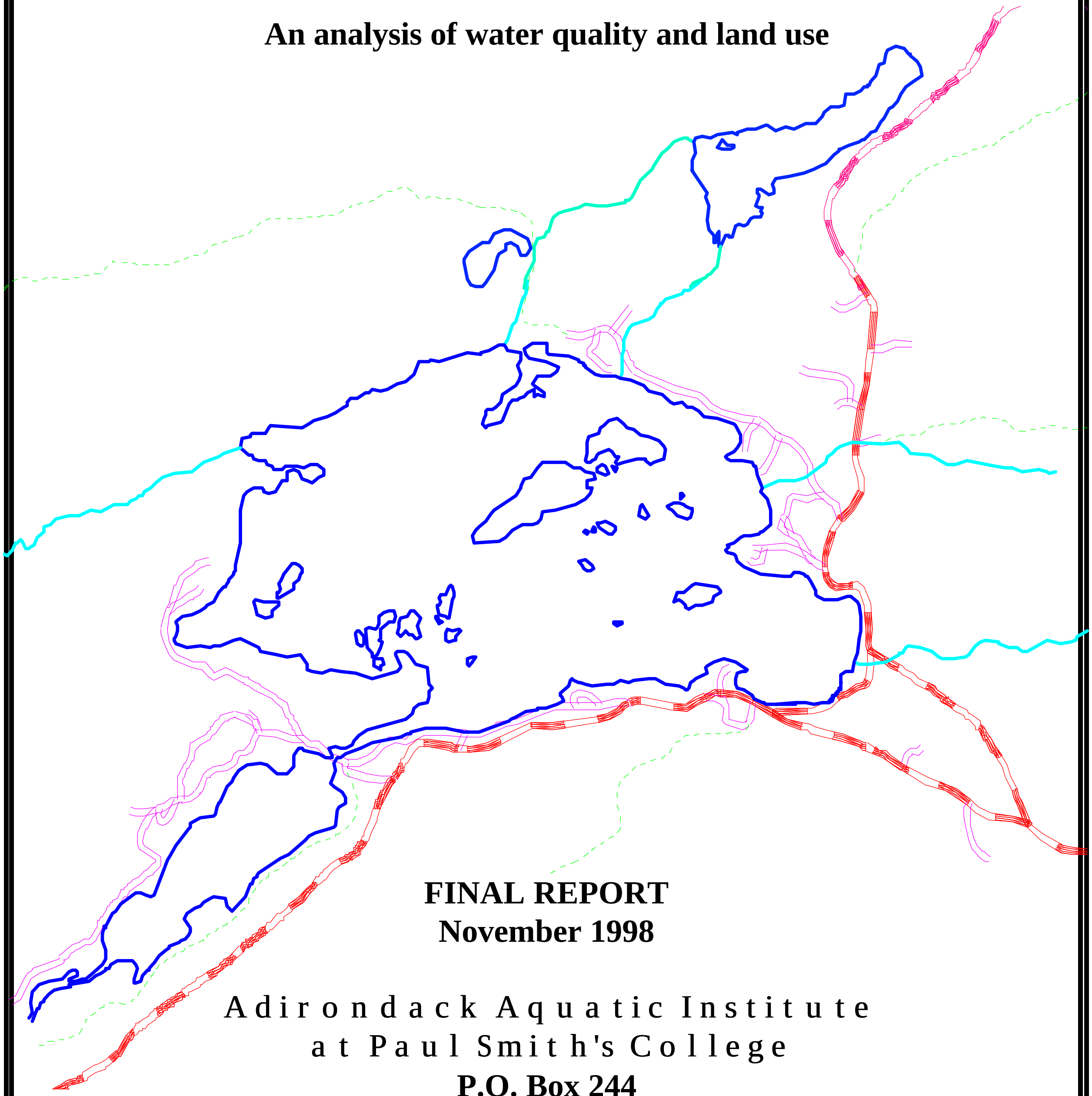
THE CARRYING CAPACITY OF BLUE MOUNTAIN LAKE

An analysis of water quality and land use



FINAL REPORT
November 1998

Adirondack Aquatic Institute
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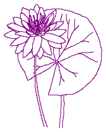

The Carrying Capacity of
BLUE MOUNTAIN LAKE

An analysis of water quality and land use

Final Report
November 1998

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Executive Summary

This report presents the findings of a three year study of Blue Mountain Lake and its watershed. Additional data from 1998 AAI volunteer monitoring program and Hamilton County's monitoring program were used in some of the trend analyses. There were two main objectives to this study. The first objective was to assess existing water quality in the lake and its tributaries. The second objective was to use the monitoring data in a water quality response model in order to predict the impact of development within the Lake's watershed. The findings of this study were also to be used in evaluating the approval of a second phase of The Woodlands development in Blue Mountain Lake.

Water quality data indicate that Blue Mountain Lake is oligotrophic but has experienced a significant decline in water quality since at least 1993. Total phosphorus concentrations have increased from around 3 parts per billion (ppb) in 1978 to between 8 and 9 ppb in 1998. Chlorophyll *a* concentrations have increased from around 1.5 ppb in 1994 to around 1.8 ppb in 1997, with an average of 3 ppb in the east basin during 1998. Transparency has decreased from around 10 meters in 1993 to around 6.5 meters in 1998.

Existing wastewater systems, which includes individual septic systems and the Adirondack Museum wastewater facility, are apparently having a significant impact on the water quality of the streams and lake. Within the streams, we observed a degradation of water quality as each summer progresses, which correlates to the seasonal loading of the systems due to summer occupancy. Within the lake, we observed the aforementioned decline in water quality. This is also evident in the lake from the sediment core work, which shows a trend of declining water quality over the past 100 years, particularly since the 1940s.

Water quality modeling showed that maximum development of the watershed, even with a mix of seasonal and year-round homes, would cause unacceptable changes in lake water quality. Modeling for a decrease in water quality to a chlorophyll *a* concentration of 2 ppb predicts total allowable new development consisting of 38 seasonal and 20 year-round homes. Given the present trend in water quality, however, it is likely that Blue Mountain Lake will reach that threshold even with the present level of development.

Existing development within the watershed needs to be examined critically and considerable effort needs to be directed towards upgrading all old and non-conforming septic systems. In addition, an alternative to stream discharge by the Museum should be investigated. Since the operation is seasonal, spray irrigation is a likely alternative that should be investigated by a qualified design engineer.

Acknowledgements

The Adirondack Aquatic Institute acknowledges the long-term financial support of this project by Mr. Bing Faxon of Potter Camp and the families that comprise the Blue Mountain Lake Water Watch. We also acknowledge lake access and boat usage provided by Mr. Faxon.

The author wishes to thank the AAI interns, AAI research associates, and Paul Smith's College staff for their contribution to the successful completion of this project.

1.0 Introduction

1.1 Purpose

This report presents the findings of a three year study of Blue Mountain Lake and its watershed. There were two main objectives to this study. The first objective was to assess existing water quality in the lake and its tributaries. The second objective was to use the monitoring data in a water quality response model in order to predict the impact of development within the Lake's watershed.

This report is divided into five sections. The first section provides an introduction and background information. The second section describe water quality in Blue Mountain Lake and its tributaries. The third section presents a hydrologic and nutrient budget analysis. The fourth section examines long-term water quality trends using historical data and data gathered during this study. The fifth section presents results of the water quality modeling analyses. Conclusions are presented in the final section of this report. Water quality data and a Glossary of Terms are provided as appendices.

1.2 Background Information

Blue Mountain Lake is located in Hamilton County, New York, at an approximate latitude and longitude of 43^o 51' 09" N, 74^o 28' 16" W (Figure 1). The surface area of Blue Mountain Lake is 1,218 acres. The elevation of Blue Mountain Lake is 1,662 feet (545.3 m) above mean sea level. Blue Mountain Lake has a maximum depth of approximately 100 feet (32.8 m), and a mean depth of approximately 46 feet (14.1 m).

Blue Mountain Lake's small watershed (6,807 acres including 1,347 acres of lake surface) is the headwaters of the Raquette River. The outlet of Blue Mountain Lake flows unrestricted through Eagle Lake, over the dam at Utowana Lake, and to Raquette Lake as the Marion River. From there, the Raquette River flows through Forked Lake, Long Lake, Raquette Pond/Tupper Lake, the Carry Falls Reservoir and a number of smaller reservoirs. The Raquette River eventually enters the Saint Lawrence River at the Canadian border in upper Franklin County.

In January 1993, the Adirondack Aquatic Institute was asked to review the site development plan and water quality response modeling prepared in support of "The Woodlands," a small development within the hamlet of Blue Mountain Lake. Our review concluded that 1) the proposed development may cause a slight (though not statistically significant) increase in in-lake phosphorus and chlorophyll concentrations and localized impacts on the bay near Potter's, 2) there was a scarcity of water quality data for the lake, and 3) developing the entire watershed would likely degrade water quality within the lake.

As a result of these findings, the planning board of the Town of Indian Lake passed a resolution stating that a five year study was to be performed. The study was to determine current lake water quality, examine water quality trends, develop watershed-specific pollutant loading parameters, and determine the maximum watershed development that could be allowed without degrading water quality in the lake. A number of lake residents, including the developer, agreed to fund the study.

This report marks the conclusion of that study. Monitoring stations were established in 1993, the first year of the study. The second year of monitoring occurred during 1994 using the same stations. Delays in funding led to a restructuring from five to three years of monitoring, with the final year of monitoring in 1997.

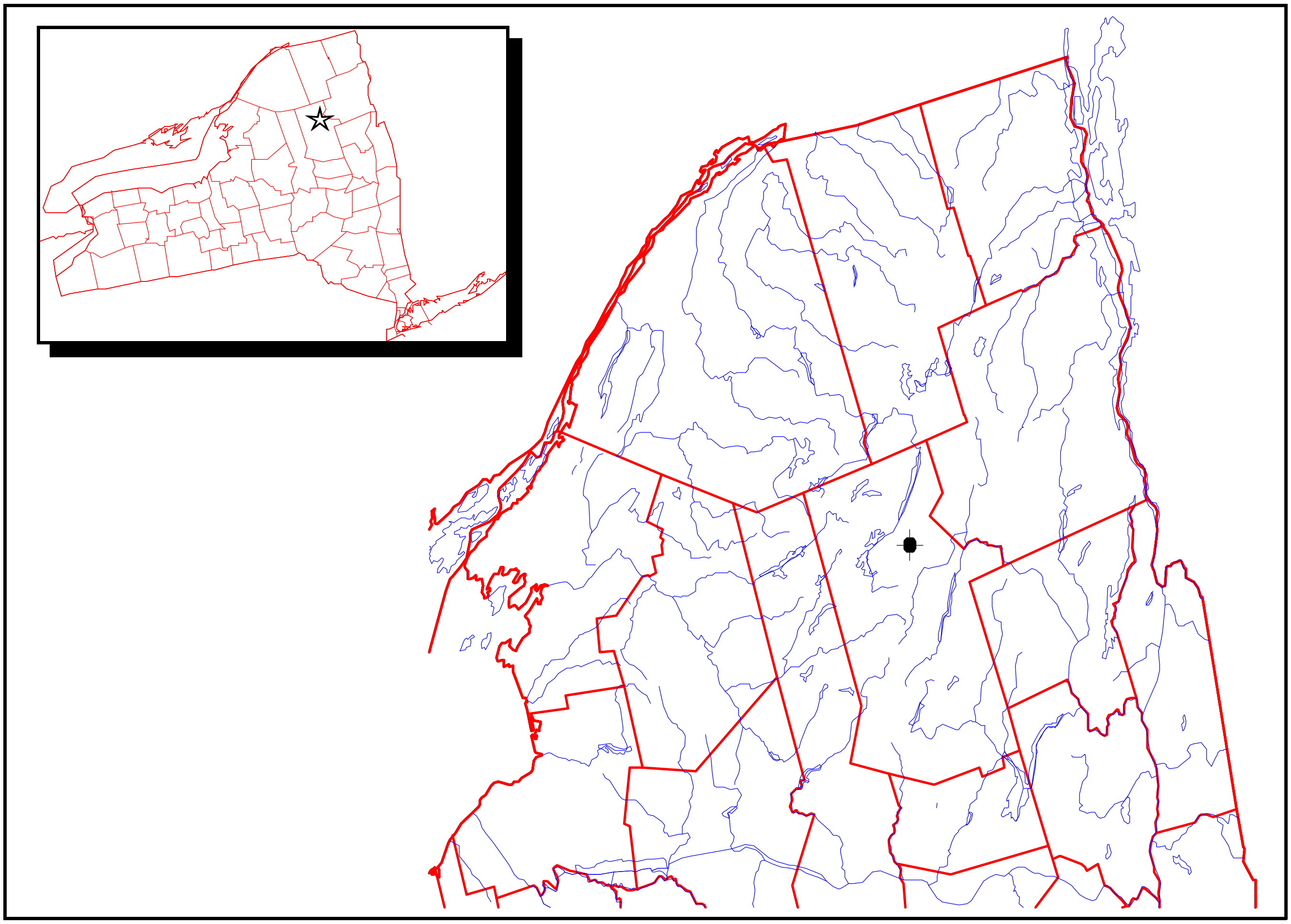

Figure 1 Location of Blue Mountain Lake in Hamilton County, New York

2.0 Monitoring Program

2.1 Methodology

This section presents methods used for sample collection and analysis in 1993, 1994 and 1997. There were two main objectives of the monitoring program at Blue Mountain Lake. One objective was to provide a sound database for tracking trends in water quality. The other objective was to develop watershed specific loading coefficients from developed and undeveloped portions of the watershed. These coefficients, along with the water quality data, were used to refine modeling input parameters in the nutrient response model, EutroMod.

Blue Mountain Lake was sampled once per month from May through September, at the deepest portion of the east and west basins of the lake (Figure 2). On each sampling date, samples were collected within the epilimnion (1½ meters below the surface) and hypolimnion (1½ meters above the bottom) at each station. These samples were analyzed for total phosphorus, unfiltered orthophosphorus, pH, and alkalinity. Additional samples were collected for chlorophyll *a*. Temperature and dissolved oxygen profiles and Secchi disk transparencies were also measured in the field at each station.

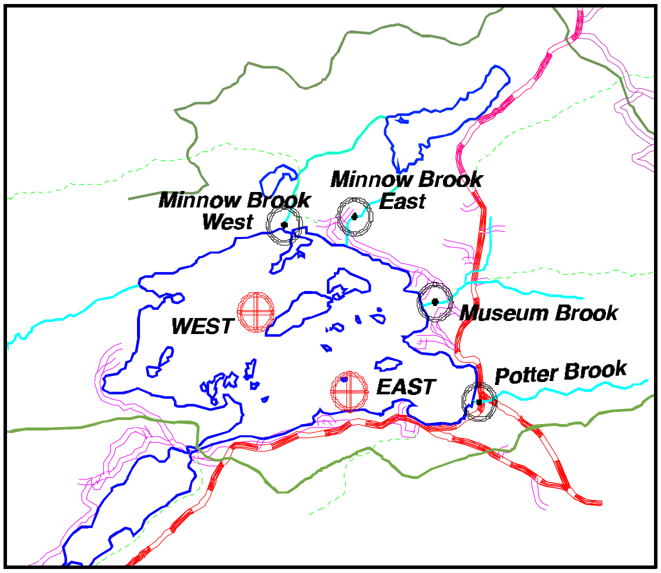

Figure 2 Location of monitoring stations

Stream monitoring stations were sampled from May through November on four tributaries to Blue Mountain Lake, which we referred to as Potter Brook, Museum Brook, Minnow Brook East and Minnow Brook West (Figure 2). These stations were selected to be in flowing water upstream of lake influence. Gage readings, instantaneous stream flow measurements, and rating curves were used to quantify flow rates, and water quality samples were collected once per month from May through November. The samples were analyzed for total phosphorus, total suspended solids, conductivity, pH and nitrate nitrogen.

Once collected, samples were placed on ice and transported to the New York State certified laboratory at Paul Smith's College for analysis. All analyses were completed within 24 hours, using procedures from Standard Methods, 17th Edition.

2.2 Lake Water Quality Results

2.2.1 pH

The acidity of water is measured as pH (concentration of hydrogen ions in water), and reported in standard units on a logarithmic scale that ranges from one to fourteen. On the pH scale, seven is neutral, lower numbers are more acidic, and higher numbers are more basic. In general, pH values between 6.0 and 8.0 are considered optimal for the maintenance of a healthy lake ecosystem. Many species of fish and amphibians have difficulty with growth and reproduction when pH levels fall below 5.5 standard units.

Table 1
Summary of Mean In-lake pH (standard units)

Station	1993	1994	1997	Average
East Basin Epilimnion	6.80	6.50	6.69	6.66
East Basin Hypolimnion	6.28	6.20	6.36	6.28
West Basin Epilimnion	6.78	6.50	6.67	6.65
West Basin Hypolimnion	6.29	6.15	6.20	6.21

Levels of pH in Blue Mountain Lake are summarized in Table 1. Blue Mountain Lake exhibited pH levels that were generally within the acceptable range for lake ecosystems and are typical for Adirondack lakes that are not impacted by acid precipitation or are not naturally acidic, such as bogs. The somewhat lower pH values in 1994 were likely due to the heavy snowfall during the winter of 1993-94. As this snow melted, large amounts of deposited acids moved into the lake without much of a chance to be neutralized by buffers within the soil. Blue Mountain Lake had pH values that were lower within the hypolimnion than in the epilimnion. Lower pH values within the hypolimnia of lakes is fairly common and is due to an increase in carbon dioxide caused by bacterial decomposition.

2.2.2 Alkalinity

Alkalinity (or acid neutralizing capacity) is a measure of the buffering capacity of water, the ability of a lake to absorb or withstand acidic inputs. In the northeast, most lakes have low alkalinities, which means that they are sensitive to the effects of acidic precipitation, particularly during the spring when large amounts of low pH snowmelt runs into the lakes. Typical summer concentrations of alkalinity in northeastern lakes are around 10 milligrams per liter (mg/L).

Alkalinity concentrations in Blue Mountain Lake are summarized in Table 2. Both stations had lower than average alkalinities in their surface and bottom waters. Like pH, it is not uncommon for alkalinity to be lower in the hypolimnia of lakes due to an increase in carbon dioxide and more acidic conditions. The low surface concentrations of alkalinity, however, mean that this lake may be susceptible to acid precipitation. It is possible that the lake experiences a brief loss of buffering capacity during the initial phase of spring runoff, resulting in a drop in pH. These spring increases in lake acidity, if they occur, would probably be stressful to fish and other aquatic organisms.

Table 2
Summary of Mean In-lake Alkalinity (mg/L)

Station	1993	1994	1997	Average
East Basin Epilimnion	3.57	3.58	3.10	3.42
East Basin Hypolimnion	1.33	2.33	1.68	1.78
West Basin Epilimnion	3.50	3.59	3.08	3.39
West Basin Hypolimnion	1.29	2.28	1.14	1.57

2.2.3 Phosphorus

Phosphorus is a key element for growth and reproduction and is the nutrient that most often controls productivity of lake systems in the northeast. Total phosphorus is a measure of all forms of phosphorus, both organic and inorganic. Total phosphorus concentrations are commonly used to assess the trophic condition of a lake. Epilimnetic (surface water) total phosphorus concentrations less than 0.010 milligrams per liter (mg/L) are associated with oligotrophic conditions and concentrations greater than 0.025 mg/L are associated with eutrophic conditions.

Total phosphorus concentrations in Blue Mountain are summarized in Table 3. Total phosphorus concentrations were within the oligotrophic range, but close to mesotrophic conditions, at both stations. Total phosphorus concentrations were slightly higher within the hypolimnia of both stations, suggesting that there may some internal loading (release) of phosphorus from the lake's sediments.

Table 3
Summary of Mean In-lake Total Phosphorus (mg/L)

Station	1993	1994	1997	Average
East Basin Epilimnion	0.008	0.007	0.009	0.008
East Basin Hypolimnion	0.014	0.014	0.015	0.014
West Basin Epilimnion	0.007	0.007	0.009	0.008
West Basin Hypolimnion	0.014	0.013	0.014	0.014

2.2.4 Chlorophyll *a*

Chlorophyll *a* is the green pigment in plants used for photosynthesis. The measurement of chlorophyll *a* provides an indication of the amount of phytoplankton (algae) growing in a lake and therefore can also be used to describe lake trophic state. Chlorophyll *a* concentrations less than 2 micrograms per liter (µg/L) are associated with oligotrophic conditions, while concentrations greater than 8 µg/L are associated with eutrophic conditions.

Chlorophyll *a* concentrations in Blue Mountain Lake are summarized in Table 4. Chlorophyll *a* concentrations were generally similar between basins, consistently higher in the east basin, and overall indicative of oligotrophic conditions.

Table 4
Summary of Mean In-lake Chlorophyll *a* (µg/L)

Station	1993	1994	1997	Average
East Basin Epilimnion	1.68	1.40	1.74	1.61
East Basin Hypolimnion	n/a	n/a	n/a	n/a
West Basin Epilimnion	1.46	1.38	1.56	1.47
West Basin Hypolimnion	n/a	n/a	n/a	n/a

2.2.5 Transparency

Transparency is a measure of water clarity in lakes and ponds. It is determined by lowering a black and white, 20 cm disk (Secchi disk) into a lake to the depth where it is no longer visible. Like chlorophyll *a* and total phosphorus concentrations, transparency is also used as an indicator of lake trophic state. Transparencies greater than 4.6 meters are associated with oligotrophic conditions, while transparencies less than 2 meters are associated with eutrophic conditions.

Secchi disk transparency values in Blue Mountain Lake are summarized in Table 5. Both stations were extremely clear, with transparencies well within the oligotrophic range. There was a noticeable trend toward lower transparencies over time at the east basin station which was not as evident in the west basin.

Table 5
Summary of Mean In-lake Transparency (meters)

Station	1993	1994	1997	Average
East Basin Epilimnion	10.0	9.7	8.5	9.4
East Basin Hypolimnion	n/a	n/a	n/a	n/a
West Basin Epilimnion	10.4	10.4	9.0	9.9
West Basin Hypolimnion	n/a	n/a	n/a	n/a

2.2.8 Temperature and Dissolved Oxygen

Vertical mixing within the water column of a lake is a function of the water's temperature dependent density gradient. In the spring and fall, lakes generally become isothermal (entirely the same temperature) and mix freely from top to bottom. As the surface water heats up in late spring/early summer, the water becomes less dense. When a lake is deep enough, and/or sheltered from the wind, the water at the bottom of the lake remains cold throughout the summer and does not mix with the warm, low density surface water. The lake is then essentially divided into three different compartments. The cold bottom waters make up the hypolimnion, and the warm surface water is called the epilimnion. The transition zone where temperatures change rapidly with depth is termed the metalimnion. The thermocline lies within the metalimnion and is the horizontal plane where there is the maximum temperature change with depth.

The amount of dissolved oxygen plays an important part in a lake’s ecosystem. The EPA published new criteria for dissolved oxygen in 1986. Their guidelines for dissolved oxygen concentrations for adult life stages of fish are 5.0 mg/L for warm-water species (i.e. bass and pike) and 6.5 mg/L for cold-water species (i.e. trout and salmon)[1]. Lakes receive most of their oxygen from the atmosphere through gas exchange at the surface. In deeper lakes that stratify, the colder bottom water (hypolimnion) is isolated from the oxygen entering the upper water (epilimnion). If the lake sediments are rich in organic matter, bacterial decomposition uses up the oxygen in the bottom waters and the hypolimnion becomes anoxic (without oxygen). If this occurs, cold water fish habitat is lost, and phosphorus within the sediments may be released into the overlying water.

Dissolved oxygen and temperature profile data for Blue Mountain Lake are presented in Appendix B. Dissolved oxygen profiles are shown in Appendix C. There were no significant differences in dissolved oxygen and temperature between the basins. Both lakes stratified thermally during the summer months and exhibited a moderate amount of dissolved oxygen depletion within the hypolimnion. Loss of oxygen in the

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[1] Ambient Water Quality Criteria for Dissolved Oxygen. Criteria and Standards Division. U.S. Environmental Protection Agency. Washington, D.C. EPA 440/5-86-003]

lake was not severe enough to preclude a coldwater fishery, although the levels may be low enough to stress coldwater fish. A dissolved oxygen maxima (peak) was observed within the metalimnion (region where temperature changes rapidly change with depth) at both stations. This is common in clearwater lakes where sunlight can penetrate into the metalimnion and provide energy for phytoplankton and picoplankton that colonize the density gradient.

2.2.9 Fecal Bacteria Results

Coliform bacteria are indicators of potential water contamination, but are not the actual pathogens that cause illness. Coliform bacteria can be numerous in the natural environment, occurring naturally in soil, water, and the intestines of animals. Total coliform is a measure of all coliform bacteria, including those of fecal and non-fecal origin. Fecal coliform and fecal *Streptococcus* bacteria are indicators of fecal pollution strictly from warm-blooded animals. Sources of fecal coliform bacteria may be natural (beaver, deer, water fowl) or cultural (septic systems, livestock).

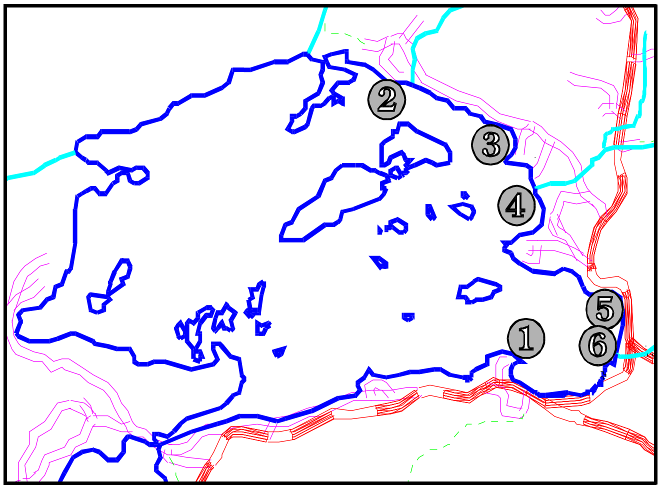

Figure 3 Location of in-lake bacteria monitoring stations

Levels of fecal coliform bacteria were measured at a number of sites within the lake during the study period (Figure 3) and the results are presented in Appendix B. Fecal coliform bacteria concentrations were low and often not present in Blue Mountain Lake.

2.3 Tributary Water Quality Results

2.3.1 pH and Alkalinity

Mean levels of pH in the tributaries of Blue Mountain Lake are summarized in Table 6. Monitoring period trends are presented graphically in Appendix C. The pH levels of each stream exhibited a spring depression related to spring snowmelt and runoff. This was most pronounced during 1994 as a result of a large snowpack and spring runoff. The pH levels typically rebounded to peak levels in July or August.

Table 6
Summary of Mean Tributary pH (standard units)

Station	1993	1994	1997	Average
Potter Brook	6.38	5.95	6.25	6.19
Museum Brook	6.26	5.67	6.18	6.04
Minnow Brook East	6.52	6.04	6.32	6.29
Minnow Brook West	6.62	6.07	6.48	6.39

Mean alkalinity concentrations are presented in Table 7. Monitoring period trends are presented graphically in Appendix C. As with pH, the streams exhibited a spring drop in alkalinity associated with the snowmelt and spring runoff. This, too, was most pronounced in 1994. Alkalinity concentrations rebounded throughout the summer and peaked in September or October.

Table 7
Summary of Mean Tributary Alkalinity (mg/L)

Station	1993	1994	1997	Average
Potter Brook	n/a	10.8	9.9	10.4
Museum Brook	n/a	8.9	10.4	9.7
Minnow Brook East	n/a	9.5	11.1	10.3
Minnow Brook West	n/a	12.5	15.2	13.9

2.3.2 Conductivity

Conductivity levels in the tributaries of Blue Mountain Lake are summarized in Table 8. Monitoring period trends are presented graphically in Appendix C. Conductivity levels in Minnow Brook West were lowest overall, and remained stable throughout the monitoring season. Conductivity in the other tributaries were relatively high, and increased during the summer months. Peak conductivity tended to occurred during August. This summer increase in conductivity was particularly evident in Museum Brook and Potter Brook and is presumably due to anthropogenic influences, particularly increased loadings from septic systems and wastewater systems that drain to the streams. Museum Brook exhibited a steady decline in annual average conductivity during the study period, although peak conductivity in this stream remained high.

Table 8
Summary of Mean Tributary Conductivity (µmhos)

Station	1993	1994	1997	Average
Potter Brook	114.8	98.4	111.1	108.1
Museum Brook	217.0	125.7	118.4	153.7
Minnow Brook East	101.8	92.8	118.2	104.3
Minnow Brook West	38.2	32.4	30.8	33.8

2.3.3 Total Phosphorus

Total phosphorus concentrations in the tributaries of Blue Mountain Lake are summarized in Table 9. Monitoring period trends are presented graphically in Appendix C. Overall the highest total phosphorus concentrations were found in Museum Brook and the lowest were in Minnow Brook East. Total phosphorus exhibited a seasonal pattern in Museum Brook and Potter Brook, with peak concentrations generally occurring during August. This correlates well with conductivity and alkalinity, which also increased during the summer, as the area experiences an increase in seasonal population.

Table 9
Summary of Mean Tributary Total Phosphorus (mg/L)

Station	1993	1994	1997	Average
Potter Brook	0.010	0.019	0.021	0.017
Museum Brook	0.018	0.037	0.018	0.024
Minnow Brook East	0.007	0.013	0.011	0.010
Minnow Brook West	0.017	0.016	0.016	0.016

2.3.4 Nitrate Nitrogen

Nitrate (combined NO_2 + NO_3) concentrations in the tributaries of Blue Mountain Lake are summarized in Table 10. Nitrate concentrations were low overall in all stations throughout the study period.

Table 10
Summary of Mean Tributary Nitrate (mg/L)

Station	1993	1994	1997	Average
Potter Brook	0.2	0.3	0.3	0.3
Museum Brook	0.9	0.3	0.4	0.5
Minnow Brook East	0.2	0.2	0.2	0.2
Minnow Brook West	0.2	0.3	0.2	0.2

2.3.5 Total Suspended Solids

Total suspended solids (TSS) concentrations in the tributaries of Blue Mountain Lake are summarized in Table 11. All stream stations had low concentrations during the study period. Mean TSS was somewhat higher during 1994 due to high values observed during the spring as a result of high stream flow in April.

Table 11
Summary of Mean Tributary Total Suspended Solids (mg/L)

Station	1993	1994	1997	Average
Potter Brook	0.8	1.8	0.8	1.1
Museum Brook	0.6	2.8	0.7	1.4
Minnow Brook East	1.1	1.7	0.9	1.2
Minnow Brook West	0.6	1.2	0.5	0.8

3.0 Hydrologic & Nutrient Budget Analysis

3.1 Rating Curve Development

During the first year of monitoring, stream gages were established at four locations (Figure 2). Flow measurements and stream level readings (gage heights) were taken concurrently on five separate occasions in 1993, five times in 1994, and eight times in 1997. These readings were used to create stream rating curves for each of the four tributaries which provide formulas for converting gage levels to a stream flow, without having to actually measure flow. Good correlation was obtained between stream level and stream flow, with r^2 values (Pearson's correlation coefficient) ranging from 0.87 to 0.98. Rating curves are provided in Equations 1 through 4.

(1) Potter Brook flow (cfs) = $0.4688 - 3.6312(\text{gage}) + 16.2819(\text{gage}^2)$; $r^2 = 0.935$
(2) Museum Brook flow (cfs) = $0.7684 - 5.9968(\text{gage}) + 6.7618(\text{gage}^2)$; $r^2 = 0.983$
(3) Minnow Brook East flow (cfs) = $10^{-0.1972} \times \text{gage}^{4.1222}$; $r^2 = 0.873$
(4) Minnow Bk W flow (cfs) = $-5.1771 + 38.5159(\text{gage}) - 89.9091(\text{gage}^2) + 72.4157(\text{gage}^3)$; $r^2 = 0.898$

3.2 Precipitation

Precipitation data from the NOAA weather station at Indian Lake[2] were extracted from our CD-ROM database and used to prepare an analysis of precipitation during the study period. Total annual and long-term annual average precipitation for the available period of record, 1949 - 1997, are presented in Figure 4. Lower than average precipitation occurred during 1993 and 1997 compared to the period of record (1949 - 1997), while 1994 had an average amount of precipitation.

Figure 5 presents the monthly total precipitation during the study years along with the long-term average monthly precipitation. Precipitation totals were greater in January, March, June, and November in 1994 compared to the other two study years and to average year conditions. Mid-summer 1993 (July & August) was drier than the other study years and compared to average year conditions.

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[2] National Climatic Data Center Station: INDIAN LAKE 2 SW, ID 4102

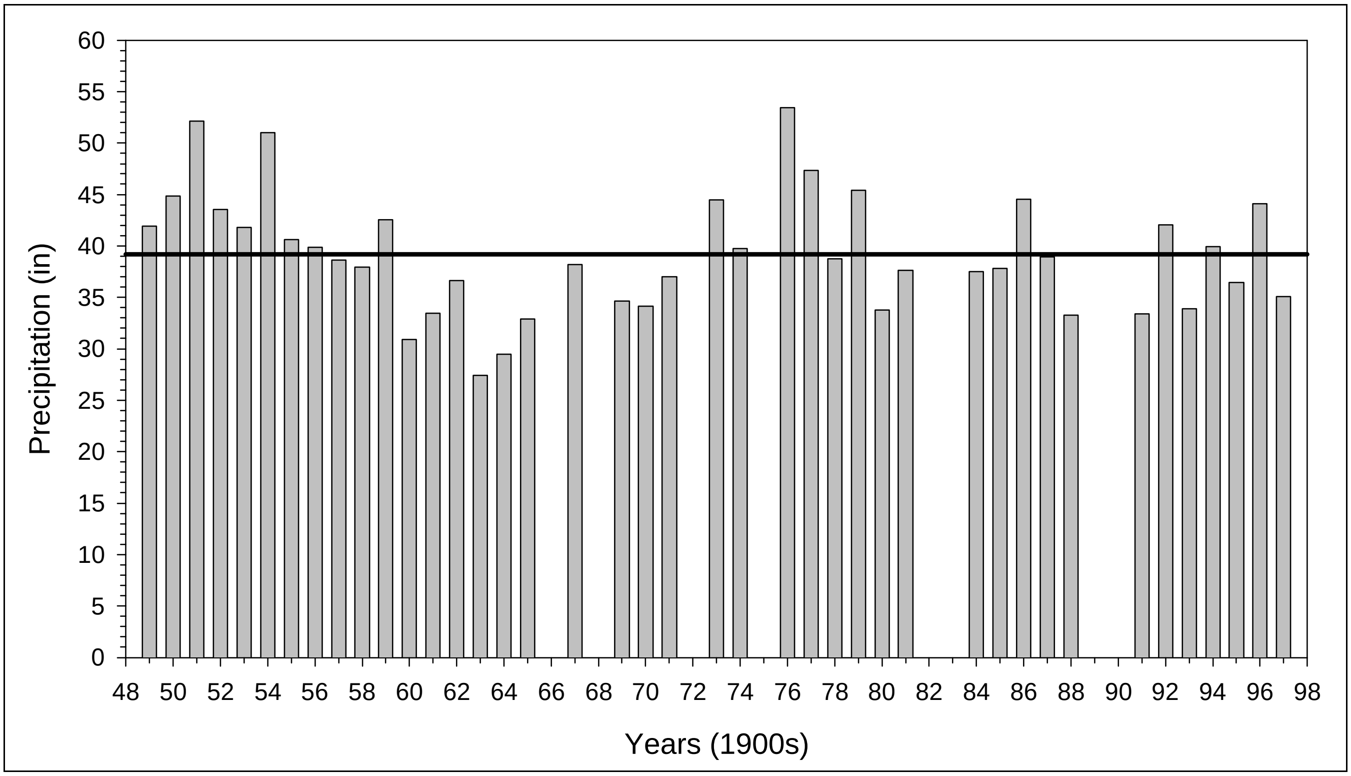

Figure 4 Annual average and long-term average (horizontal line) precipitation at IndianLake

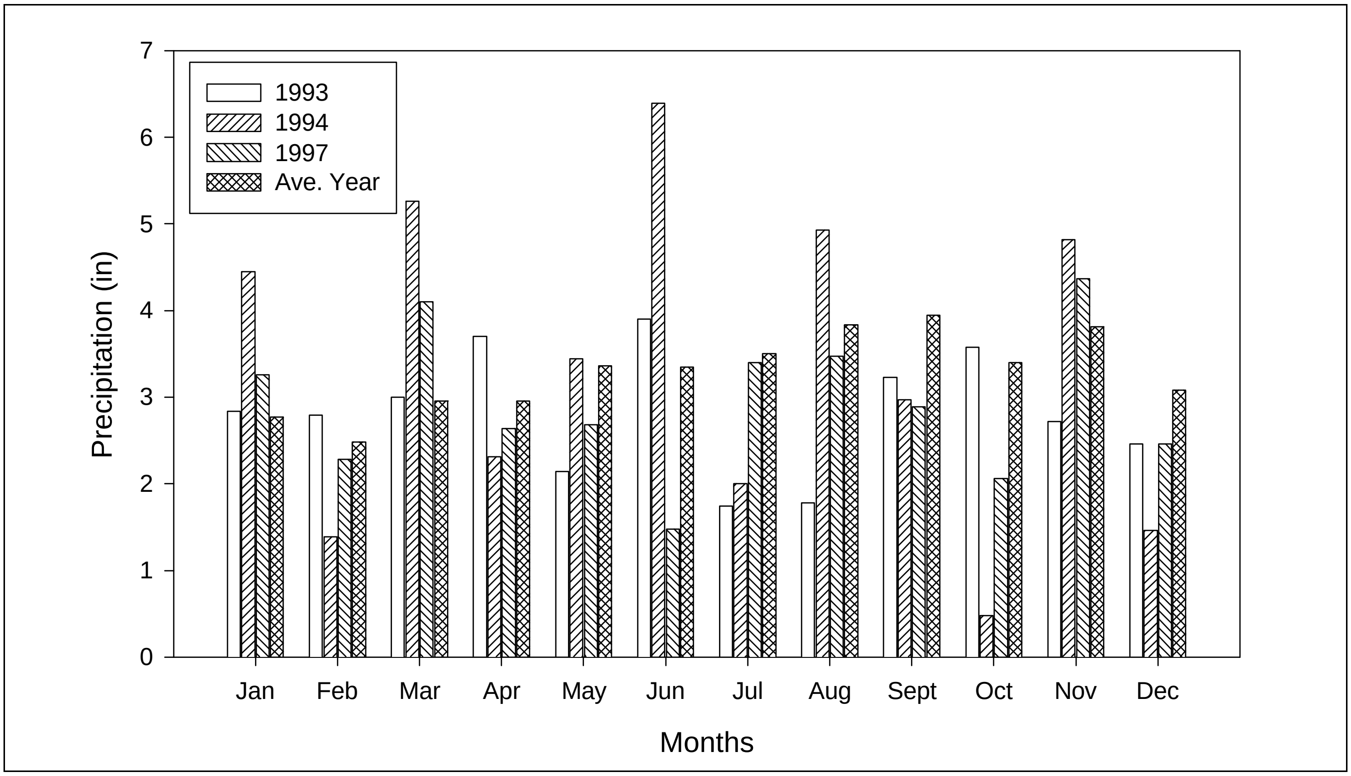

Figure 5 Monthly total precipitation an Indian Lake during study period and for average year

3.3 Subwatershed Loading

The phosphorus load or mass contributed to the lake from a sub-watershed during a specific time period can be calculated by multiplying stream flow by the in-stream phosphorus concentration. This provides a measure of the relative contribution of a sub-watershed to the overall phosphorus budget of the lake. However, streams with high flows but low total phosphorus concentrations can contribute more phosphorus to a lake than streams with high total phosphorus concentrations but low flows. A calculation of the amount of phosphorus contributed per unit area of land provides a more balanced analysis of the level of disturbance within a watershed or phosphorus contribution of a sub-watershed. Unit area loads also allow a more direct comparison of sub-watersheds from around a lake or between lakes.

Annual total phosphorus loading and unit area loading for each tributary are presented in Table 12. Measured concentrations and flows were used to calculate monthly phosphorus loads, which were then averaged across the three study years, providing mean monthly phosphorus loads for the period April through November. This was converted to an annual estimate by increasing the sum of the study period monthly loads by the annual fraction it represented. The unit load was calculated for each tributary by dividing the estimated annual load by the sub-watershed area.

Table 12
Annual total phosphorus loads for Blue Mountain Lake

Station	Mean Study Load (kg/244 days)	Annual Load (kg/year)	Watershed Area (ha)	Unit Load (mg/m^2/yr)
Potter Brook	12.44	18.60	206.20	9.02
Museum Brook	50.12	74.97	361.00	20.77
Minnow Brook East	37.05	55.42	251.30	22.05
Minnow Brook West	18.66	27.92	337.70	8.27

Museum Brook contributes the highest phosphorus loading to Blue Mountain Lake on an annual basis, with a total load of 75 kg (165 pounds) per year. Museum Brook also had the second highest unit load, contributing nearly 21 milligrams of phosphorus per square meter per year (mg/m^2/yr). Minnow Brook East contributes the second highest loading of phosphorus to the lake, with a total load of 55.4 kg (122 lbs) per year. Minnow Brook East had the highest unit load, contributing around 22 mg/m^2/yr. The Museum Brook sub-watershed is the largest of the four monitored tributaries. Much of its land is undeveloped Resource Management and some Wild Forest. Therefore, the large load of phosphorus from this tributary must be attributed to the development concentrated along Route 28N. There are a number of homes and camps adjacent to the stream. In addition, the Adirondack Museum has a wastewater discharge directly to the stream.

Potter Brook and Minnow Brook West contributed the smallest loads of phosphorus to the lake and both had low unit loading values (9.0 and 8.3, respectively). Although Minnow Brook West contributed the higher annual load of phosphorus of these two tributaries, this was only a function of the greater flow in that stream.

The unit load value and the measured water quality in the two streams indicate Minnow Brook West to be the least impacted of the four monitored tributaries.

4.0 Water Quality Trends

The purpose of this section of the report is to compare the pertinent information from past water quality studies to current conditions in order to describe historical changes in the water quality of Blue Mountain Lake.

4.1 Past Water Quality Studies

There have been a number of studies of Blue Mountain Lake, some of which provide useful information for trend analysis. These studies were summarized in detail in the 1994 Blue Mountain Lake report[3]. The studies were: 1933 NYS Conservation Dept., 1978 Don Charles, 1982 NYS Dept. of Environmental Conservation, 1993 - present Hamilton County Soil & Water Conservation District, and 1993 US EPA EMAP.

AAI began monitoring Blue Mountain Lake in 1993 as part of an investigation of water quality and watershed nutrient loading. In 1998, residents of Blue Mountain Lake began to participate in the Adirondack Clean Waters Initiative Volunteer Monitoring Program sponsored by the Resident's Committee to Protect the Adirondacks (RCPA) and AAI. The volunteer data, which included one sampling event performed by AAI personnel and two by volunteers, were included in the trend analyses.

4.2 Analysis of Water Quality Trends

4.2.1 Total Phosphorus

Figures 6 and 7 presents average epilimnetic total phosphorus concentrations for the east and west basin, respectively. Total phosphorus concentrations in the lake have been increasing steadily since at least 1978. This increase has been slightly faster or more pronounced in the east basin of the lake. Based upon these data, the lake has gone from solidly oligotrophic to near mesotrophic in less than 20 years.

4.2.2 Chlorophyll *a*

Figures 8 and 9 presents average chlorophyll *a* data for the east and west basin, respectively. Chlorophyll *a* levels in the lake have remained low throughout the period of record, exhibiting a slight decrease between 1978 and the mid-1990s. There is some indication that chlorophyll *a* levels have been increasing since 1994, particularly in the east basin of the lake. The much higher concentrations of chlorophyll *a* in the east basin during 1998 may be related to the effect of a wet summer and increased runoff from the developed portion of the watershed.

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[3] Martin, M.R. The Limnological Condition of Blue Mountain Lake: final report of the 1994 monitoring season. May 1995.

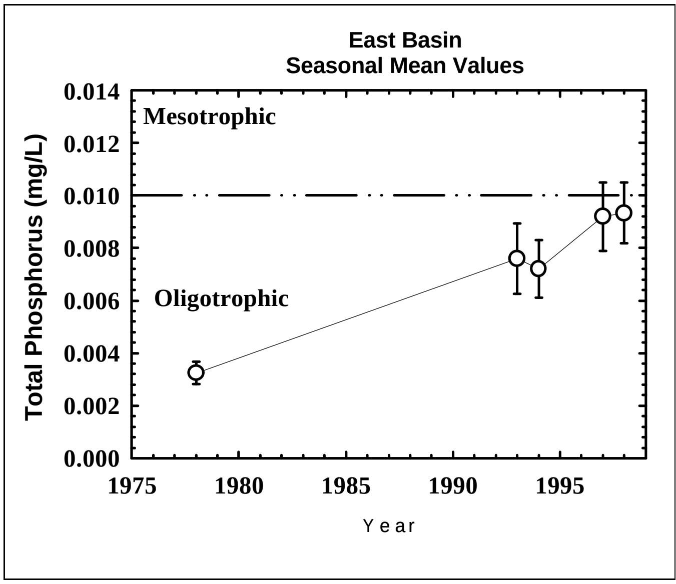


Figure 6 Seasonal mean total phosphorus in the east basin of Blue Mountain Lake, with 95% confidence intervals

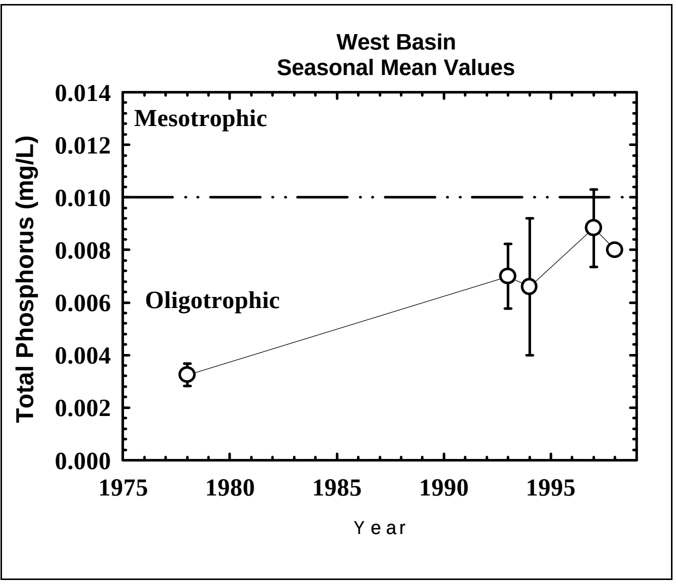


Figure 7 Seasonal mean total phosphorus in the west basin of Blue Mountain Lake, with 95% confidence intervals

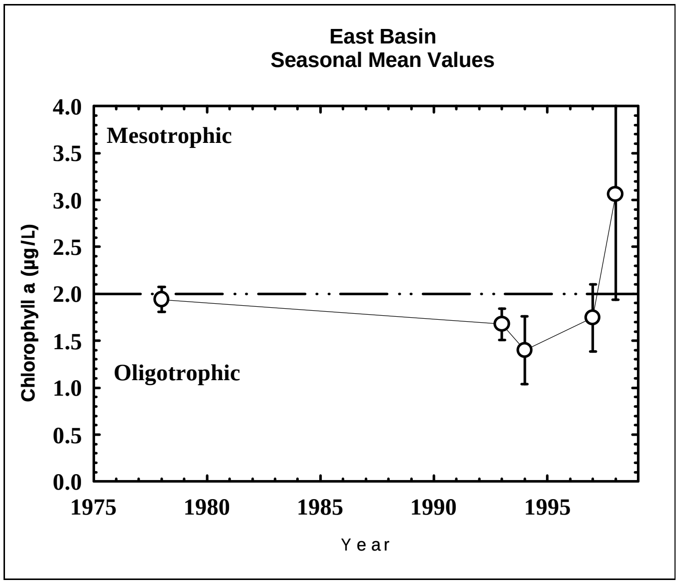


Figure 8 Seasonal mean chlorophyll *a* in the east basin of Blue Mountain Lake, with 95% confidence intervals

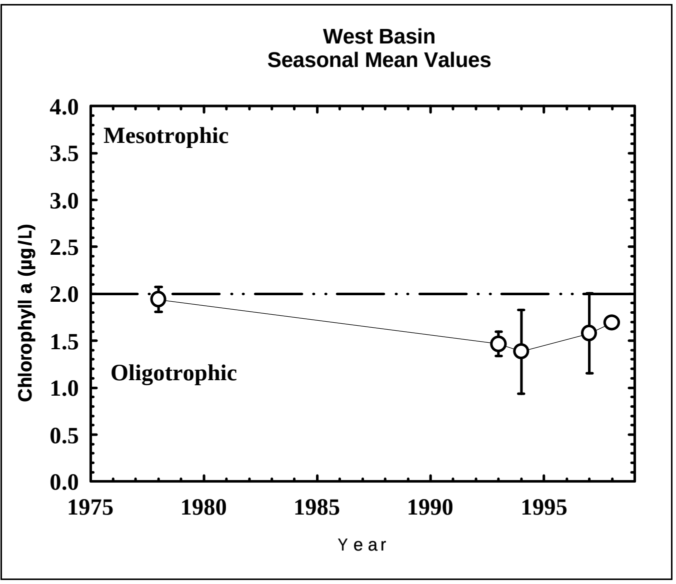


Figure 9 Seasonal mean chlorophyll *a* in the west basin of Blue Mountain Lake, with 95% confidence intervals

4.2.3 Transparency

Figures 10 and 11 presents average transparency data for the east and west basin, respectively. Transparency has remained within the oligotrophic range throughout the period of record, although it was closest to mesotrophic levels in 1933 and 1998. Transparency appears to have increased steadily in Blue Mountain Lake between 1933 and 1993. Transparency has exhibited a steady decline since 1993 and had returned to 1933 levels in 1998. This trend was slightly more pronounced in the east basin of the lake.

4.2.4 pH

Figures 12 and 13 presents average pH data for the east and west basin, respectively. The pH of Blue Mountain Lake has exhibited a slight but steady decline since 1933. The pH level of the lake dropped from above 7.0 units to around 6.5 units during that time period.

4.2.5 Alkalinity

Figures 14 and 15 presents average alkalinity data for the east and west basin, respectively. The alkalinity of Blue Mountain Lake, like pH, has exhibited a steady decline over the period of record, dropping from around 9 mg/L in 1933 to between 3 and 4 mg/L in 1998. The slight rebound in alkalinity in1998 may be due to higher algal productivity as shown by the increase in chlorophyll *a* concentrations that year.

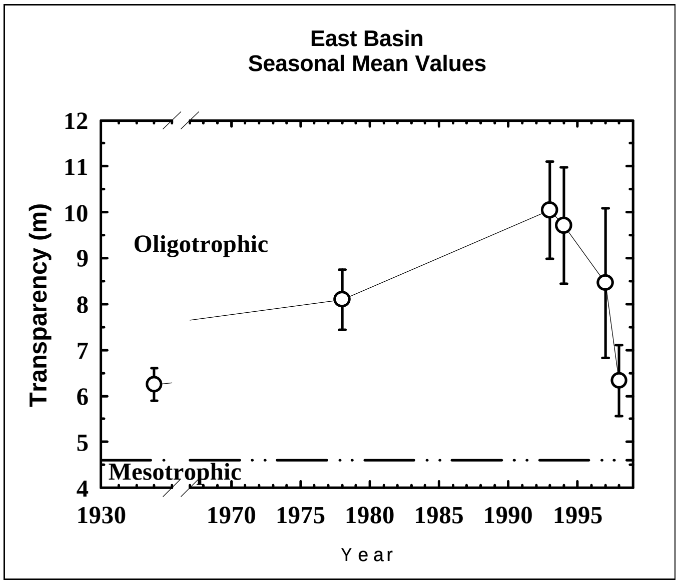


Figure 10 Seasonal mean transparency in the east basin of Blue Mountain Lake, with 95% confidence intervals

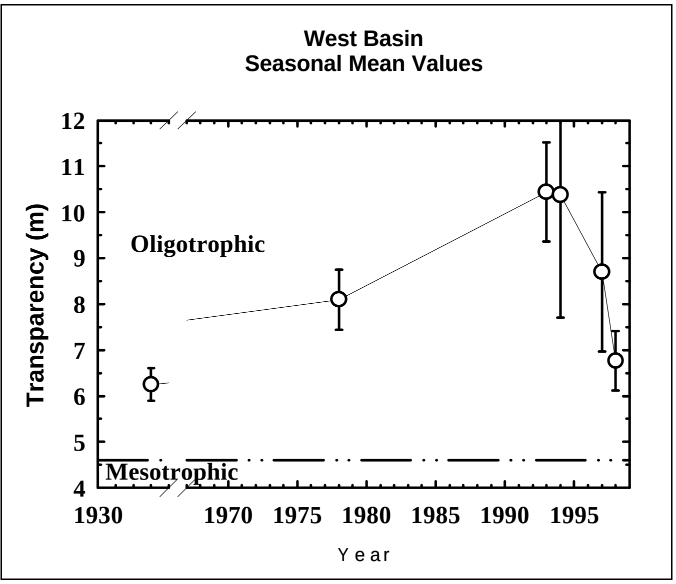
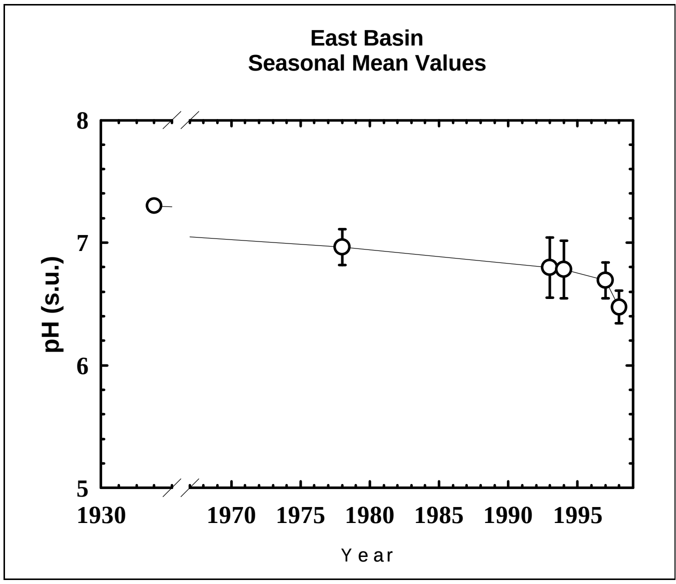


Figure 11 Seasonal mean transparency in the west basin of Blue Mountain Lake, with 95% confidence intervals



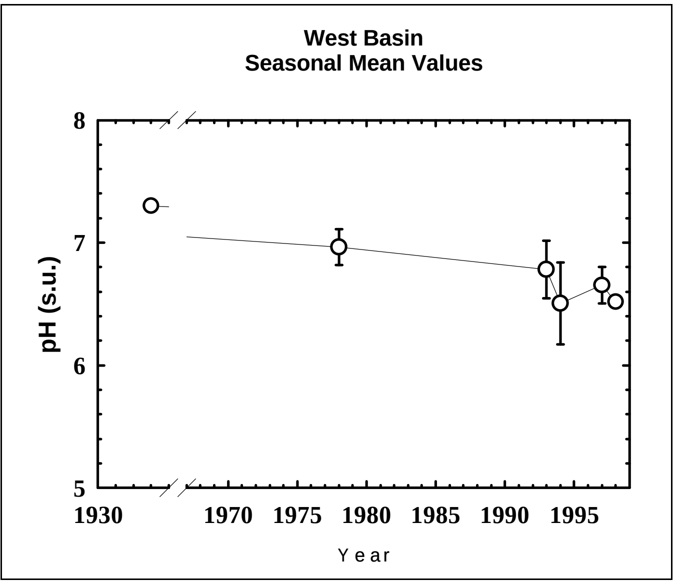
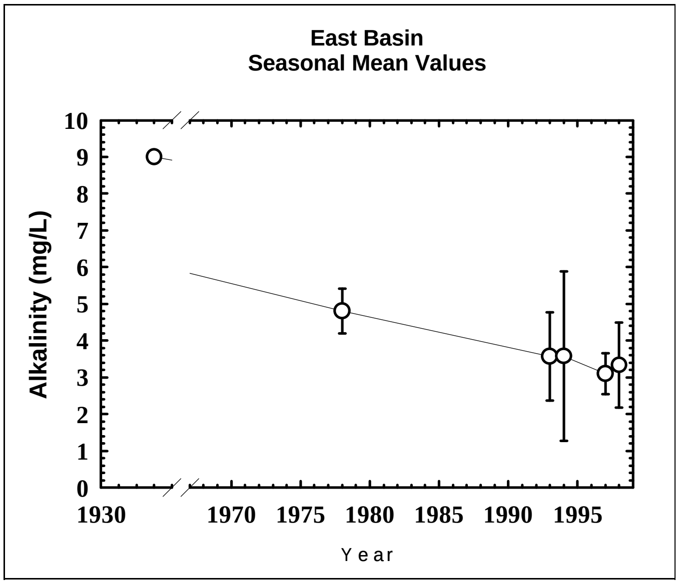


Figure 12 Seasonal mean pH in the east basin of Blue Mountain Lake, with 95% confidence intervals

Figure 13 Seasonal mean pH in the west basin of Blue Mountain Lake, with 95% confidence intervals



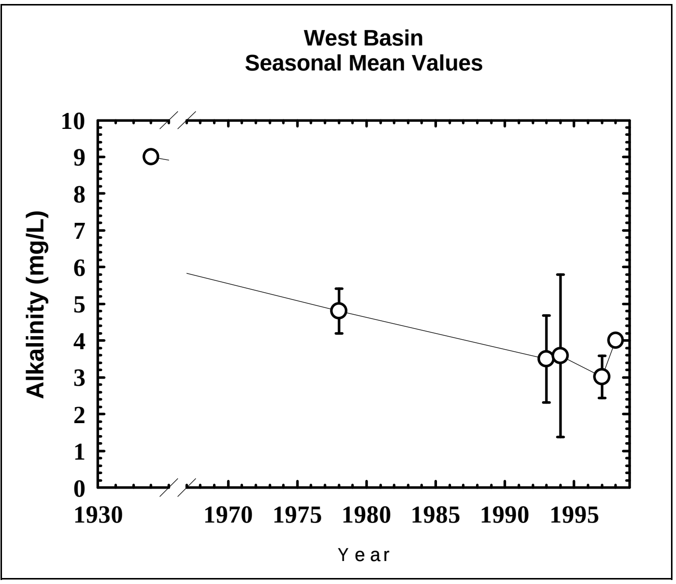


Figure 14 Seasonal mean alkalinity in the east basin of Blue Mountain Lake, with 95% confidence intervals

Figure 15 Seasonal mean alkalinity in the west basin of Blue Mountain Lake, with 95% confidence intervals

4.3 Sediment Core Analysis[4]

A sediment core study of Blue Mountain Lake was undertaken by Dr. J. Curt Stager in order to provide a long-term record of water quality that would otherwise be unavailable. The remains of diatoms (single-

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[4] This section by Dr. J. Curt Stager, AAI Research Associate and associate professor at Paul Smith's College

celled algae with glass shells, called “frustules”) preserved in the lake sediments were used to infer past water conditions on a qualitative basis. The results of this study provide a historical framework for evaluating water quality conditions and trends.

4.3.1 Materials And Methods

The 29 cm core was collected from the east basin water quality station (Figure 2) with a gravity coring device[5] and subsampled in the field in the fall of 1994. Twelve subsamples were submitted to AECL Laboratories, Chalk River, Ontario, for lead-210 dating. Seven subsamples were digested in hydrogen peroxide to remove organic debris, and the remaining diatom frustules were mounted on microscope slides for identification and enumeration according to standard methods. Approximately 400 frustules were identified per slide, and water quality conditions were inferred from the diatom assemblages.

4.3.2 Results

The lead-210 dating analysis of the sediments indicated that the core represents approximately 200 years of record. The oldest direct lead-210 date obtained was 1849 A.D. for the 16.0-17.0 cm level, and the bottom of the core (29.0 cm) yielded an extrapolated date of approximately 1720 A.D.

Most of the diatom frustules present in the core were from planktonic rather than bottom-dwelling species, as expected for an offshore site. Overall diatom abundance and the low relative abundances of bottom-dwelling species varied little in the core.

The lower half of the core, which predates 1860 A.D., contained diatom assemblages dominated by *Cyclotella* species typical of slightly to moderately productive (oligotrophic to mesotrophic) Adirondack lakes of neutral to slightly acidic pH. The abundance of *C. stelligera* was particularly indicative of clear-water conditions.

The upper half of the core, representing the time period 1860-to-1994, still contained numerous *Cyclotella*, but also contained increasing numbers of diatoms which are common in lakes of moderate, rather than low productivity. Most notable among these species were *Aulacoseira ambigua*, *Tabellaria flocculosa*, and *Asterionella formosa*.

Aulacoseira ambigua became more abundant in the upper half of the core while a related species, *A. lirata*, declined. In the Adirondacks, *A. lirata* is associated with slightly lower concentrations of total phosphate and chloride than *A. ambigua*[6].

Tabellaria flocculosa and *A. formosa*, which often appear or increase in Adirondack lakes which experience disturbances such as road salt contamination or nutrient enrichment, increased steadily after 1900 A.D., and reached their highest abundances in the uppermost sample (1994 A.D.) (Figure 22).

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[5] Stager, J.C. Simple gravity corer suitable for educators. *Journal of Paleolimnology* 7:253-255.

[6] Dixit, S.S., and J.P. Smol. 1994. Diatoms as indicators in the Environmental Monitoring and Assessment Program-Surface Waters (EMAP-SW). *Environmental Monitoring and Assessment* 31:275-306.

4.3.3 Interpretation

The story inferred from the diatom record of Blue Mountain Lake is one of moderate human impact on the lake since the mid-nineteenth century (Figure 22). The lake was more productive during the 1900's than it was between 1700 and 1860 A.D. This can be reasonably attributed to some or all of a wide range of natural activities, such as blowdown events and forest fires, and human activities in the lake basin since the mid-1800's, including road construction and maintenance, forest cutting, soil erosion, building construction, and wastewater disposal.

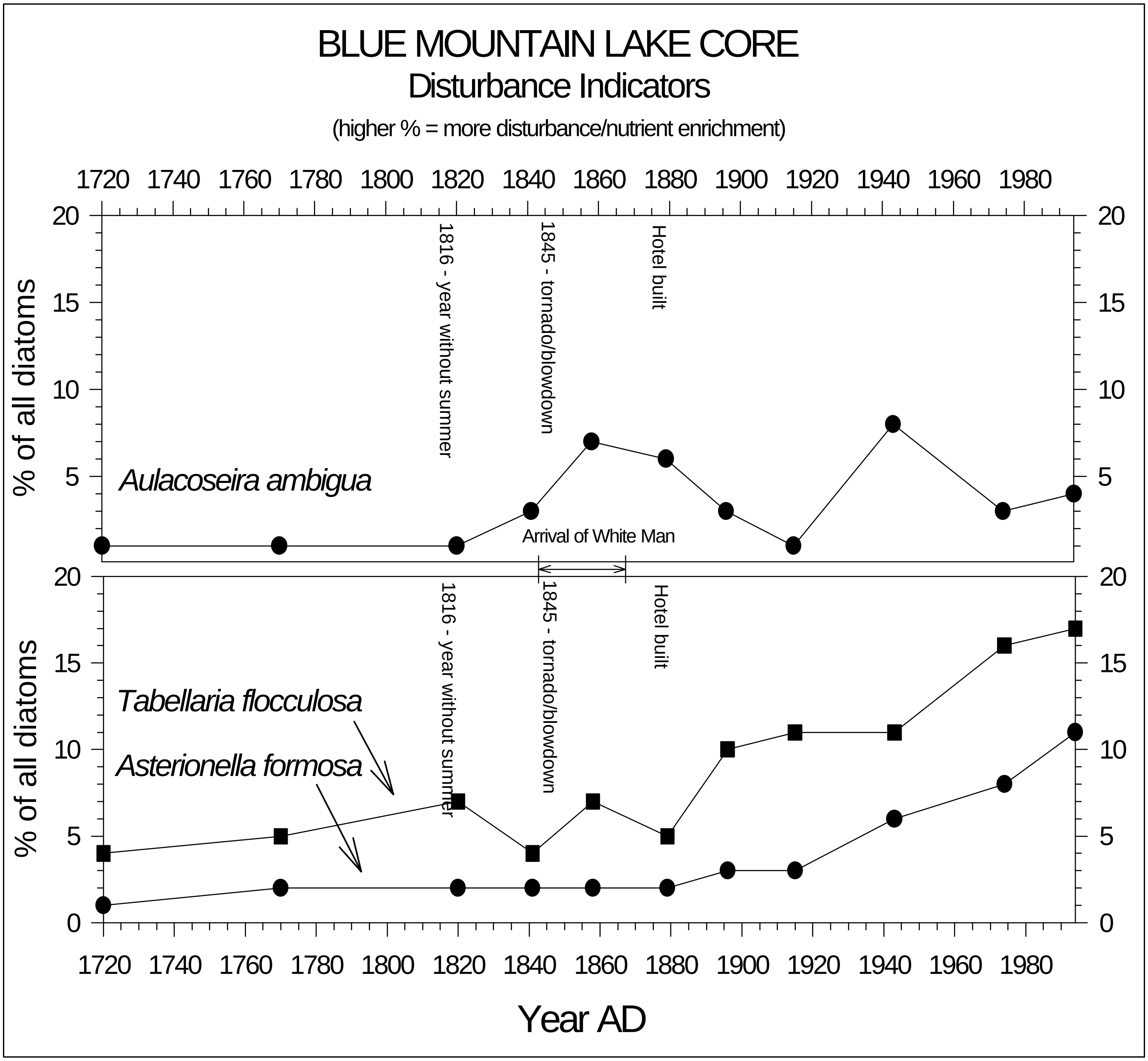

Figure 16 Sediment core analysis of Blue Mountain Lake showing percent composition of disturbance indicator diatom species

5.0 Watershed Modeling

The effect of development within the Blue Mountain Lake watershed on the water quality of Blue Mountain Lake was modeled using EutroMod. Input variables were selected to best represent existing conditions and projected levels of development, and based upon our current knowledge and best professional judgement. While actual present day per capita numbers may vary slightly from those used in this analysis, those differences are not likely to result in significant changes in the results of the analysis. However, as with any model, the results given here should only be used as a guideline in assessing development within the watershed.

5.1 Existing Development and Development Potential

A Geographic Information System (GIS) was used to analyze land use and zoning within the Blue Mountain Lake watershed. Streams, rivers, lake shoreline, roads, trails, and structures were digitized from 7 ½ minute, 1:24000 series NYS Department of Transportation (DOT) topographic maps. Watershed boundaries were drawn on the DOT maps and also digitized. APA land classification were obtained from the Adirondack Park Agency. Land classification and development analysis for the Blue Mountain Lake watershed is presented in Figure 17 and Table 13.

Existing development within the watershed was calculated by examining the number and location of structures in the Blue Mountain GIS. There are several drawbacks to this methodology. The type of structure (ie., house, boat house, garage) can not be determined from the maps. In addition, the structures shown on the DOT maps were based upon 1954 USGS quadrangles, therefore any structures which were either torn down or built since that time would not show up in the GIS data layer. Based upon the GIS, there were a

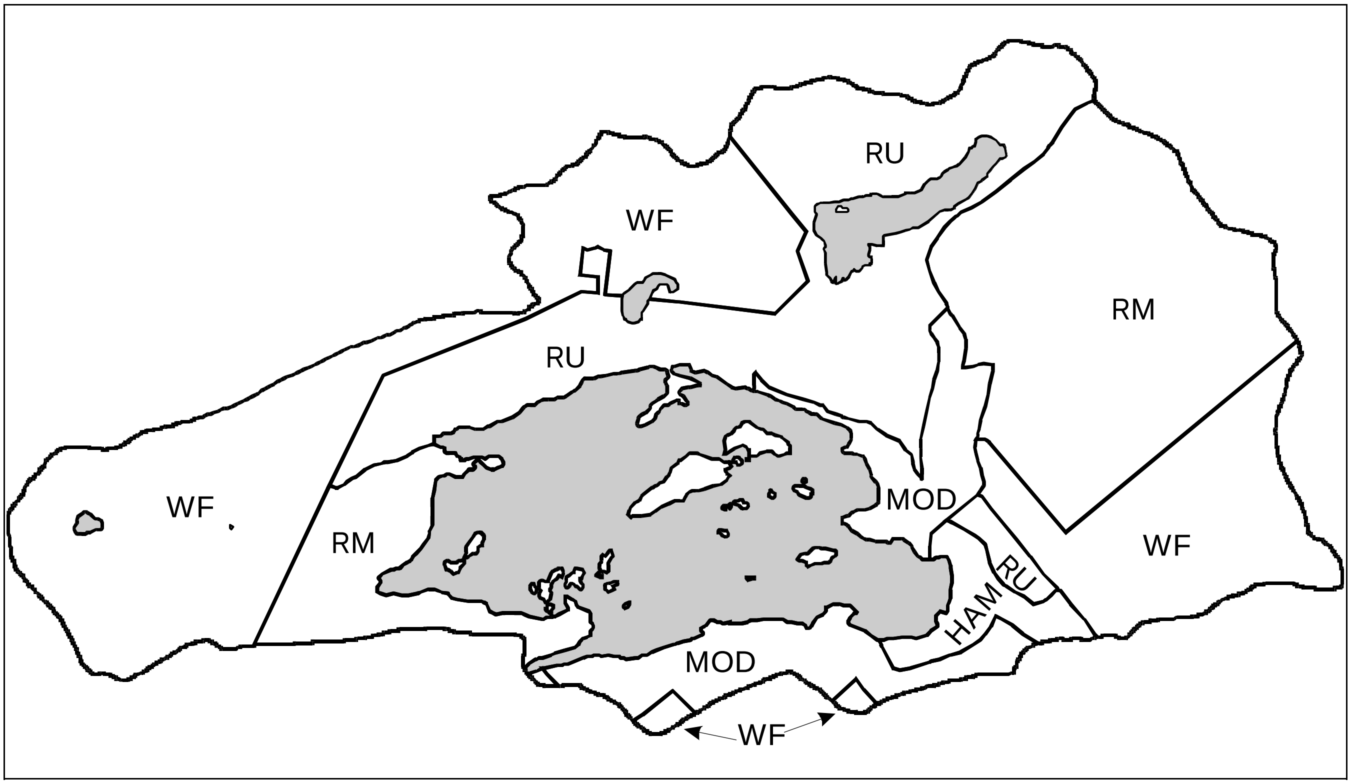

Figure 17 APA Land Use Classifications within the Blue Mountain Lake watershed (see Table 13 for legend

total of 259 structures within the watershed, including 89 along the shorefront. Approximately half (130) of those structures were within the zone of influence for modeling (within 200 m of Blue Mountain Lake or its tributaries). The initial modeling effort in 1993 had estimated 142 structures within 200 m zone around the lake. This count included rental cabins and a few stores and churches but did not include dwellings along any of the tributaries. A conservative value of 130 dwellings was used for this modeling analysis.

The zone of influence can be described as that area within 200 meters of surface water. It is important from a modeling perspective since there is a modeled impact directly related to the number of septic systems within this zone and the number of capita-years applied to those septic systems. Development of land outside of the zone of influence is important as well. Conversion of land use from forested to residential anywhere within the watershed results in increased phosphorus loading. For the purpose of this discussion, “shorefront homes” will be used interchangeably with “homes within the zone of influence.” Bear in mind that this category of homes includes any dwelling within 200 meters of the lake or its tributaries.

The development potential of the watershed was determined by examining the APA land clasifications within the watershed. The maximum number of homes within the zone of influence was calculated by dividing the amount of shorefront in a given zone by the minimum lot width for that classification (shorefront/minimum lot width) and taking into account the minimum lot size. The maximum number of shorefront homes was calculated by subtracting the number of shorefront homes within a given APA class from the total amount of homes that could be built within that APA class on an areal basis (# of shorefront homes minus zone area divided by minimum lot size). This type of analysis may tend to overestimate the number of allowable homes, since actual home construction is limited by suitable site conditions for the construction of homes, septic systems, roads and utility access. Based upon this analysis, there are a potential 347 homes within the 200 meter zone of influence and therefore the potential for an increase of 217 new homes within the 200 m zone over existing conditions.

Table 13
Development Potential of Blue Mountain Lake Watershed

Code	Classification	Min. Lot Size (ac)	Min. Lot Width (ft)	Area in watershed (ac)	Shoreline in watershed (ft)	Maximum shorefront homes†	Max. non-shore homes
HAM	Hamlet	0.25	50	136	3,756	75	470
MOD	Moderate Intensity	1.3	100	512	17615	176	217
RU	Rural Use	8.5	150	1,272	13,225	88	55
RM	Resource Management	42.7	200	1,475	15,301	8	26
WF	Wild Forest & Wilderness	n/a	n/a	1,982	n/a	n/a	n/a
					TOTALS	347	768

†zone of influence

5.2 Per Capita Calculations

Per capita estimates, the number of person-years spent near the lake, is an important part of the model. These numbers provide a basis for gauging model predictive performance and can be modified to simulate various development scenarios within the watershed. Per capita calculations were performed for those occupied structures within the 200 meter zone zone of influence around Blue Mountain Lake and its tributaries. The number of seasonal versus year round homes was estimated using a ratio of 35:65 for year-round to seasonal homes[7]. Existing development therefore consists of 85 seasonal and 45 year-round homes. Maximum new development would consist of 141 seasonal and 76 year-round homes. The capita-years for existing development and maximum development scenarios were calculated using 3.5 persons per home or camp. Seasonal homes and camps were assumed to be occupied for three months. Per capita numbers are summarized in Table 14.

In addition to homes and camps, the Adirondack Museum is the only other major source that contributes to phosphorus loading within the watershed. Assuming 100,000 visitors per year with an average length of visit of 2 to 4 hours, the Adirondack Museum occupancy is between 23 and 46 capita years. This is the equivalent of 6.5 to 13 year-round homes or 26 to 53 seasonal homes.

Based upon these numbers, Blue Mountain Lake has a current population within the 200 meter zone of influence of 255 to 278 capita years and the potential for a total population within the 200 meter zone of influence of 644 to 667 capita years.

Table 14
Capita-year calculations for Blue Mountain Lake Watershed

Usage	Existing Development		Maximum New Development	
	# of homes/camps	capita-years	# of homes/camps	capita-years
Seasonal	85	74.4	141	123.4
Year-round	45	157.5	76	266.0
Total	130	231.9	217	389.4

5.3 Additional Model Inputs

Median total phosphorus concentrations from the Blue Mountain tributaries were used as input to the EutroMod model. Undeveloped areas (forest) were assigned the lowest tributary median total phosphorus value, which was 0.009 mg/L in Minnow Brook East. Developed areas were assigned the highest tributary median value, which was 0.024 mg/L in Museum Brook. Both of these values are lower than the estimated values used during the 1993 model (0.015 mg/L for forest and 0.074 mg/L for developed areas).

The precipitation value used in 1993 modeling runs was revised to match the measured long-term annual average from the NCDC station at Indian Lake (see Section 3.2). Lake and watershed areas used in 1993

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[7] 1990 Census Bureau

modeling runs were revised to match values determined from the Blue Mountain GIS. Phosphorus retention of septic system effluent by soil used in 1993 modeling runs was reduced to 10 percent for systems within the modeled zone of influence. This more closely matches that determined by top researchers in studies of similar lakes in the Canadian Shield[8].

The standard EutroMod model was found to predict phosphorus well but chlorophyll *a* and transparency poorly. Carlson's empirical formulae for predicting chlorophyll *a* and transparency from total phosphorus[9] were substituted for this portion of the model, producing much better results. An under-prediction of transparency in the lake is likely due to the better than average water clarity (lack of dissolved and particulate materials) in Blue Mountain Lake.

5.4 Model Results

The EutroMod model was run with the modifications and inputs as mentioned in the preceding sections. In the following list of model runs, "low" and "high" refer to the level of Museum contribution as explained in Section 5.2. Model runs consisted of existing development low (255 capita-yrs), existing development high (278 capita-yrs), maximum development (high only, 667 capita-yrs), and chlorophyll *a* criteria of 2 µg/L. A maximum chlorophyll *a* criteria of 2 mg/L was selected to determine the level of acceptable development since 2 mg/L is the boundary between oligotrophic and mesotrophic conditions and is close to existing conditions. Capita-years input was changed and land use was changed accordingly until a chlorophyll *a* level of 2 was predicted.

Results from the modeled scenarios are summarized in Table 15. The "existing high" was a better predictor of existing in-lake water quality than "existing low." The number of new homes under modeled scenarios was calculated by assuming the year-round to seasonal ratio would remain at 35:65.

Predicted water quality for each scenario is presented in Figures 18 through 20 for total phosphorus, chlorophyll *a* and transparency, respectively. The model predicted total phosphorus well using the "Existing High" scenario. The "Maximum Development" scenario predicted a total phosphorus concentration of around 0.013 mg/L, well into the mesotrophic range. The "chlorophyll *a* = 2" scenario predicted a phosphorus concentration of around 0.010 mg/L, which is at the oligotrophic-mesotrophic border.

The model predicted chlorophyll *a* concentration (1997 average) well using the "Existing High" scenario. The 1998 chlorophyll *a* concentration was high due to an unusually high readings in the east basin of the lake in August. This high concentration, though, unusual was replicated both by samples collected by the volunteer monitor and AAI personnel. The "Maximum Development" scenario predicted a chlorophyll *a* concentration of around 3 µg/L, which is in the mesotrophic range. The "chlorophyll *a* = 2" scenario predicted a chlorophyll *a* concentration of 2 µg/L, which is at the oligotrophic-mesotrophic border.

The model under-predicted lake transparency under both the "Existing High" and "Existing Low" scenarios. This may be due to the fact that Blue Mountain Lake has clear water (low color and particulate

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[8] Dillon, P.J., W. A. Scheider, R. A. Reid, and D.S. Jeffries. 1994. *Lakeshore capacity study: Part I — Test of effects of shoreline development on the trophic status of lakes.* Lake and Reserv. Manage. 8(2): 121-129 and P. Dillon, pers. comm. IN Martin et. al. 1998. The State of Upper Saranac Lake, section 9.3.3

[9] Carlson, R.E. 1977. *A trophic state index for lakes.* Limnology and Oceanography. 22(2): 361-369

matter) compared to many lakes, including perhaps the data set used to develop the empirical predictive formulae used by the model. The 1997 and 1998 average transparency (both stations together) in Blue Mountain Lake was 8.6 m and 6.6 m, respectively. The model predicted transparency of around 6 meters under both "Existing" scenarios. The "Maximum Development" scenario predicted a transparency of around 4 meters, which is in the mesotrophic range. The "chlorophyll *a* = 2" scenario predicted a transparency of around 5.2 meters.

Table 15
Summary of EutroMod Results for Blue Mountain Lake

Model Run	Water Quality Parameters		
	Total Phosphorus (mg/L)	Chlorophyll *a* (µg/L)	Transparency (m)
Actual 1997	0.009	1.65	8.8
Actual 1998	0.009	1.70	6.4 (east basin)
Existing Low	0.008	1.61	5.9
Existing High	0.009	1.69	5.8
Max. Development	0.013	2.97	3.9
Chl. *a* = 2 µg/L	0.010	2.00	5.2

Model Run	General Land Use (acres)		
	Forest	Rural Residential	Lakeside Residential
Existing Low	5,101	109	249
Existing High	5,101	109	249
Max. Development	1,403	2,695	1,361
Chl. *a* = 2 µg/L	3,077	1,590	637

Model Run	Level of Development (total homes is sum of year round & seasonal)		
	Total Capita-years (additional)	Total Year round Homes (additional)	Total Seasonal homes (additional)
Existing Low	255	45	85
Existing High	278	45	85
Max. Development	667 (389)	121	227
Chl. *a* = 2 µg/L	382 (104)	65 (20)	123 (38)

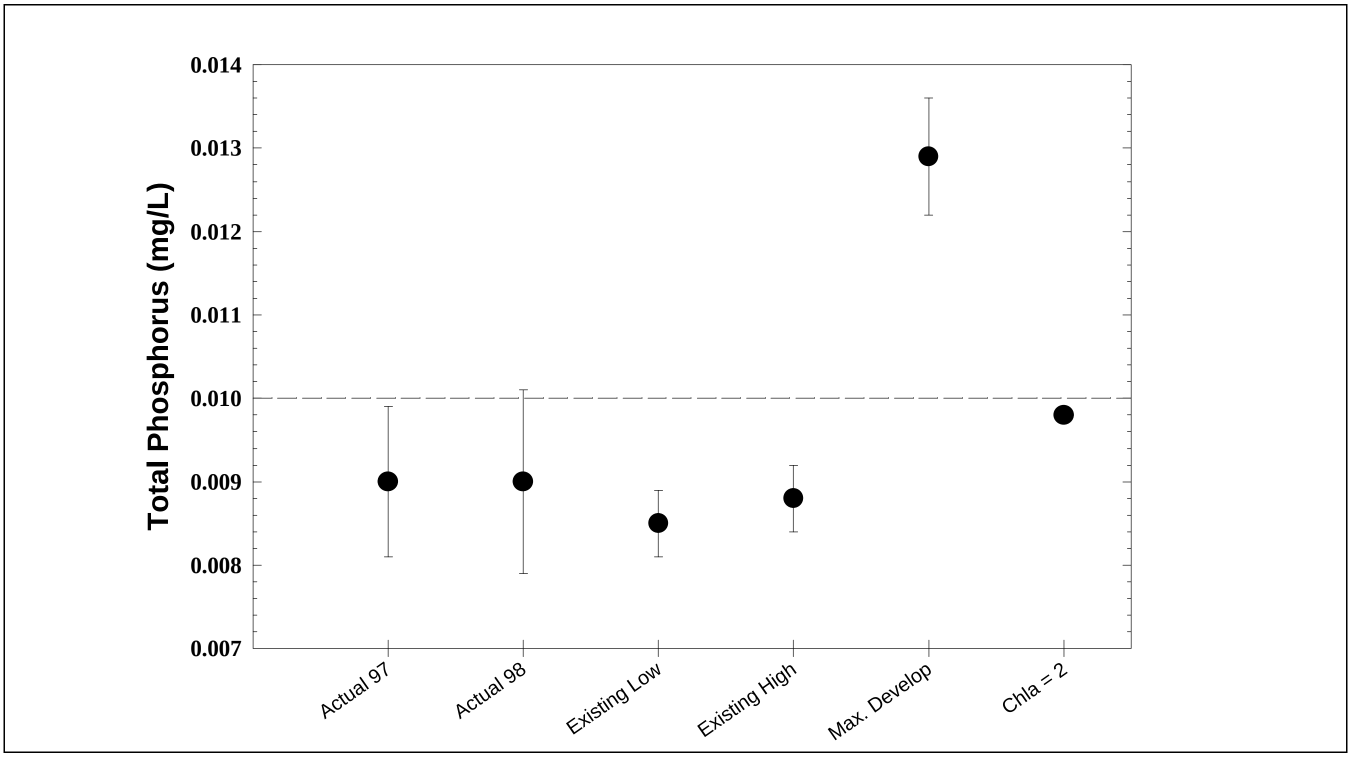

Figure 18 Prediction of total phosphorus concentrations in Blue Mountain Lake under various development scenarios. Dashed line indicates oligotrophic-mesotrophic boundary.

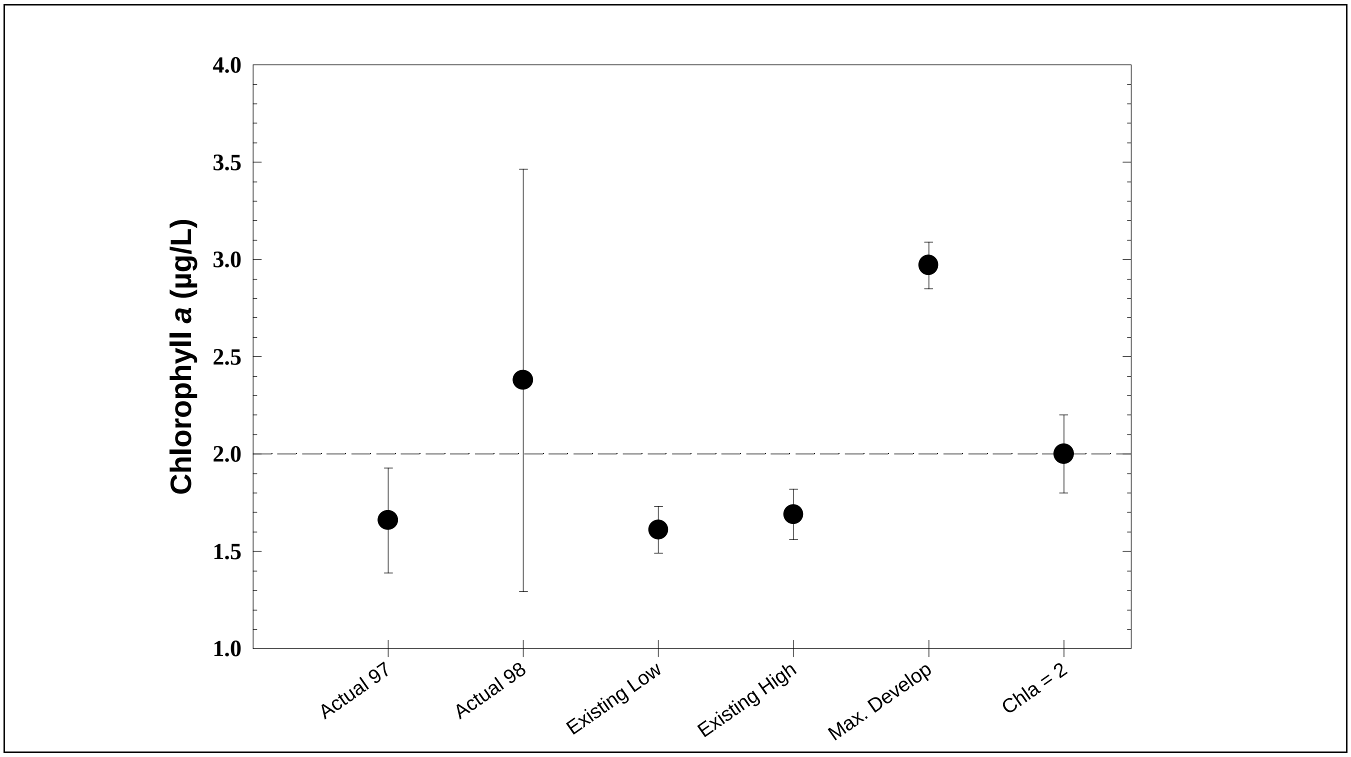

Figure 19 Prediction of chlorophyll *a* concentrations in Blue Mountain Lake under various development scenarios. Dashed line indicates oligotrophic-mesotrophic boundary.

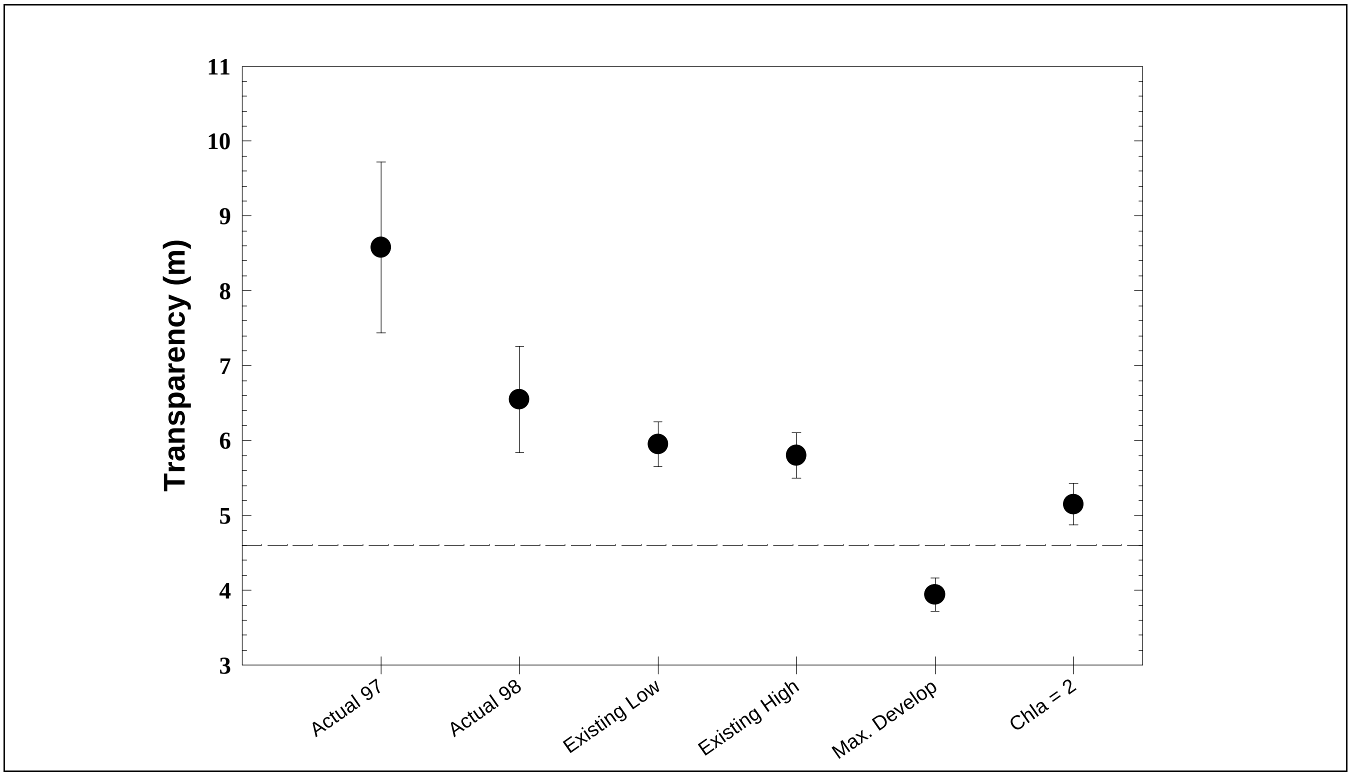

Figure 20 Prediction of transparency in Blue Mountain Lake under various development scenarios. Dashed line indicates oligotrophic-mesotrophic boundary.

6.0 Conclusions

Blue Mountain Lake is an oligotrophic lake with relatively low concentrations of total phosphorus and chlorophyll *a* and relatively high transparency. Water quality has changed significantly over the past century due primarily to human activities. Monitoring data shows that the lake has experienced significant changes in water quality particularly since 1993. Some of those changes may be associated with the blowdown and storm events of 1994. However, the long-term trend has been decreasing water quality since at least the late 1970s. These changes include an increase in total phosphorus and chlorophyll *a* concentrations and a decrease in lake transparency. Total phosphorus concentrations have increased from around 3 ppb in 1978 to between 8 and 9 ppb in 1998. Chlorophyll *a* concentrations have increased from around 1.5 ppb in 1994 to around 1.8 ppb in 1997, with an average of 3 ppb in the east basin during 1998. Transparency has decreased from around 10 meters in 1993 to around 6.5 meters in 1998.

The lake has become more acidic during the period of record. Levels of pH have decreased from around 7.3 units in 1933 to around 6.5 units in 1998. Alkalinity has decreased from 9 ppm to around 4 ppm during the same period. It is possible that the increasing acidity of the lake was responsible for improving transparency and chlorophyll *a* up until the early 1990s, when nutrient enrichment of the lake had occurred to a degree sufficient to negatively impact transparency and chlorophyll *a*.

The lake experiences a moderate loss of dissolved oxygen in the bottom waters during the summer months. This appears to be somewhat more apparent in the east basin of the lake, perhaps due to increased nutrient loading to the east basin from the hamlet and surrounding developed land or differences in basin morphology.

Museum Brook was the most impacted of the four monitored tributaries, while Minnow Brook East was the least impacted. Phosphorus sources to Museum Brook include a number of camps built close to the stream in areas of poor soil and bedrock and the direct stream discharge of wastewater by the Museum.

Existing wastewater systems, which include individual septic systems and the Museum wastewater facility, are apparently having a significant impact on the water quality of the streams and lake. Within the streams, we observed a degradation of water quality as each summer progresses, which correlates to the seasonal loading of the systems due to summer occupancy. Within the lake, we observed the aforementioned decline in water quality during the past 6 years. This is also evident in the lake from the sediment core work, which shows a trend of declining water quality over the past 100 years, particularly since the 1940s.

Water quality modeling showed that maximum development of the watershed, even with a mix of seasonal and year-round homes, would cause unacceptable changes in lake water quality. Modeling for a decrease in water quality to a chlorophyll *a* concentration of 2 ppb predicts total allowable new development consisting of 38 seasonal and 20 year-round homes. Given the present trend in water quality, however, it is likely that Blue Mountain Lake will reach that threshhold even with the present level of development.

Existing development within the watershed needs to be examined critically and considerable effort needs to be directed towards upgrading all old and non-conforming septic systems. In addition, an alternative to stream discharge by the Museum should be investigated. Since the operation is seasonal, spray irrigation is a possible alternative that should be investigated.

APPENDIX A

GLOSSARY OF LAKE AND WATERSHED TERMS

APPENDIX B

WATER QUALITY DATA

APPENDIX C

ADDITIONAL FIGURES