for phosphorus concentrations in China Lake are consistent with recorded mean epicore total phosphorus for surrounding lakes (Table 5). Mean epicore values were compared
Figure 25. Total phosphorus at varying depths compared among Site 1, 2, and 3 of China Lake as measured by CEAT during summer 2005. Note that the y-axis scale differs for each site. See Figure 12 for site location.
to represent the most comprehensive value of total phosphorus in the top strata of the lakes. Threemile Pond measured 40 ± 2 ppb (CEAT 2004), Webber Pond measured 24.9 ± 2.8 ppb (CEAT 2003), East Pond measured 21.8 ± 0.9 ppb (CEAT 1999), Great Pond measured 14.2 ± 3.5 ppb (CEAT 1999), and Long Pond, North Basin measured 6.3 ± 1.1 ppb (CEAT 1995). The comparative values of mean surface total phosphorus are consistent with the trophic status of the six lakes, with China Lake, Threemile Pond, Webber Pond, and East Pond being the most eutrophic with the highest concentration of total phosphorus, Great Pond having slightly lower, and Long Pond, North Basin having the lowest total phosphorus concentrations.

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

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

*Figure 26.* Historic phosphorus data for Site 1 of China Lake (MDEP 2005C). Summer (June-August) and Fall (September-October) 2005 data were collected from 1-8 m deep.
The concentration peaks during the summer and fall blooms, corresponding to spring and fall turnover and remixing of phosphorus from the bottom. For the last 26 years, total phosphorus has ranged in concentration from 10.5 to 20.3 ppb. The fall of 1984 was the first recorded phosphorus level exceeding 15.0 ppb. Since then, fall levels have decreased below 15 ppb only twice (Figure 26). Historically, summer phosphorus levels have been lower than fall levels, but have been slowly increasing over approximately the last ten years (Figure 26).

BIOTIC PARAMETER

Chlorophyll-α

Introduction

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

Methods

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

Results and Discussion

In 2005, CEAT measured chlorophyll-α concentration profiles on 22-Jun-05, 3-Aug-05, 16-Aug-05, and 19-Sep-05 (Figure 27). In general, concentrations were relatively high at shallow depths, staying high until approximately 7 m. Chlorophyll-α is the indirect measurement of algae content. The inability of light to penetrate depths greater than 7 m precludes the existence of photosynthetically active algae at these depths, making the drop in chlorophyll-α concentrations directly correlated with the drop in dissolved oxygen (a byproduct of photosynthesis). There was a trend in chlorophyll-α concentration toward high values in the late summer. These data and the
Figure 27. Chlorophyll-α profiles at Site 1, 2, and 3 of China Lake during the summer 2005. See Figure 12 for site location.
trends of DO and Secchi disk readings correlate well with the late summer algal bloom in China Lake, confirming the propensity of China Lake to advancing stages of eutrophication. In China Lake, chlorophyll-a concentrations have been measured during the summer in selected years since 1978 (MDEP 2005c). Mean chlorophyll-a concentration was consistently greater than 5 ppb between 1984 and 2003. The highest level was recorded in 1999 and measured 20.4 ppb (Figure 28).

![Figure 28](image)

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

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

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

Data overlays produce interactive maps, in which relevant layers may be chosen for display at any one time, expediting data analysis. Interactive maps are a visual representation of the relationships between layers, enabling spatial analyses, such as locating all of the streams within a watershed. Additionally, symbols can be applied to features based on their attributes. For example,
shoreline residential lots can be assigned different colors depending on buffer strip effectiveness. Also, feature patterns and densities can be detected based on their distribution.

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

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

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

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

INTRODUCTION

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

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

METHODOLOGY

To conduct a survey of the land use in the China Lake watershed, black and white aerial photographs and color Digital Orthophoto-Quadrangles (DOQs) were imported into GIS. GIS analysis was undertaken utilizing ArcGIS® 9.0 software. ArcGIS® facilitated the digital manipulation of land use types to determine total areas of each land use type within the China Lake watershed for both 1965 and 2003. For both the 1965 and 2003 surveys, ArcGIS®
displayed the aerial photographs or DOQs and facilitated the creation of a layer of digital polygons to represent each land use type. CEAT created digital polygons representing each land use area for both surveys so that the polygons filled the entirety of the watershed. The direct watershed boundary of China Lake and two subsidiary watershed boundaries (Evans Pond and Hunter Brook watersheds) were downloaded from MEGIS and compiled utilizing ArcGIS® to form the complete China Lake watershed (See GIS: Introduction and Methods).

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

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

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

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

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

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

**Reverting land**: Land of forest-like characteristics, without a closed canopy, generally the product of early succession and reversion of fallow fields. Reverting land generally maintains the basic shape of previous human use.
Cropland: Agricultural land exhibiting ordered rows characteristic of planting techniques for corn and similar crops.

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

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

Commercial/Municipal land: Land characterized by structures of size and situation uncommon to residential lands and also by the availability of parking often associated with commercial operations. Commercial land was designated to include the smallest land area that encompassed all of the buildings, parking areas and other areas of identifiable impervious surfaces. Municipal land was characterized by a large central structure, parking areas and recreational areas. Schools were demarcated to include only the impervious land; recreational fields were marked as grassland.

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

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

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

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

The roads of China Lake were not surveyed using GIS analysis due to the inability of DOQs to display the full road area. The canopy of the coniferous and mixed forest obscured the area of smaller camp roads. GIS analysis in these circumstances was not the most accurate method to measure the area of the roads. Unable to determine road area from the 2003 DOQs, current road area was used in the study, assuming that the area of roads has changed very little since 2003. Substituting current road area for the 2003 road area, the possibility of road
construction presented a source of error. However, the DOQs were produced recently (approximately 2½ years earlier), reducing the likelihood of error due to road construction. The current road area within the watershed was measured in a comprehensive field survey, measuring length and average width of every road to calculate area (see Watershed: Road Survey). Current road area was then added to the 2003 survey. To allow for the addition of the current road within the watershed, an area of the same size was subtracted proportionately from each land use type. Subtracting the representative area proportionately from each land use type ameliorated the effects of adding the current road area, maintaining a constant watershed area. For the 1965 land use survey, road area was not included. Similar to the 2003 survey, road area could not be measured using ArcGIS®. A field survey to estimate road area for 1965 was impossible because present roads are different (construction, size) from roads in 1965.

In the land use survey of 1965, 16 aerial photographs were obtained from the Colby Environmental Assessment Center (CEAC) and two additional photographs of the northwest and eastern extremities of the watershed were obtained from the Kennebec County Farm Service Agency Service Center Office. The aerial photographs were originally taken on 6-May-65 by the United States Department of Agriculture (USDA). The photographs were taken at a scale of 1:20,000 and printed in large format (approximately 60 cm x 60 cm). Each photograph was scanned, arranged, and combined in Adobe Photoshop CS® to form a single composite digital image. The resulting image was then imported into ArcGIS®. Once imported into ArcGIS®, it was necessary to assign coordinate values to the composite image. In contrast to DOQs, neither the aerial photographs nor the composite image were pre-referenced by the easting and northing coordinate system of ArcGIS®. The coordinate system was applied to the 1965 composite image through a system of georeferencing, whereby physical features within the image were matched to corresponding features in a pre-existing layer. In our survey, the composite image was matched to the georeferenced roads layer of the China Lake watershed downloaded from MEGIS. To exclude error of road construction and development between 1965 and 2005, only prominent intersections of well established roads were utilized to georeference to the composite image. The watershed boundary was then overlaid in ArcGIS®, land use areas were identified, polygons drawn around each land use area (filling the watershed) and total areas for each land use type calculated.
Some of the land use types could not be identified in the 1965 aerial photographs. This inability was either due to lack of resolution or color, inconsistent contrast, or inadequacy of historical information. Such was the case for the forest land use types (coniferous forest, mixed forest and deciduous forest) where poor resolution and contrast in addition to lack of color obscured differences between the forest land use types in the 1965 black and white aerial photographs. Indistinguishable in the 1965 photographs, all three forest land use types were grouped together and designated as forest for the 1965 land use analysis.

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

Conducting a land use survey presents many possible sources of error. Identifying land use types correctly from aerial photographs and DOQs can be difficult due to poor resolution, contrast, objects obscuring the view, breaks in photographs, or seasonal vegetative changes. Many identification problems were specific to the 1965 survey where resolution of the aerial photographs was inferior to the DOQs, and also where the process of compilation and georeferencing created artifacts in the compiled image. To minimize these errors, members of CEAT employed several techniques. To combat the issues of resolution and artifacts in the 1965 survey photographs, thorough care was taken in the compilation and georeferencing process to minimize artifacts and errors and produce the most accurate possible image to survey. Secondly, members of CEAT worked cooperatively in both surveys, cross-referencing the identification of
other members to insure consistency and accuracy. Additionally for the 2003 survey, groundtruthing methods were employed to obtain greater accuracy. For the 1965 survey, where groundtruthing was impossible, members of CEAT had to rely entirely on cross-referencing strategies for correct land use identification. However, through the experience of groundtruthing for the 2003 survey, the members of CEAT gained competence in land use identification and felt confident in the land use identifications of the 1965 survey.

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

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

Additionally, CEAT created a land use change map employing the maps from both surveys. Rather than mapping all the possible changes between land use types, the types were grouped into two broad classes for both surveys, based upon similarity of erosion and phosphorus loading potential. The two land use classes were developed and undeveloped land. Developed land, which includes residential, commercial/municipal, and agricultural land, has a high erosion and phosphorus loading potential. Undeveloped land, which includes forest, wetlands and reverting land, has a low erosion and phosphorus loading potential. Maps from 1965 and 2003 surveys were overlaid in ArcGIS®, and changes in land use classes were generated as a separate layer.
using the raster generator and spatial analyst functions of ArcGIS®. Using the new layer, changes in land use classes were designated positive, neutral, or negative their effect on phosphorus loading potential. A positive land use change was consisted of a change from developed to undeveloped land. A neutral land use change consisted of a land use type change within the developed and undeveloped land use classes. A negative land use change consisted of a change from undeveloped to developed land.

COMPARISON OF 1965 AND 2003 LAND USE PATTERNS

Watershed Description

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

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

Wetlands

Introduction

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

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

**Results and Discussion**

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

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

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Percent in 1965 (%)</th>
<th>Percent in 2003 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Land</td>
<td>21.3</td>
<td>14.1</td>
</tr>
<tr>
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</tr>
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<td>2.0</td>
</tr>
<tr>
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<td>1.9</td>
</tr>
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<td>10.1</td>
</tr>
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<tr>
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<td>Wetlands</td>
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Figure 30. Land use patterns of China Lake watershed in 1965 derived from aerial photographs from the Colby Environmental Assessment Center and the United States Department of Agriculture.
Figure 31. Land use patterns of China Lake watershed in 2003 derived from Digital Orthophoto-Quadrangles downloaded from the Maine Office of Geographical Information Systems.
Figure 32. Areas of land use change in the China Lake watershed from 1965 to 2003. Positive land use change, which may decrease phosphorus loading, is defined as the change from developed land including residential, commercial/municipal, and agricultural to undeveloped land, including forest, wetlands, and reverting land. Negative land use change, which may increase phosphorus loading, is defined as undeveloped land changing to developed land. Neutral land use change, which causes little if any change in phosphorus loading, is defined as a change of land use type within either the broader developed or undeveloped category.
Figure 33. Percent land cover of China Lake watershed for 1965 and 2003 as determined using aerial photographs obtained from the Colby Environmental Assessment Center and the United States Department of Agriculture and Digital Orthophoto-Quadrangles obtained from the Maine Office of Geographic Information Systems, respectively.
Forest

Introduction

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

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

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

Results and Discussion

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

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

Introduction

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

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

Results and Discussion

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

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

Introduction

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

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

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

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

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

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

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

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

Introduction

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

Results and Discussion

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

Introduction

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

Results and Discussion

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

Roads

Introduction

The roads within the China Lake watershed were downloaded from MEGIS and analyzed for the 2003 map; road data could not be obtained from the 1965 aerial photographs. The total area for the 2003 map was calculated by measuring the roads during a road survey (see Watershed Development: Road Survey). While this survey was conducted in 2005, it was assumed that the roads and their respective areas did not change significantly over those two
years. The original 2003 digitized map had to be modified to include the road area proportionate to the percentages of land use. Roads play an important role in lake health (Davis et al. 1978). Their impervious nature can directly affect runoff qualities and quantities, by channeling water toward or away from the lake. This allows a small land use area to contribute disproportionately to phosphorus loading in a water system.

**Results and Discussion**

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