LAUREL LAKE DIAGNOSTIC AND FEASIBILITY STUDY PLAN LEE & LENOX, MASSACHUSETTS

Prepared For:	**Town of Lee** Robert Nason Town Administrator 32 Main Street Lee, Massachusetts 01238
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Project No.:	**L123-000**
Date:	**December 31, 2002**

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EXECUTIVE SUMMARY

Environmental Science Services, Inc. (ESS) conducted a thorough investigation of Laurel Lake in the towns of Lee and Lenox located in western Massachusetts during the summer and early fall of 2002. The investigation was initiated to serve as the basis for the development of a lake and watershed management plan. The primary issue facing Laurel Lake is the ongoing encroachment of aquatic and semi-aquatic vegetation. In particular, the exotic and invasive species Eurasian watermilfoil (*Myriophyllum spicatum*) has recently begun to expand its coverage into the lake's open water habitat resulting in the exclusion of the more desireable native plant species.

The current study included an assessment of a number of physical, chemical and biological characteristics of the lake. Based on these assessments it is apparent that although Laurel Lake enjoys relatively good water quality at present, nutrient levels in the lake (particularly phosphorus) are approaching levels characteristic of a mesotrophic (moderate amounts of nutrients) system. The lake is and has been receiving nutrients (primarily phosphorus and nitrogen) from its watershed predominately during wet weather events. These nutrients have the potential to fuel the growth of algae (phytoplankton) within the water column. In addition, the particulate forms of these nutrients, which are primarily carried to the lake via stormwater runoff, settle to the lake bottom and contribute to the already rich, organic muck that is ideally suited to the growth of rooted vegetation (macrophytes).

Dense beds of aquatic macrophytes currently occupy a significant portion (approximately 38 acres) of the lake's shallow water areas (littoral zone), and inhibit recreational activities in several areas of the lake. The densest weed beds were observed to occur within Laurel Lake's northern and western coves near the inlets from Sargent Brook and the unnamed tributary that enters the main basin through the culvert beneath Laurel Lake Crossroads as well as within the narrows approaching the lake's outlet. In addition to Eurasian watermilfoil, several other aquatic plant species were observed to be at levels that would be considered excessive, including: coontail (*Ceratophyllum demersum*), waterweed (*Elodea canadensis*), brittle waternymph (*Najas minor*), large-leaved pondweed (*Potamogeton amplifolius*), and water celery (*Valisneria americana*).

In order to maintain the integrity of this open water system, it is recommended that management actions such as drawdown and/or herbicide application be implemented in order to control nuisance plant species while maintaining a healthy balance of native plants. In addition, it is recommended that efforts be made to ensure that development and activities within the watershed be carried out in a manner that is protective of the lake's generally good water quality conditions. Finally, it is recommended that efforts be made to continue to monitor the plant community and water quality conditions in the lake to identify any future problems, should they arise, and to track the success or failure of any implemented management actions.

Estimated costs for improving the lake will be dependent upon the level of implementation. Estimated costs for controlling the existing vegetation problem in accordance with the recommended management program should be anticipated on the order of between $50,000 and $60,000. Costs to prepare an educational brochure ($2,500) are also recommended in order to ensure that water quality remains high. Additional study, at an estimated cost of $12,000 will be needed to assess and develop recommended solutions for addressing possible groundwater contamination identified in the Lenox portion of the lake. Given the extent of the investment needed to restore Laurel Lake, it would be wise to establish a long-term monitoring program that could be conducted annually or semi-annually to assess basic water quality and the condition of the aquatic plant community. An estimated cost for such a program would be $5,000/year, but would provide early warning of potential problems and could save money over the long term if problems are addressed before conditions worsen.

1.0 INTRODUCTION

The desire to assess the extent and cause of the nuisance weed problem prompted the initiation of a limnological investigation at Laurel Lake, located in the towns of Lee and Lenox, Massachusetts. ESS conducted the study during the summer and early fall of 2002. The investigation included an evaluation of watershed features as well as the physical, chemical, and biological features of the lake.

The goals of the investigation were defined during the initial "kick-off" meeting with representatives from the Town of Lee (Robert Nason and Gregory Federspiel) and the Laurel Lake Preservation Association (LLPA) on August 9, 2002. During this kick-off meeting it was made clear to ESS that a perceived increase in nuisance weeds, particularly Eurasian watermilfoil (*Myriophyllum spicatum*) was the primary concern. The recent spread of this plant was reported to be adversely affecting the recreational utility of the lake by impeding swimming, boating and aesthetic enjoyment. Although a hydro-rake has been employed annually in an effort to control the spread of watermilfoil (and other nuisance weeds) adjacent to the two town beaches located at the lake, little effort has been expended to prevent the spread of weeds in other areas of the lake. Consequently, each of the major coves of the lake and most other gently sloping shoreline segments now possess weeds at historically high densities.

With respect to the perceived water quality of the lake, it was made clear that most watershed stakeholders are very pleased with the present quality and clarity of the water. The stated goal for water quality was to maintain this quality by ensuring that development or activities within the watershed are compatible with maintaining current conditions.

The investigation of Laurel Lake consisted of eight key components: 1) assessing the in-lake water quality, including a phytoplankton and zooplankton analysis; 2) evaluating the quantity and quality of water entering the lake from tributaries and storm drains and leaving the lake from its outlet structure, during dry weather and wet weather conditions; 3) assessing the quantity and quality of groundwater entering the lake along key shoreline segments; 4) assessing the lake's aquatic plant community; 5) documenting fish and wildlife occurring in the lake and watershed via direct observation and through a historic data review; 6) characterizing and determining the quality of in-lake sediments; 7) assessing aquatic invertebrate communities in and around the lake; and 8) using data collected and long-term climatological data to calculate the annual hydrologic and nutrient budget for the lake.

The investigation was conducted in order to provide viable management alternatives and approximate cost estimates for improving the overall quality of Laurel Lake. A lake and watershed management plan has been prepared for the Town of Lee.

2.0 STUDY APPROACH

The Laurel Lake watershed assessment consisted of a review of background information, field data collection, nutrient and hydrologic modeling, and the preparation of a management strategy. Water quality information provides insight into potential sources and the degree of pollutant loading to the system. While longer-term (multiple years) measurement would be desirable, this brief investigation provides sufficient data to make reasonable assumptions regarding pollutant inputs and in-lake water quality.

Background data and general lake and watershed information were compiled from existing sources, including the United States Geological Survey (USGS, 2000) topographic map (Figure 1), 1999 Massachusetts Geographical Information System (GIS) land-use data (Figure 2), sewerage and zoning maps provided by the Towns of Lee and Lenox, and several historic studies of Laurel Lake provided by the LLPA. Refer to Table 1 for land-use information.

Field data was collected in accordance with the sampling protocols outlined in Appendix A and included the following key tasks:

- Water depth and sediment depth was measured along eleven (11) appropriately spaced transects crossing the lake. Data collected was used to develop water depth contours (Table 2 and Figure 3) and a sediment depth profile (isopac map) of the basin (Table 2 and Figure 4).
- Water quality was monitored at the deepest spot in the lake at the lake surface, at mid-depth (approximately 5.5 meters below the surface) and just above the lake bottom. In addition, water quality was assessed at the two main tributaries to the lake (Sargent Brook and the unnamed tributary that enters the lake beneath Laurel Lake Crossroads), its outlet, and at the storm drains that discharge from Route 20 to the lake near the boat ramp (Figure 5). Water quality monitoring of the in-lake station was conducted during two dry weather days. The tributaries and the outlet were sampled once during dry weather and twice during wet weather. Only one storm drain was observed to be flowing at the time of sample collection throughout the study period and this drain was sampled during wet weather conditions. Dry weather samples were obtained on August 27th, and September 26th, 2002, while wet weather samples were obtained on September 15th, and October 11th, 2002. The following water quality parameters were assessed during each field visit, as applicable: Secchi disk transparency, temperature, dissolved oxygen, conductivity, fecal coliform, total phosphorus, dissolved phosphorus, nitrate nitrogen, total Kjeldahl nitrogen, ammonia nitrogen, alkalinity, hypolimnetic iron, pH, flow rate and turbidity. Refer to Tables 3, 4 and 5 for field and laboratory water quality data and Figure 6 for the temperature and dissolved oxygen profiles from the in-lake station.
- Groundwater quantity and quality was evaluated from three pre-selected shoreline segments on September 26th, 2002 (Figure 5). The following groundwater quality parameters were assessed: temperature, pH, conductivity, ammonia nitrogen, nitrate nitrogen, dissolved phosphorus and total iron. Refer to Tables 6 and 7 for field and laboratory groundwater quality data.
- One composite sediment sample was collected from the deepest portions of Laurel Lake on September 26th, 2002. The composite sample consisted of 3 sediment grab samples that were combined in the field (Figure 5). In order to ascertain the potential for sediment to influence water quality and plant growth, sediment samples were analyzed for the following parameters: total phosphorus, total nitrogen, percent water, and percent organic content. In

addition, sediment samples were analyzed for arsenic, cadmium, chromium, copper, lead, mercury, nickel, vanadium, zinc, polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPH), and sediment grain size as per the 401 Water Quality Certification for Discharge of Dredge and Fill Materials (314 CMR 9.00). Results are presented in Table 8 and sediment quality guidelines are presented in Table 9.

- Aquatic and semi-aquatic plant species occurring in the lake were documented on August 28th, 2002 (Table 10). Areas of plant coverage within the lake and the distribution of the dominant plant species were mapped (Figures 7 and 8).
- Phytoplankton and zooplankton were assessed on August 28th, 2002 and these data were used to infer the trophic status of the lake as indicated by the planktonic community composition and abundance (Tables 11 and 12).
- Fish and wildlife communities occurring in the lake and within its watershed were documented via direct observation throughout the course of the study, through the NEWild (Thomasma et. al, 1999) program and by searching the Natural Heritage and Endangered Species Program (NHESP) for rare and endangered species (Appendix B). Wildlife species that were observed or are expected to occur within the Laurel Lake watershed are presented in Table 13.
- Aquatic invertebrates were collected from three sampling locations on September 26th, 2002. Sampling locations are depicted in Figure 5 and data is presented in Table 14.

The hydrologic (water flow) and nutrient (phosphorus and nitrogen) budgets for Laurel Lake were calculated from long-term climatological data and from field data collected during this study (Appendix B). Nutrient budgets were determined using a variety of limnological modeling techniques based on watershed features and field data specific to the lake. The modeling effort relied heavily upon system hydrology and in-lake nutrient concentrations. Nutrient loading to the lake was further categorized by itemizing various inputs to the lake from the land use data and tributary data collected as part of this study.

One important value of the current investigation, in addition to evaluating water quality and recommending appropriate management techniques, is the broad range of environmental variables that have been examined. The data collected as part of this relatively comprehensive study will provide an excellent framework by which the success of implemented management actions can be measured.

3.0 STUDY RESULTS

3.1 Watershed Features

A USGS topographic map was used to identify the watershed of Laurel Lake (Figure 1). Although this is likely to be a very close approximation of the true watershed boundary, it is possible that the storm drainage systems in the watershed might not mirror surface topography. Barring a more detailed analysis of the storm drainage system, the watershed, including Laurel Lake, was calculated to be approximately 1,824 acres or slightly more than 10 times the area of the lake itself. Generally speaking, when a lake's watershed area is 10 times the area of the lake or less, the lake usually does not experience significant water quality problems.

The majority of land within the Laurel Lake watershed is forested (40%) and a lesser component is devoted to residential (19%) and cropland (14%). Other land uses include pasture, wetlands, open land, recreational land, commercial, urban open, water, and woody perennial (Figure 2, Table 1). Although the majority of the Laurel Lake watershed is vegetated, Route 20, a heavily traveled roadway, abuts the lake along its eastern shoreline.

Further delineation of the watershed allowed ESS to designate four (4) discrete sub-basins (Figure 2, Table 1). Land use data of these sub-basin delineations indicate that sub-basin 1, located south of the lake, is predominately comprised of cropland (49%) and forest (33%); sub-basin 2, located west of the lake, is predominately comprised of forest (44%), residential (21%), urban open (11%), and cropland (11%); sub-basin 3, located north of the lake, is predominately comprised of forest (36%), residential (21%), cropland (21%) and participation recreation (11%); and sub-basin 4, located east of the lake, is predominately comprised of forest (63%), residential (20%) and participation recreation (11%).

Soils in the watershed were characterized based on the most recent Soil Survey of Berkshire County Massachusetts (USDA 1988). Soils in the watershed are predominately comprised of the Amenia-Pittsfield-Farmington Series, which are very deep to shallow soils that are moderately well drained to excessively drained. These soils are generally loamy soils formed on glacial till derived from limestone, on uplands.

3.2 Lake Features

3.2.1 Physical Characteristics

Laurel Lake is approximately 165 acres in size (Table 2). Its two major tributaries, Sargent Brook and an unnamed tributary, feed the lake. Soukup (1974) identified a third, smaller tributary east of Sargent Brook but it was determined that this feature was of little significance to in-lake water quality due to its relatively minor flow. Laurel Lake is primarily fed by Sargent Brook, which flows into the lake along the northeastern edge. The headwaters of Sargent Brook emanate from a forested area located approximately 1.3 miles north of the lake. Sargent Brook flows adjacent to several relatively large commercial and residential land parcels and intersects two heavily traveled roads (Route 7 and Plunkett Street) before discharging into Laurel Lake. The second tributary flows into the lake along its northwestern edge. This unnamed tributary is culverted under Laurel Lake Crossroads and drains an upgradient wetland and small ponded region.

The outlet from Laurel Lake is located at its southeastern end (Figure 5) and consists of a stone outlet structure and spillway. Water flowing over the spillway flows through a commercial area before crossing Route 20 and emptying into the Housatonic River. Water is also diverted from the lake to a paper manufacturing facility at its outlet structure. The intake for this diversion is reportedly located at an approximate depth of 10 feet below normal lake elevation.

Water depths were measured in the lake along 11 transects spanning the lake on August 28^{th}, 2002. The maximum depth observed was 52 feet, with an average water depth of 25.0 feet (Table 2). The northern and western coves of the lake are shallow (<5 feet) and have a gently sloped basin. These conditions are conducive to the establishment of dense plant growths. The deepest area in the lake (>50 feet) is centrally located within the basin. Calculations based on our bathymetric survey indicate that the lake has an approximate volume of just less than 180 million cubic feet of water (Table 2).

ESS conducted a thorough review of existing data for Laurel Lake and its watershed. Municipal representatives at the Towns of Lee and Lenox were contacted in order to obtain town sewer and zoning maps. Lenox sewer systems within the Laurel Lake watershed are limited to three areas: a relatively extensive system along Stockbridge Road and Kemble Street; a system located just south of the intersection of Routes 7 and 20; and a system which occurs along Coldbrooke South Drive and Walker Street. Lee sewer systems in the Laurel Lake watershed are confined to a relatively small area, associated with residences in the southeastern corner of the watershed, along Route 20.

Several historic studies of Laurel Lake were provided by the LLPA to ESS (Soukup 1974, Carr Research Laboratory, Inc. 1976, Livingston and Bentley 1971, Ludlam 1978, Kofta Technologies Services 1998). Historical data obtained from these reports will be referenced throughout this document whenever applicable. ESS will incorporate zoning and aquifer protection data from MassGIS into this draft report upon receipt of the requested materials.

3.2.2 Chemical Characteristics

3.2.2.1 Surface Water Analysis

Water quality was monitored at the deepest spot in the lake, designated as Sites LL-1S, LL-1M, and LL-1B for surface, middle (5.5 meters below surface) and bottom sampling locations, respectively (Figure 5). Water quality monitoring stations were also established at both tributaries (Sargent Brook and the unnamed tributary at Laurel Lake Crossroads), a site immediately downstream of the outlet and at a storm drain located at the boat launch, designated as Sites LL-2, LL-3, LL-4 and LL-5, respectively (Figure 5).

Water quality monitoring occurred on two dry weather dates (defined as a minimum of 72 hours antecedent with less than 0.1 inch of rainfall) at the in-lake station (Sites LL-1S, LL-1M, and LL-1B) on August 27th and September 26th, 2002. Water quality was monitored at the tributaries on one dry weather date (August 27th, 2002) and on two wet weather dates (September 15th and October 11th, 2002). Wet weather conditions were defined as a precipitation event of $\geq$0.25 inches, which was preceded by a minimum of 72 hours with less than 0.1 inch of rainfall). It should be noted that flow was not observed at the outlet sampling station at any time during this study and therefore, water quality data are not presented for this sampling site. All other surface water quality data are presented in Tables 4 and 5.

Although three storm drains were identified to discharge to Laurel Lake during field reconnaissance efforts, only one storm drain was observed to be flowing at the time of sample collection (LL-5). This storm drain was sampled once during wet weather conditions on October 11th, 2002 (Figure 5, Table 4 and 5).

Dissolved Oxygen and Temperature

Dissolved oxygen is the amount of molecular oxygen (O_2) dissolved in water. Dissolved oxygen below 5 mg/L is generally considered unsuitable for many forms of aquatic life. Additionally, release of phosphorus (which promotes algal and plant growth) from bottom sediments can often be enhanced under anoxic (no oxygen) or very low oxygen (<1.0 mg/L) conditions. Temperature and dissolved oxygen are typically measured within the water column to determine the extent of lake stratification. Dissolved oxygen and temperature profiles for the dry weather sampling dates are presented in Table 3 and profiles are depicted graphically in Figure 6.

Temperature profiles for Laurel Lake indicate that the lake was stratified during both August and September 2002 with the thermocline occurring at an approximate depth of 7.0 meters. In all instances, the dissolved oxygen levels in the epilimnion (i.e., waters above the thermocline) are greater than 5 mg/L and therefore, reflect a moderately well oxygenated environment; however, the lake bottom was found to be poorly oxygenated ($\leq$ 1.0mg/L). Livingston and Bentley (1971) also documented the development of an anoxic hypolimnion (waters below the thermocline) during summer months in Laurel Lake.

Dissolved oxygen levels from the Sargent Brook (LL-2), the unnamed tributary (LL-3), and the storm drain (LL-5) were 6.65, 7.41 and 7.80 mg/L, respectively, representing well-oxygenated environments (Table 4). These observed levels of oxygen would provide adequate habitat for maintaining fish communities and many other aquatic organisms. Average dissolved oxygen, measured as percent saturation, was slightly depressed (67.3%) for Sargent Brook, however, and was slightly below Massachusetts state standards (Table 4).

Conductivity

Conductivity measures the resistance of a solution to electrical flow and can be used as an indirect measure of dissolved solids in water, which in turn can be an indication of water fertility. Livingston and Bentley (1971) reported conductivity values of 344 µmhos/cm from the surface waters at Laurel Lake during their study.

Average conductivity values observed by ESS at the in-lake stations (Sites LL-1S, LL-1M and LL-1B) ranged from 538 to 637 µmhos/cm (Table 4). Elevated conductivity values exhibited from within Laurel Lake are most likely due to the natural weathering of the substantial limestone (calcium carbonate) deposits underlying the lake's basin rather than being related to excessive nutrient inputs.

Average conductivity values from Sargent Brook (LL-2) and the unnamed tributary (LL-3) were 890 and 637 µmhos/cm, respectively. Although the elevated conductivity values exhibited at Sargent Brook (LL-2) may be attributed in part to the weather processes of underlying limestone sediments within the tributary, it is also likely that run-off from upgradient commercial and residential areas and Route 7 may contribute to the elevated levels observed. Therefore, it is likely that flows from Sargent Brook may be contributing, at least to some degree, to the lake's fertility. Average conductivity values for the storm drain (LL-5) were 553 µmhos/cm, comparable to the levels observed within the lake itself (Table 4).

Turbidity

Turbidity is an indirect measure of the quantity and size of particles (sediment, algae cells, debris, etc.) in a water sample. Turbidity values less than 10 NTU (nephelometric turbidity units) are generally assumed to have minimal impact on habitat and biota. Average turbidity values exhibited at in-lake stations (Sites LL-1S, LL-1M and LL-1B) ranged from 1.7 to 4.6 NTU, indicating the presence of a relatively insignificant amount of particulate matter in the water column (Table 4). Average turbidity levels at Sargent Brook (LL-2), the unnamed tributary (LL-3) and the storm drain (LL-5) were 1.65, 4.35, and 0.75 NTU, respectively.

pH

The pH value is a measure of acids and bases dissolved in water. In general, pH values for most lakes and streams in Massachusetts range from 6.0 to 7.5 SU (standard units). However, most lakes in the Berkshires are influenced by underlying limestone deposits and therefore often have values in excess of 8.0 SU (exhibiting more basic conditions) due to the breakdown of calcium carbonate (limestone) which produces a strong base, calcium hydroxide, and a weak acid, carbonic acid. As such, the Massachusetts state standard for pH may not be applicable to the present assessment (Table 4).

The pH values measured at the in-lake stations (Sites LL-1S, LL-1M and LL-1B) were very basic, averaging 8.9, 8.7 and 7.7 SU, respectively. Average pH levels at Sargent Brook (LL-2), the unnamed tributary (LL-3) and the storm drain (LL-5) were 8.2, 8.6, and 8.7 SU, respectively. These conditions serve to protect the lake by neutralizing any atmospheric acid deposition (acid rain) that may be impacting the lake. Livingston and Bentley (1971) reported pH values of 8.6 SU from the surface waters at Laurel Lake, suggesting that pH levels have been relatively stable over time.

Water Transparency

Water transparency (or clarity) in Laurel Lake was measured in the field with a Secchi disk at the in-lake station. Factors such as plankton concentration, water color, and suspended particles within the water column directly impact Secchi depth measurements.

Secchi depth values were high throughout the study and ranged between 3.2 and 3.4 meters (Table 4). Typically, Secchi depths from 3 to 4 meters are indicative of mesotrophic (moderate fertility) waterbodies (Canavan and Siver, 1995) and would be considered very good for a Massachusetts lake. However, Soukup (1974) reported that Laurel Lake had an average Secchi depth of 5 meters, indicating that water clarity may have decreased by as much as 36% over the past 25 years. It should be noted that this study only sampled the lake on two dates during a single season and that although this decreased clarity certainly warrants further and more regular monitoring, it does not necessarily indicate a long-term trend.

Fecal Coliform

Fecal coliform bacteria are used as an indication of potential sewage contamination since these bacteria are commonly found in both human and animal feces. Fecal coliform bacteria are not harmful themselves, but are believed to be indicative of the presence of other more harmful pathogens. For Massachusetts Class B waters, fecal coliform values averaging less than 400 colonies/100mL during dry weather conditions and equal or less than 2,000 colonies/100mL during wet weather conditions are considered acceptable for primary contact recreation by the State of Massachusetts (MADEP, 1996).

Fecal coliform values measured at the in-lake station (LL-1S) were low and exhibited <10 colonies/100mL on both dry weather sampling dates (Table 5). These values are well below state standards and therefore, may be considered acceptable for primary contact recreation by the State of Massachusetts (MADEP, 1996).

Similarly, fecal coliform values were low from Sargent Brook (LL-2) with only 60 colonies/100mL during the August 28th, 2002 dry weather sampling event. Fecal coliform levels were not assessed during wet weather events. These low values are well below state standards and therefore, may be considered acceptable for primary contact recreation by the State of Massachusetts (MADEP, 1996).

Although these data provide adequate background information from which to develop a management program for the lake, additional bacteria sampling (including both fecal coliform and *E. coli*) during wet weather events would aid in accurately characterizing the degree of bacterial contamination within the lake.

Phosphorus and Nitrogen

Phosphorus and nitrogen are essential plant nutrients. Excessive concentrations of one or both of these nutrients can result in undesirable growth of algae in the water column (phytoplankton) and accumulations of attached algae (periphyton) on the shallower bottom sediments (within the euphotic zone). In addition, excessive quantities of these nutrients can also promote rooted plant growth.

Phosphorus

The limestone deposits underlying Laurel Lake and the majority of the watershed may have significant implications with regard to controlling phosphorus availability within the lake. Interestingly, as limestone deposits naturally weather, calcium carbonate in the water forms crystals (precipitate out of solution) on aquatic vegetation, often encasing the submerged portion of the plant in a crystallized structure. During this process, some of the available phosphorus in the water column may strongly adhere to the crystalline structure, rendering an appreciable quantity of phosphorus unavailable for further biotic uptake (WDNR, 1999). Although this process does not remove the phosphorus from the lake, it may help strip it from the water column during the critical growing season when plants are active.

Typically, phosphorus values no greater than 0.02 mg/L phosphorus are desirable for maintaining low algal biomass and high water clarity, while concentrations above 0.05 mg/L phosphorus are considered excessive and indicative of a hyper-eutrophic system (Canavan and Siver, 1995).

Average total phosphorus values measured at the in-lake stations (Sites LL-1S, LL-1M and LL-1B) were 0.02, 0.02, and 0.20 mg/L, respectively. These data suggest that excessive phosphorus is available within the lake but may be confined to the hypolimnion (bottom portion) of the basin (Table 5). These data, in combination with the dissolved oxygen profile data, suggest that anoxic conditions on the lake bottom are promoting the release of sediment bound phosphorus into the water column. This phosphorus rich bottom water would be circulated throughout the lake during periods when the thermocline is not established, typically during the spring and fall when the lake “turns over”.

Slightly elevated average total phosphorus values (0.04 mg/L) were also observed at the unnamed tributary sampling station (LL-3), suggesting that flows from this tributary may be contributing nutrient rich waters into the basin. Average total phosphorus values from Sargent Brook (LL-2) and the storm drain (LL-5) were sufficiently low (0.02 and 0.01 mg/L, respectively). Livingston and Bentley (1971) reported ortho-phosphate values of 0.037 and 0.006 mg/L from the surface waters at Laurel Lake suggesting that phosphorus levels may be variable within the lake over time but do not appear to be increasing appreciably.

Average dissolved phosphorus levels within the in-lake stations were fairly uniform and ranged from 0.01 to 0.02 mg/L. Similarly, average dissolved phosphorus values at the tributaries (LL-2 & LL-3) and the storm drain (LL-5) sampling station were low and ranged from 0.01 to 0.02 mg/L (Table 5). Data indicate that a high percentage (up to 100%) of the phosphorus in the lake and its tributaries is in its dissolved state, and therefore would be readily available for uptake by the plant and algal communities.

Hypolimnetic Total Iron

Levels of total iron in the hypolimnetic (bottom) waters are often of interest when developing a lake management plan due to the ability of iron molecules to sequester available phosphorus and render it unavailable for further biotic uptake. Specifically, if elevated levels of iron are present in the water column, they promote the formation of iron phosphates, which are highly insoluble in oxygenated water. Under these conditions, elevated levels of phosphorus in the water are exhibited when iron levels are at less than five times the phosphorus level.

Total iron was measured one time during the course of the study period and totaled 3.1 mg/L at the in-lake bottom site (LL-1B), while total phosphorus totaled 0.2 mg/L at this same site (Table 5). This iron:phosphorus ratio (15.5:1) is significantly greater than the 5:1 ratio, indicating that there may be sufficient iron levels available in the hypolimnion to counteract elevated phosphorus values and render them biologically inert.

Nitrogen

Nitrate-nitrogen, one of the several major forms of nitrogen, within Laurel Lake was generally low compared to the normal background level (0.05 mg/L) for Massachusetts lakes and ponds (MAPC 1983). Nitrate-nitrogen averaged 0.01 mg/L for all in-lake sampling stations in Laurel Lake (Table 5). Nitrate-nitrogen levels from the inflowing tributaries were slightly greater than those exhibited from the in-lake sampling sites, averaging 0.05 and 0.02 mg/L for Sargent Brook (LL-2) and the unnamed tributary (LL-3), respectively. Nitrate-nitrogen values were low for the storm drain (LL-5) which averaged 0.01 mg/L (Table 5). Despite the periodic occurrence of slightly elevated nitrate-nitrogen values from Sargent Brook (LL-2), nitrate-nitrogen does not appear to be problematic in Laurel Lake at this time.

Similarly, ammonia-nitrogen concentrations were also found to be low (averaging $\leq$0.02 mg/L) at the tributaries (LL-2 & LL-3), the storm drain (LL-5) and the surface and middle in-lake sampling stations (LL-1S & LL-1M) (Table 5). Ammonia-nitrogen was greatest at the in-lake bottom station (LL-1B), averaging 0.6 mg/L (Table 5). These data indicate that neither wet nor dry weather flows are a major contributor of ammonia-nitrogen to Laurel Lake, although there does appear to be a significant reserve of this nutrient in the hypolimnetic layer. Livingston and Bentley (1971) reported ammonia values of 1.059 mg/L from the surface waters at Laurel Lake, substantially higher than those found during this study.

The last form of nitrogen assessed as part of this study was total Kjeldahl nitrogen or TKN. TKN is a measure of the amount of ammonia and organic nitrogen in a sample. Average TKN values for the in-lake station were 0.8 mg/L, 0.6 mg/L and 1.5 mg/L for LL-1S, LL-1M, and LL-1B, respectively (Table 5). Average TKN values at the inflowing tributaries (LL-2 & LL-3) sampling stations and the storm drain (LL-5) ranged from 0.2 to 0.3 mg/L (Table 5).

Together, TKN and nitrate form the significant portion of total nitrogen that is typically observed in aquatic systems (nitrite, not analyzed in the present study, is typically present as an insignificant fraction comprising total nitrogen). Typically, total nitrogen values no greater than 2.0 mg/L are desirable for maintaining high water quality, while concentrations above 10.0 mg/L are considered excessive and indicative of a hyper-eutrophic system. Average total nitrogen levels for in-lake stations were 0.8, 0.6, and 1.5 mg/L for LL-1S, LL-1M and LL-1B, respectively (Table 5). These data suggest that only moderate levels of nitrogen are available within the lake with the majority of this confined to within the hypolimnetic zone during the growing season. Average total nitrogen levels were lower for other inflowing sampling stations and totaled 0.25, 0.32, and 0.31 mg/L for Sargent Brook (LL-2), the unnamed tributary (LL-3) and the storm drain (LL-5), respectively (Table 5).

Alkalinity

Alkalinity is a measure of the buffering capacity, or ability of the waterbody to neutralize strong acids. Lakes with high alkalinity can neutralize the deleterious effects from acid rain. The main source of alkalinity is usually from carbonate rocks, such as limestone. Average alkalinity levels for in-lake stations were 126, 130, and 169 mg/L for LL-1S, LL-1M and LL-1B, respectively. The average alkalinity level for Sargent Brook (LL-2) was 241 mg/L (Table 5). Alkalinity values in excess of 25 mg/L generally suggest that there will be adequate buffering capacity to neutralize acidic inputs.

3.2.2.2 Groundwater Analysis

Groundwater analysis was conducted by ESS on September 26th, 2002 in order to identify the shoreline segments within the lake that may be contributing elevated levels of nutrients to the basin. Groundwater analysis is also critical towards developing an accurate estimate of the nutrient and hydrologic load that the lake is receiving. Refer to Tables 6 and 7 for groundwater quality data.

Groundwater flows were characterized at three shoreline segments in Laurel Lake, which were selected based on topography and housing features (density) (Figure 5). Segment 1 was located within the northern cove of the basin adjacent to a residential area. Segment 2 was located along the southern edge of the basin and was intended to characterize groundwater flows from a steeply forested slope representing background conditions. Segment 3 was located along the northeastern edge of the basin, adjacent to a residential area (Figure 5).

The seepage surveys were conducted according to the methods outlined in Mitchell et al. (1988 and 1989). Seepage quantity was estimated by installing two seepage meters per defined shoreline segment and measuring the change in volume in the attached bag. Change in volume multiplied by a conversion factor relating the allotted seepage time to an entire day and another conversion factor relating the seepage meter area to a square meter, yields the liters of inseepage (positive value) or outseepage (negative value) per square meter per day (Table 6). Seepage meters occupied approximately one quarter of a square meter and were left in place for 2.03 to 3.35 hours. Most seepage values were positive, indicating that at the time of sampling, inseepage was occurring (Table 6).

During spring, precipitation will typically raise the lake level faster than the groundwater elevation, resulting in net outflow around the sandy edge of the lake. During dry periods, the lake elevation will decline in response to surface water outflow and evaporation, while the groundwater elevation will decline more slowly, mainly in response to well withdrawal. Groundwater will seep into the lake when lake elevation drops below the groundwater elevation. Local variation is also possible, allowing water to flow into one part of the lake and out of another.

Groundwater flow may also change direction throughout the summer, as precipitation changes the lake level more rapidly than the groundwater level, and greater evaporation and surface outflow draw the lake down again. The generally silty substrate on a lake bottom can impede the movement of groundwater into a lake, particularly in deeper waters (Figure 4). Groundwater seepage into Laurel Lake averaged 28.4 $L/m^2/D$ (Table 6); this value is nearly double the typical rate and may be the result of the steep shoreline topography.

Groundwater seepage quality was assessed through sampling with a Littoral Interstitial Porewater (LIP) sampler. Porewater extracted from several locations in each segment was tested in the field for temperature, conductivity, and pH, and then sent to a laboratory for the remaining analyses.

Porewater conductivity was very high, and totaled 838, 677, and 707 µmhos/cm for Segment 1, Segment 2, and Segment 3, respectively. Similar to surface water quality data, it is most likely that the elevated conductivity values exhibited in groundwater flows are due to the underlying limestone geology of the region, rather than being indicative of any impaired water quality condition from anthropogenic sources.

In groundwater, dissolved phosphorus values in excess of 0.05 mg/L are of concern in terms of eutrophication, and values in excess of 0.10 mg/L can cause serious deterioration of conditions if the phosphorus is biologically available. However, larger values in porewater do not necessarily translate into lake water column values of the same magnitude. As mentioned above when discussing hypolimnetic iron, high iron levels in groundwater are known to promote the complexing of iron phosphates, which are highly insoluble in oxygenated water. For phosphorus to become available in the water column at a significant level, it must therefore enter the waterbody at an elevated concentration with concurrent iron levels at less than five times the phosphorus level.

Total dissolved phosphorus in Laurel Lake porewater ranged from <0.01 to 0.03 mg/L with a total average of 0.015 mg/L (Table 7). Total iron in groundwater levels ranged from 0.05 to 1.12 mg/L with an average of 0.44 mg/L. Two groundwater sampling segments, Segments 1 and 3, had iron:phosphorus ratios > 5:1, while Segment 2 has an iron:phosphorus ratio of < 5:1. These data indicate that there is not always a sufficient iron level to counteract the elevated phosphorus values entering the lake.

Nitrate nitrogen values in Laurel Lake porewater were <0.01, 0.04 and, 0.09 mg/L for Segment 1, Segment 2, and Segment 3, respectively. The average of these data is 0.045 mg/L (Table 7), which is within the range (0.01-0.5 mg/L) considered characteristic of "pristine" water quality conditions with respect to nitrogen. Values over 1.0 mg/L are unusual without some form of urban or agricultural influence, while values over 10 mg/L would be considered a health hazard for human consumption.

Levels of ammonia-nitrogen considered indicative of impaired water quality conditions are similar to those reported above for nitrate-nitrogen, as these nutrients are derived from a common source. Measured ammonia-nitrogen concentrations were 1.38 mg/L, 0.27 mg/L, and 0.16 mg/L for Segment 1, Segment 2, and Segment 3, respectively (Table 7). The elevated values that were observed for Segment 1 might be the result of activities along the residential or agricultural portions of the upgradient shoreline.

Typically, in healthy aquatic systems, the sum of nitrate and ammonium nitrogen, or soluble inorganic nitrogen (SIN) may reach up to approximately 1.0 mg/L. Values much over 1.0 mg/L raise suspicions of septic leachate contamination. Within the groundwater entering Laurel Lake, SIN values were 1.13, 0.09, and 0.25 mg/L for Segment 1, Segment 2, and Segment 3, respectively with an average value of 0.49 mg/L (Table 7). The elevated SIN values from Segment 1 suggest that there may be septic leachate contamination occurring at this part of the lake.

3.2.2.3 Sediment Characterization and Analysis

A qualitative characterization of in-lake sediment was determined by visually inspecting and describing bottom conditions along 11 transects positioned throughout the basin on August 28th, 2002 (Figure 4). The majority of the lake basin is covered by silt; however, most shoreline areas ($\leq$10 feet from the water's edge) are dominated by sand or a sand and silt mixture. Significant deposits of silt occur within the northern and western cove, downgradient of Sargent Brook and the unnamed tributary. These silt deposits may be due to the input of sediment laden stormwater from tributaries following precipitation events, or, more likely, these areas have been slowly filling in over time as vegetation grows year after year in these more shallow portions of the lake. The accumulation of these sediments, in turn, continues to fuel the growth of nuisance aquatic plants and enable them to slowly expand their coverage into even deeper waters.

In addition to the qualitative sediment characterization, a quantitative assessment of sediment quality was performed for Laurel Lake on September 26th, 2002. The purpose of the soft sediment analysis was to screen sediment for pollutants and to assess the potential for any reported pollutants to affect ecological and/or human health. Sediment quality is an indicator of long-term contaminant contributions from the watershed to a lake. Moreover, sediment quality can affect the health of aquatic organisms exposed to the sediment and can ultimately result in the bio-accumulation of contaminants within higher trophic levels of the food chain, including fish and humans. This characterization of sediments is part of a "screening process" designed to reveal, if present, the severity of sediment contamination and to aid in the development of future management strategies.

Results of the sediment sampling and subsequent laboratory analysis are presented in Table 8. Grab samples were collected from the lake bottom using an Ekman dredge, which collects the soft sediment and the associated organic bottom material. Samples were collected from three different locations within the lake basin and composited to prepare a single sample from the lake for laboratory analysis (Figure 5). The relatively shallow grab samples collected are representative of the depth of muck that is biologically available to organisms within the lake and that may possibly be affecting conditions within the lake's water column or contributing to rooted aquatic plant growth. Sediment samples were analyzed for the following parameters: total phosphorus, total nitrogen, percent water, percent organic content, arsenic, cadmium, chromium, copper, lead, mercury, nickel, vanadium, zinc, PCBs, PAHs, TPH, and sediment grain size.

Sediment quality guidelines by which environmental impairment is defined is based on the Long and Morgan freshwater criteria (1995) which presents threshold levels of chemical contaminants that affect human and environmental health. Under this classification scheme, contaminant levels below the Effects Range Low (ER-L) value represent a condition in which adverse biologic effects would be rarely observed (Table 9). Concentrations equal to and above the ER-L, but below the Effects Range Medium (ER-M), represent a condition in which adverse biological effects would be expected to occasionally occur. Finally, concentrations equivalent to and above the ER-M value represent a condition in which adverse biologic effects would be expected to frequently occur.

A second sediment quality classification system is based on the Great Lakes sediment quality criteria established by the United States Environmental Protection Agency (USEPA 1977) (Table 9). These standards describe a range of threshold values, which are considered to reflect "unpolluted" to "severely polluted" conditions.

Further evaluation of sediment quality was based on Massachusetts Interim Policy for Sampling, Analysis, Handling and Tracking Requirements for Dredged Sediment Reused or Disposed at Massachusetts Permitted Landfills (Interim Policy # COMM-94-007) (Table 9). The Interim Policy integrates the applicable elements of the Massachusetts Department of Environmental Protection's (MADEP) Interim Policy BWP-94-037 and 401 Water Quality Certification regulations at 314 CMR 9.00 (2000, the MADEP plans to promulgate Comprehensive Dredging and Disposal Regulations in the near future). Once the potential for sediment removal has been established, the allowable method for sediment removal was determined according to 314 CMR 9.03.

Sediment acquired from sampling sites was defined as impaired when any of the measured sediment quality parameters report values in exceedance of the threshold guidelines. In the absence of standards and/or threshold concentration levels, sediment data was qualitatively assessed based on the Best Professional Judgment (BPJ) of ESS scientists.

Of the potential contaminants investigated, arsenic and lead were the only parameters found to exceed the ER-L guideline due to a reported concentration of 9.8 and 67.6 mg/Kg, respectively (Table 8), indicating that prolonged exposure to the sediments may detrimentally affect the biological community. According to the Great Lakes sediment quality criteria, levels of arsenic and zinc (118.0 mg/L) are greater than what is characteristic of unpolluted sediments and levels of values for lead and total phosphorus (1,000 mg/kg) are above the level characteristic of severely polluted sediments.

The sediment sampled from Laurel Lake is well below state criteria for disposal at Massachusetts lined landfills and is classified as Category 1 Type A material, the most chemically benign sediment category according to 314 CMR 9.03. This designation allows for sediments to be hydraulically or mechanically dredged. Land disposal would be approvable; however, control of effluents would be required throughout the removal and disposal process.

PCBs are very similar, chemically, to many pesticides; however, most PCB compounds were intended for use in closed systems such as electrical transformers and capacitors. Some were also used as lubricants or as heat transfer and hydraulic fluids. Fortunately, PCBs were not detected in sediment samples collected from Laurel Lake.

PAHs are generated through the incomplete combustion of carbon compounds, often associated with industrial activities. PAHs may attach to small particles in the atmosphere and be transported for considerable distances before returning to earth directly, or in rainfall, and therefore, may be ubiquitously distributed in the environment in low concentrations (The Green Lane, 2001). Many PAHs are quite persistent and some are potent carcinogens in mammals (Rand & Petrocelli 1985). Fortunately, PAHs were not detected in sediment samples collected from Laurel Lake.

Sediment particle size is a measurement that refers to the relative quantity of sediment sizes that are present in a sediment sample. Samples collected from Laurel Lake consisted primarily of silts and clays, fine sands and medium sands with these size fractions accounting for approximately 52%, 25%, and 23% of the material present in the lake basin, respectively (Table 8). Large pulses of fine sediments typically are transported and deposited to waterbodies during moderate and extreme storm flow conditions.

3.2.3 Hydrologic and Nutrient Loading

It is possible to estimate the amount (load) of phosphorus and nitrogen being contributed to Laurel Lake by its watershed when an estimate of water flowing into the lake and the concentration of each nutrient in this water is known. Water flowing into Laurel Lake comes from three primary sources: surface water, groundwater, and direct precipitation.

Surface water flows can be estimated from actual flow data or from known relationships for water yield from similar watersheds. Two inflowing tributaries to the lake exist; however, surface water also enters the lake directly during rain events as overland runoff. The average annual flow rate to the lake was calculated to include both sources of flow and was based on the area of the watershed and local precipitation data. An estimate of the rate of groundwater movement into the lake was based on averages obtained for New England lakes and lakes of similar geo-morphometry as well as from direct measurement through the use of seepage meters. Inputs from direct precipitation were determined from long-term climatological data for the region and the known surface area of the lake.

Estimated average water input to Laurel Lake from surface water, groundwater, and direct precipitation is 4.067, 0.435, and 0.57 cfs, respectively, for a total average annual flow of 5.07 cfs (Table 15, Appendix C). This flow will vary appreciably among seasons and weather conditions. Surface water runoff contributes significantly (80.2%) to the total lake inflow, while groundwater inflow (8.6%) and precipitation (11.2%) makes up the remainder. Typically, surface water flow can be further divided into dry weather (background) flows and wet weather (storm) flows. For Laurel Lake, dry weather flows were calculated to be approximately 0.25 cfs, while wet weather flows were calculated to be 3.82 cfs.

Based on total lake volume and the calculated flow through the lake, average detention time was calculated to be 410.5 days (1.12 years) (Table 15). Detention time represents the duration of time necessary to exchange the volume of water in the lake one time. Flushing rate is the inverse of detention time, and represents the number of times per year the lake volume is replaced; for Laurel Lake the flushing rate is about 0.9 times per year. This is a relatively slow flushing rate, but would be anticipated for a large, deep lake with a relatively small watershed.

When detention time is known, a calculation can be made to determine response time (time needed for a lake to fully realize nutrient inputs), which for Laurel Lake ranges between 747 days and 1,246 days. Since Laurel Lake's detention time (410.5 days) is less than its response time, the effect of nutrients entering the lake are not likely to be expressed fully before passing through the system (i.e., the conditions within the lake are not necessarily reflective of the water quality it may receive).

The nutrient water quality data can be placed into further perspective once the values are interpreted as a measurement of the nutrient load to Laurel Lake (Table 16, Appendix C). In order to accurately characterize in-field conditions as precisely as possible with the relatively limited data that was obtained during the field collection effort, the following items were incorporated into the model:

1) Nutrient levels from the in-lake bottom station were relatively high (LL-1B) and disproportionally affected the averages of nutrient concentrations within the basin. In order to correct this problem, average in-lake nutrient levels used during the modeling effort were calculated from surface and middle depths (LL-1S & LL-1M) only.
2) Because the sampling station downgradient of the outlet was not flowing on any of the sampling dates, no data was obtained for this sampling site. Instead, average in-lake nutrient data from the surface station (LL-1S) was used as a substitute for average nutrient concentrations at the sampling station downgradient of the outlet.
3) Precipitation data utilized for modeling was reported as the average annual precipitation for Pittsfield, MA (44.8 inches).

A calculation of minimum nutrient load was made by multiplying the volume of the lake by its flushing rate and the average concentration of the nutrient observed during this study. The minimum phosphorus and nitrogen loads delivered to Laurel Lake were determined to be 0.12 $g/m^2/yr$ (80.0 kg/yr) and 4.61 $g/m^2/yr$ (3,078 kg/yr), respectively, based on the in-lake concentration data collected during this study (Table 16, Appendix B). The actual load of phosphorus or nitrogen will exceed the estimated minimum load as a consequence of loss processes that reduce the in-lake concentration over time. Since phosphorus is viewed as the nutrient that controls productivity in this freshwater lake, emphasis is placed on a more detailed modeling analysis of its loading to Laurel Lake.

A more detailed and realistic estimate of nutrient loading can be obtained by using a combination of actual field data and in-lake modeling theory. Nutrient loads are calculated based on nutrient values measured within the lake and hydraulic features of the lake. The predicted phosphorus load necessary to achieve the values found in Laurel Lake ranges between 0.19 $g/m^2/yr$ (127 kg/yr) and 0.35 $g/m^2/yr$ (234 kg/yr) (Vollenweider 1975, Reckhow 1977) based on this approach (Table 16, Appendix C). The average predicted phosphorus load for all models was 0.26 g/m2/yr (174 kg/yr). The nitrogen load necessary to achieve the observed in-lake concentrations was estimated to be 7.98 g/m2/yr (5,328 kg/yr) (Bachmann 1980) in this manner (Table 16).

Historic accounts document that annual nitrogen loading to Laurel Lake is 8.21 $g/m^2/yr$ (5,479 kg/yr) (Carr Research Laboratory, Inc., 1976). These nitrogen loading values are very similar to those predicted by the Bachmann (1980) model. Interestingly, this study reported that the summer ratio of biologically available nitrogen to phosphorus was 1, indicating that the Lake is very nitrogen limited. Typically, nitrogen to phosphorus ratios less than 15 are indicative of nitrogen limited waterbodies, while ratios in excess of 15 are considered phosphorus limited waterbodies. Based on data obtained by ESS during the 2002 sampling effort, the in-lake nitrogen to phosphorus ratio is 39, indicating that at present Laurel Lake is strongly phosphorus limited.

Vollenweider (1968) established criteria for calculating the phosphorus load below which no productivity problems were expected (permissible load) and above which productivity problems were almost certain to persist (critical load). These loading limits are also based on the hydraulic properties of the lake and depend upon average depth and detention time. The average of phosphorus loads estimated for the lake through in-lake modeling (173 kg/yr) is essentially equivalent to the permissible level of 174 kg/yr, but fortunately considerably lower than the critical level of 347 kg/yr (Table 16). This indicates that phosphorus in Laurel Lake is approaching levels which are likely to result in degraded water quality conditions in the future if left unchecked. This knowledge is useful for determining the value of the various management alternatives, and can be particularly helpful when prioritizing their order of implementation under fiscal constraints.

Similar loading limits for nitrogen have not been established, owing to the less predictable relationship between nitrogen, lake hydrology, and primary productivity. Although nitrogen data are very useful in understanding lake conditions and processes, phosphorus is the logical target of management actions aimed at controlling algal biomass and plant growth.

An itemized phosphorus load can be developed when nutrient data from each of the various sources has been determined. Annual phosphorus loading itemized by sources to Laurel Lake suggests that the actual load of phosphorus could be lower than the load indicated by the in-lake models or concentration. The wet weather surface flow inputs stand out as the dominant influence at just over 93.8 kg/yr, and representing more than 73% of the total estimated phosphorus load (Table 17). In contrast, the phosphorus load being contributed via direct precipitation and groundwater were estimated to be approximately 12% and 5%, respectively.

These estimates are based on the relatively limited number of samples collected over a very short period of time (one summer) and could be greatly influenced by the conditions prior to the commencement of the sampling or by the size of the particular storm events sampled.

A third approach for estimating the nutrient load to Laurel Lake, that may be the most insightful method when long term data are not available, would be to calculate the nutrient load generated by each acre of land in the watershed based on its use (Tables 18 and 19). Attenuation coefficients are used to calculate the total load that actually would be expected to reach the lake based on the structure of the watershed and its relative distance from the lake. The watershed to Laurel Lake is relatively small and is primarily comprised of forested, agricultural, and residential areas. An average of 48% of the phosphorus and nitrogen load generated within the watershed would be expected to reach Laurel Lake; however, this varies for each watershed sub-basin.

Tables 18 and 19 summarize the above calculation for the Laurel Lake watershed. The expected average nitrogen load to Laurel Lake using these calculations would be roughly 2,021 kg/yr and the expected average phosphorus load to the lake would be roughly 330 kg/yr. The phosphorus load, of primary interest, is significantly higher than the effective load (i.e., 173 kg/yr) suggested by in-lake models. It is likely that much of the incoming phosphorus to the lake is rapidly taken up by aquatic plants and algae growing in the lake.

Several historic studies of Laurel Lake were provided to ESS by the LLPA for the purpose of determining historic hydrologic and nutrient loads. Unfortunately, in the majority of cases, historic reports did not include all of the necessary hydrologic and nutrient water quality data needed for modeling. One historic study, conducted by Kofta Technologies Services (1998), did report the necessary parameters needed for ESS to model the lake's hydrologic and nutrient budgets. However, some of this data was reported in unusual units and in an inconsistent fashion throughout the report, rendering it unreliable. Representatives associated with the 1998 study, currently affiliated with the Tri-Town Health Department (Lee-Lenox-Stockbridge), were contacted regarding this matter and stated they would attempt to clarify this matter in the near future.

3.2.4 Biological Community

3.2.4.1 Macrophytes

Macrophytes refer to the more complex aquatic plants found in association with aquatic environments. These plants may or may not have roots and can be broadly grouped into three categories based on their growth habits: the emergent plants, the floating-leafed plants, and the submerged plants. Macrophytes are critical elements of the littoral zone (shallow water areas), providing structure and habitat for fish and invertebrate communities, and helping to mediate some of the nutrient interactions between land and water. However, in areas subject to elevated nutrient and sediment loads, aquatic plant growth of "nuisance species" may become excessive and result in significant habitat degradation. High densities of "nuisance" plant species may choke out native wetland vegetation, displace animals dependent upon open water areas, hinder recreational activities and impede the downstream connectivity of waterways.

Historic reports indicate that invasive, exotic plant growths have been a concern to Laurel Lake watershed residents for some time. Specifically, previous studies document the establishment of "massive beds" of *Myriophyllum spicatum* var. *exalbescence* up to 5 meters in depth within the northern and western coves of the basin. In addition, the exotic species curly pondweed (*Potamogeton crispus*) has been documented at nuisance levels within the basin, becoming dominant during the late summer (Soukup 1974, Livingston and Bentley 1971). In addition, Livingston and Bentley (1971) reported that a well-defined zonation of plants occurs within the lake, most notably consisting of a nodding waternymph (*Najas flexilis*) zone from 1.5 to 3 meters in water depth.

Aquatic plants in Laurel Lake were mapped by ESS on August 28th, 2002, shortly after the time that would be considered the peak of the growing season. A description of the location and size (amount of area covered) of major plant beds and an estimate of plant percent cover throughout the entire lake's surface area is presented in Figures 7 and 8. In addition, a list of all plant species identified in Laurel Lake has been prepared (Table 10).

The aquatic plant community of Laurel Lake on August 28, 2002 was dominated by coontail (*Ceratophyllum demersum*), waterweed (*Elodea canadensis*), Eurasian watermilfoil (*Myriophyllum spicatum*), brittle waternymph (*Najas minor*), large-leaved pondweed (*Potamogeton amplifolius*), and wild celery (*Vallisneria americana*) (Figure 7, Table 10). Other commonly observed aquatic plants include watershield (*Brasenia schreberi*), bladderwort species (*Utricularia spp.*), water smartweed (*Polygonum punctatu*), and numerous pondweed species (*Potamogeton* *spp.*). In total, 36 aquatic or semi-aquatic plant species were identified within Laurel Lake during 2002 (Table 10).

The plant community of Laurel Lake is characterized by the presence of invasive, aquatic plants, which commonly infest New England lakes and ponds. Elevated abundances of plant growths (i.e., >50% plant cover) were present in three general locations within the lake basin (the northern cove downgradient of Sargent Brook, the western cove downgradient of the unnamed tributary, and the southern area near the outlet structure). These beds of dense aquatic plant growths currently account for a significant portion of the shallow water area of the lake (approximately 38 acres in total) (Figure 8).

Particularly significant are the dense beds of floating-leafed and submergent plants, such as watershield, coontail, waterweed and pondweeds, which are well-established downgradient of both inflowing tributaries. These species were documented to occur at abundances that would impede recreational activities and significantly impair habitat quality for native flora and fauna through the reduction of fundamental, life-sustaining resources such as oxygen, space and light.

Also of concern is the distribution of exotic plant species, Eurasian watermilfoil and brittle waternymph, located throughout the basin. These aggressive species may out-compete native species for resources, resulting in the displacement of native flora from the lake. Populations of these species should be continuously monitored in order to detect any significant changes in distribution within the basin or signs of population expansion. The high water clarity in Laurel Lake and gently sloping shorelines in many parts of the basin provide suitable habitat for the continued colonization of milfoil growths into deeper portions of the lake.

3.2.4.2 Phytoplankton

Phytoplankton communities are considered by the scientific community to represent very good indicators of water quality (Triphonova, 1988) and are often used as an early warning to predict changes in communities further up in the food chain (Steiman 1998).

Phytoplankton were collected from Laurel Lake on August 28th, 2002. The most common species found were *Oocystis pusilla* (phylum *Chlorophyta*; 33%, *Rhodomonas minuta* (phylum *Cryptophyta*; 21%), *Cryptomonas erosa* (phylum *Cryptophyta*; 17%), and *Chroococcus minimus* (phylum *Cyanophyta*; 12%) (Table 11). The most abundant by volume, were *Oocystis pusilla* (33%), *Cryptomonas erosa* (28.9 %) *and Oscilatoria sp.* (phylum *Cyanophyta* 19.9%). When found in large densities, the *Cyanophta* (commonly referred to as bluegreens) may occur as filamentous growths or as an aggregation of spherical cells and produce bottom or surface mats. Some forms of these algae produce toxins, which are harmful to aquatic fauna and humans. The *Chlorophyta* (commonly referred to as the greens) may occur as filamentous, single celled or as colonial growths. These algae may also form mats and cause water discoloration. These algae are less toxic than the *Cyanophyta*, but do impart some objectionable tastes and odors for recreational enthusiasts. The *Cryptophyta* generally consist of unicellular protozoan (swimming) organisms. These species occur in both freshwater and marine environments and are often considered to be an important food source for smaller plankton, including ciliates and dinoflagellates.

The total phytoplankton biovolume and density is 113,502 μm^3/ml and 381 individuals/ml, respectively. In general, phytoplankton densities <500 individuals/ml are considered low; however, this threshold value may be variable depending on geographic region of the state and can be misleading if very large aggregates of individuals form colonies and filaments which are typically counted as one individual. These data suggest that the phytoplankton community in Laurel Lake may be considered low at present. Historic studies of Laurel Lake indicate that samples contained 1,324 areal standards per millimeter in 1976 and therefore, the lake was reported to be in fair condition (Carr Research Laboratory, Inc., 1976).

The Trophic State Index (TSI) refers to the amount of organic matter produced by the planktonic algae in a waterbody. Lakes that produce lots of algae are called "eutrophic" (TSI = 51-80%) or highly productive, while those with little algae are called "oligotrophic" (TSI = 0-30%), and in-between states are termed "mesotrophic" (TSI = 31-50%). The TSI for Laurel Lake is 34.2% (Table 11). These data indicate that water quality conditions at Laurel Lake are generally healthy and that the lake may be considered in a mesotrophic condition.

3.2.4.3 Zooplankton

Zooplankton are microscopic animals that freely float in open water, eat bacteria, algae, detritus and sometimes other zooplankton and are in turn eaten by planktivorous fish. Laurel Lake had a relatively low zooplankton density when it was sampled on August 28th, however, zooplankton densities can vary greatly according to season and even time of day. The lake was found to support a diverse zooplankton community (Table 12) that was dominated by the Cladoceran species *Daphnia mendotae* (a member of the arthropod class: crustacea) and the Rotiferan species *Keratella cochlearis*. An evaluation of the density of edible zooplankton species can be made based upon the availability of the different species as food items for particular species of fish, in particular salmonids, (Brooks 1969) (Kerfoot 1980), (Zaret 1980), (Carpenter & Mitchell 1993). In Laurel Lake the percentage of these edible zooplankton (a fraction of the arthropod zooplankton only) was found to be 73.1% (Table 12). Even though the edible zooplankton percentage was high which is indicative of a healthy "intensity of planktivory" (Allan Vogel pers. comm.), the zooplankton samples are indicative of a reduced or limited grazing potential and may indicate an inadequate food supply for small fish due to the low density (and thus biomass) overall.

3.2.4.4 Invertebrates

ESS conducted an assessment of the benthic organisms in Laurel Lake on September 26th, 2002. Invertebrates were sampled using a D-frame net with a 500 µm mesh size at three locations within the lake: the area downgradient of Sargent Brook, the area downgradient of the outlet, and an area along the southern edge of the basin (Figure 5). At each sampling location the net was used to disturb the sediments and agitate plants in order to collect a sample representative of the resident benthic community.

The sampled areas downgradient of Sargent Brook and downgradient of the outlet were representative of fast flowing or *lotic-type* habitats. Detritus overlying a gravel and cobble substrate characterized both sampling locations. The sampled location along the southern edge of the basin was characteristic of a ponded or *lentic-type* habitat. At this location, a variety of substrate types were observed including silt, sand, gravel, and cobbles.

Twenty-seven invertebrate taxa were identified from the three invertebrate sampling locations (Table 14). The majority of the taxa from the areas downgradient of Sargent Brook and downgradient of the outlet (particularly the riffle beetles and stoneflies) are indicative of flowing waters. Also observed at these locations was the alderfly (*Sialis spp*.), which is often associated with habitats that possess accumulated detritus. The majority of other invertebrate taxa identified from all sampling locations may be considered generalists (opportunistic species) with regard to habitat preferences and are indicative of clean and moderately clean habitats. Moreover, several "sensitive benthos" species (EPA 2002) (stoneflies, crayfish, alderflies, mayflies and riffle beetles) were observed from several samples. It should be noted, however, that some of the invertebrate species obtained from the area along the southern edge of the basin may be regarded as moderately tolerant of pollution. In addition, the presence of pouch snails (*Physella* sp.) at this sampling location may be indicative of nutrient enriched conditions (EPA 2002).

3.2.4.5 Fish, Wildlife, and Critical Habitat

Information obtained from the Massachusetts Division of Fish and Wildlife indicates that Laurel Lake is stocked biannually with trout (usually rainbows and browns) in the spring and fall in order to maintain populations throughout the year.

MassWildlife referred to Laurel Lake as one of the “best bets” for largemouth bass fishing in the state of Massachusetts. Other fish species reported for the lake include largemouth bass, chain pickerel, yellow perch, white perch, rock bass, bluegill, pumpkinseed, black crappie, smallmouth bass, carp, brown bullhead, white sucker, rainbow smelt, and golden shiner. Broodstock salmon are also stocked into the lake whenever the fish are available.

ESS contacted the Massachusetts Division of Fisheries & Wildlife to obtain information on threatened or endangered species that are listed in the Laurel Lake watershed (Figure 1) and an area approximately 2,000 feet downstream of the outlet. A letter from the Massachusetts Division of Fisheries & Wildlife dated October 24th, 2002 (Appendix B) indicates that this area intersects priority habitat for the hairy honeysuckle (*Lonicera hirsuta*), an endangered plant species, the tule bluet (*Enallagma carunculatum*), a damselfly species of special concern, hemlock parsley (*Conioselium chinese*), a plant species of special concern, and Labrador bedstraw (*Gallium labradoricum*), a plant species of special concern. In addition, the study area is near the priority habitat for Hill’s pondweed (*Potamogeton hillsii*), a plant species of special concern and the Jefferson salamander (*Amystoma jeffersonianum*), an amphibian of special concern. However, it is important to note that none of these priority habitats occur in the investigated areas downstream of the outlet structure.

Much of Laurel Lake is surrounded by forested land, which provides suitable habitat for wildlife, particularly birds and small mammals (Table 2). ESS personnel noted wildlife and wildlife indicators during each field visit to Laurel Lake and these data, along with data from the NEWild program (Thomasma et. al, 1999) have been summarized in Table 13. In particular, ESS personnel noted the presence of large flocks (~20 individuals) of Canada geese (*Branta canadensis*) utilizing the basin on several dates. Large populations of waterfowl can contribute a significant source of nutrients (up to 1 kg/bird/year of phosphorus) into the waterbody through their defecation. This additional input of nutrients can serve to fuel nuisance algal blooms and aquatic plant growths and in extreme circumstances may hinder activities for recreational enthusiasts as a result of introduced bacteria and associated pathogens.

4.0 MANAGEMENT FEASIBILITY ASSESSMENT FOR LAUREL LAKE

4.1 Management Objectives

Just how a lake is managed will depend upon its intended uses, which are decided partly based on environmental law (e.g., protection of certain habitats or species) and partly on human needs and desires. Laurel Lake is ideally suited to serving a variety of human purposes, including boating, fishing, skating, and passive aesthetic enjoyment. Such uses are threatened or impaired during the growing season due to the growth of nuisance aquatic weeds. Laurel Lake also serves as habitat for a variety of aquatic and semi-aquatic life forms, both plant and animal. This lake is not a potable water supply, although it interacts with groundwater. The priority of uses has not been completely defined, but enjoyment of the lake is perceived to have decreased in recent years as a result of increasing plant densities, particularly the density of the invasive and exotic species, Eurasian watermilfoil. The goals of the management section of this report are to assess the long-term management options for Laurel Lake.

The selection of management actions should be driven by the long-term management objectives of the Laurel Lake community. Management for recreation is not the same as management for fish yield, which is dissimilar to management for wildlife viewing. The recreational goal is believed to be appropriate for Laurel Lake at this time, as this water body is intended to provide opportunity to a wide variety of users as evidenced by the two public beaches, the state boat ramp and other privately owned shoreline amenities. Management goals for Laurel Lake should include: providing adequate habitat for waterfowl, fish, reptiles and amphibians; unhindered opportunity for motorized and non-motorized watercraft; and aesthetic appeal for passive users. Maintaining the generally good water quality is also a priority.

More specifically, physical features of the lake are to be managed to provide appropriate fish habitat, maximize safety for human users, minimize shoreline erosion, and prevent excessive plant growths or other abnormal biological nuisances. Short-term management effort is clearly needed with regard to rooted aquatic plant nuisances, while long-term management should be directed toward protecting water quality and providing a sustainable solution to the rooted aquatic plant problem.

With the preferred uses in mind, the following specific management objectives are suggested:

1. Control and limit aquatic plant growths to levels appropriate for habitat enhancement, recreational use, and safety considerations.
2. Curtail excessive nutrient (phosphorus) and related pollutant inputs associated with storm events, thereby improving water quality.
3. Further investigate the potential sources of ammonia-nitrogen to groundwater, particularly along the shoreline segment defined in this study as Segment 1 (west of the Sargent Brook inlet).
4. Establish a cost-effective monitoring program that provides early warning of potential problems and that tracks the progress of any implemented management measures in achieving stated goals.

4.2 Management Options

The range of options for managing Laurel Lake is not especially large, particularly given that a downstream water user has a right to the top 12 feet of water. Management methodologies can be subdivided in a number of ways, but those subdivisions tend to deal with the details of application, not the fundamental approach. With a specific management objective in mind, management methodologies can be examined to determine the applicability and feasibility of options for meeting that objective. A review of these management options for the four suggested management objectives is presented below.

4.2.1 Control and Limit Aquatic Plant Growths

Readily available phosphorus in the water column, good water clarity, and an expansive, organically-rich soft substrate in the shallower portions of the lake contribute to excessive growths of nuisance aquatic plants, predominantly Eurasian watermilfoil, and to some extent, large-leafed pondweed. These growths occur throughout much of the lake's littoral zone. The rooted plant growth is at a level that is obviously impairing the recreational utility of the lake, particularly during the summer months. When aquatic plants are allowed to grow to these densities, they have reduced cover and food value to fish or waterfowl. In fact, dense plant growth as observed in the major coves of the lake, can actually be a detriment to fish health (causing fish die-offs) during the nighttime hours when plants can consume oxygen within the water column resulting in anoxic conditions.

Eurasian watermilfoil (*Myriophyllum spicatum*) is a perennial plant with stems arising from short rhizomes with fibrous roots. This species of milfoil is locally abundant and aggressive in numerous lakes and ponds throughout the Berkshires and New England. Milfoil plants can flower and may produce viable seeds; however, dispersal typically relies on vegetative reproduction (plant fragmentation).

Control of Eurasian milfoil has been extremely successful when attempted. Biological controls (milfoil beetles), benthic barriers, hydro-raking, or dredging could all provide some level of control. Traditional harvesting, which has rarely been capable of eradicating any species would prove problematic in Laurel Lake. Traditional harvesting is not a recommended approach since milfoil fragments would be likely to spread to currently uncolonized areas.

Although complete eradication of milfoil is unlikely, the plant does not have to be the primary component of the plant community and should not exist where any substantive recreational and habitat value are desired. Control methods for this species are similar to those of many rooted aquatic plants.

The large-leafed pondweed currently present in Laurel Lake is a native species, however, this species can grow to dominate a lake. Control of large-leafed pondweed can be achieved by either chemical or mechanical (harvesting) methods; however, given the presence of milfoil within the lake, it would be unwise to use a mechanical approach. Chemical treatment would consist of treating with fluridone (trade name Sonar).

A full discussion of each of the plant management alternatives that might be employed in Laurel Lake is provided below.

Dredging (Not Recommended)

Removing nutrient rich sediments and deepening waterbodies is sometimes used to control nuisance aquatic vegetation. This would be a major undertaking at Laurel Lake, when considering both the associated permitting issues and project expense. Most successful dredging operations designed to control rooted plant growth target reaching a minimum depth of 8-10 feet in order to preclude light for plants to grow. In Laurel Lake, the target depth would need to be substantially greater (between 15 and 20 feet) as a result of the lake's clear water. Since a large portion of the lake already exceeds this depth, dredging would actually need to be conducted around the perimeter of the lake resulting in extremely steep, and potentially undesirable, bottom slopes.

Dredging may be applicable on a limited basis, possibly focusing on specific areas in which increasing the depth and removing sediments and associated plant biomass would be desirable. Hydraulic or suction dredging can be performed while the lake is full. This involves the use a barge with an auger head that grinds the lake sediments into a slurry and pumps them to a nearby containment basin. Locating and obtaining suitable upland location near the lake to create an adequate containment basin may prove to be the greatest obstacle to overcome. Another concern would be whether the desired 15-20 foot depths could be attained, since most suction-type dredges can only slurry the unconsolidated sediments and penetration into an existing "hard" refusal layer is not possible. If depths of only 15 feet or less could be achieved, rooted plant growth would not be discouraged.

The costs associated with a limited dredging project of just 8-10 acres would be substantial. Feasibility, design and permitting fees alone would be expected to exceed $50,000. The actual operation costs would ultimately depend upon the approach and amount of material being dredged. Assuming a conservative dredging estimate of 8 feet of sediment over eight acres yields a sediment volume of nearly 105,000 cubic yards. Given a dredging unit cost of $10-$15/cubic yard yields a dredging cost of roughly $1,050,000-$1,575,000. Costs may also run higher depending upon certain permit conditions or other complicating factors. It should also be noted that dredging does not always eliminate nuisance aquatic vegetation problems, and other in-lake management activities may still be required in order maintain desired conditions.

The next steps in the pursuit of a dredging project, should such a project be desired, would be assessment of funding options and initiation of the permitting process (ENF filing for MEPA review). These activities might be expected to cost between $15,000 and $20,000, but are essential to facilitating such a project.

Drawdown (Recommended for Further Consideration)

Drawdown involves lowering the water level of a lake to expose bottom sediments and associated plants to drying and/or freezing. Drawdown sometimes offers a low or no-cost management alternative. It is suitable for use in deeper waterbodies, where an ample water volume will remain to support fish and other aquatic organisms. Laurel Lake is sufficiently deep and could be lowered enough to control rooted vegetation without adversely affecting the aquatic fauna and adjacent wetland areas.

Drawdown can be effective against species which reproduce mainly by vegetative means (such as milfoil), but is generally ineffective against annual plants which depend on seeds for regrowth each year (such as large leaf pondweed), as the seeds are often stimulated by the drawdown rather than destroyed.

Drawdown can be conducted at any time, but the interaction of drying and freezing is preferred suggesting that late autumn and winter drawdown will be most effective. Performing an effective drawdown depends on the ability to control the water level and the configuration and type of bottom sediments, which must at least partially de-water. Laurel Lake is equipped with an appropriate means for implementing a drawdown of sufficient depth (>6 feet) necessary for the purpose of managing plants. However, it is reported that release of water from the lake is at the discretion of and controlled by a downstream paper mill. If drawdown were to be considered further, it would be essential to determine whether a winter drawdown program, as described above, would be acceptable, at least on a trial basis.

Costs to initially design and permit such a drawdown would be approximately $12,000, but would be essentially zero once the program became established. Permitting would need to demonstrate that the project meets MADEP's interim guidelines for drawdown, and permission would need to be granted through the local Conservation Commission as a Notice of Intent (NOI).

Bottom Water Aeration (Not Recommended)

Aeration of a lake's bottom waters is sometimes effective at reducing the frequency of algae blooms by reducing or eliminating the release of phosphorus from lake sediments. Aeration does not offer any control over vascular (rooted) plants. Since algal blooms are not a problem in Laurel Lake at this time, aeration is not a recommended management technique.

Benthic Barriers (Recommended on a Limited Basis)

Benthic barriers are negatively buoyant materials, usually in sheet form, which can be applied on top of plants to limit light, physically disrupt growth, and allow unfavorable chemical reactions to interfere with further development of plants. A variety of solid and porous materials have been used. Commercial production of effective materials has occurred since the late 1970's, although creative lake managers found ways to cover plants long before then. In theory, benthic barriers should be a highly effective plant control technique, at least on a localized scale. In practice, however, there have been many difficulties in the deployment and maintenance of benthic barriers, limiting their utility in the broad range of field conditions.

The ability of vegetative fragments to recolonize porous (mesh) benthic barriers has made porous barriers less useful for combating infestations by milfoil on any but the smallest scale, as sheets must be removed and cleaned at least yearly. Solid barriers have been more useful, although gas entrapment has been troublesome; billowing occurs without venting and anchoring, yet appropriate venting and anchoring creates problems for eventual maintenance or redeployment. Expense dictates that only limited areas can be treated without re-use of a deployed barrier. Nevertheless, benthic barriers are capable of providing control of milfoil, and other undesirable growth, on at least a localized basis and have such positive side effects as creating more edge habitat within dense plant assemblages and minimizing turbidity generation from fine bottom sediments.

Plants under the barrier will usually die completely after about a month, with solid barriers more effective than porous ones in killing the whole plant. Barriers of sufficient tensile strength can then be moved to a new location, although continued presence of at least solid barriers restricts recolonization.

Cost and labor are the main factors limiting the use of benthic barriers in most lakes, and would be prime deterrents in Laurel Lake. Cost per installed square foot is on the order of $1.20, leading to an expense of over $50,000 per acre. Bulk purchase and use of volunteer labor can greatly decrease costs, but use over the entire area infested with nuisance vegetation is highly unlikely.

The application of solid barriers such as Palco Pond Liner is useful in controlling small (<1 acre) beds of rooted aquatic plants where the material is left in place and where effort is expended on removing any peripheral growths. Redeployment of barriers will reduce the overall cost of this approach and is consistent with the goal of restoring a desirable plant assemblage to areas infested with milfoil, but is likely to require additional effort at the original application site to prevent recolonization. Such effort might include hand harvesting of milfoil plants for at least two growing seasons after removal of the barrier, or might involve augmentation of the native population in the formerly covered area.

Benthic barriers offer some potential for localized control of nuisance vegetation in Laurel Lake. The use of benthic barriers by individuals or small groups would seem to be a logical approach to weed control in critical use areas or by individual property owners.

Biological Controls (Recommended as a Possible Approach)

The purpose of a biological control is not to eradicate a species, but to prevent it from becoming problematic. Biological controls do not work as rapidly as other management techniques. Depending on the size of the infestation, it may take 5-7 years before any level of control is observed.

Eurasian milfoil has been shown, at least experimentally, to be able to be controlled using "milfoil beetles" (*E. leconteii*). The larvae of this beetle burrow into the stems of the milfoil plant, consuming the plant tissue within the stem, which ultimately results in the collapse of the plant to the pond bottom. As a control technique, the beetle larvae are introduced to a lake by placing infested milfoil strands within the targeted milfoil beds of the lake. Costs for this treatment are variable, however, typically a strand of infested milfoil typically will cost $1 "installed". Costs for milfoil beetle control in Laurel Lake would be expected to cost between $8,000 and $14,000 with an additional $4,000 recommended for monitoring of potential effects. This approach has been reportedly implemented in Goose Pond in Lee, Massachusetts, with varying degrees of success. The best results are achieved in controlling milfoil in lakes with dense, monotypic stands of milfoil with several years being required to measure a positive effect.

Biological controls for the other problem species, including large leaf pondweed, are almost unknown. An herbivorous fish (*Ctenopharyngodon idella*, the grass carp) has been used for general macrophyte control in smaller lakes in Connecticut and New York, but has not shown a preference for any one species. Given little choice, it might reduce plant densities in Laurel Lake, but the stocking of this non-native fish is currently illegal in Massachusetts.

Harvesting (Not Recommended)

Harvesting includes a wide range of plant removal techniques; the simplest form is hand pulling of selected plants. Successively more complicated approaches include manual cutting, mechanical cutting and collection, aquatilling (underwater rototilling), suction dredging, and hydro-raking (mechanical whole plant harvesting with some collection of sediment). Harvesting can be an effective longer-term control technique when the target plants reproduce by seed and harvesting is timed properly to eliminate annual seed production. Usually several successive years of effort are necessary, as seeds deposited prior to management can be expected to germinate over more than one year. There is some evidence that intense harvesting of plants reproducing by vegetative propagation limits survival over the winter, but the effect varies by species and location. Harvesting can be an effective short-term control strategy for any aquatic plant nuisance, analogous to mowing the lawn.

Harvesting techniques which allow plant fragments to escape are generally not appropriate for longer-term control of species that reproduce vegetatively, and may actually be counterproductive to control. While short-term control may be achieved in the target area, long-term control is rare since viable plant fragments typically colonize new sites. Any of the cutting techniques without collection, and often even with collection effort, can be expected to result in the spread of vegetatively reproducing species. For that reason, only harvesting approaches with a very low probability of fragments being left in the water (e.g., hand harvesting or hydro-raking) are appropriate for longer-term control of the milfoil problem in Laurel Lake.

Harvesting would be an acceptable management alternative for the large-leafed pondweed problem; however, such efforts could only be conducted *after* Eurasian watermilfoil has been controlled chemically (with fluridone – see below) or biologically (with weevils). Harvesting of large-leafed pondweed it is not recommended solely due to the risk of fragmenting and spreading the milfoil, which often occurs within the same plant beds.

Costs associated with hydro-raking in Laurel Lake would depend upon the area to be harvested. Hydro-raking generally costs $160/hour and in a lake of this size would require a second boat at a cost of $120/hour to efficiently transport the removed plant biomass to shore. It generally takes between 12 to 24 hours of time to hydro-rake one acre depending upon the type of plant and the overall plant density. If hydro-raking were employed to remove targeted plants from all of Laurel Lake the total cost for the project would range between approximately $65,000 and $130,000 for approximately 19 acres of plants from areas with greater than 50% coverage and depths of less than 8 feet (the depth to which a hydro-rake can effectively harvest). In addition, trucking costs for removal of the plant material will range from $50,000 to $75,000 assuming a contracted company is hired. Some discount on the entire project might be achieved; perhaps 10%, due to economies of scale, however this would still be an expensive undertaking.

Although it is understood that limited hydro-raking is currently ongoing at Laurel Lake on an annual basis, it appears that this approach is only effective in a very limited area in the immediate vicinity of the public beaches. Given other possible alternatives, and the risk of exacerbating the milfoil problem, hydro-raking or any other form of harvesting is not a recommended approach for Laurel Lake.

Chemical Control (Recommended)

There are few aspects of plant control that generate more controversy than chemical control through the use of herbicides, which are a subset of all chemicals known as pesticides. Part of the problem stems from pesticides which have come on the market, enjoyed widespread use, been linked to environmental or human health problems, and been banned from further use. Many pesticides in use even 20 years ago are not commonly used or even approved for use today.

Yet as chemicals are an integral part of life and the environment, it is logical to seek chemical solutions to problems such as plant species which grow to nuisance proportions, just as we seek physical and biological solutions. Current pesticide registration procedures are far more rigorous than in the past. While no pesticide is considered unequivocally "safe," a premise of federal pesticide regulation is that the potential benefits derived from use outweigh the risks when the chemical is used according to label restrictions.

The most cost-effective and appropriate means by which to achieve the goal of reducing aquatic weed biomass in Laurel Lake over the short term would be chemical treatment. Among the variety of herbicides available today, only one has potential applicability for the nuisance plant species found in Laurel Lake. This is fluridone (tradename Sonar), a systemic chemical that affects target plants by inhibiting critical metabolic pathways after uptake through roots, leaves or shoots. Fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4[1H]-pyridinone) is the only approved herbicide that would be recommended for controlling milfoil, the most abundant nuisance species in Laurel Lake. It should be possible to use fluridone at a dose of 15 to 20 ppb (parts per billion) to selectively remove milfoil and perhaps weaken the large-leafed pondweed while enabling the native species to survive and recolonize areas of the lake formerly occupied by nuisance species. Fluridone is reported to have been applied to the pond located at the Fox Hollow Apartment complex for the purposes of controlling Eurasian watermilfoil. This property is within the Laurel Lake watershed and the treatment was permitted through the Lee Conservation Commission.

Fluridone, which is the active ingredient in Sonar, obtained Federal registration in 1986 and has been in widespread use since the late 1980's. It currently comes in two formulations, an aqueous suspension (Sonar AS) and a slow release pellet (Sonar SRP). Fluridone inhibits carotene synthesis, which in turn exposes the chlorophyll (active photosynthetic pigment) to photodegradation. Most plants are negatively sensitive to sunlight in the absence of protective carotenes, resulting in chlorosis of tissue and death of the entire plant with prolonged exposure to a sufficient concentration of fluridone. Fluridone has been used to control milfoil as well as certain other species in many state waterbodies with up to three years of success from a single treatment.

For susceptible plants, lethal effects are expressed slowly in response to treatment with fluridone. Existing carotenes must degrade and chlorosis must set in before plants die off; this takes several weeks to several months, with 30-90 days given as the observed range of time for die off to occur following treatment. Fluridone concentrations should be maintained in the lethal range (15 to 20 ppb) for the target species for at least three weeks. This presents some difficulty for treatment in areas of substantial water exchange, but the slow rate of die off minimizes the risk of oxygen depletion or the formation of algal blooms. The need for prolonged exposure to an adequate fluridone concentration also creates a potential conflict with use of waters for irrigation or other agricultural purposes. Laurel Lake water is reportedly drawn from shallow private wells along its shoreline. Additional well supplies including municipal, agricultural and commercial wells would need to be further investigated prior to permitting.

Fluridone is considered to have low toxicity to invertebrates, fish, other aquatic wildlife, and humans. It is not known to be a carcinogen, oncogen, mutagen or teratogen. Substantial bioaccumulation has been noted in certain plant species, but not in animals. The U.S. EPA has designated a tolerance level of 0.5 ppm (mg/l or mg/kg) for fluridone residues or those of its degradation products in fish or crayfish. The U.S. EPA has set a tolerance limit of 0.15 ppm (150 ppb) for fluridone or its degradation products in potable water. The recommended dose in Laurel Lake would be no more than 0.02 ppm (20 ppb).

Label restrictions for Sonar AS include maintenance of a distance of one quarter mile (1,320 ft) between treatment locations and potable water intakes, although there are no federal restrictions on the use of treated water at concentrations <0.02 ppm (20 ppb); the required distance is assumed to allow sufficient dilution to eliminate all possible effects from water collected by intakes. In addition, most forms of water filtration, including charcoal filtration, would eliminate any fluridone residues that may persist within the water column.

It would be necessary to maximize contact time in Laurel Lake to ensure effectiveness and limit downstream impacts, but this could be accomplished if treatment is conducted during late summer when conditions are typically drier. Pelletized Sonar SRP could be used, but the nature of the organic mucks in the pond may cause incomplete release of fluridone from the pellets through "plugging." Consequently, use of the liquid Sonar AS is preferred in this case. It may be appropriate to apply sequential treatments (2 likely) to minimize downstream transport while maintaining the desired concentration throughout the lake.

Given the species present in Laurel Lake, treatment with the systemic herbicide Sonar, which has fluridone as its active ingredient, would be likely to provide the desired range and longevity of control over the plant species present with the least number of adverse side effects. Costs would range from about $325-375 per treated acre. Assuming a 165-acre treatment of Laurel Lake, an initial treatment cost of approximately $53,500 to $61,500 would be expected with repeat treatments on at least a 3- to 4-year cycle. This cost would include appropriate funding for permitting this effort though both the Lee and Lenox Conservation Commissions and includes a limited budget for follow-up monitoring. However, issues with respect to use in an aquifer zone, downstream users of water, and possible downstream impacts may have to be thoroughly investigated before permitting can be undertaken. This could add another $3,000 - $5,000 to the cost, but will determine whether or not the treatment can be performed. Given the potential for success with this form of weed control compared to other described options, chemical control with fluridone is likely to produce the best control with the fewest impacts to native plants, wildlife or other users of the lake.

Costs in the permitting process could escalate if there is any significant opposition to the treatment. Permits could be denied, appealed, or rigorously conditioned, the last of which could add cost both through constraints on the treatment process and monitoring expense. Costs cannot be precisely estimated, but the cost of the treatment could rise as much as 25%, and could require additional monitoring costs specific to the effects of chemical treatment.

Although the decision whether to employ the use of chemicals is entirely up to the community and watershed stakeholders, treating the nuisance vegetation with a U.S. EPA/MADEP registered aquatic herbicide will probably be the most cost-effective management alternative at Laurel Lake, particularly if coupled with a partial lake drawdown during treatment. Treatment with fluridone will provide for species selective plant control. Typically a late spring or early summer treatment will provide a minimum of two seasons worth of control and possibly three or four years of control. Plant regrowth in subsequent seasons is often reduced, allowing reductions in the frequency of chemical application required.

4.2.2 Curtail Excessive Contaminant Loading

Existing water quality within Laurel Lake is generally acceptable or superior for most intended uses of the lake (boating, wildlife viewing, fishing, etc.). However, concentrations of phosphorus, considered to be the most important plant nutrient, were relatively high during storm events in both of the major tributaries to the lake. Although not currently a problem, the condition may worsen as additional development of the watershed occurs.

The loading of other contaminants such as sediment, nitrogen, bacteria and salt to Laurel Lake is most likely erratic and largely a function of episodic storm events and seasonal conditions. The two tributary sites that were monitored were found to presently be delivering moderate contaminant loads; this would be expected given the extent of watershed development.

Loading analysis suggests that the phosphorus load to Laurel Lake is nearly equal to the permissible level, suggesting that eutrophic conditions may soon be experienced in the lake if loading increases. Preventative management actions within the drainage basin are justified, and primary consideration should be given to managing nutrient (especially phosphorus), sediment and even fecal coliform inputs. Stormwater runoff is believed to be responsible for a major fraction of the phosphorus load. Possible actions include behavioral modifications, increased street sweeping and catch basin cleaning, and additional land use planning.

Behavioral Modifications: Behavioral modifications include alteration of individual or group practices that lead to increased runoff or pollutant loading. Actions relating to lawn care, yard waste disposal, automotive cleaning and maintenance, and deicing would be likely targets for this approach. Modifications are usually attained by a combination of education and regulation, but there are practical limits in an urban environment. Most behavioral controls are best implemented on a voluntary basis, but are unlikely to provide more than a 5 to 10 percent reduction in loads. Mandatory controls are better suited to situations of clear non-compliance, as with illegal hook-ups to the storm drainage system or Title V violations. Since many of the homes surrounding the lake and within the watershed area are sewered, it is likely that Title V violations are occurring in a relatively limited number of homes. Further study should be conducted to identify specific violations or to identify areas in which stormwater runoff quality is exceedingly poor. Such a study might require a search of the Board of Health records for systems that are not conforming to Title V specifications or may involve expanded monitoring of discharges at key locations within the watershed to define any "hot spots." Funding on the order of $8,000 is estimated be necessary, although some cost savings may be achieved by having volunteers conduct their own research at the Board of Health in the towns of Lee and Lenox.

Another significant source of contaminant loading is often more controversial. The presence of waterfowl is generally considered an aesthetic amenity and indicator of a healthy aquatic system. However, an overabundance of waterfowl, and in particular, geese, has definite implications on system conditions and recreational utility. The presence of geese (and other waterfowl that conduct land-based foraging) at Laurel Lake must be balanced against the need to minimize nutrient inputs and maintain useable space around the lake. Most community residents would probably consider elimination of geese desirable, particularly if the geese were supplanted by a higher diversity of ducks, wading birds and other migratory species. Canada geese pose the greatest problem, as they are large, abundant, and do more damage to the lake than most other species.

Perhaps the single greatest influence on the abundance of Canada geese is the ease with which water to land transitions can be made. These birds prefer to land and take off in water, but spend considerable time on adjacent lawn areas. When fences or vegetative barriers have been erected at the edge of the water, geese become less common.

There are typically no permits or tangible costs associated with any of the above-described behavioral modifications, but compliance is difficult to measure and major changes in water quality are rarely observed as a result. It would be beneficial; however, to encourage appropriate residential property management through the development of an educational brochure aimed at informing watershed residents of their link to water quality and role in protecting it. Such a brochure could be professionally produced and distributed for an estimated cost of $2,500 and for significantly less if produced by a small group of motivated volunteers.

Increased Street Sweeping and Catch Basin Maintenance: By increasing the frequency of street sweeping and catch basin cleaning, the towns of Lee and Lenox could remove some potential runoff pollutants. Catch basins should be cleaned at least once or twice per year, although this does not happen in many municipalities. Street sweeping could be performed far more frequently, as sediment (and the associated phosphorus) should be removed from the street between storms. A frequency of at least monthly would be necessary, perhaps even more often. Additionally, vacuum equipment is far more effective than conventional brush technology, which picks up less than half the load in most cases.

A program which provides monthly vacuuming of all streets and semi-annual cleaning of all catch basins in the Laurel Lake watershed would carry a capital cost of over $50,000 and an operational cost of at least $10,000/year. This approach would address only those pollutants on roadways or trapped by catch basins. While roadway pollutants could be an important source of contamination, contaminants on lawns are likely to be at least equally important, and would not be appropriately addressed by a street-sweeping program.

Beyond normal street and catch basin maintenance, this approach has only limited merit for the Laurel Lake watershed.

Land Use Planning: The lake is a reflection of its watershed, which is currently well developed around only a portion of the lake's perimeter and even less so the majority of its watershed. It is recommended that efforts be made to preserve natural areas not subject to protection (as with wetlands) and encourage best management practices for agriculture (including gardens) and construction. Costs for such actions are highly variable and unpredictable, but could be minimal with thoughtful use of existing regulations and programs. Performing a build-out analysis (about $3,000) for the Laurel Lake watershed would be beneficial toward determining how water quality would change if all available sites were developed. A build-out analysis would also discuss how such impacts might be mitigated for any future development.

4.2.3 Identify Potential Sources of Groundwater Contamination

Potential sources of groundwater contamination located immediately upgradient of groundwater seepage Segment 1 (Figure 5) should be more closely investigated. Segment 1 receives its groundwater from a relatively large area, identified as watershed sub-basins 2 and 3 on Figure 2. The majority of the groundwater entering the lake through Segment 1 is most likely generated within sub-basin 3 or the portion of sub-basin 2 located east of Laurel Lake Road. This area of the watershed is more densely developed and investigations may require research into Town of Lenox Board of Health records on well water quality and Title V compliance for individual lots in the groundwater-shed. Costs for a thorough investigation, including selected well water sampling, would be on the order of $12,000.

Such a program may be warranted at the current time to ensure that conditions within the lake do not continue to worsen. If funding is not presently available for such a program, it could be delayed until the recommended long-term annual monitoring program (defined under Section 4.2.4) has gathered data indicating a trend toward poorer water quality within the lake despite the implementation of watershed management actions (as described under Section 4.2.3).

4.2.4 Long-term Annual Monitoring of Laurel Lake

In addition to the three objectives discussed above, it would be of great benefit to the future protection and management of Laurel Lake to implement a cost-efficient, long-term annual monitoring program. This would provide continuous background data for the purpose of tracking the effectiveness of future management practices that may be implemented. Since water quality is currently acceptable, the monitoring program for water quality should focus on tracking in-lake conditions during the peak growing season each year. This will allow quantification of the normal range of parameter values and recognition of any potentially detrimental shifts or trends. Phosphorus and nitrogen levels would be the key variables in this regard. Also, assessment of easily measured field parameters (pH, oxygen, temperature, conductivity, turbidity and Secchi depth) would be beneficial. Evaluation of plant species density and distribution should be the focus of biological monitoring.

Evaluating water quality and plant coverage trends truly requires several years of continuous data, with multiple sample dates in each year. Evaluation of management techniques would be more immediate, allowing comparisons between pre- and post-management periods. It would seem most appropriate to collect a single sample from a central area of the lake's main basin in June and August to represent the period of greatest usage and potential impact. If funding were available, it would be useful to include investigative sampling to further characterize stormwater and tributary inputs over time. Annual plant mapping should also be conducted, with particular attention to the growth and spread of nuisance and potential invasive species.

A proposed monitoring plan is outlined in Table 20. This program, if implemented for Laurel Lake alone would cost approximately $5,000 per year. Substantial cost savings could be achieved if implemented in conjunction with monitoring programs for other area lakes. Most of the tasks could be carried out through a volunteer monitoring program at a reduced cost after some initial training and equipment purchases. The value of a long-term database collected through such a simple program would be extremely valuable.

5.0 RECOMMENDED LAKE AND WATERSHED MANAGEMENT PROGRAM

Based on the previous discussion and consideration of options, the recommended program for achieving the stated objectives would include four distinct phases: aquatic weed control, nutrient source control through public education, investigation of potential sources of groundwater contamination, and annual monitoring.

1. Control and limit rooted aquatic plants, with emphasis on Eurasian watermilfoil and large-leafed pondweed by a combination of the following means:

   a) It is recommended that a treatment with the aquatic herbicide fluridone (Sonar) to reduce plant densities, with effort directed toward the control of milfoil ($325-$375/acre). This effort should be implemented in conjunction with a limited summer drawdown to retain as much of the chemically treated water within the lake and therefore increasing contact time with the plants and the effectiveness of the treatment. Actual treatment costs for the recommended herbicide program are expected to range from about $53,500 to $61,500 on a semi-annual basis, although longer control may be achieved. Herbicide treatment is essential to restoring the lake and allowing other longer-term solutions to be utilized.

   b) If herbicide treatment is delayed or denied, other plant management actions that could be considered, at least on a property by property basis, could include the use of benthic barriers combined with hand pulling and even manual re-vegetation of areas treated with the barriers. Costs and the level of treatment may be highly variable with this approach; however, an estimate of $50,000 per acre should be anticipated. Benthic barriers would only be feasible if employed on a smaller scale in specific high-use or access areas and not as a lake-wide solution.

   c) One longer-term solution that may prove effective is the use of the aquatic beetle larvae (*E. lecontii*). This biological alternative to chemical treatment may be desired in the event that the community does not deem chemical application acceptable. For Laurel Lake the biological control effort is likely to cost on up to $26,000 and the effectiveness of the approach will be uncertain. Monitoring is essential to such a project to determine whether the beetle larvae have over wintered and to ensure that the milfoil does not continue to spread throughout the lake.

   d) A second alternative long-term solution, which could be combined with any of the above described management alternatives, may be to conduct a winter lake level drawdown to a target depth of more than 6 feet. Specific details will need to be evaluated prior to permitting such an activity. Details to be considered must include: ability of watershed to refill lake as needed, potential for impact to adjacent wells or wetlands, ideal release rate, and the compatibility of such a program with the downstream water users and resources. Costs to initially design and permit such a drawdown would be approximately $12,000, but would be essentially zero once the program became established.

2. Curtail excessive nutrient and related pollutant inputs associated with storm events, thereby improving aquatic conditions and improving water quality through emphasis on behavioral

modifications by watershed residents. Develop and distribute an educational brochure for watershed residents. This could be prepared by an outside consultant at a cost of approximately $2,500, or with some research, by a motivated group of volunteers for substantially less. If there is enough interest, a workshop explaining the problem and the necessary management actions could also be conducted as part of the educational program for very little additional expense.

3. Potential sources of groundwater contamination located immediately upgradient of groundwater seepage Segment 1 (Figure 5) should be more closely investigated. This area of the watershed is more densely developed and investigations may require research into Town of Lenox Board of Health records on well water quality and Title V compliance for individual lots in the groundwater-shed. Costs for a thorough investigation, including selected well water sampling, would be on the order of $12,000.

   This program may be warranted at the current time to ensure that conditions within the lake do not continue to worsen. However, if funding is not presently available for such a program, it could be delayed until the recommended long-term annual monitoring program (see below) has gathered data indicating a trend toward poorer water quality within the lake despite the implementation of watershed management actions.

4. Establish a monitoring program to provide early warning of future problems and to track the progress of management efforts. An annual cost of $5,000 is expected, exclusive of any special monitoring costs that may be required by local permitting authorities in association with plant control techniques.

Finally, the potential sources of funding for management actions with the appropriate contact information and submission deadlines are outlined in Appendix E. Although the list provided does not represent all of the potential sources of funding, the list does include the major sources of funding currently available at the state and federal level for water quality and aquatic habitat restoration.

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7.0 GLOSSARY

Abiotic: A term that refers to the nonliving components of an ecosystem (e.g., sunlight, physical and chemical characteristics).

Algae: Typically microscopic plants that may occur as single-celled organisms, colonies or filaments.

Alkalinity: A measure of the buffering capacity of a system, typically measured as milligrams of calcium carbonate per liter. Lakes and ponds with an alkalinity below 10mg CaC03/L may be susceptible to acidification.

Anoxic: Greatly deficient in oxygen.

Aquifer: A water-bearing layer of rock (including gravel and sand) that will yield water in usable quantity to a well or spring.

Aquatic plants: A term used to describe a broad group of plants typically found growing in water bodies. The term may generally refer to both algae and macrophytes, but is commonly used synonymously with the term macrophyte.

Bacteria: Typically single celled microorganisms that have no chlorophyll, multiply by simple division, and occur in various forms. Some bacteria may cause disease, but many do not and are necessary for fermentation, nitrogen fixation, and decomposition of organic matter.

Bathymetric Map: A map illustrating the bottom contours (topography) and depth of a lake or pond.

Best Management Practices (BMPs): Any of a number of practices or treatment devices that reduce pollution in runoff via runoff treatment or source control.

Biomass: A term that refers to the weight of biological matter. Standing crop is the amount of biomass (e.g., fish or algae) in a body of water at a given time. Biomass is often measured in grams per square meter of surface.

Biota: All living organisms in a given area.

Cultural Eutrophication: The acceleration of the natural eutrophication process caused by human activities, occurring over decades as opposed to thousands of years.

Ecosystem: An interactive community of living organisms, together with the physical and chemical environment they inhabit.

Endangered/Threatened Species: An animal or plant species that is in danger of extinction that is recognized and protected by state or federal agencies.

Erosion: A process of breakdown and movement of land surface that is often intensified by human disturbances.

Eutrophication: The process, or set of processes, driven by nutrient, organic matter, and sediment addition to a pond that leads to increased biological production and decreased volume. The process occurs naturally in all lakes and ponds over thousands of years.

Exotic Species: Species of plants or animals that occur outside of their normal, indigenous ranges and environments. Populations of exotic species may expand rapidly and displace native populations if natural predators are absent or if conditions are more favorable for the exotics growth than for native species.

Fecal Coliform Bacteria: Found in the intestinal tracts of mammals, this bacteria in water or sludge is an indicator of pollution and possible contamination by pathogens.

Filamentous: A term used to refer to a type of algae that forms long filaments composed of individual cells.

Groundwater: Water found beneath the soil surface and saturating the layer at which it is located.

Habitat: The natural dwelling place of an animal or plant; the type of environment where a particular species is likely to be found.

Herbicide: Any of a class of compounds that produce mortality in plants when applied in sufficient concentrations.

Infiltration Structures: Any of a number of structures used to treat runoff quality or control runoff quantity by infiltrating runoff into the ground. Includes infiltration trenches, dry wells, infiltration basins, and leaching catch basins.

Invasive: Spreading aggressively from the original site of planting.

Littoral Zone: The shallow, highly productive area along the shoreline of a lake or pond where rooted aquatic plants grow.

Macroinvertebrates: Aquatic insects, worms, clams, snails and other animals visible without aid of a microscope that may be associated with or live on substrates such as sediments and macrophytes. They supply a major portion of fish diets and consume detritus and algae.

Macrophytes: Macroscopic vascular plants present in the littoral zone of lakes and ponds.

Mesotrophic: A trophic state (degree of eutrophication) in which a lake or pond is slightly nutrient rich and sustains moderate levels of biological productivity. Moderately dense macrophyte growth, moderate sediment accumulation, occasional algae blooms, moderate water transparency and infrequent oxygen depletion in the hypolimnion are common characteristics.

Morphometry: A term that refers to the depth contours and dimensions (topographic features) of a lake or pond.

Nonpoint Source: A source of pollutants to the environment that does not come from a confined, definable source such as a pipe. Common examples of non-point source pollution include urban runoff, septic system leachate, and runoff from agricultural fields.

Nutrient Limitation: The limitation of growth imposed by the depletion of an essential nutrient.

Nutrients: Elements or chemicals required to sustain life, including carbon, oxygen, nitrogen and phosphorus.

Oligotrophic: A trophic state (degree of eutrophication) in which a lake or pond is nutrient poor and sustains limited levels of biological productivity. Sparse macrophyte growth, low rates of sediment accumulation, rare algae blooms, high water transparency, and rare occurrences of oxygen depletion in the hypolimnion are common characteristics.

pH: An index derived from the inverse log of the hydrogen ion concentration that ranges from 0 to 14 indicating the relative acidity or alkalinity of a liquid.

Photosynthesis: The process by which plants use chlorophyll to convert carbon dioxide, water and sunlight to oxygen and cellular products (carbohydrates).

Phytoplankton: Algae that float or are freely suspended in the water.

Pollutants: Elements and compounds occurring naturally or man-made introduced into the environment at levels in excess of the concentration of chemicals naturally occurring.

Secchi disk: A black and white or all white 20 cm disk attached to a cord used to measure water transparency. The disk is lowered into the water until it is no longer visible (secchi depth). Secchi depth is generally proportional to the depth of light penetration sufficient to sustain algae growth.

Seepage meter: A device used to measure the groundwater volume entering a lake, pond or stream over time.

Sediment: Topsoil, sand, and minerals washed from the land into water, usually after rain or snowmelt.

Septic system: An individual wastewater treatment system that includes a septic tank for removing solids, and a leachfield for discharging the clarified wastewater to the ground.

Septic System Leachate: The clarified wastewater discharged into ground from a septic system.

Siltation: The process in which inorganic silt settles and accumulates at the bottom of a lake or pond.

Stormwater Runoff: Runoff generated as a result of precipitation or snowmelt.

Temperature Profile: A series of temperature measurements collected at incremental water depths from surface to bottom at a given location.

Thermal Stratification: The process by which a lake or pond forms several distinct thermal layers. The layers include a warmer well-mixed upper layer (epilimnion), a cooler, poorly mixed layer at the bottom (hypolimnion), and a middle layer (metalimnion) that separates the two.

Thermocline: A term that refers to the plane of greatest temperature change within the metalimnion.

TKN: Total Kjeldahl nitrogen, essentially the sum of ammonia nitrogen and organic forms of nitrogen.

Turbidity: A measure of the light scattering properties of water; often used more generally to describe water clarity or the relative presence or absence of suspended materials in the water.

Vegetated Buffer: An undisturbed vegetated land area that separates an area of human activity from the adjacent water body; can be effective in reducing runoff velocities and volumes and the removal of sediment and pollutant from runoff.

Water Column: Water in a lake or pond between the interface with the atmosphere at the surface and the interface with the sediment at the bottom.

Water Quality: A term used to reference the general chemical and physical properties of water relative to the requirements of living organisms that depend upon that water.

Watershed: The surrounding land area that drains into a water body via surface runoff or groundwater recharge and discharge.

Zooplankton: Microscopic animals that float or are freely suspended in the water.