Chapter 3. Water Quality

3.1 INTRODUCTION

This chapter provides a brief overview of federal and state water quality regulations, summarizes available information on water quality for the lakes and ponds in the Lake Sunapee Watershed.

The data used to develop this water quality summary was collected from a number of different programs. The different programs often collected different parameters at different time periods. Analysis of this water quality data reveals several areas of concern. Potential pollution sources and management recommendations are discussed in Chapters Five and Six, respectively. It is critical to maintain good water quality in both raw and finished water for numerous reasons including: safeguarding of fisheries, protecting recreational water resources, minimizing drinking water treatment costs, and protection of public health.

3.2 REGULATORY BACKGROUND

The State of New Hampshire has numerous statutes and rules that are designed to protect lakes. Over the past two decades NH DES has made a major effort to remove point discharges of sewage and waste from lakes and from tributaries to lakes. A brief summary of some of the laws and regulations that help protect New Hampshire lakes is presented in Table 3.1

Table 3.1 List of pertinent statutes established to protect ground and surface water quality. Refer to statute as identified for specific land use criteria.

Provision	Regulatory Authority
1. All lakes are classified at least Class B. The goal is that these waterbodies are suitable for fishing, swimming, and other recreational activities, and violations of assigned classifications are not allowed.	RSA 485-A:11 RSA 485-A:8,II RSA 485-A:12
2. No discharge is allowed to a lake without a permit. It is prohibited to discharge marine toilets into a lake.	RSA 487:2
3. Graywater (sink and shower wastes) from boats cannot be discharged into a lake.	RSA 487:3
4. No new point sources of phosphorus to lakes are allowed, and no new discharges of phosphorus to tributaries of lakes are allowed that would encourage weed or algae growth.	Env-WS 1703.14
5. All surface waters shall be restored to meet the water quality criteria for their designated classification.	Env-WS 1703
6. Automobiles and other petroleum powered vehicles lost through the ice into a lake must be removed.	RSA 485-A:14

Provision	Regulatory Authority
7. No person shall excavate, remove, fill, dredge or construct any structures in or on any bank, flat, marsh, or swamp in and adjacent to any waters of the state without a permit from the department.	RSA 482-A:3 485-A:17
8. No construction or transportation of forest products (skidding etc.) can occur in or on the border of the surface waters of the state without a permit. Forestry activities are subject to the conditions of RSA 227-J:9 when in or near wetlands and surface waters.	RSA 485-A:17 RSA 227-J:9
9. No earth moving activities are allowed near a lake without a permit.	RSA 485-A:17
10. No subsurface disposal system may be installed near a lake without a permit and without meeting minimum standards.	RSA 485-A:29 RSA 483-B Env-WS 1008.04
11. It shall be unlawful for any person to dispose of, discard, or store any pesticides or pesticide containers in such a manner as to pollute any water supply or waterway.	RSA 430:41
12. Structures near lakes or tributaries to lakes cannot be converted from seasonal to year round use or expanded in size such that the load on the sewage disposal system is increased, unless an application for approval of the sewage disposal system is submitted.	RSA 485-A:38 Env-WS 1004.14
13. No property with a sewage disposal system located within 200 feet of a great pond can be offered for sale until a licensed sewage disposal designer has performed a site assessment to determine if the site meets current standards for sewage disposal systems.	RSA 485-A:39 Env-Ws 1025
14. The Lakes Management and Protection Program established a lakes coordinator and lakes management advisory committee to prepare: (1) statewide lake management criteria and (2) guidelines for the development of local lake management and shoreland protection plans.	RSA 483-A
15. The Shoreland Protection Act provides minimum protective standards for activities occurring within 250 feet of all fresh water bodies listed in the official list of public waters published by the department pursuant to RSA 271:20, II and rivers, meaning all year-round flowing waters of fourth order or higher.	RSA 483-B

Provision	Regulatory Authority
16. No household cleaning products except those used in dishwashers shall be distributed, sold, or offered for sale in New Hampshire which contains a phosphorus compound in excess of a trace quantity.	RSA 485-A:56
17. No exotic aquatic weeds shall be offered for sale, distributed, sold, or imported, purchased, propagated, transported, or introduced in the state.	RSA 487:16a
18. Permits are also required for the following activities, and permits will not be issued if lake quality is to be endangered: a. Groundwater discharges b. Underground storage tanks c. Solid waste landfills d. Sludge pits e. Hazardous waste sites	RSA 485-A:13 RSA 146-A RSA 149-M RSA 149-M RSA 147-A

Surface Water Quality Standards

Surface water quality in the United States is protected under the federal Clean Water Act. Federal standards promulgated under this act have been adopted by the State of New Hampshire in the form of surface water standards. The water quality standards establish the baseline quality that all surface waters of the State must meet in order to protect their intended uses. These standards are the yardstick for identifying where water quality violations exist and for determining the effectiveness of regulatory pollution control and prevention programs. The standards are composed of three parts: classifications, the criteria, and the anti-degradation regulations. All three are described below.

Waterbody Classification

All State surface waters (i.e. perennial and seasonal streams, lakes, ponds, and tidal waters) have either a Class A or Class B classification. The majority of waters fall under the Class B classification. Class A waters are intended to be and generally are waters of the highest quality and are considered potentially usable for water supply after adequate treatment. Discharge of sewage or wastes is prohibited to Class A waters. Class B waters are considered acceptable for Aquatic Life Use, Fish Consumption, Primary Contact Recreation (i.e. swimming), Secondary Contact Recreation (i.e. minor water contact through activities such as boating), Wildlife, and after adequate treatment for use as water supplies. Each surface waterbody regardless of class must meet the following water quality criteria:

- The presence of pollutants in the receiving waters is not the basis for further introduction of pollutants. The failure of waters to meet certain criteria due to natural causes does not necessitate the modification of the assigned water use classification.

- All waters shall be free from pollutants in concentrations or combinations that settle to form harmful deposits; float; produce odor, color, taste, or turbidity that is not naturally occurring; result in the dominance of nuisance species, or prevent recreational activities.

- The level of radioactive materials shall not be in concentrations or combinations that would be harmful to human, animal, or aquatic life; would result in radionuclides in aquatic life exceeding recommended limits for consumption by humans; or would exceed EPA's Drinking Water Regulations.

- Tainting substances shall not be present in combinations that individually or in combination produce undesirable flavors in aquatic organisms.

- Toxic pollutants, unless naturally occurring, shall be in concentrations that will not injure plants, animals, humans, or aquatic life; persist in the environment; or accumulate to harmful levels in aquatic organisms.

Table 3.2 Designated Uses for New Hampshire Surface Waters. (Source: NH DES 2004 New Hampshire Consolidated Assessment and Listing Methodology).

Designated Use	NH DES Definition	Applicable Surface Waters
Aquatic Life	Waters that provide suitable chemical and physical conditions for supporting a balanced, integrated and adaptive community of aquatic organisms.	All surface waters
Fish Consumption	Waters that support fish free from contamination at levels that pose a human health risk to consumers.	All surface waters
Shellfish Consumption	Waters that support a population of shellfish free from toxicants and pathogens that could pose a human health risk to consumers.	All tidal surface waters
Drinking Water Supply After Adequate Treatment	Waters that with adequate treatment will be suitable for human intake and meet state/federal drinking water regulations.	All fresh surface waters
Primary Contact Recreation (i.e. swimming)	Waters suitable for recreational uses that require or likely to result in full body contact and/or incidental ingestion of water.	All surface waters
Secondary Contact Recreation	Waters that support recreational uses that involve minor contact with the water.	All surface waters
Wildlife	Waters that provide suitable physical and chemical conditions in the water and the riparian corridor to support wildlife as well as aquatic life.	All surface waters

According to NH DES, all waterbodies in the watershed are classified as Class B waters except for Lake Sunapee which is classified as Class A.

> Law of 1969 178:1 On and after the effective date of this Act the surface waters of Lake Sunapee shall be classified in accordance with the provisions of RSA 149 as amended as Class A waters.

Water Quality Criteria

The second major component of the water quality standards is the criteria. These are numerical or narrative criteria which define the water quality requirements for Class A and Class B waters. A waterbody that meets the criteria for its assigned classification is considered to meet its intended use (State of New Hampshire 2006 Section 305(b) Water Quality Report). Water quality criteria for each classification are found in RSA 485-A:8, I-V and in the State of New Hampshire Surface Water Quality Regulations (Env-Ws 1700).

Antidegradation

The purpose of the antidegradation provisions in the water quality standards is to preserve and protect the existing beneficial uses of the State's surface waters and to limit the degradation allowed in receiving waters. Antidegradation regulations are included in Env-Ws 1708 of the New Hampshire Surface Water Quality Regulations. Pursuant to RSA 485-A:8, discharges containing "sewage" or "wastes" are not allowed in Class A waters. Consequently, degradation of Class A waters is prohibited.

NH DES 305(b) Water Quality Report

Biennially, NH DES is required by the Environmental Protection Agency to assess surface water quality. NH DES uses assessment units as the basic unit of record for conducting and reporting the results of water quality assessments. Assessment units are intended to be representative of homogenous units. Sometimes assessment units represent an entire waterbody. In other instances, an assessment unit may represent a town beach or portion of a waterbody. All surface waters were assessed by NH DES in 2006 to determine if they support their designated uses. During this reporting cycle, wildlife was not assessed because an assessment methodology for wildlife has yet to be developed.

There is a statewide fish consumption advisory or ban in effect for the general population for one or more fish species due to the atmospheric deposition of mercury. For this reason, all state waterbodies have been classified as "Not Supporting" the fish consumption designated use.

All of the lakes and ponds have been classified as "impaired" due to atmospheric deposition of mercury, and are required to complete a Total Maximum Daily Load study for mercury in the future.

Drinking Water Regulations

New Hampshire drinking water regulations are based on the Federal Safe Drinking Water Act (SDWA), enacted in 1974, and amended in 1986 and 1996. The Act requires that each state adopt standards that are no less stringent than the federal regulations. SDWA authorizes the Environmental Protection Agency to develop primary drinking water regulations that incorporate maximum contaminant levels (MCLs), maximum contaminant level goals (MCLGs), and treatment techniques for dozens of contaminants in order to protect public health.

Some of the contaminants have "chronic" effects which are the result of long term exposure. Consequently the MCLs for contaminants with chronic effects are established based on exposure over an average lifespan of seventy years. Contaminants which have more immediate or "acute" effects are based on short-term exposure. Examples of contaminants which cause acute effects are bacteria, pathogens, or viruses. These contaminants are also regulated to assure public health safety.

The New Hampshire Drinking Water Regulations mirror the SDWA regulations. They address the quality of finished water, before it is delivered to the consumer.

3.3 SUMMARY OF SURFACE WATER QUALITY DATA

Water quality in waterbodies throughout the watershed has been investigated at various times by the New Hampshire DES Lakes and Ponds Inventory Program and the Volunteer Lake Assessment Program (VLAP). For example, water quality data has been collected at Lake Sunapee since 1986. Every year VLAP volunteers collect data from four deep spot stations, nine near shore stations and numerous tributary stations. (Figure 3.2 & 3.3). In addition, VLAP monitors are active in six other lakes and ponds; Baptist Pond, Chalk Pond, Dutchman Pond, Ledge Pond, Little Sunapee Lake and Mountainview Lake. See Figures 3.4 – 3.8 for maps of the sampling stations. Maps are available as PDFs in the Appendices. The Observations and Recommendations Reports and Tables for the biennial reports for each of these lakes and ponds can be found in the digital appendices on the CD.

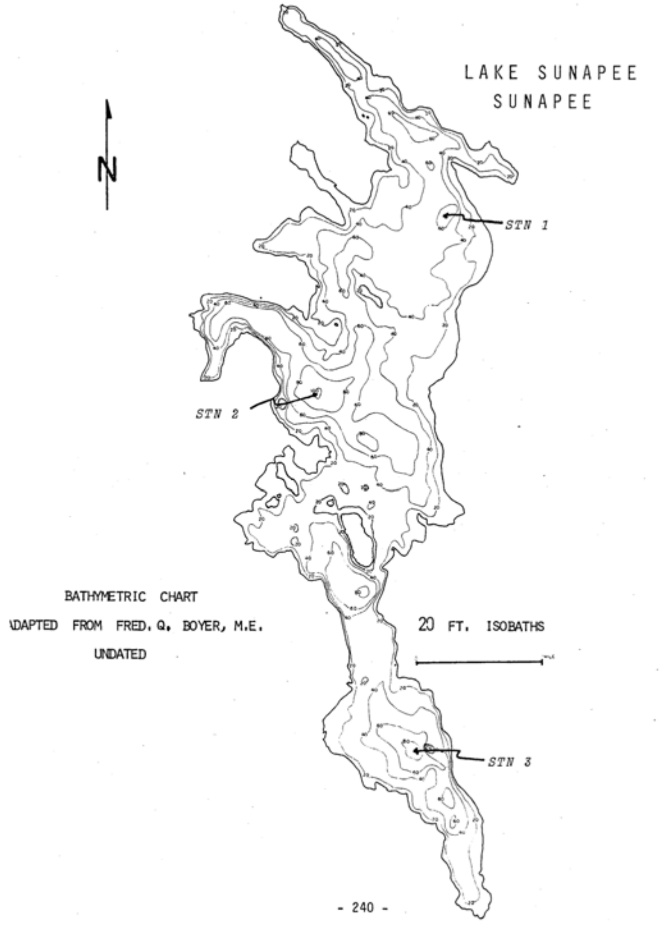


Figure 3.1 Bathymetry for Lake Sunapee.
(Source: NHDES Watershed Management Bureau, Volunteer Lakes Assessment Program)

Figure 3.2 Monitoring Stations where biological and chemical parameters are measured by Volunteer Lake Assessment Volunteers in Lake Sunapee. (Source: NH DES)

Table 3.6 Summary of raw water sample results for selected biological and chemical parameters for waterbodies in the Lake Sunapee Watershed (Source: 2006 VLAP Reports).

Waterbody	pH	Acid Neutralizing Capacity	Phosphorus Historical Trends	Conductivity	Dissolved Oxygen - Hypolimnion	Chlorophyll-a	Cyanobacteria
Lake Sunapee Deep Spots	Satisfactory, note higher acidity in the hypolimnion	Moderately Vulnerable	Oligotrophic conditions Not significantly changed, at 6.5 µg/L average in lake. less than state median for P	Greater than the state median, increasing	High in the epilimnion, but depleted in the hypolimnion – potential internal phosphorus loading	Not significantly changed, historical data show the average is less than the state median	*Anabaena*, *Gleotrichia* and small amounts of *Microcystis* and/or *Oscillatoria*
Lake Sunapee Near Shore	Slightly Acidic	Moderately Vulnerable	Mesotrophic Conditions Generally increasing levels of P, greater than state median	Greater than the state median, increasing	High in the epilimnion, but depleted in the hypolimnion – potential internal phosphorus loading	Not significantly changed, some stations demonstrating improvement	*Gleotrichia*
Lake Sunapee Tributaries	Slightly Acidic	_____________	Relatively high (>25ug/L) on some sampling events	Wide range of values, mean annual conductivity has increased	_______________	_______________	_______________
Baptist Pond	Slightly Acidic	Moderately Vulnerable	Mesotrophic Conditions Increasing P (worsening)	Greater than state median	High	Increasing , greater than the State Median	Small amount of *Anabaena* and *Mycrocystis*
Chalk Pond	Slightly Acidic	Moderately Vulnerable	Oligotrophic Conditions Not significantly changed	Slightly lower than the state median, but increasing	High	Not significantly changed, historical data show the average is less than the state median	No data
Dutchman Pond	Slightly Acidic, note higher acidity in the hypolimnion	Extremely Vulnerable Much less than state median	Mesotrophic Conditions Highly variable P concentrations	Stable and low	High	Not significantly changed, historical data show the average is less than the state median	*Anabaena* and *Oscillatoria* were reported in the 2006 sample
Little Lake Sunapee	Slightly Acidic, note higher acidity in the hypolimnion	Moderately Vulnerable	Oligotrophic Conditions in the epilimnion and Mesotrophic Conditions in the hypolimnion, variable P	Greater than the state median, increasing	Lower in metalimnion and hypolimnion than the epilimnion – potential internal phosphorus loading	Variable, but overall increasing	*Coelosphaerium, Anabaena* and *Oscillatoria* were reported in the 2006 sample
Mountainview Lake	Slightly Acidic note higher acidity in the hypolimnio	Moderately Vulnerable Slightly greater than the state median	Mesotrophic conditions not significantly changed, P concentrations slightly	Greater than the state median, increasing	Much lower in hypoliminion – potential internal phosphorus loading	Not significantly changed, historical data show the average is slightly greater than the state median	A small amount of *Anabaena* was detected in the 2006 sample

	n		greater than state median				

This section of the Plan summarizes water quality information from the Volunteer Lake Assessment program for each of the lakes and ponds as summarized in Table 3.6. Under phosphorus, it also contains a description and the results of the Water Quality Model.

Background

Trophic Levels and Flushing Rate

Lakes typically go through a natural aging process as the result of sedimentation processes and nutrient additions. Trophic level or lake “age” is determined by a number of factors including water transparency, nutrient enrichment, planktonic growth, presence of aquatic plants, types of fishery (cold or warm), and dissolved Oxygen content. As lakes age, the aforementioned characteristics change. For example, oligotrophic water bodies are considered to be in an early stage of development. Waterbodies in this trophic stage are characterized by clear water, low nutrient enrichment, low productivity, few aquatic plants, presence of a coldwater fishery and high dissolved oxygen content. Eutrophic waterbodies on the other hand, have high nutrient enrichment, high productivity as evidenced by much planktonic growth, extensive aquatic plant beds, sediment accumulation on the lake bottom, have warmwater fish species, and are susceptible to algae blooms and summer fish kills. Mesotrophic characteristics fall somewhere in between eutrophic and oligotrophic.

Another important parameter which relates to trophic level is the flushing rate. The flushing rate is the number of times a lake flushes (i.e., a volume of water equal to the lake’s volume passes through the lake) in one year, expressed to the nearest 0.1 times/year. This rate incorporates the amount of inflow with the waterbody volume in order to produce a measure of lake water exchange (Jeer et Al., 1997). The flushing rate is important to consider when examining the effect of pollution loads, nutrient additions, or water diversions. In general, the lower a lake’s flushing rate, the more susceptible the waterbody is to nutrient or pollutant additions. This is because nutrients or pollutants are less likely to be flushed from the waterbody.

NH DES has determined that the median flushing rates for New Hampshire lakes and ponds is 3.0 times/year.

pH

The parameter pH is a measure of hydrogen ions in the water, or in general terms, the acidity. pH is measured on a logarithmic scale of 0 to 14. The lower the pH, the more acidic the solution, due to the higher concentration of hydrogen ions. Lake pH is important for the survival and reproduction of fish and other aquatic species. There are several reasons and conditions which affect waterbody acidity. For example, many lakes exhibit lower pH values in deeper waters than nearer the surface. Decomposition carried out by bacteria in the lake bottom causes the pH to drop, while photosynthesis in the upper layers can cause pH to increase. A difference in pH from surface to bottom layers is greatest in a thermally stratified lake. Waterbody pH may be influenced by wetlands where tannic and humic acids are released to the water by decaying plants, thereby creating more acidic waters (VLAP, 2003). After the acidic spring-time snow melt or a significant rain event, surface water may have a lower pH than deeper waters and may take several weeks to recover.

New Hampshire lakes historically have had pH values in the mid to upper sixes, in most cases. A pH of between 6.5 and 7.0 is ideal (VLAP, 2003). As the pH decreases to between 5 and 6, many fish and aquatic organisms become stressed, and some species disappear because they are unable to tolerate acidic conditions. Fish typically are unable to tolerate acidic conditions below a pH of 5. The mean pH value for the epilimnion (upper layer) in New Hampshire lakes and ponds is 6.6, which indicates that the surface waters in the state tend to be slightly acidic.

Annual sampling data collected by the VLAP volunteers indicates that water in these waterbodies is “slightly acidic” but generally satisfactory for aquatic life purposes. The higher hypolimnion acidity in certain lakes may be attributable to the natural processes of decomposition and release of acidic by-products. It is noted that tributary sampling for pH is no longer conducted as pH is largely influenced by natural conditions rather than human activity, and the time spent is not justified. However, ongoing lake monitoring of pH is wise for tracking impacts of acid rain over the long term.

Acid NeutralizingCapacity (ANC)

Alkalinity is the measure of a lake’s capacity to neutralize acid inputs. This value is often referred as “acid neutralizing capacity (ANC). New Hampshire has had historically low alkaline waters because of the State’s granitic bedrock and there is some evidence that overall alkalinity has decreased in recent years. If the buffering capacity of a lake is lost, conditions for aquatic life will be adversely affected by acid rain inputs (NH DES, 2005). The mean ANC for New Hampshire lakes and ponds is 6.6 mg/L (VLAP 2004 Report).

Most waterbodies in the Sunapee watershed have been relatively stable in their ANC, and data indicate a “moderate vulnerability” to acidic inputs. However, Dutchman Pond and Ledge Pond sampling data indicate that these waterbodies are “extremely vulnerable” to acidic inputs with values less than 2mg/L and are much less than the state median for ANC.

Total Phosphorus, Goal and the Water Quality Model

Total phosphorus is a measure of all the forms of phosphorus (organic and inorganic) present. Phosphorus, along with nitrogen is a plant limiting nutrient, meaning that the amount of available phosphorus influences the amount of algae growth that can occur. Phosphorus concentration directly relates to trophic state. For example, values less than 8 ug/L are considered “ideal” and generally indicate oligotrophic conditions. Values greater than 20 ug/L are considered “more P than desirable” and indicate eutrophic conditions. Mesotrophic conditions exist between these two values and are considered "average." Values in excess of 40 ug/L are considered "excessive."

Phosphorus is an important indicator of pollution because this nutrient occurs naturally at very low levels in lakes and ponds in New Hampshire. The median summer total phosphorus concentration in the epilimnion of New Hampshire lakes and ponds is 12 ug/L. The median summer total phosphorus concentration in the hypolimnion of New Hampshire lakes and ponds is 14 ug/L.

Phosphorus levels across the watershed lakes, ponds and tributaries varies greatly. The Sunapee Deep Spots, Chalk Pond, Ledge Pond and Little Sunapee Lake appear to present oligotrophic conditions. Lake Sunapee Deep Spots average 6.5 µg/L. However, the near shore stations on Lake Sunapee and the tributaries are showing a substantial increase in concentrations of phosphorus, some samples showing greater than 25ug/L. This should concern water quality monitors and watershed residents as the implication is that non-point sources of phosphorus are increasing, and the subsequent effect on in-lake water quality and aesthetics will be significant. It is highly recommended that a non point source prevention program be implemented throughout the watershed as a first step in maintaining the high quality resources here. The goal of the Watershed Plan is to limit in-lake concentration to 8 µg/L through the watershed action plan.

Monitoring tributaries to a waterbody after snow-melt and during rain events can help to determine the source of phosphorus loading. Better quantification of the source and timing of addition of this nutrient can create a better understanding of the lake's functioning and help to identify tools for better lake management.

As part of the NH DES Pilot Grant Watershed Project, phosphorus is the focus of a conceptual model adopted for the management of the watershed. In 2007, Geosyntec Consultants, Inc. (Geosyntec) was contracted by the New Hampshire Department of Environmental Services (NH DES) to develop a water quality model for the Lake Sunapee Watershed. The water quality model that was developed by Geosyntec incorporates a Monte Carlo simulation to evaluate total phosphorus (TP) loading from the Watershed under two land use conditions: current land use and full build-out land use.

Water Quality Model for the Lake Sunapee Watershed Description & Methodology

Land Use Analysis

A land use analysis was conducted to evaluate land use conditions for the Watershed. Land use condition describes the type (e.g., residential, commercial, etc.) and/or cover (forested, wetland, etc.) of the land area within the Watershed and is used as an input to the model. For this modeling application, the Watershed's land use area, excluding the water surface area, was grouped by town. Land uses were grouped by town because of the following: (1) final build-out conditions and zoning requirements, where available, were provided at the town level; and (2) grouping by town facilitates land use development planning based on predicted water quality impacts.

Current Condition

The current land use condition was adapted from the 1995 Lake Sunapee Watershed Study prepared by the Upper Lake Sunapee Regional Planning Commission (ULSRPC). The 1995 Study used 1992 and 1993 aerial photography to determine land use characteristics for each town. The 1995 Study used the following land use categories: agriculture, forest, transportation, commercial/industrial, outdoor use areas, and residential. The 1995 study was used as the current condition based on the following assumptions: (1) Current land use distributions described in the study are comparable with those distributions described in the 1995 Study for full build-out; and (2) Current digital land use data that are readily available are based on aerial images between 1992 and 1995 (National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) land use data) and between 1990 and 1995 (New Hampshire GRANITE data) and do not reflect more accurate information for the current land use condition when compared to the 1995 study.

Full Build-Out Condition

The full build-out condition was based on information provided by the UVLSRPC presented in a Technical Memorandum entitled *Update of 1995 Lake Sunapee Build-out Analysis* dated December 2006 (2006 Memo). The full build-out condition described in the 2006 Memo was reported as projected population at full build-out per town (i.e., population density). The projected population density at full build-out was
then converted to projected developed land area at full build-out as follows:
(1) The projected increase in population density was calculated by subtracting the projected population at full build-out (2006 Memo) from the current population described in the 1995 Study.
(2) The projected increase in population density for each town was converted into the projected number of homes per each town using standard values for the average household size descried in the 2006 Memo. This calculated value represents the number of new homes to be constructed to reach full build-out.
(3) This value was multiplied by the average lot sizes described in the 2006 Memo to estimate the projected increase in developed area in each town. The average lot sizes were different for each town and are based on the most recent zoning requirements.
(4) The projected increase in developed land area was then added to the developed area for the current condition. This value represents the total projected developed land area in each town at full build-out.
The projected increase in developed area was then incorporated into a full build-out land use condition that describes the land use of the entire Watershed at full build-out condition. Given the proportion of forested land use in the Lake Sunapee watershed, it was assumed that all development is likely to occur in areas which are currently forest. In addition, it was assumed that all build-out would occur as residential or mixed residential development. Furthermore, it was assumed that the current developed portions of the Watershed would not be redeveloped to a higher population density. Based on these assumptions, a projected forested land use area was calculated for each town by subtracting the area to be developed to reach full build-out from the current forested area in each town.

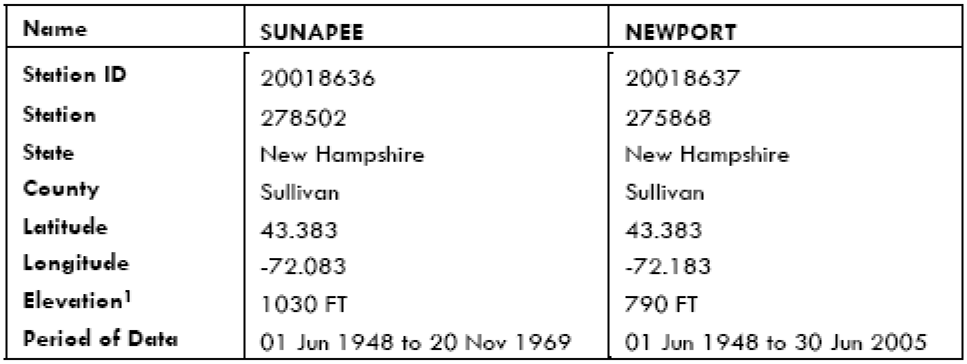
Water Quality Model with Monte Carlo Simulation Input Parameters

The Monte Carlo water quality assessment tool (M-CAT) model was developed to assess storm water quality impacts associated with land use. The model is an empirical, volume-based, pollutant loading model. The model was developed to assess the potential impact of development (e.g., changes in land use) on water quality of Lake Sunapee. Measured runoff volumes and water quality characteristics of storm water are highly variable. To account for this variability, a statistical modeling approach was used to estimate a distribution of storm water volume, concentration of pollutants in storm water runoff, and a statistical description of the overall pollutant load (total mass of pollutants) in storm water runoff associated with each development condition. A statistical description of storm water provides an indication of the average characteristics and also the variability of the water quality parameters of storm water, and the probability of compliance with regulatory criteria or water quality goals. The M-CAT does not forecast runoff characteristics or regulatory compliance for specific storms or monitoring periods. The M-CAT model is based on relatively simple expressions describing rainfall/runoff relationships and estimated pollutant concentrations in storm water runoff. The volume of storm water runoff was estimated using a modification to the Rational Formula, an empirical expression that relates runoff volume to the rainfall depth and the broad basin characteristics. The pollutant concentration in storm water runoff was represented by an expected average pollutant concentration, called the event mean concentration (EMC). EMC data were taken from published values presented in literature as described below, and are strongly dependent on land-use type and impervious surface area. As with all environmental modeling, the precision of results is heavily dependent on how well the hydrologic and water quality data describe the actual site characteristics. Local and regional data were used to the fullest extent possible to reduce variability in predictions. It is important to remember that, in addition to precision, the predictions of relative differences are also important. The input parameters for the water quality model fall into four main categories shown below. Each of the categories of input data is evaluated for accuracy reflecting the project site conditions: (1) rainfall data; (2) runoff coefficients; (3) land use data; and (4) storm water pollutant EMCs.

Rainfall Data:

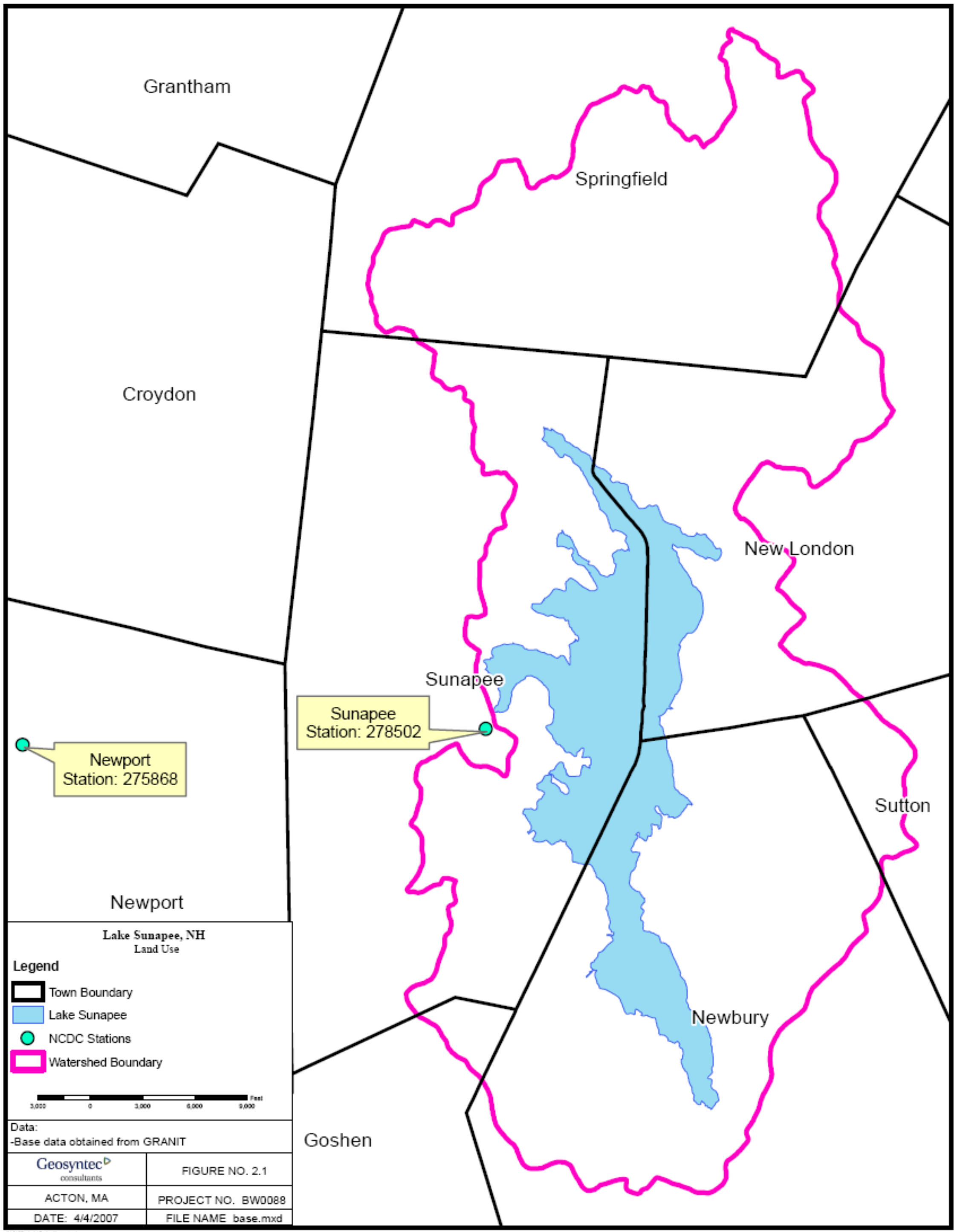
Rainfall data for the model was taken from the NOAA National Climatic Data Center (NCDC). NCDC hourly precipitation data was downloaded from two stations: the Sunapee, NH Station No. 20018636, and the Newport, NH Station No. 275868. Information for each of the stations is presented in Table 3. The two stations are the closest in proximity to Lake Sunapee and have a combined historical period between 4/16/1954 and 6/30/2005. The Sunapee gauge included historical hourly precipitation data between 6/1/1948 through 11/20/1969. The Newport gauge included historical hourly precipitation data between 6/1/1948 through 6/30/2005 (last data point of published hourly precipitation data available through the NOAA NCDC data set at the time of this water quality evaluation). The data was combined to provide a longer period of record for the model input. These data did not overlap in time series so a side-by-side comparison of the data could not be performed. However, the gauge locations were plotted over the isohyetal maps for the northeast region (Cornell University, 1993). In general, the isohyets in the region New Hampshire region span in an east-west orientation and therefore the general deviation in annual precipitation is from north to south. The Sunapee and Newport gauges are both located at latitude 43.8333. Since the gauges are in an east west orientation, both gauges are likely to experience similar annual precipitation. In addition, the stations are located 5.01 miles apart and both gauges are located within a 7 mile radius of Lake Sunapee, immediately west of the Watershed. Figure 2.1 identifies the location of the two rainfall monitoring stations used in this study.

Table 2.1. Summary of NCDC Station Information



Name	SUNAPEE	NEWPORT
Station ID	20018636	20018637
Station	278502	275868
State	New Hampshire	New Hampshire
County	Sullivan	Sullivan
Latitude	43.383	43.383
Longitude	-72.083	-72.183
Elevation[1]	1030 FT	790 FT
Period of Data	01 Jun 1948 to 20 Nov 1969	01 Jun 1948 to 30 Jun 2005

1. Elevation data provided are in feet above sea level.



Runoff Coefficients:

Runoff coefficients used in the Lake Sunapee model framework were based on land use and are a function of impervious area. The Simple Method (Schueler 1987), a general runoff coefficient equation, was considered most appropriate for this level of analysis. The Simple

Method describes the runoff coefficient as a function of impervious area and is further described in the modeling procedure below.

Land Use Data:

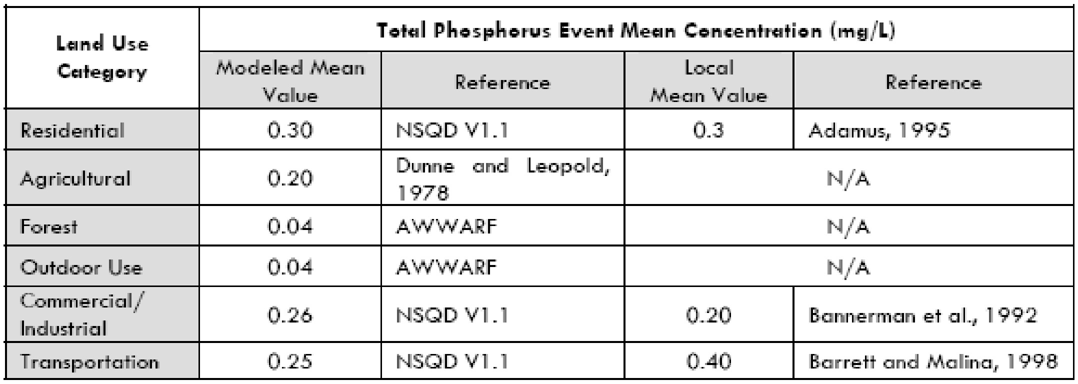
Land use data is generally the most accurately quantified input parameter in water quality models.The land use input data for the current conditions and projected conditions at full build-out area were derived from the land use analysis described in Section 2.1. The percent impervious values used in the water quality model for developed portions of the Watershed were based upon the values reported by the National Storm Water Quality Database (NSQD) Version 1.1 (dated February 15, 2006), prepared by University of Alabama.

Storm Water Pollutant EMCs:

Storm water pollutant EMCs were taken from the best available published data and where possible taken from studies that were conducted in the northeastern United States. These sources included the following: (1) The NSQD Version 1.1; (2) American Water Works Association Research Foundation (AWWARF) Report, dated 2006; and (3) Dunne and Leopold, 1978. The AWWARF Report and the Dunne and Leopold report published EMC data specific to the northeast region. The NSWQ includes EMC data from over 200 municipalities located within the continental United States. Published EMC data typically includes only mean EMC values that are commonly used in simple land use based pollutant models. Published EMC studies do not typically report EMC statistical parameters including the standard deviation which characterizes the statistical distribution of the EMC data, which is necessary for a statistical water quality modeling approach. The NSQD Version 1.1 reports both mean and standard deviation values for the general land use categories used in this model and was therefore used for the majority of EMC data input to the model. To ensure that the NSWQ data closely represent storm water quality in the northeast, NSQD V1.1 EMC mean values were compared to EMC mean values from studies conducted in the northeast. A comparison of EMC data is presented in Table 4.

The residential land use EMC mean values reported in the NSQD are approximately equal to the EMC reported for the northeast region (Adamus, 1995). The commercial/industrial and transportation NSQD EMC values were slightly different than those published values for the northeast area. However, the model describes the water quality impacts associated with change in residential and forested areas and assumes that the change in commercial/industrial and transportation is negligible as further described in Section 3. Therefore, because statistical parameters are available for those EMCs in the NSQD V1.1, the NSQD V1.1 values for commercial/industrial and transportation were used in the model input. The majority of "Outdoor Recreation" lands within the Lake Sunapee watershed are forested and therefore were modeled using EMC data for forest land use.

Table 2.2. Comparison of Total Phosphorus EMC Data



Land Use Category	Total Phosphorus Event Mean Concentration (mg/L)			
	Modeled Mean Value	Reference	Local Mean Value	Reference
Residential	0.30	NSQD V1.1	0.3	Adamus, 1995
Agricultural	0.20	Dunne and Leopold, 1978	N/A	
Forest	0.04	AWWARF	N/A	
Outdoor Use	0.04	AWWARF	N/A	
Commercial/ Industrial	0.26	NSQD V1.1	0.20	Bannerman et al., 1992
Transportation	0.25	NSQD V1.1	0.40	Barrett and Malina, 1998

Water Quality Model with Monte Carlo Simulation Procedure

A Monte Carlo simulation method was used to develop the statistical description for storm water quality for Lake Sunapee. In this approach, the storm water characteristics from a single arbitrary rainfall event are first estimated. The rainfall depth of an arbitrary event was determined by randomly sampling from the historical rainfall information. Similarly, an arbitrary EMC was determined by randomly sampling from the distribution of EMCs in a manner that preserves the mean and standard deviation of the EMC input data. The randomly determined rainfall volume and EMC were used to determine runoff volume, pollutant concentration, and pollutant load of a single arbitrary storm event. This procedure was then repeated ten thousand (10,000) times, recording the volume, EMC, and load from each random storm event. The statistics of these recorded results provide a description of the average characteristics and variability of the volume and water quality of storm water runoff. The modeled pollutant was total phosphorus. The steps in the Monte Carlo Water Quality Model are as follows and are further described below:

1. Develop a statistical description of storm events & pollutant concentration in storm runoff.
2. Estimate the volume of storm runoff from a random storm event for each land use area.
3. Estimate a random pollutant concentration in storm runoff for each land-use area.
4. Calculate the total runoff volume, pollutant load, and concentration in runoff from the modeled portion of the project.
5. Estimate a random number of storms per year based on available historical records. To estimate a single random annual load, repeat steps 2 - 4 by random number of storms per year, summing the loads from each random storm event.
6. Repeat steps 2 - 5 a total of 10,000 times for each pollutant modeled, recording the estimated pollutant concentration, and annual load for each iteration.
7. Develop a statistical representation (mean annual value) of the recorded storm water pollutant loads and concentrations.

Each of the seven steps is described below.

Step 1 – Statistical Representation of Storm Events

The M-CAT model is set up to accept data files from the National Atmospheric and Oceanic Administration (NOAA) that have been processed through the SYNOP rainfall processing tool. The SYNOP tool processes hourly rain gauge data into storm event data using storm event criteria input by the user. Input criteria include an inter-event period and a minimum storm event depth. For the purpose of this model, a standard period of six hours was used for the inter-event period. A minimum storm depth of 0.10 inches was selected, because rain events smaller than this tend to produce little if any runoff (USEPA, 1989; Schueler, 1987). **Storm Depth** An arbitrary storm depth for each iteration was determined by randomly sampling from the population of 4,427 storms generated by the rainfall analysis. The historical record of storm depths was sampled such that each storm was pooled sequentially throughout the entire population of storms. This sequence was repeated until a total of 10,000 iterations were performed.

Step 2 – Estimate the Volume of Storm Runoff from a Random Storm Event.

The runoff volume from each storm event was estimated with the following modification to the Rational Formula: $Q=R_vPA$ (1) where:

Q = the storm water runoff volume (ft^3/year);
P = the rainfall depth of the storm event (ft);
A = the drainage area (ft^2); and
R_v = the mean volumetric runoff coefficient, a unit-less value that is a function of the imperviousness of the drainage: Runoff Coefficient = 0.009 × (% Impervious) + 0.05. (2)

Total storm water runoff volume was determined as the sum of runoff from each land-use type:

$$Q_{total} = \sum_{lu} Q_{lu} = R_{v\,lu} P A_{lu} \qquad (3)$$

where lu designates the land-use type. It was assumed that rain falls uniformly over all land-uses within a town during each storm event.

The steps used to calculate the volume of runoff from a random storm event were:

Step 2a - Obtain a rainfall depth by randomly sampling from the 4,427 storm events as described in step 1.

Step 2b - For each land-use area calculate a runoff volume using equation (1). The same rainfall depth is applied to each land-use area.

Step 2c - Sum the runoff volumes from each land-use area to obtain the total runoff from the town for a particular storm event with equation (3).

Pollutant Load and Concentrations

Step 3 - Estimate a Pollutant Concentration in Storm Water Runoff from Each Land Use Area.

TP was modeled as the pollutant of concern for the purpose of the Lake Sunapee analysis. The distribution of land use-based TP concentrations in storm runoff was modeled using published TP EMC data as described above. The distribution of TP EMC data for all land-use categories were assumed to be log-normally distributed (NSQD V1.1). It is also assumed that runoff concentration is independent of rainfall depth, and is also independent of runoff concentration in neighboring land-use areas. The TP pollutant concentration in storm water runoff from each land-use area was estimated by randomly sampling from the associated EMC distribution (log-normal) estimated from the NSQD. The runoff concentration from each land-use area was evaluated with the expression:

$$C_{land-use} = \exp\left(\mu_{\ln x} + \sigma_{\ln x} R_N\right) \qquad (4)$$

where:

$\mu_{\ln x}$ = the log-normal mean;

$\sigma_{\ln x}$ = the log-normal standard deviation; and

R_N = a standard normal random variable.

Step 4 – Calculate the Total Runoff Volume, Pollutant Load, and Pollutant Concentration in a Random Storm Event

Step 4A - The total runoff volume in the watershed was calculated by summing the runoff from each land use area calculated using equation (3) as discussed in Step 2:

$$Q_{total} = Q_{land-use1} + Q_{land-use2} + \ldots + Q_{land-usei} \qquad (5)$$

where the same random rainfall event was used to calculate runoff volume in each of the land-use areas.

Step 4B - The total pollutant load was calculated by:

$$L_{total} = Q_{land-use1} C_{land-use1} + \ldots + Q_{land-usei} C_{land-usei} \qquad (6)$$

where the runoff from each individual land-use area was calculated with equation (3) discussed in step 2, and the concentration in each individual land-use area was calculated with equation (4) discussed in step 3.

Step 4C - The average pollutant concentration in runoff from the entire watershed from a single storm event was calculated by dividing the total watershed load by the total watershed runoff volume:

$$C_{total} = L_{total} / Q_{total} \qquad (7)$$

where the runoff from individual land-uses is calculated from step 2 and the concentration in individual land-uses in calculated by step 3.

Pollutant Loads and Concentrations Leaving the Project Site (Step 5):

The annual pollutant load is simply the sum of pollutant loads generated from all storms in a given year. Thus, to compute an annual pollutant load, the number of storms in a random year must first be determined. This was accomplished by randomly sampling from the distribution using the expression:

$$\mathrm{N}_{\mathrm{storms}} = 15.4 + 6.2 R_N \qquad (8)$$

where RN = a standard normal variant with a mean of 0 and a standard deviation of 1. The number of storms was rounded to the nearest whole number, and in cases where zero or a negative number of storms was obtained, the distribution was re-sampled until a positive number was obtained (years without any storms did not occur in the available period of record so this situation was not simulated in the water quality model).

Next, steps 2-4 were repeated Nstorms times, recording the total pollutant load from each random storm event. Finally, the individual storm loads were summed to obtain the total annual pollutant load.

Determine Distribution of Storm Concentration and Annual Loads (Steps 6 and 7): Steps 2-5 were repeated a total of 10,000 times, recording the pollutant concentration and annual load from each iteration. The resultant distributions can be used to present frequency distribution for pollutant concentrations or loads using statistics calculated from the 10,000 Monte-Carlo iterations.

RESULTS

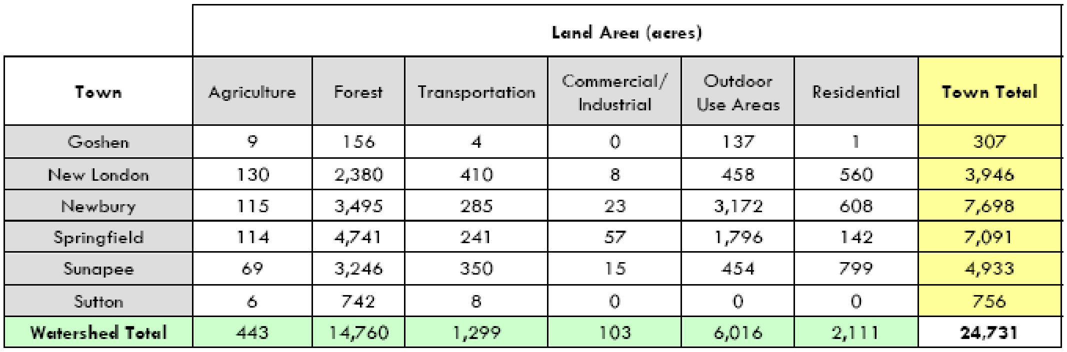
Land Use Analysis

Two land use conditions were analyzed for this model application; current land use and a full build-out condition land use. The results of the land use analysis are described below.

3.1.1 Current Condition

Current land uses were adapted from the 1995 Study prepared by the ULSRPC and are summarized in Table 3.1on the following page.

Table 3.1. Current Condition Land Use Analysis Summary (areas are reported in acres)

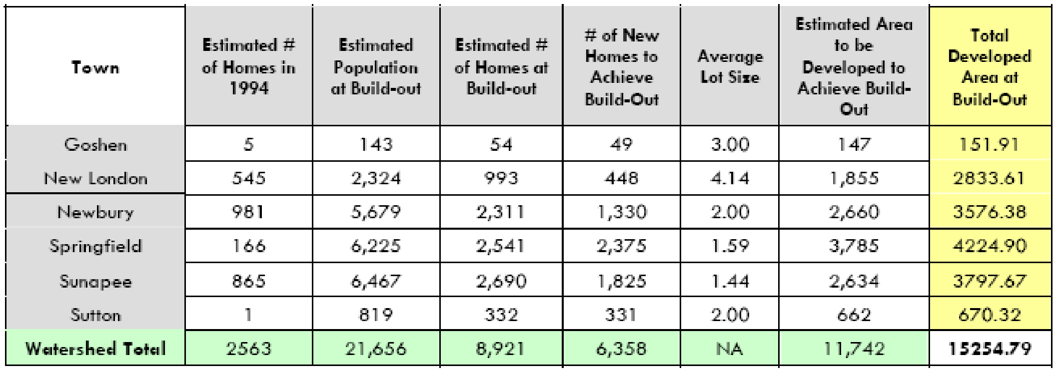


	Land Area (acres)						
Town	Agriculture	Forest	Transportation	Commercial/ Industrial	Outdoor Use Areas	Residential	**Town Total**
Goshen	9	156	4	0	137	1	307
New London	130	2,380	410	8	458	560	3,946
Newbury	115	3,495	285	23	3,172	608	7,698
Springfield	114	4,741	241	57	1,796	142	7,091
Sunapee	69	3,246	350	15	454	799	4,933
Sutton	6	742	8	0	0	0	756
Watershed Total	443	14,760	1,299	103	6,016	2,111	**24,731**

3.1.2 Full Build-Out Condition

The full build-out condition was based the projected population density and the projected number of homes provided by the UVLSRPC as summarized in column 1 and 2, respectively, of Table 3.2. The number of new homes required to achieve full-build-out was estimated by subtracting the number of existing homes in 1994 (1995 Study) from the number of homes at build-out (column 2). The number of new homes was then multiplied by the average lot area for each town (column 4) to estimate the area to be developed to achieve build-out. The lot areas were derived from the current zoning criteria for residential development described in the 2006 Memo.

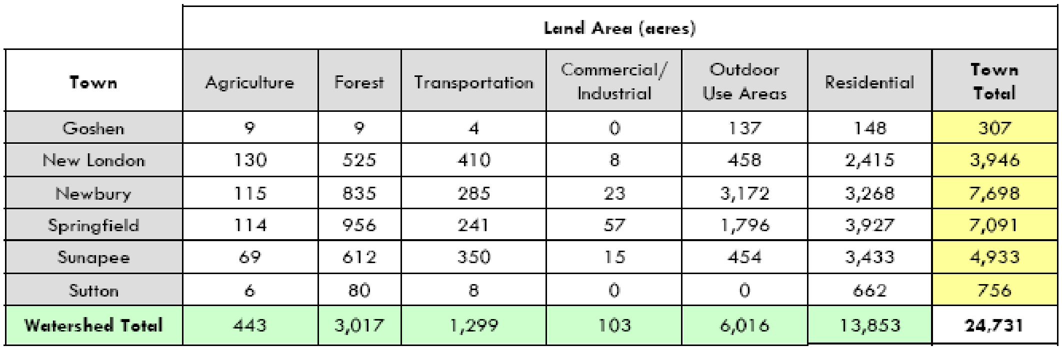
Table 3.2. Estimated Build-Out Population and Development Summary



Town	Estimated # of Homes in 1994	Estimated Population at Build-out	Estimated # of Homes at Build-out	# of New Homes to Achieve Build-Out	Average Lot Size	Estimated Area to be Developed to Achieve Build-Out	Total Developed Area at Build-Out
Goshen	5	143	54	49	3.00	147	151.91
New London	545	2,324	993	448	4.14	1,855	2833.61
Newbury	981	5,679	2,311	1,330	2.00	2,660	3576.38
Springfield	166	6,225	2,541	2,375	1.59	3,785	4224.90
Sunapee	865	6,467	2,690	1,825	1.44	2,634	3797.67
Sutton	1	819	332	331	2.00	662	670.32
Watershed Total	2563	21,656	8,921	6,358	NA	11,742	**15254.79**

The estimated total area of development at full build-out condition was then used to develop full buildout land use conditions. As described in Section 2.1, Geosyntec assumed that future development would occur in areas that are currently forested. A summary of anticipated land use conditions at full build-out is summarized in Table 3.3 on the following page.

Table 3.3. Estimated Full Build-Out Land Use Condition Summary



	Land Area (acres)						
Town	Agriculture	Forest	Transportation	Commercial/ Industrial	Outdoor Use Areas	Residential	**Town Total**
Goshen	9	9	4	0	137	148	307
New London	130	525	410	8	458	2,415	3,946
Newbury	115	835	285	23	3,172	3,268	7,698
Springfield	114	956	241	57	1,796	3,927	7,091
Sunapee	69	612	350	15	454	3,433	4,933
Sutton	6	80	8	0	0	662	756
Watershed Total	443	3,017	1,299	103	6,016	13,853	**24,731**

The net changes in land use to achieve full build-out are predicted to occur in forested and residential areas. These changes consist of a reduction in forested land cover areas, not including those with the land use category of open space, and a corresponding increase in residential land use area. Goshen is predicted to have a 94.3% reduction in forested area (from 156 acres to 9 acres), resulting in a with a 99.4% increase in residential area (from 1 acre to 148 acres). New London is expected to experience a 77.9% reduction in forested area with a 76.8% increase in residential area. Newbury is expected to experience a 76.1% reduction in forested area with a 81.4% increase in residential area. Springfield is expected to experience a 79.8% reduction in forested area with a 96.4% increase in residential area. Sunapee is expected to experience a 81.1% reduction in forested area with a 76.7% increase in residential area. Sutton is expected to experience a 89.3% reduction in forested area with a 100% increase in residential area. This represents an anticipated 79.6% net reduction of forested area in the Watershed and an anticipated 84.8% increase in residential area in the Watershed.

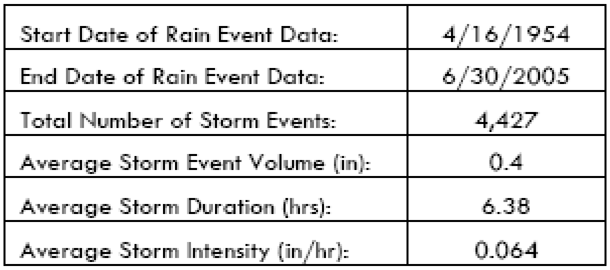
Water Quality Model with Monte Carlo Simulation Input Parameters

The input parameters for the M-CAT model fall into the following four main categories, which are described below: (1) rainfall data; (2) runoff coefficients; (3) land use data; and (4) storm water pollutant EMCs.

Rainfall Data:

Hourly precipitation data for the model was taken from two NOAA NCDC stations (Sunapee, NH Station No. 20018636, and Newport, NH Station No. 275868). The combined rainfall data set for Sunapee and Newport stations included hourly precipitation data between 4/16/1954 and 6/30/2005 and includes 4,427 individual storm events with an accumulation of 0.10 inches or more. A summary of the rainfall data used in the model is included in Table 3.4. A complete record of rainfall data input to the M-CAT is provided in Appendix A.

Table 3.4 M-CAT Rainfall Data Summary

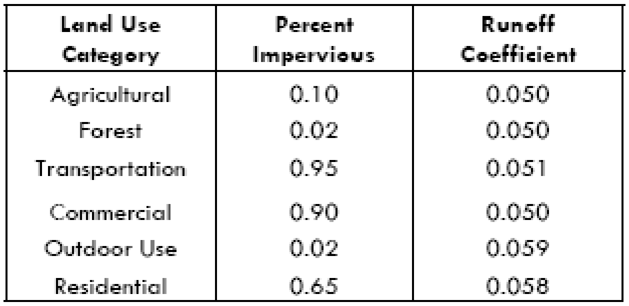


Start Date of Rain Event Data:	4/16/1954
End Date of Rain Event Data:	6/30/2005
Total Number of Storm Events:	4,427
Average Storm Event Volume (in):	0.4
Average Storm Duration (hrs):	6.38
Average Storm Intensity (in/hr):	0.064

Runoff Coefficients/Land Use Data

Runoff coefficients used in the Lake Sunapee model framework were based on land use and are a function of impervious area. The percent impervious values used in the water quality model for developed portions of the Watershed were based upon the values reported by NSQD V1.1. Percent impervious values used the model are summarized in column 2 of Table 3.5. The corresponding runoff coefficients using the Simple Method are summarized in column 3 of Table 3.5.

Table 3.5. Summary of Percent Impervious Values for Land Use Category

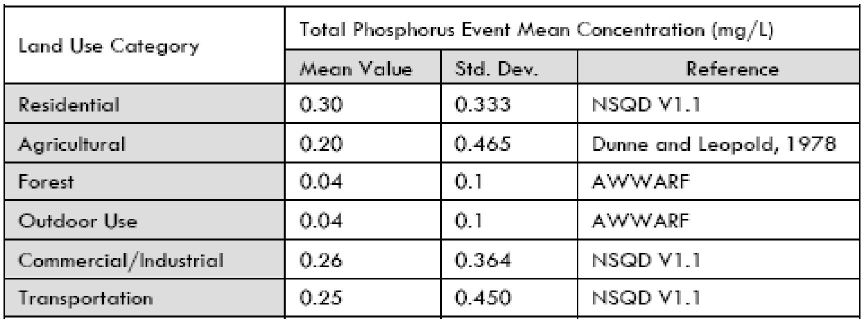


Land Use Category	Percent Impervious	Runoff Coefficient
Agricultural	0.10	0.050
Forest	0.02	0.050
Transportation	0.95	0.051
Commercial	0.90	0.050
Outdoor Use	0.02	0.059
Residential	0.65	0.058

Storm Water Pollutant EMCs:

Storm water pollutant EMCs were taken from the best available published data as described in Section 2.1. A summary of EMC data used in the Watershed model is included in Table 3.6. TP EMCs ranged from 0.04 mg/L for both forest and outdoor use to 0.30 mg/L for residential land uses. Outdoor Use land use was modeled as forested land cover as the majority of outdoor recreation areas in the Lake Sunapee region is forested and as such is conservatively modeled as such.

Table 3.6. Summary of Total Phosphorus EMC Data for each Land Use Category

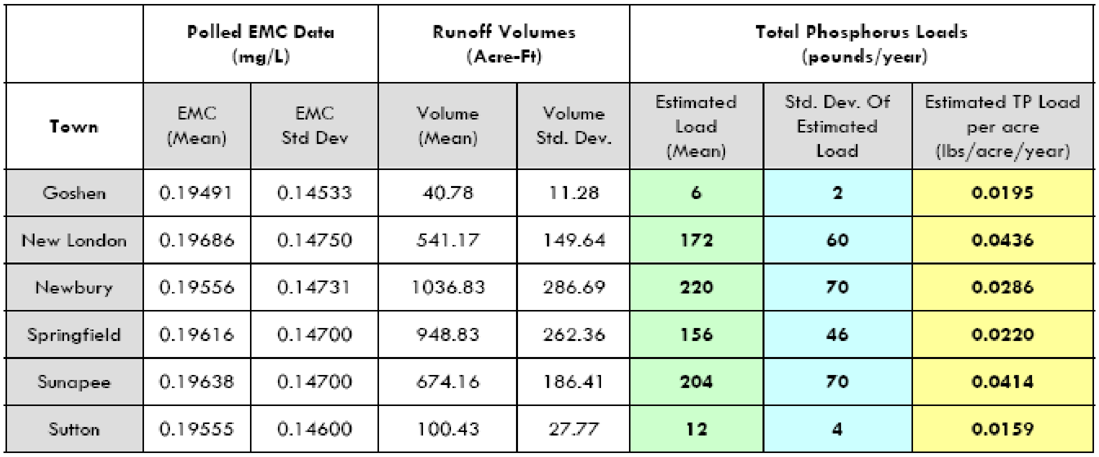


Land Use Category	Total Phosphorus Event Mean Concentration (mg/L)		
	Mean Value	Std. Dev.	Reference
Residential	0.30	0.333	NSQD V1.1
Agricultural	0.20	0.465	Dunne and Leopold, 1978
Forest	0.04	0.1	AWWARF
Outdoor Use	0.04	0.1	AWWARF
Commercial/Industrial	0.26	0.364	NSQD V1.1
Transportation	0.25	0.450	NSQD V1.1

Water Quality Model with Monte Carlo Simulation Procedure

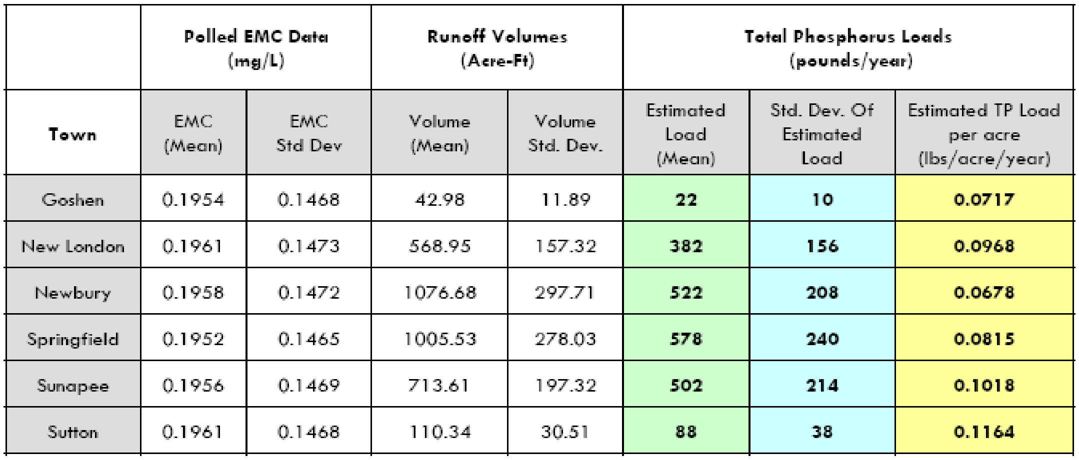
The M-CAT was run using the input data described above a total of 10,000 iterations recording the polled TP EMC, runoff volume and TP load in tons of TP per year (tons/yr) for each town. The statistics of these recorded results for the current condition and full build-out condition is provided in Table 3.7 and 3.8, respectively. These data provide a description of the average characteristics and variability of the volume and water quality of storm water runoff. A comparison of the data is discussed in Section 4.0.

Table 3.7. Current Condition Total Phosphorus M-CAT Summary



	Polled EMC Data (mg/L)		**Runoff Volumes (Acre-Ft)**		**Total Phosphorus Loads (pounds/year)**		
Town	EMC (Mean)	EMC Std Dev	Volume (Mean)	Volume Std. Dev.	Estimated Load (Mean)	Std. Dev. Of Estimated Load	Estimated TP Load per acre (lbs/acre/year)
Goshen	0.19491	0.14533	40.78	11.28	**6**	**2**	**0.0195**
New London	0.19686	0.14750	541.17	149.64	**172**	**60**	**0.0436**
Newbury	0.19556	0.14731	1036.83	286.69	**220**	**70**	**0.0286**
Springfield	0.19616	0.14700	948.83	262.36	**156**	**46**	**0.0220**
Sunapee	0.19638	0.14700	674.16	186.41	**204**	**70**	**0.0414**
Sutton	0.19555	0.14600	100.43	27.77	**12**	**4**	**0.0159**

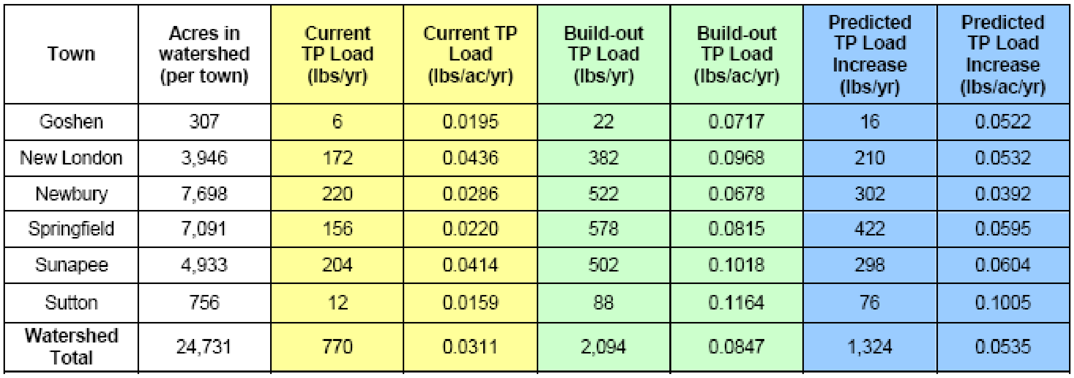
Table 3.8. Full Build-Out Condition Total Phosphorus M-CAT Summary



	Polled EMC Data (mg/L)		**Runoff Volumes (Acre-Ft)**		**Total Phosphorus Loads (pounds/year)**		
Town	EMC (Mean)	EMC Std Dev	Volume (Mean)	Volume Std. Dev.	Estimated Load (Mean)	Std. Dev. Of Estimated Load	Estimated TP Load per acre (lbs/acre/year)
Goshen	0.1954	0.1468	42.98	11.89	**22**	**10**	**0.0717**
New London	0.1961	0.1473	568.95	157.32	**382**	**156**	**0.0968**
Newbury	0.1958	0.1472	1076.68	297.71	**522**	**208**	**0.0678**
Springfield	0.1952	0.1465	1005.53	278.03	**578**	**240**	**0.0815**
Sunapee	0.1956	0.1469	713.61	197.32	**502**	**214**	**0.1018**
Sutton	0.1961	0.1468	110.34	30.51	**88**	**38**	**0.1164**

A summary of estimated total phosphorus loads for each town and for the Watershed is presented below in Table 3.9. A comparison of the data to water quality criteria and eutrophication benchmarks is discussed in Section 4.0.

Table 3.9. Comparison of TP Load for each town for Current and Full Build-Out Conditions

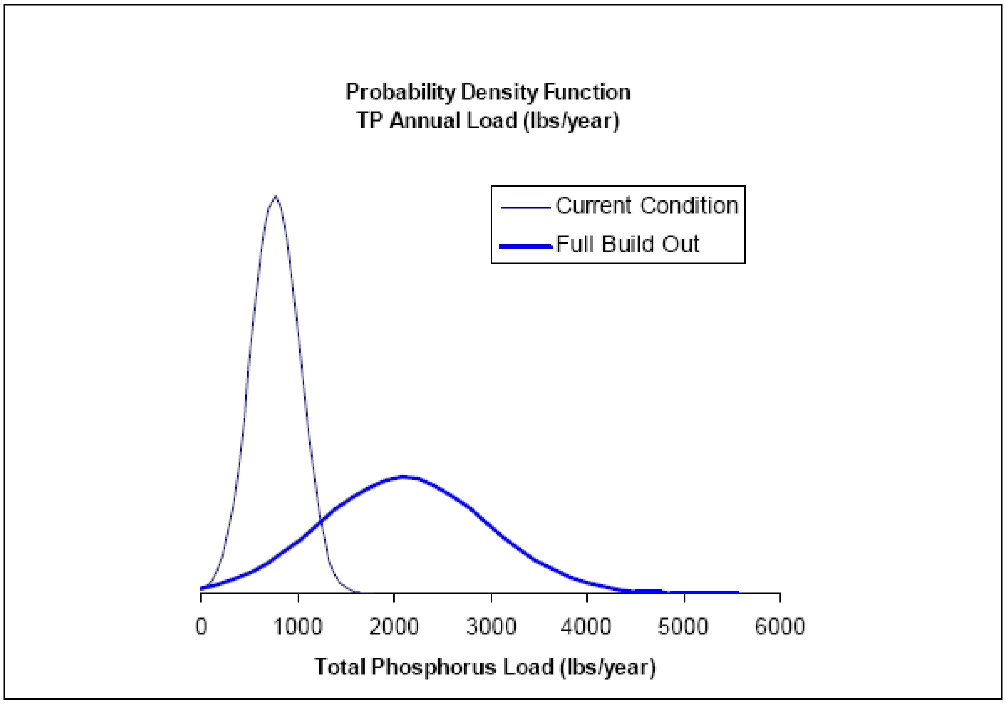


Town	Acres in watershed (per town)	Current TP Load (lbs/yr)	Current TP Load (lbs/ac/yr)	Build-out TP Load (lbs/yr)	Build-out TP Load (lbs/ac/yr)	Predicted TP Load Increase (lbs/yr)	Predicted TP Load Increase (lbs/ac/yr)
Goshen	307	6	0.0195	22	0.0717	16	0.0522
New London	3,946	172	0.0436	382	0.0968	210	0.0532
Newbury	7,698	220	0.0286	522	0.0678	302	0.0392
Springfield	7,091	156	0.0220	578	0.0815	422	0.0595
Sunapee	4,933	204	0.0414	502	0.1018	298	0.0604
Sutton	756	12	0.0159	88	0.1164	76	0.1005
Watershed Total	24,731	770	0.0311	2,094	0.0847	1,324	0.0535

- The largest relative increase in mean annual TP load in the Watershed is anticipated to take place in Sutton. The estimated annual TP load from Sutton at full build-out (88 lbs. per year) is predicted to shift from having the Watershed's lowest current TP load per acre (0.0159 lbs/ac/yr) to having the Watershed’s highest TP load per acre (0.1164 lbs/ac/yr). The estimated TP load from the town of Sutton at full build-out has one of the lowest standard deviations and therefore one of the highest confidence intervals for the predicted loads.
- Newbury has both the largest land area in the Watershed and the largest predicted current phosphorus load (220 lbs/yr). However, among all towns in the watershed, Newbury has the lowest predicted per-acre increase in loading rate at full build-out (0.0392 lbs/ac/yr).
- At full build-out, Springfield is predicted to have 3.7 times its current phosphorus load and become the Watershed's top contributor of phosphorus.
- The smallest relative increase in mean annual TP load in the Watershed is predicted to take place in New London. At full build-out, the estimated TP load from New London is expected to increase 2.2 times the current load. As shown above, the standard deviations for predicted phosphorus loads in the current condition range between ±2 lbs/yr and ±70 lbs/yr. Standard deviations for phosphorus loads in the build-out condition range between ±10 lbs/yr and ±208

lbs/yr. The build-out condition data has a higher standard deviation because the EMC data for residential land has a higher standard deviation than the EMC data for forested land use. Since forest land is converted to residential land in the full buildout scenario, the standard deviation increases accordingly. A probability density function was graphed for TP load (lbs/year) from the entire Watershed for both conditions and is shown on Figure 3.1. The estimated distribution of TP load for the current condition has a higher confidence interval with a mean TP load of 770 lbs/year and a standard deviation of ±252 lbs/yr. Specifically, approximately 68% of the 10,000 TP loads predicted by the model for the current condition were between 518 lbs/year and 1,022 lbs/year. The predicted distribution of TP loads for the full build-out condition has a lower confidence interval with a mean TP load of 2,094 lbs/year and a standard deviation of ±866 lbs/year. Approximately 68% of the of the 10,000 TP loads predicted by the model were between 1,228 lbs/year and 2,958 lbs/year. The coefficient of variation (CV) represents a measure of dispersion of the probability distribution and is defined as the standard deviation divided by the mean. The CV associated with the current condition is 33% while the CV associated with the full build-out condition is 41%.

Figure 3.1 TP Load Probability Density Function



DISCUSSION

The predicted TP load for the Watershed's full build-out condition is 2,094 ± 866 lbs/year. This represents an approximate increase of 2.7 times the mean TP load estimated for the current land use condition (770 ±252 lbs/yr). To understand the potential implications of this phosphorus load increase, Geosyntec evaluated Lake Sunapee's current trophic status and its sensitivity to changes in phosphorus load. Standard eutrophication benchmark values were evaluated and a literature review was conducted to determine the relationship between Lake Sunapee's external phosphorus loads and in-lake trophic status. Eutrophication is the gradual process of nutrient enrichment in aquatic ecosystems, such as lakes. Eutrophication occurs naturally as lakes become more biologically productive over geological time, but this process may be accelerated by human activities that occur in the watershed. Nutrients that contribute to eutrophication can come from many natural and anthropogenic sources, such as fertilizers applied to agricultural fields, golf courses, and suburban lawns; deposition of nitrogen from the atmosphere; erosion of soil containing nutrients; and sewage treatment plant discharges. Land development not only increases the sources of nutrients, but also decreases opportunities for natural attenuation (e.g. uptake by vegetation) of such nutrients before they can reach a water body. Nutrients such as phosphorus and nitrogen can stimulate abundant growth of algae and rooted plants. Over time, this enhanced plant growth leads to reduced dissolved oxygen in the water, as dead plant material decomposes consumes oxygen. Phosphorus is typically the “limiting nutrient” for freshwater lakes, which means that plant productivity is most often controlled by the supply of this nutrient. As such, increases in phosphorus load in a lake watershed are closely correlated with increases in plant productivity and accelerated eutrophication. Surface water bodies are categorized according to trophic state as follows:

Oligotrophic: Low biological productivity. Oligotrophic lakes are very low in nutrients and algae, and typical have high water clarity and a nutrient-poor inorganic substrate. Oligotrophic water bodies are capable of producing and supporting relatively small populations of living organisms (plants, fish, and wildlife). If stratified, hypolimnetic oxygen is abundant.

Mesotrophic: Moderate biological productivity and moderate water clarity. A mesotrophic water body is capable of producing and supporting moderate populations of living organisms (plant, fish, and wildlife).

Eutrophic: High biologically productivity due to relatively high rates of nutrient input and nutrient rich organic sediments. Eutrophic lakes typically exhibit periods of oxygen deficiency and reduced water clarity. Nuisance levels of macrophytes and algae may result in recreational impairments.

Hypereutrophic: Dense growth of algae throughout the summer. Dense macrophyte beds, but extent of growth is light-limited due to dense algae and associated low water clarity. Summer fish kills are possible.

The Carlson Trophic State Index (TSI) is one of the most commonly used means of characterizing a lake's trophic state. As illustrated in the figure below, the TSI assigns values based upon formulas which describe the relationship between three parameters (total phosphorus, chlorophyll-a, and Secchi disk clarity) and the lake's overall biological productivity. As shown in the figure below, TSI scores below 40 are considered oligotrophic, scores between 40 and 50 are mesotrophic, scores between 50 and 70 are eutrophic, and scores from 70 to 100 are hypereutrophic.

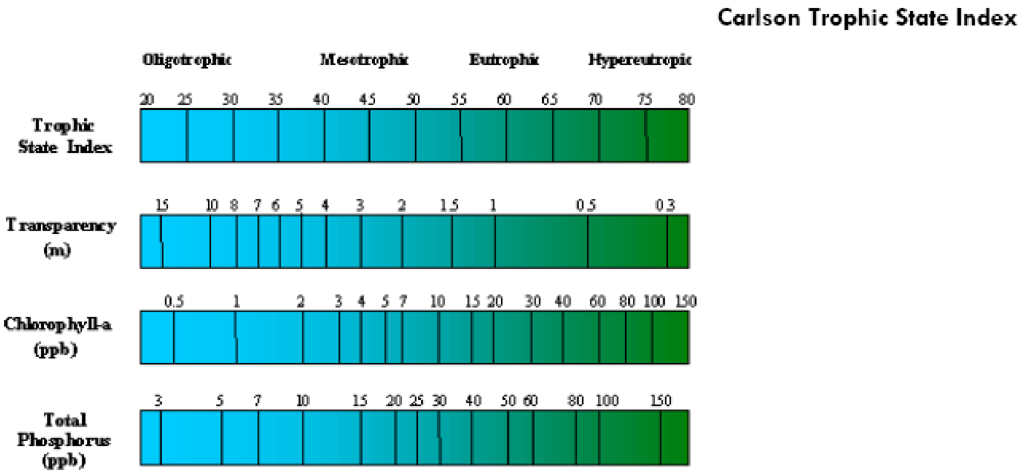


Figure from 1988 Lake and Reservoir Restoration Guidance Manual. USEPA. EPA 440/5-88-002.

NH DES categorizes lakes into trophic state according to total phosphorus concentration:

Total Phosphorus (ug/L)	Trophic Status
<10	Oligotrophic
10-20	Mesotrophic
>20	Eutrophic

Based on data for Lake Sunapee from 7 September 1995 and 28 February 1996, NH DES classified Lake Sunapee as an oligotrophic lake (NH DES Water Supply and Pollution Control Division-Biology Bureau, Lake Trophic Data). (*Note: Lake trophic data from this time period was assessed by Geosyntec to represent the current condition of the lake because of its relative proximity to the 1994 land use data which was used in the model to represent the current condition.)* In-lake total phosphorus concentrations from the above dates ranged from 1 ug/L to 9 ug/L, with a mean concentration of 5.3 ug/L.

Stauffer (1985) identified that approximately 8% of external phosphorus loads are retained within a lake annually. Stauffer (1985) also showed that, for oligotrophic lakes in the northeastern United States, there is a linear relationship between in-lake eutrophication level and external loading by the following:

$$TP_y = 8.5 + 0.081(L_{TP})(q_s^{-1}) \qquad (10)$$

Where:

TP_y = In-lake Total Phosphorus concentration (mg/L)

L_{TP}= external TP loading to the lake in mg P/m^2*yr

q_s=lake overflow rate in m/yr.

The equation above was used to calculate the annual phosphorus loading rate that would be predicted to result in an in-lake total phosphorus concentration of 10 ug/L, the threshold value required to tip Lake Sunapee from oligotrophic to mesotrophic according to the NH DES trophic status classification. Assuming that (1) the annual storm water volume represents the lake overflow rate, and (2) a Lake surface area of 4,090 acres, the resulting L_{TP}

value was calculated to be 1,060 lbs/yr. This means that an annual phosphorus load of 1,060 lbs/yr is predicted to be Lake Sunapee's "tipping point" between oligotrophic status and mesotrophic status.

According to the M-CAT model developed by Geosyntec, the full build-out condition for the Lake Sunapee watershed will yield a predicted TP load of 2,094 tons/year with a standard deviation of ±866 lbs/yr. The "tipping point" TP loading rate loading rate described above (1,060 lbs/yr) is within the 84% confidence interval for the build-out condition predicted by the M-CAT model. This means that 84% of the 10,000 TP loads calculated by the model for the build-out condition were predicted to be greater than or equal to 1,060 lbs/yr. As such, the model predicts with a high degree of confidence that the full build-out scenario for the Lake Sunapee watershed will result in a phosphorus load that will shift Lake Sunapee from oligotrophic status to mesotrophic status.

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Conductivity

Conductivity is the numerical expression of the ability of water to carry an electrical current. It is determined primarily by the number of ionic particles present. The soft waters of New Hampshire have traditionally had low conductivity values, generally less than 50 uMhos/cm. However, specific categories of good and bad levels cannot be constructed for conductivity because variations in watershed geology can result in natural fluctuations in conductivity. Generally, values in New Hampshire lakes exceeding 100 uMhos/cm indicate cultural, meaning human, disturbances. An increasing conductivity trend typically indicates point sources and/or non-point sources of pollution are occurring within the watershed. The median conductivity for New Hampshire lakes is 40uMhos/cm while the mean conductivity is 59.4 uMhos/cm. (VLAP 2006).

For the most part, conductivity values are increasing across the watershed, and in some cases is already higher than the state median. In particular, the Lake Sunapee nearshore, deep spots and tributary stations have been showing increases on the 2-3% per year range. There is an anomaly in the 2006 data in that the values decreased for these samples. This has been attributed to the higher than usual rainfalls and spring runoff which likely diluted the conductivity concentrations for this sampling period.

The increasing conductivity concentrations indicate impacts from human activities such as land development, road runoff, agricultural runoff and failing septic systems. Shoreline surveys of the lake shore and contributing tributaries would help identify sources of conductivity, human and naturally occurring.

Dissolved Oxygen

The presence of dissolved oxygen is vital to bottom-dwelling organisms as well as fish and amphibians. If the concentration of dissolved oxygen is low, typically less than 5 mg/L, species intolerant, meaning sensitive, to this situation, such as trout, will be forced to move up closer to the surface where there is more dissolved oxygen but the water column is generally warmer, and the species may not survive.

Temperature is also a factor in the dissolved oxygen concentration. Water can hold more oxygen at colder temperatures than at warmer temperatures. Therefore, a lake will typically have a higher concentration of dissolved oxygen during the winter, spring, and fall than during the summer. (VLAP 2006)

Dissolved oxygen concentrations in all of the lakes and ponds in the watershed appears to be very good. It should be noted that in aging lakes which may be stratified, the hypolimnion layer will tend to show oxygen depletion as a result of natural processes of decomposition. In some cases the oxygen depletion at the lake bottom may reach a critical low and cause phosphorus which is bound up in the sediment to be released back into the water column. This is known as *internal phosphorus loading.* Careful monitoring and control of additional phosphorus inputs to these lakes is critical to maintaining the dissolved oxygen balance.

Chlorophyll –a

Algae, formally referred to as phytoplankton are photosynthetic plants that contain chlorophyll but do not have true roots, stems, or leaves. They do, however, grow in many forms such as aggregates of cells (colonies), in strands (filaments), or as microscopic single cells. They may also be found growing on objects, such as rocks or vascular plants, on the lake bottom or free-floating in the water column.

VLAP uses the measure of chlorophyll-a as an indicator of the algae abundance. Because algae is a plant and contains the green pigment chlorophyll, the concentration of chlorophyll measured in the water gives an estimation of the concentration of algae. If the chlorophyll-a concentration increases, this indicates an increase in the algal population. Generally, a chlorophyll-a concentration of less than 5 mg/m^{3}typically indicates water quality conditions that are representative of oligotrophic lakes, while a chlorophyll-a concentration greater than 15mg/m^3 indicates eutrophic lakes. A chlorophyll concentration greater than 10 mg/m^3 generally indicates an algae bloom, an undesirable reproduction of algae, is occurring. The median chlorophyll concentration for New Hampshire lakes is 4.58 mg/m^3 and the mean is 7.16 mg/m^3 (VLAP 2006).

Chlorophyll-a concentrations throughout the watershed tend to be low, which indicates good water quality and implies a low abundance of algae. In order to maintain this condition of low chlorophyll-a concentrations and subsequent minimal appearance of algae, it is important to monitor in-lake and tributary contributions of phosphorus which is the nutrient which promotes algal growth.

Cyanobacteria

Cyanobacteria are bacterial microorganisms that photosynthesize and may produce chemicals toxic to other organisms, including humans. Many species of cyanobacteria may accumulate to form surface water blooms. They produce a blue-green pigment but may impart a green, blue, or pink color to the water. Cyanobacteria occur in all lakes, everywhere. There are many types of cyanobacteria in New Hampshire lakes. Most cyanobacteria do not have the ability to produce toxins. In New Hampshire, there are several common cyanobacteria that include: *Gleotrichia*, *Merismopedia, Anabaena, Oscillatoria*, *Coelosparium*, *Lyngbya,* and *Mycrocystis. Anabaena* produces neurotoxins that interfere with the nerve function and have almost immediate effects when ingested. *Mycrocystis* and *Oscillatoria* are known for producing hepatotoxins (liver toxins) known as microcystins. *Oscillatoria* and *Lyngbya* produce dermatotoxins which cause skin rashes. (VLAP 2006).

Cyanobacteria are present in very limited amounts across the watershed. It is important for water quality monitors to continue tracking this phytoplankton. As in-lake phosphorus levels increase, and conditions become favorable, such as August warm sunny days, cyanobacteria can bloom and present a serious health threat for humans and their pets.

3.4 CONCLUSIONS

There are multiple signs that Lake Sunapee and the other watershed lakes and ponds are threatened. While on the surface, these lakes and ponds appear to be high quality and healthy, they remain in a very delicate balance. Each of the water quality indicators summarized above demonstrate that the systems may be on the edge of a downward track.

This trend is shown in the decreasing dissolved oxygen concentrations in the hypolimnion coupled with increasing phosphorus concentrations from the near shore and tributary stations as well as in-lake. Increasing conductivity and the potential for algal blooms and cyanobacterial growth are all indicators of land use activities resulting in non-point source pollution.

In addition to the concerns raised by these results, there is a demonstrated need for more information about these waterbodies. For example, more in-depth investigations of the largest contributors of stream flow to Lake Sunapee is recommended. These include Otter Brook, Chandler Brook, Johnson Brook, Blodgett Brook, Pike Brook, King Hill Brook, and Herrick Cove. Stormwater sampling should be conducted wherever feasible as well.

All is not so bleak though, the Lake Sunapee Watershed benefits from several very active, committed organizations and citizen volunteers. Chapter Six presents the recommendations of the Lake Sunapee Watershed Planning Committee to address many of the water quality concerns raised in this chapter.