3. ASSESSMENT OF WATER QUALITY

3.1 APPLICABLE WATER QUALITY STANDARDS AND CRITERIA

3.1.1 Designated Uses & Water Quality Classification

Designated Uses

The State of New Hampshire has numerous statutes and rules that are designed to protect lakes. Over the past three decades NHDES has made a major effort to ensure that lakes support all designated uses. Designated uses for freshwater are presented in Table 5. All the designated uses for fresh surface waters are present in Lake Sunapee.

Classification

In the 1950s, Lake Sunapee met the standards to be named a Class A (drinking water quality) lake in New Hampshire. All other lakes and ponds in the watershed are classified as Class B. While there is no functional difference in terms of designated use support for Class A and Class B waters (Table 5), they are defined differently (Table 6, following page). Specific water quality standards are somewhat different for Class A vs Class B waters (Table 7, following page).

Table 5 - Designated Uses for Fresh New Hampshire Surface Waters
(adapted from NHDES, 2018a)

Designated Use	NHDES 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
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 surface waters
Primary Contact Recreation	Waters suitable for recreational uses that require or are 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

Table 6 - New Hampshire Surface Water Classifications	
Classification	**Description (RSA 485-A:8)**
Class A	Class A waters shall be of the highest quality. There shall be no discharge of any sewage or wastes into waters of this classification. The waters of this classification shall be considered as being potentially acceptable for water supply uses after adequate treatment.
Class B	Class B waters shall be of the second highest quality. The waters of this classification shall be considered as being acceptable for fishing, swimming and other recreational purposes and, after adequate treatment, for use as water supplies.

3.1.2 Water Quality Standards and Criteria

Criteria for parameters relevant to this plan are presented in Table 7.

Table 7 - Selected NH Water Quality Standards and Criteria Relevant to the Lake Sunapee Watershed Plan			
Parameter	**Class A**	**Class B**	**Citation**
Dissolved Oxygen	75% saturation, min 6.0 mg/l	75% saturation, min 5.0 mg/l	Env-Wq 1703.07
Dissolved Oxygen - lakes	Top 25% of depth – 75% saturation. >5.0 mg/l below. Must support designated uses	Top 25% of depth – 75% saturation. >5.0 mg/l below. Must support designated uses	Env-Wq 1703.07
Phosphorus	None unless naturally occurring	Concentrations low enough to support designated uses unless naturally occurring	Env-Wq 1703.14 (a), (b)
Phosphorus	No new or increased discharge	No new or increased discharge	Env-Wq 1703.14 (d)
Chloride (acute)	860 mg/l	860 mg/l	Env-Wq 1703.21
Chloride (chronic)	230 mg/l	230 mg/l	Env-Wq 1703.21

Several waterbodies in the Sunapee Watershed have been determined by NHDES to be impaired relative to designated uses. Lake Sunapee, Little Lake Sunapee and Baptist Pond are listed (NHDES 2018b) as impaired (severe, non-supporting) for aquatic life due to inadequate dissolved oxygen levels. Baptist Pond is also listed for exceedance of criteria for total phosphorus and chlorophyll-*a.* A number of tributary streams and ponds in the Sunapee Watershed are listed as impaired for aquatic life use due to low pH.

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.

3.1.3 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. Relevant provisions relative to this plan include; ENV-WQ 1708.03 which states "a proposed discharge or activity shall not eliminate any existing uses or the water quality needed to maintain and protect those uses" and Env-Wq 1708.05 which states "discharges containing "sewage" or "wastes" are not allowed in Class A waters."

3.2 ASSIMILATIVE CAPACITY ANALYSIS

3.2.1 Data Review

Historic Lake Sunapee Data Assessment

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 many factors including water transparency, nutrient enrichment, planktonic growth, presence of aquatic plants, types of fishery (cold or warm), and dissolved oxygen content. Lake characteristics change as lakes age. For example, oligotrophic waterbodies are considered young or in an early stage of development. Waterbodies in this trophic stage are typically characterized by clear water, low nutrient concentrations, low productivity, few aquatic plants, presence of a cold-water fishery and high dissolved oxygen content. Eutrophic waterbodies are considered old or transitioning towards wetlands. Eutrophic lakes typically have high nutrient concentrations which fuel high planktonic and benthic algal growth, extensive aquatic plant beds, sediment accumulation on the lake bottom and frequent algal blooms. Mesotrophic characteristics fall between eutrophic and oligotrophic.

In New Hampshire, designated uses and the water quality to protect those uses are regulated through the Water Quality Standards, which include RSA 485-A:8 - the Classification of Water, and Env-Wq 1700 - the Surface Water Quality Regulations (Section 3.1). To protect the aquatic life designated use, criteria for total phosphorus and chlorophyll-*a* have been set. (Table 8).

Table 8 - TP and Chl-*a* Criteria for Aquatic Life Designated Use

Trophic State	TP (µg L-1)	Chl-*a* (µg L-1)
Oligotrophic	< 8.0	< 3.3
Mesotrophic	< or = 12.0	< or = 5.0
Eutrophic	< or = 28	< or = 11

Lake Sunapee and many of the lakes and ponds in the Lake Sunapee Watershed are considered oligotrophic although several of the watershed lakes are mesotrophic and have become so at a faster than natural rate due to development and changes in the watershed.

Surface Water Quality in the Lake Sunapee Watershed

Water quality in Lake Sunapee and lakes and ponds in the watershed has been monitored periodically by a number of state agencies and local associations since 1939 (NH Fish and Game 1977) and consistently since 1986 as a part of the Volunteer Lakes Assessment Program (VLAP). In Lake Sunapee, VLAP volunteers and LSPA staff collect data from four deep spot stations, nine near shore stations and numerous tributary stations (Appendix A, VLAP Monitoring Stations Map 7). VLAP monitors are active in six other lakes and ponds; Baptist Pond, Chalk Pond, Dutchman Pond, Little Lake Sunapee, Mountainview Lake and Otter Pond. Recent water quality data throughout the Sunapee Watershed are readily available on the LSPA website through an interactive mapping program (http://www.lakesunapee.org/trends-concerns). The most recent VLAP water quality reports can also be found there. This monitoring program is critical to the understanding of long-term trends in Lake Sunapee, upstream lakes and ponds and the tributaries. This section contains a summary of those results that are directly relevant to this plan. The reader is directed to the LSPA website above for all parameters and current interpretation. Figure 6 on the following page is from one of the VLAP reports for a deep station in Lake Sunapee. This figure illustrates the low phosphorus and chlorophyll-*a* concentration over time and high transparency depths.

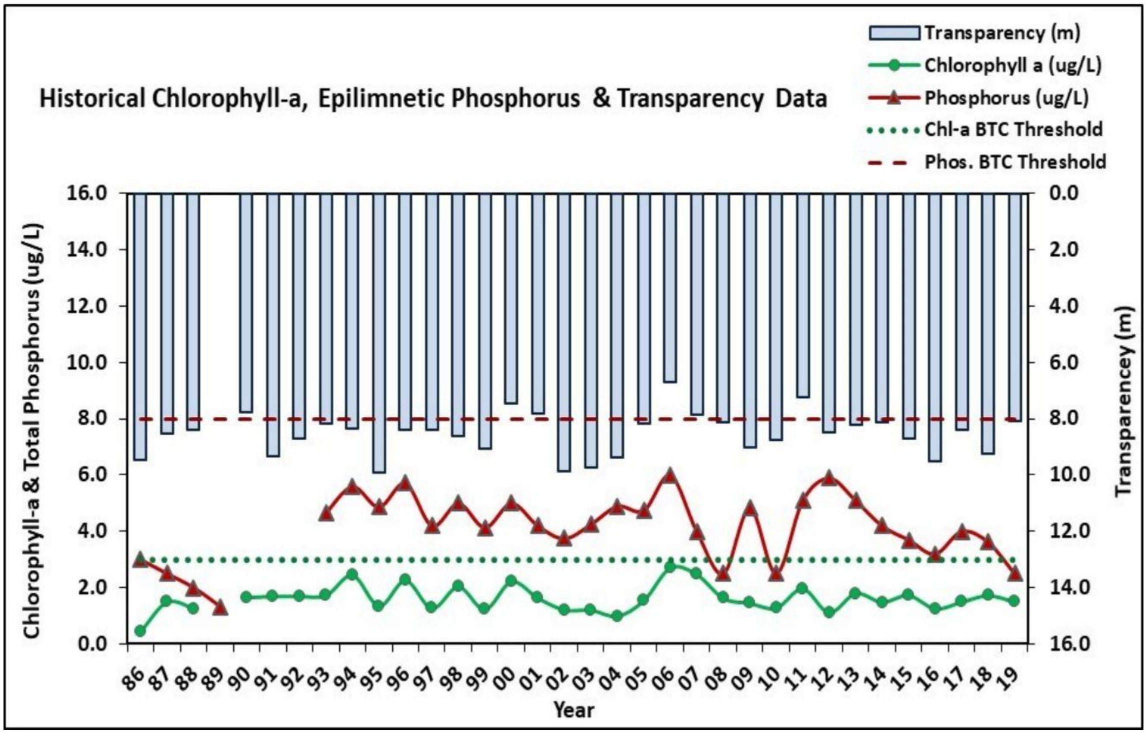

Figure 6. Historic VLAP Monitoring Results for a Deep Station in Lake Sunapee.

The following section of the Plan summarizes water quality information from the Volunteer Lake Assessment Program (NHDES 2017) for each of the lakes and ponds as summarized in Table 9 on the following pages. These results are discussed because they represent a useful long-term dataset as well as a good representation of current conditions.

Table 9 - Summary of Water Sample Results for Selected Biological and Chemical Parameters for Waterbodies in the Lake Sunapee Watershed (Source: NHDES 2017).

Waterbody	Phosphorus	Chlorophyll-*a*	Transparency	Conductivity	pH and Alkalinity	Dissolved Oxygen - Hypolimnion
Lake Sunapee Deep Spots	Oligotrophic conditions - not significantly changed, much less than state median for P.	Not significantly changed, historical data show the average is less than the state median.	High transparency, stable over time.	Greater than the state median, significantly increasing.	Satisfactory, note higher acidity in the hypolimnion, moderately vulnerable to acidification.	High in the epilimnion but depleted in the hypolimnion – possible risk for future internal loading.
Lake Sunapee Near Shore	Mesotrophic conditions - generally increasing levels of P but highly variable among stations, greater than state median.	Not significantly changed, stations demonstrating some year to year variability.	Stable at all stations except 110 where transparency is significantly decreasing.	Greater than the state median, significantly increasing.	Slightly acidic, moderately vulnerable.	Not applicable
Lake Sunapee Tributaries	Low to moderate levels - somewhat higher in summer.	Not applicable	Not applicable	Wide range of values, some stations are consistently high.	Slightly acidic at most stations and below desirable at some stations.	Not applicable
Baptist Pond	Mesotrophic conditions - phosphorus exceeds threshold for mesotrophic lakes at times, particularly in hypolimnion.	Greater than the state median but stable with some year-to-year variability	Transparency below average and decreasing over time	Slightly greater than state median, stable.	Slightly more Acidic than desirable range.	Insufficient data to assess.
Chalk Pond	Oligotrophic conditions - not significantly changing.	Slightly greater than threshold for oligotrophic lakes. Highly variable.	Transparency decreasing over time.	Close to the state median, but significantly increasing.	Stable, in desirable range with moderate variability among years.	Insufficient data to assess.

Table 9 - Summary of Water Sample Results for Selected Biological and Chemical Parameters for Waterbodies in the Lake Sunapee Watershed (Source: NHDES 2017).

Waterbody	Phosphorus	Chlorophyll-*a*	Transparency	Conductivity	pH and Alkalinity	Dissolved Oxygen - Hypolimnion
Dutchman Pond	Mesotrophic conditions - but trending towards oligotrophic.	Not significantly changed, below threshold for oligotrophic lakes. Historical data show the average is less than the state median and variable.	Very good but decreasing over time.	Stable and low.	Slightly acidic, lower than desired range.	Insufficient data to assess.
Little Lake Sunapee	Oligotrophic conditions in the epilimnion and mesotrophic conditions in the hypolimnion, variable P.	Low but variable. Stable over time.	Transparency decreasing over time.	Greater than the state median, stable but variable.	Slightly acidic, note higher acidity in the hypolimnion.	Lower in metalimnion and hypolimnion than the epilimnion – potential for future internal phosphorus loading.
Mountainview Lake	Mesotrophic conditions - not significantly changed, P concentrations slightly less than state median.	Not significantly changing, historical data show the average is approximately equal to state median.	Transparency decreasing over time.	Greater than the state median, highly variable.	Slightly acidic note pH decreasing over time.	Much lower in hypoliminion – potential for future internal phosphorus loading.
Otter Pond	Mesotrophic range and stable over time.	Lower than state median but increasing over time.	Transparency decreasing over time.	Above state median and increasing.	Generally within desired range but epilimnetic values occasionally low. Decreasing over time.	Much lower in hypoliminion – potential for future internal phosphorus loading.

3.2.2 Water Quality Parameters

Total Phosphorus

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. In most lakes, phosphorus is the critical nutrient to algal growth meaning that the more phosphorus in a lake, the greener the lake appears. Conversely, restricting the input of phosphorus to a lake typically leads to clearer water. Phosphorus concentration directly relates to trophic state as described above. For example, values less than 8 µg/L are considered "ideal" and generally indicate oligotrophic conditions. Values greater than 28 µg/L are considered "more P than desirable" and indicate eutrophic conditions. Mesotrophic conditions exist between these two values and are considered "average."

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 µg/L. The median summer total phosphorus concentration in the hypolimnion of New Hampshire lakes and ponds is 14 µg/L.

Based on data from the past 10 years, phosphorus concentrations across the watershed vary greatly. The Sunapee deep spots, Chalk Pond and Little Lake Sunapee have low enough phosphorus concentrations to support an oligotrophic classification. However, the near shore stations on Lake Sunapee, many tributaries and several lakes and ponds in the watershed show higher concentrations of phosphorus more representative of mesotrophic conditions. In general, these higher concentrations are associated with the more developed portions of the watershed. This suggests that there are existing controllable sources of phosphorus. It is also clear that increasing these sources further will result in a decline of water quality in Lake Sunapee. The data support development of this plan to reduce phosphorus input to Lake Sunapee. This will maintain the current oligotrophic state of the lake into the future.

Chlorophyll-a

Algae 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 (benthic algae) or free-floating in the water column (phytoplankton). Cyanobacteria, while not technically plants, share characteristics with both algae and bacteria.

Both algae and cyanobacteria contain chlorophyll-*a* (a green pigment). VLAP uses the measure of chlorophyll-*a* as an indicator of algal and cyanobacterial abundance. The concentration of chlorophyll-*a* measured in the water gives an estimation of the amount of algae and cyanobacteria present. If the chlorophyll-*a* concentration increases, this indicates an increase in the algal and/or cyanobacteria population. A chlorophyll-*a* concentration of less than 3 µg/l typically indicates water quality conditions that are representative of oligotrophic lakes (Table 9, page 24) while a chlorophyll-*a* concentration greater than 11 µg/l indicates eutrophic conditions. A chlorophyll-*a* concentration greater than 10 µg/l generally indicates an algae bloom that is visible.

Chlorophyll-*a* concentrations throughout the watershed tend to be low, which indicates good water quality and implies a low abundance of algae however, Baptist, Chalk and Otter ponds have shown chlorophyll-*a* concentrations that are greater than the threshold for oligotrophic lakes. The concentration in Otter Pond is increasing. This is particularly important to Lake Sunapee as water from the Otter Pond drainage is the largest single source of water to Lake Sunapee.

Transparency

Secchi transparency is a measure of the clarity of water measured by lowering a standard black and white disk into the water column until it disappears from view. Transparency is valued by stakeholders and is one of the easiest parameters to understand. Transparency is affected by growth of algae and cyanobacteria, the presence of organic and inorganic particles in the water column and the color of the water.

Transparency at deep water sites in Lake Sunapee is good however, a decline in transparency over time has been noted in Sunapee nearshore sites and throughout the lakes and ponds in the Sunapee Watershed. Reduction of algal growth related to phosphorus enrichment (a part of this plan) is expected to help slow or reverse the declining transparency trend.

Cyanobacteria

Cyanobacteria (formerly known as blue-green algae) are microorganisms that photosynthesize and share characteristics of both algae and bacteria. Cyanobacteria are some of the oldest and widespread organisms on earth and many produce and release toxins into the water, at times. These toxins can be a concern for drinking water supplies and for recreational contact and are considered "unregulated contaminants". Most cyanobacteria toxins are not released until the cell dies and the cell wall ruptures. There are several types of toxins including hepato (liver), dermo (skin), and neurotoxins (nervous system). There have been a number of blooms and scums in local waters but, toxin concentrations at a level of concern have not been reported to date. LSPA currently assesses toxicity for advisory purposes.

The likelihood of cyanobacteria blooms at nuisance levels rises with increased phosphorus concentrations. Most cyanobacteria tend to rapidly reproduce or "bloom" in high-nutrient (eutrophic) waters. However, some species, such as *Gloeotrichia echinulate* (a species that has been blooming in Lake Sunapee), can bloom and form a surface scum in low-nutrient (oligotrophic) waters. The proliferation of this organism throughout the northeast despite relatively low water column phosphorus concentrations is currently the focus of ongoing research by LSPA's Scientific Advisory Committee (SAC). One likely mechanism is the transport of previously deposited sediment phosphorus up into the water column as cells leave their resting stage on the bottom. This nutrient transport may be an important mechanism for moving phosphorus that was previously unavailable for phytoplankton growth up into the water column for use by *Gloeotrichia* or other algae and cyanobacteria. Transported phosphorus either leaks out of live *Gloeotrichia* cells or is released as *Gloeotrichia* cells die and decompose.

Other species of cyanobacteria are present at times in small numbers. These include *Anabaena*, *Microcystis, Oscillitoria* and others. These species are more likely to be problematic in the formation of floating scums or toxin production if they were found in bloom concentrations. As with all cyanobacteria species, the presence of low concentrations of phosphorus greatly diminishes the likelihood that these species will occur in problematic concentrations

Conductivity

Conductivity is a measure of the ability of water to carry an electrical current. The soft (low ion) waters of New Hampshire have traditionally had low conductivity values, generally less than 50 µS/cm. Elevated values in New Hampshire lakes typically suggest non-natural sources. Foremost among these non-natural sources is road salt applied in the winter which enters surface water throughout the year either directly through highway runoff during snowmelt or more slowly through storage in soils and groundwater. At very high levels, chloride (an ion in road salt) can be toxic to aquatic organisms. High input of saline water can also restrict mixing in lakes and ponds, reducing the re-oxygenation of bottom waters (Novatny and Stefan 2012).

Conductivity values are above the state median and/or increasing throughout the Lake Sunapee Watershed (Table 9, page 24). This is very likely to be attributable to the use of road salt in the watershed of these lakes and ponds. Only Morgan and Dutchman Ponds are currently showing no increase in conductivity. These ponds have little to no road area and associated salt use in their watersheds.

Beginning in 2019, the LSPA began measuring chloride levels at water quality stations throughout the watershed to corroborate rising conductivity levels.

pH

pH is a measure of the acidity of water. pH ranges from 0 to 14 with 7 being neutral. pH below 7 is acidic while pH above 7 is basic. Lake pH is important for the survival and reproduction of fish and other aquatic species as well as governing many chemical reactions. pH is affected by both external and internal factors in lakes. Acid rainfall and release of tannic and humic acids from watershed wetlands both cause a decrease in pH in lakes. Photosynthesis by plants and algae in lakes can increase pH by using carbon dioxide in the water. Respiration and decomposition decrease lake pH by generating carbon dioxide. Because there is typically more decomposition and respiration at depth in lakes than at the surface due to light availability, pH is often lower in bottom waters.

New Hampshire lakes historically have had pH values between 6.5 and 7. A pH of between 6.5 and 8.0 is desired (NHDES 2017). 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. Most lakes and ponds in the Lake Sunapee Watershed are slightly acidic. Baptist and Dutchman Ponds exhibit pH values slightly below the desired range. Similarly, a number of the tributaries to Lake Sunapee exhibit pH values below the desired range.

Alkalinity (Acid neutralizing capacity)

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 alkalinity 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, pH typically drops and conditions for aquatic life are adversely affected. The mean alkalinity for New Hampshire lakes and ponds is 4.9 mg/L (NHDES per. comm).

Most waterbodies in the Sunapee Watershed have been relatively stable with respect to alkalinity, and data indicate a "moderate vulnerability" to acid.

Dissolved Oxygen

The presence of dissolved oxygen is vital to bottom-dwelling organisms as well as fish and amphibians. Dissolved oxygen concentrations lower than 5 mg/L are not tolerated well by most aquatic organisms. The lowest dissolved oxygen concentrations are often found in the deepest sections of lakes where there is insufficient light for generation of oxygen by plants and algae through photosynthesis. In thermally stratified lakes like Lake Sunapee, deeper waters are isolated from the water surface and atmospheric reaeration throughout much of the summer and winter exacerbate the problem. Low oxygen concentrations at depth often results in organisms moving up in the water column where they are vulnerable to predation or forced to live in warmer water than preferred.

Dissolved oxygen concentrations in the hypolimnion (deeper layers) of Lake Sunapee and several of the watershed lakes and ponds are depressed in the summer at deep stations (Table 9, page 24). This causes stress or in extreme cases mortality for aquatic life, particularly cold-water fish species, and can result in remobilization of phosphorus from the sediments that then fuel further algal growth. Nutrients (primarily phosphorus) can be used as a surrogate for dissolved oxygen if it is determined that the oxygen demand is primarily related to excessive plant and algal growth and not to sediment oxygen demand. The shape of the oxygen profiles in Lake Sunapee suggest that sediment oxygen demand is not the primary driver of low hypolimnetic dissolved oxygen (Figure 7). In Lake Sunapee, depressed dissolved oxygen is seen throughout the hypolimnion not just near the sediment-water interface. A sharp decline in dissolved oxygen only near the sediment water interface suggests sediment oxygen demand. A decline throughout the hypolimnion suggests in-lake productivity and associated decay of algal cells as the cause of the oxygen demand. Because in-lake productivity (algal growth fueled by phosphorus) is likely driving the observed dissolved oxygen depletion, reduction in phosphorus concentrations should result in higher dissolved oxygen concentrations and fewer violations of dissolved oxygen standards in the future. For this plan, phosphorus will be used as a surrogate for dissolved oxygen.

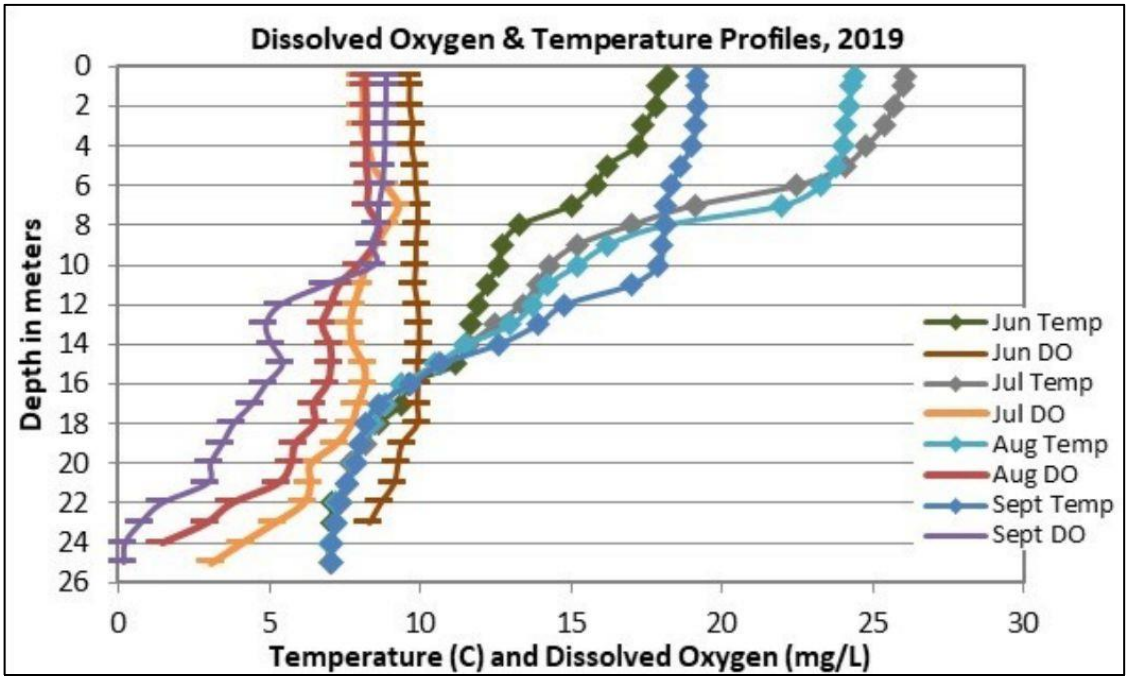

Figure 7. Lake Sunapee Deep Station Oxygen Profiles from Summer of 2019 Showing Oxygen Depletion Throughout the Lower Part of the Water Column in Late Summer.

3.2.3 Long Term Water Quality Summary

Sediment, nutrients and other stormwater contaminants such as chlorides (measured, in part, through conductivity) are major water quality concerns in the Lake Sunapee Watershed. Based on long-term data, Lake Sunapee and other waterbodies have seen increases in total phosphorus concentrations (TP) and specific conductivity. Sediment loading primarily from stormwater runoff impacts, has added to increases in turbidity and decreases in clarity. Current and future potential water quality degradation due to climate change with accompanying increases in precipitation/storm severity and occurrence increase the need to address stormwater runoff issues.

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 are either stable or may be vulnerable.

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, there are few available data for Star Lake or Morgan Pond, as well as, a number of tributaries. Recommendations to improve data collection in these areas are discussed further in Section 5.7.

Recent (2009-2018) Lake Sunapee Data Assessment for Model Calibration

An analysis of the existing water quality data available for the last ten years (2009-2018) for Lake Sunapee was performed to determine if the median total phosphorus (TP) and mean chlorophyll-*a* values meet the Tier 2 High Quality Water criteria set by NHDES and to provide benchmarks for calibration of the LLRM water quality model (Section 3.5). Secchi disk transparency data were also compiled as Secchi disk transparency is a response variable in the LLRM modeling effort being undertaken to support the watershed plan. The major source of the water quality data comes from measurements and samples collected by LSPA and volunteers under the VLAP program.

Lake Sunapee has four deep water sites with approximately five monthly samples collected each year from May through September. Phosphorus and chlorophyll-*a* data collected from the epilimnion (upper surface layer) between May and September were used to determine the summer median TP and mean chlorophyll-*a* values for each waterbody. This time period approximately coincides with the period of time that the lake is stratified. The median and mean values for each water quality parameter (TP, chlorophyll-*a*, Secchi depth) for Lake Sunapee (Table 10) were arrived at by first determining the median or mean value of each water quality parameter for each site sampled during 2009 to 2018. For Lake Sunapee, these stations are called 200, 210, 220 and 230. The distribution of values from each site were compared to other sites using a Z-test (Appendix D). This series of tests indicated that there are no statistically significant differences in the mean between any of the four sites for the 2009 through 2018 time period for phosphorus, chlorophyll-*a* or Secchi disk transparency. This allowed the data from all four sites to be pooled to represent the overall lake value for phosphorus, chlorophyll-*a* and Secchi disk transparency.

Table 10 - Summary of Pooled Epilimnetic Water Quality Data for 10-year Period (2009-2018) for Lake Sunapee (Stations 200, 210, 220 and 230)

Parameter	Sunapee 2009-2018
Total Phosphorus (µg/l)	
Mean	5
Median	5
N (Samples)	176
Chlorophyll-*a* (µg/l)	
Mean	1.6
Median	1.6
N (Samples)	175
Secchi disk transparency (m)	
Mean	8.4
Median	8.4
N (Readings)	155

Data from this trophic state assessment support the classification of oligotrophic for Lake Sunapee based on both total phosphorus and chlorophyll-*a* concentration. The phosphorus, chlorophyll-*a* and Secchi disk transparency values from this analysis were used as the primary calibration for the water quality model (Section 3.5).

3.2.4 Assimilative Capacity Analysis

The assimilative capacity of a water body describes the amount of pollutant that can be added to that water body without causing a violation of the water quality criteria. The water quality nutrient criterion for phosphorus has been set at 8 µg L^{-1} for an oligotrophic waterbody (high quality water) and <=12 µg L^{-1} for a mesotrophic waterbody. The NHDES requires 10% of the state standard to be kept in reserve, therefore phosphorus levels must remain below 7.2 µg L^{-1} for oligotrophic and < 10.8 µg L^{-1} for mesotrophic waterbodies to be in the Tier 2 High Quality Water category. An example of the calculations for an oligotrophic classed waterbody is shown below.

Assimilative Capacity (AC) for Total Phosphorus (TP)

- Total AC = Water Quality Standard (8 µg L^{-1} TP) – Best Possible WQ (0 µg L^{-1} TP) = 8.0 µg L^{-1} TP
- Reserve assimilative capacity = 0.10 x Total AC = 0.8 µg L^{-1} TP
- Remaining assimilative capacity = 7.2 µg L^{-1} – Existing WQ

An analysis of a waterbody's assimilative capacity is used to determine the total assimilative capacity, the reserve assimilative capacity, and the remaining assimilative capacity of each water quality parameter being considered in a waterbody (see Figure 8). This information is then used to determine water quality goals and actions necessary to achieve those goals. The assimilative capacity analysis is conducted in accordance with NHDES (2008a).

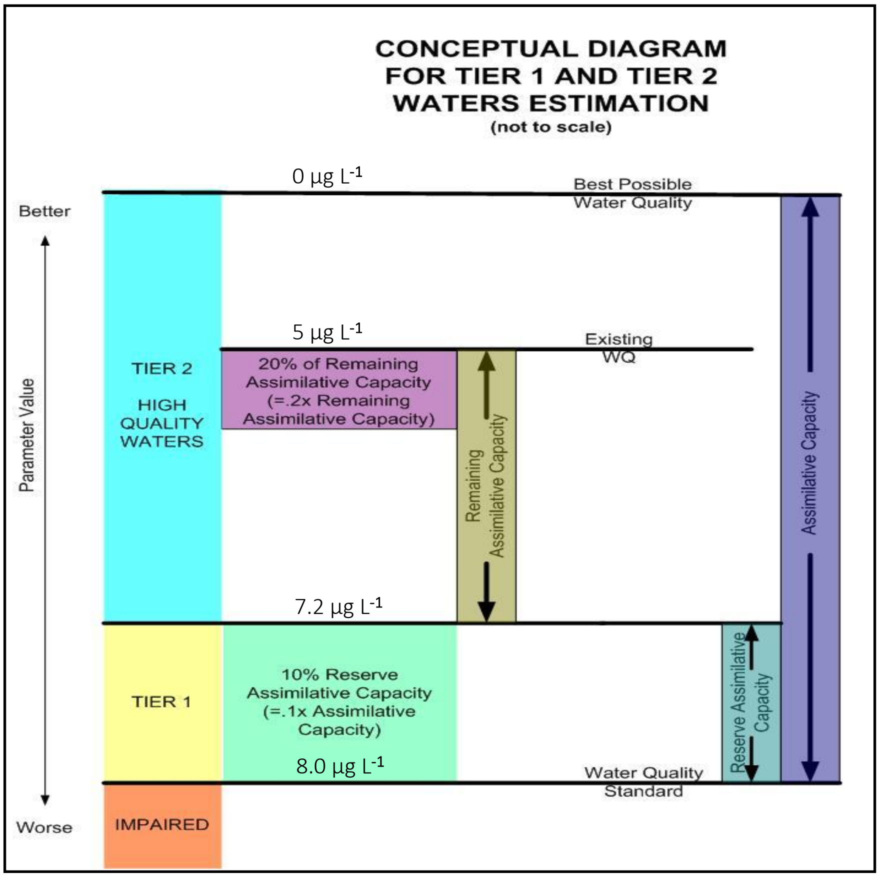

Figure 8. Conceptual Diagram for the Determination of Assimilative Capacity for an Oligotrophic Waterbody.

Results of Assimilative Capacity Analysis

The existing median TP value for Lake Sunapee of 5.0 µg L^{-1} results in a remaining assimilative capacity of 2.2 µg L^{-1}, which qualifies Lake Sunapee in Tier 2 for an oligotrophic waterbody (see Figure 9). The existing chlorophyll-*a* mean value of 1.6 µg L^{-1} is also below the NH State Nutrient Criterion of <3.0 µg L^{-1} for the aquatic life designated use set for an oligotrophic water body.

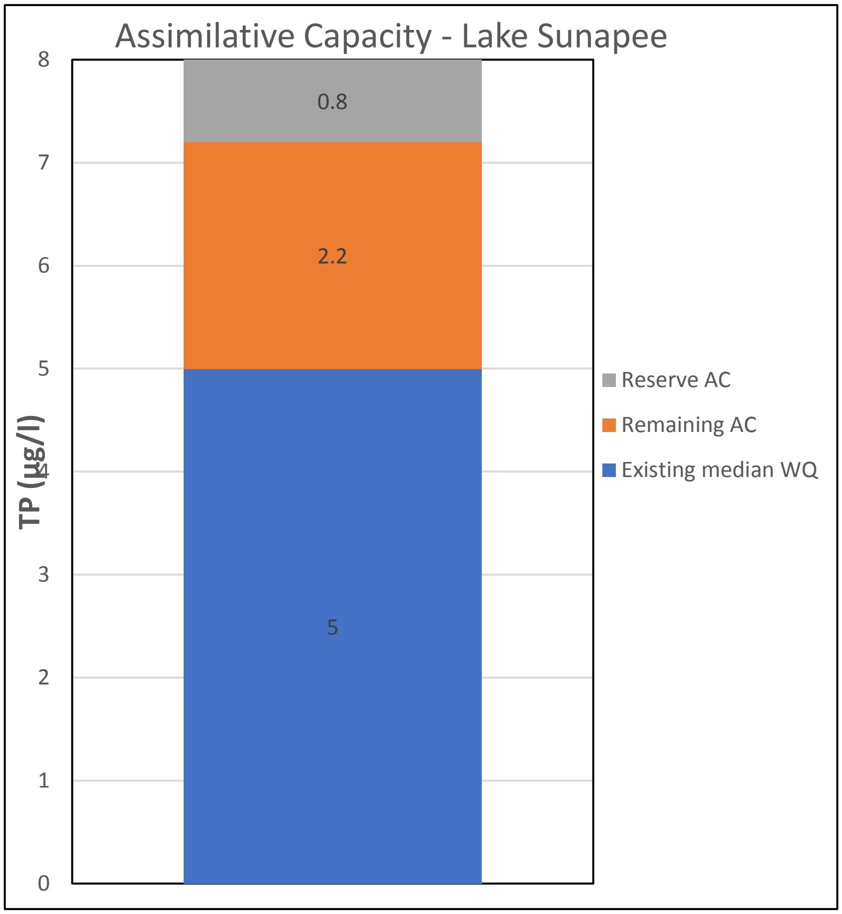

Figure 9. Graph Depicting the Results of the Assimilative Capacity Analysis for Total Phosphorus for Lake Sunapee.

3.2.5 Establishment of a Water Quality Goal

On June 11, 2019, a Water Advisory Group meeting was held at the LSPA Learning Center with 11 in attendance. Group members consisted of LSPA staff, WMP consultants, a NHDES representative and community representatives that were willing and able to participate in this process. The purpose of this meeting was to establish a water quality goal based on preliminary results of the modeling and realistic expectations for phosphorus reduction through remediation of known sources through best management practices (BMPs) and other non-structural strategies for reducing phosphorus loading such as education, zoning and ordinance improvement. Current phosphorus loading to Lake Sunapee is summarized in Figure 10.

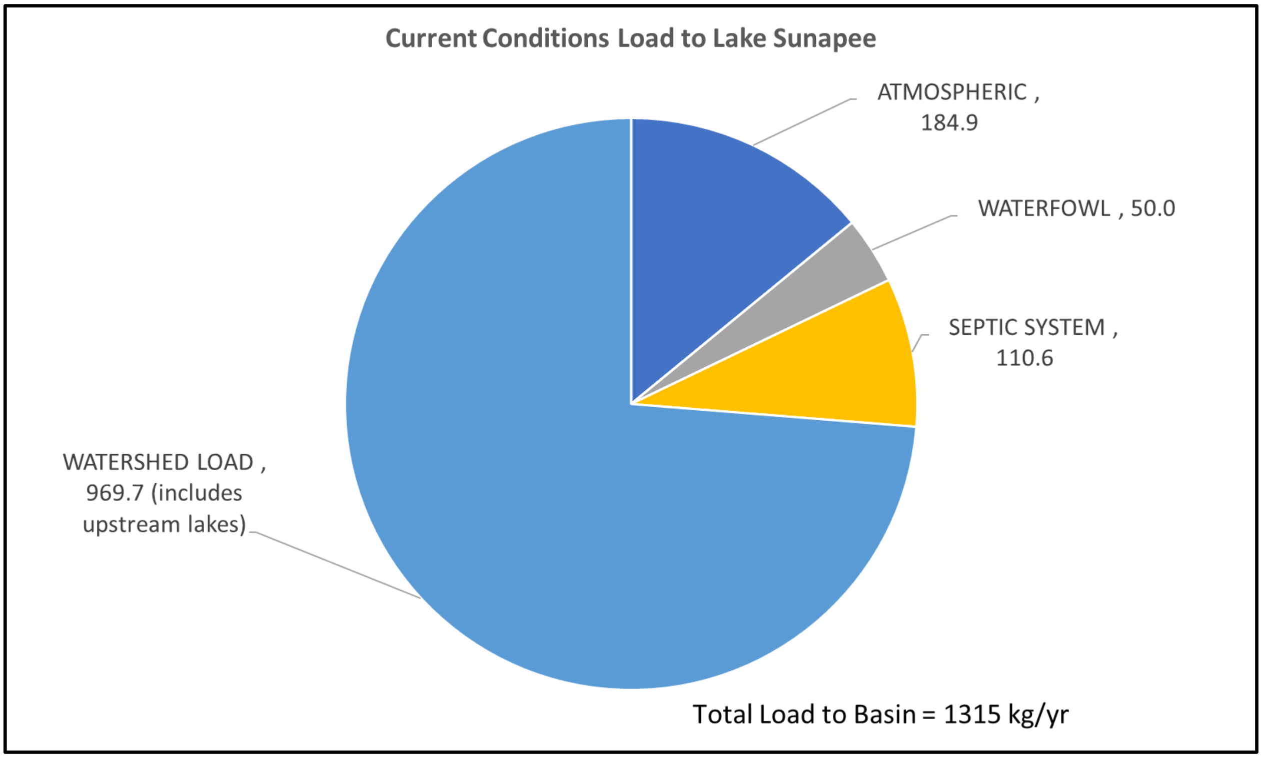

Figure 10. Current Phosphorus Loading to Lake Sunapee.

The project team presented current and future scenarios in relation to in-lake phosphorus loading to the group based on land cover analysis and buildout scenarios (see Figure 11 on following page). Three possible directions were presented for the group to discuss (see insert). In taking the proactive approach, scenarios were presented based on annual increase, no change or several levels of reduction/offset in kg of phosphorus entering Lake Sunapee. Realistic removal rates were discussed based on the proposed water quality improvement sites identified in the watershed survey and from potential reductions coming from septic system upgrades, zoning and ordinances, land conservation and public education campaigns as part of this plan.

Based on the information presented, a consensus was established by the group that an in-lake total phosphorus reduction/offset of 7.5% or 100 kg/yr by 2030 was achievable. This number was also chosen based on the confidence that LSPA as a long-standing organization has the ability and support to meet this goal.

Potential directions

- Use up some of the remaining assimilative capacity by allowing some increase in lake total phosphorus
- Maintain water quality in Sunapee as it is. No change in total phosphorus.
- Recognize that growth and change will occur in the watershed in the future. Reduce total phosphorus now to improve water quality and as a buffer later.

Figure 22 in Section 3.5.7 shows phosphorus export by sub-watershed. These data will be used to prioritize areas for future management of phosphorus loads.

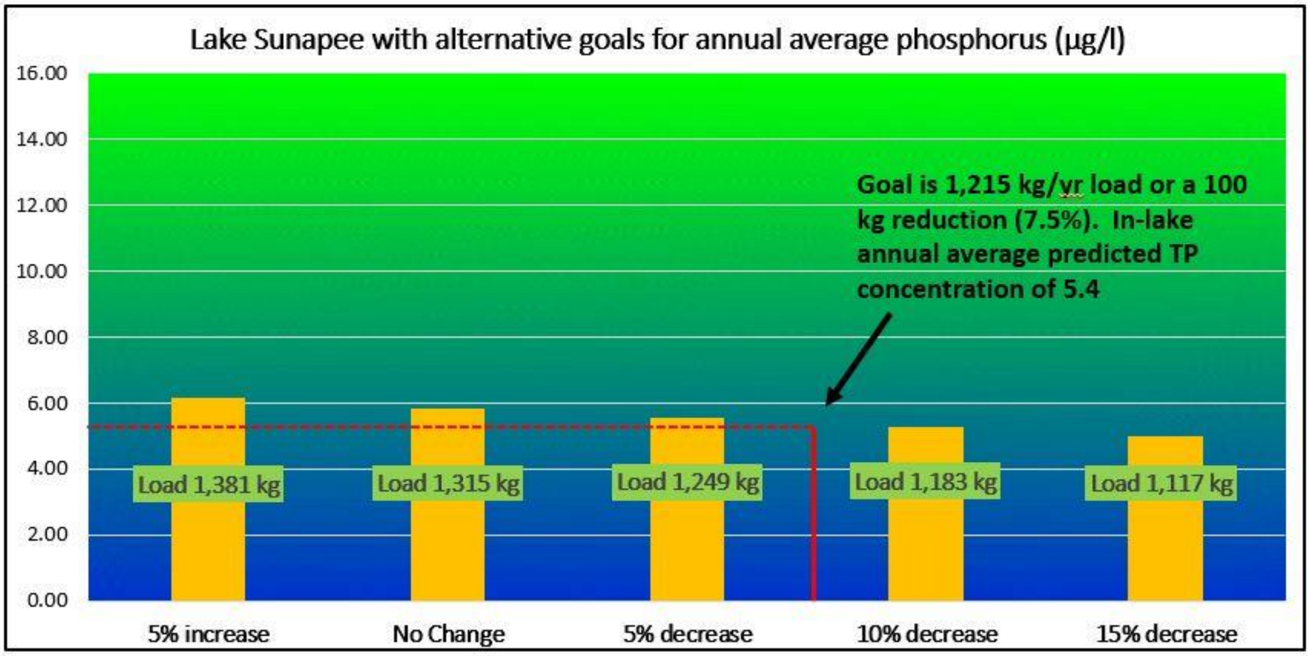

Figure 11. Loads to Lake Sunapee Under Various Future Management Scenarios.

3.3 FUTURE LAND USE PROJECTIONS: BUILDOUT ANALYSIS

The primary goal of the buildout analysis was to reasonably predict building growth throughout the watershed, so that the associated land use adjustments can be utilized to predict water quality impacts to Lake Sunapee, at specific points in the future. Typically, buildout predictions can be based on 1) a specific time interval into the future (i.e. 10 or 20 years from the present) or 2) at a point in the future a certain degree of buildout will potentially occur (i.e. full or half buildout). For this project, both a full and half buildout scenario was developed. A 10-year buildout analysis was also performed, with the thought that this Plan would be revisited and potentially updated 10 years following completion.

The results of the 10-year and the full buildout scenarios were used as input to the watershed model discussed in Section 3.5, facilitating a comparison of existing watershed conditions to the potential buildout scenarios, and an evaluation of impacts to lake water quality based on those specific changes in land use. It is important to note that the buildout analysis was completed using current growth rates, buildable land, zoning and ordinances. Future growth may be different than projections if any of these factors change. Implementation of this watershed plan is an important step towards ensuring that future growth in the Sunapee Watershed can be accommodated without sacrificing water quality.

3.3.1 Collection of Municipal Zoning Information

The project team coordinated with LSPA, the towns of Sunapee, New London and Newbury and staff at NHGRANIT to obtain GIS, zoning and relevant data used to support development of the buildout scenarios. The Town of Newbury was particularly helpful in attaining relevant data, having provided building and zoning data for several towns in the region. In addition to zoning data, environmental resource data were obtained from some towns, NHGRANIT and the USDA NRCS. Communication and data requests were typically submitted via phone calls and emails. Data was transferred by each respective party via cloud-based servers, via email or data download from websites. All data received was GIS-based and incorporated into a GIS database and map project. These data are available to the stakeholders through LSPA as a planning tool going forward.

Similar to the use of a GIS-based system for the project as a whole, a GIS-based platform was chosen as the best system to store and manipulate the buildout data due to the inherent geographic nature of the buildout data, the ease of use and tools available to process data provided by GIS, and the fact that GIS is considered the industry standard for buildout and similar analyses.

3.3.2 Modeled Growth Rate Scenarios

As discussed in Section 2.2.1, historical building permit data from the towns of Sunapee, New London and Newbury were obtained to facilitate development of building growth rate estimates. Annual building permits, dating back to the 1700s and up to 2019, were plotted in Excel and best fit trend lines were fitted to each set of data. Exponential growth curves provided the best fit for each town. The exponential growth curves were then used to predict building growth into the future, for each respective town. An example plot with a best fit trend line is provided in Figure 12.

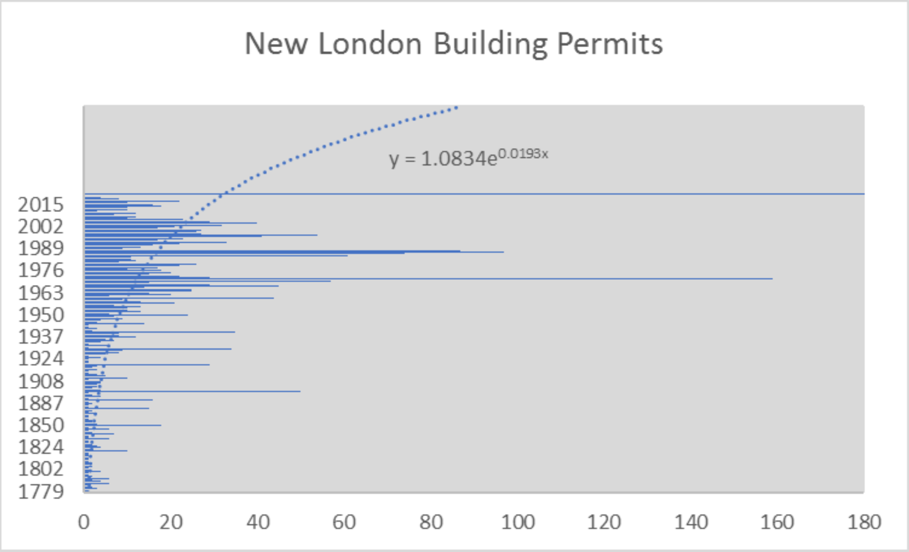

Figure 12. Number of Building Permits Registered in New London, Years 1779 – 2019.

While historical building permit data were not available for Goshen, Springfield and Sutton, the exponential growth curve with the lowest rate of growth (New London) was used to predict growth for those three towns in the buildout analysis, since recent building growth in these towns is significantly lower than growth in Sunapee and Newbury over a similar time period.

3.3.3 Buildout Methodology

The following provides the general steps executed as part of the buildout analysis. All steps were performed in the GIS project, unless otherwise noted:

- The Lake Sunapee Watershed boundary was used to define the portions of each town within the watershed to be analyzed.
- Parcels, property boundaries and zoning information for each town were added to the project.
- The following shapefiles were added to the project, to define areas where building could not occur:
    - Existing buildings and developed land
    - Existing roads, railroads and pipelines
    - Surface water (i.e. lakes, ponds, streams, wetlands)
    - River corridors and flood zones
    - Steep slopes (> 15%)
    - Conservation land
- For the full and half buildout scenarios, future buildable area was simulated per a building density consistent with each town's current zoning standards and minimum lot size requirements. According to the analysis, the full and half buildout scenarios are estimated to occur in years 2050 and 2034, respectively, considering the growth rates discussed above.
- For the 10-year buildout scenario, future buildable area was simulated using the growth rates discussed above and per a building density consistent with each town's current zoning standards and minimum lot size requirements.

Note that while Sunapee, New London and Newbury have specific zoning regulations with multiple zoning districts (i.e. residential, commercial, village, agriculture, etc.) and varied minimum lot size requirements, Goshen, Springfield and Sutton do not have specific zoning regulations in place. The entirety of each town is currently specified as Rural Residential, with the minimum lot size set to 2 acres for Goshen and Sutton, and 1.5 acres for Springfield.

3.3.4 Buildout Results and Use in Water Quality Models

Results for all three buildout scenarios are provided in tables located in Appendix E. The data in each table provide land use adjustments relative to the base 2018 land use data. A comparison of the buildout results compared to the base 2018 land use data indicates the following:

- The percent of developed land (i.e. residential, commercial, roads, outdoor recreation land uses) in 2018 was 12.8%, and that increased to 22.8%, 29.0% and 45.2% for the 10-year, half and full buildouts, respectively.
- The percent of undeveloped land (i.e. open areas, pasture, forest) in 2018 was 85.5%, and that decreased to 75.3%, 69.0% and 52.5% for the 10-year, half and full buildouts, respectively.
- The percent increase in the amount of residential land use, relative to 2018 was 216%, 289% and 479% for the 10-year, half and full buildouts, respectively.
- Dutchman Pond, Morgan Pond and Star Lake sub-basins are projected to have the largest percent increases in developed land. The high percent increases are a function of the lack of developed land that currently exists in these sub-basins, and the amount of buildable land and potential for future development, as identified by this buildout analysis.

The changes in land use for each respective buildout scenario with respect to the base 2018 land use data (Appendix E) were incorporated into the water quality model by modifying the distribution of land uses in the water quality model. A new model run was executed for each buildout scenario. In general, phosphorus loadings increased relative to increases in development. A more detailed discussion of the water quality model with respect to incorporation of buildout data, and the relative impact to water quality in Lake Sunapee with respect to each buildout scenario is provided in Section 3.5.

3.4 WATERSHED SEPTIC SYSTEM SURVEY ASSESSMENT

Based on modeling generated for this plan, it is estimated that nearly 10% of the phosphorous loading into Lake Sunapee comes from septic systems (Section 3.5). In an effort to learn more about the status of septic systems in the watershed, a septic system survey was sent out in September 2019 to 498 properties within 250 feet of waterbodies in the Lake Sunapee Watershed, not on town sewer (see Appendix F for methodology and survey form). The survey was timed to arrive in mailboxes just before EPA's annual "SepticSmart" week to help raise awareness and educate homeowners about the importance of septic system maintenance. We provided two incentives to increase survey responses, including a gift certificate to a local restaurant for including name and address on the survey form, and a septic tank pumping discount from a local septic service company.

A total of 110 property owners responded (22%) by mail or online. The survey included questions about the type of wastewater system on the property, the age of the system, how often the tank is pumped, the occupancy of the property including length of time each year and average number of occupants, appliances used regularly, etc.

Results from the survey showed that 96% of respondents have a septic system comprised of a tank and a leach field. One homeowner has a cesspool and three of the respondents were not sure what type of wastewater system they have on their property Thirty-nine percent (39%) of the systems are more than 25 years old, followed by 29% in the 1-10 year old age category and 25% in the 10-20 year old age category. Only 5% of respondents were not sure of the age of their system and one person left that question blank (Figure 13).

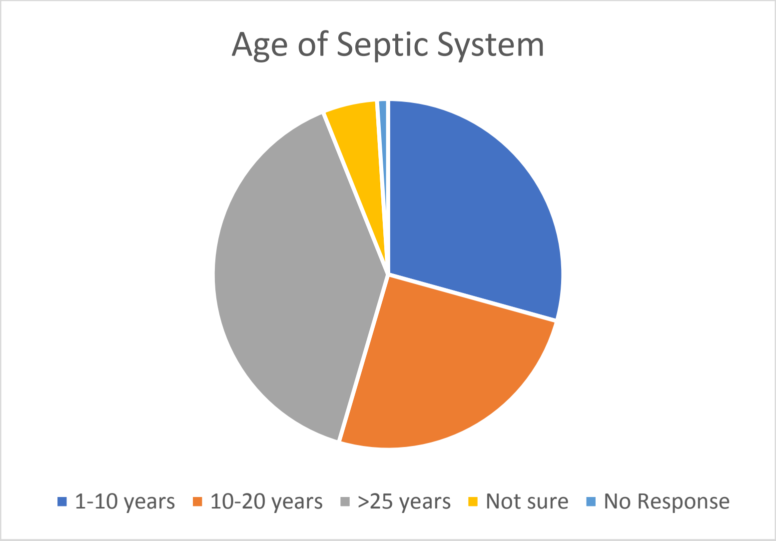

Figure 13. Age of Septic Systems in Lake Sunapee Watershed.

The usage breakdown in terms of length of time each year was almost evenly split among three categories: 2-3 months (31%), 4-6 months (36%) and more than six months (32%) (Figure 14). More than half of the properties (54%) reported an average occupancy of 1-2 people each year, followed by 3-4 people (32%) (Figure 16 on next page). Just over 50% of respondents have their septic tank pumped every 3-5 years as recommended by the EPA and 34% have their tank pumped even more frequently (every 1-2 years). Thirteen percent of homeowners have their septic systems pumped every 6-10 years, 1% reported never having it pumped and 2% have newer systems so they have not established a regular pumping schedule yet (Figure 15). About 85% of the property owners use a washing machine, dishwasher, or both, and close to a quarter use a water softener. Fourteen percent of respondents reported they use a garbage disposal too. Nearly 80% use phosphate-free cleaning products in the home—a sign that more labels are being read when products are purchased and that residents understand the harmful effects of additional phosphorous going into the watershed and waterbodies.

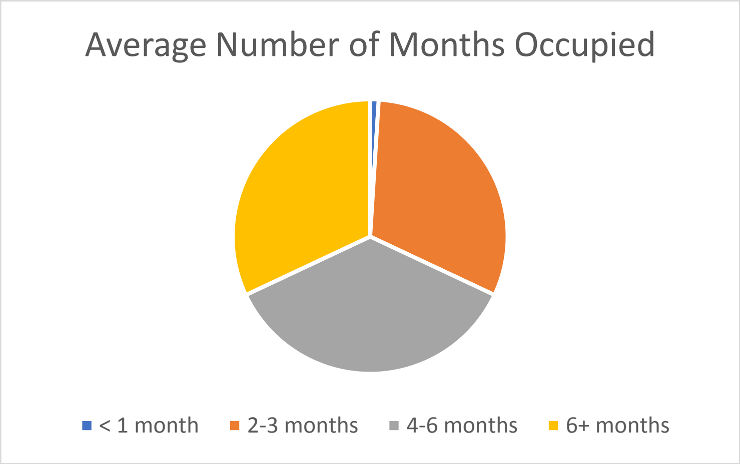

Figure 14. Average Number of Months a Property is Occupied per Year.

Given the amount of phosphorus loading that comes from septic systems and how it can negatively affect water quality, septic system maintenance should be a top priority. LSPA has outlined an ongoing septic system outreach plan (see Section 5.3 for more details) to remind homeowners about the importance of taking care of their septic systems. One thing this survey did not address was the perception of water quality in Lake Sunapee. This might be a good question to ask homeowners in the future to see if they understand how failing septic systems can negatively affect water quality.

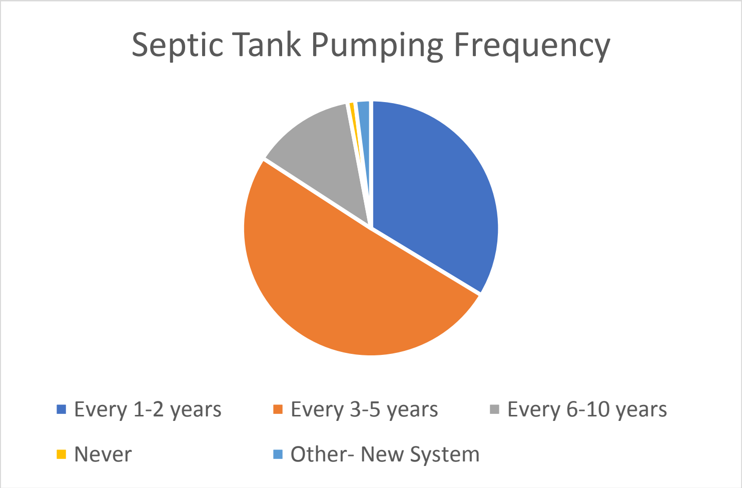

Figure 15. Septic Tank Pumping Frequency.

If we use this as a representative sample of all homeowners on waterbodies in the watershed, this may imply that one in every six households are not maintaining their systems properly and at least one in every three households have systems that are 25 years old or older. Overall, there appeared to be some confusion about the difference between a tank inspection and system inspection. A system inspection includes assessing the condition of components including septic tank, distribution box and the leach field. It is likely that most people are under the impression that the entire system has being inspected at the time of tank pumping while it is not. While the results of this survey were not received in time to incorporate into the water quality model, they will be important to both the education components of this plan and future watershed modeling and planning efforts.

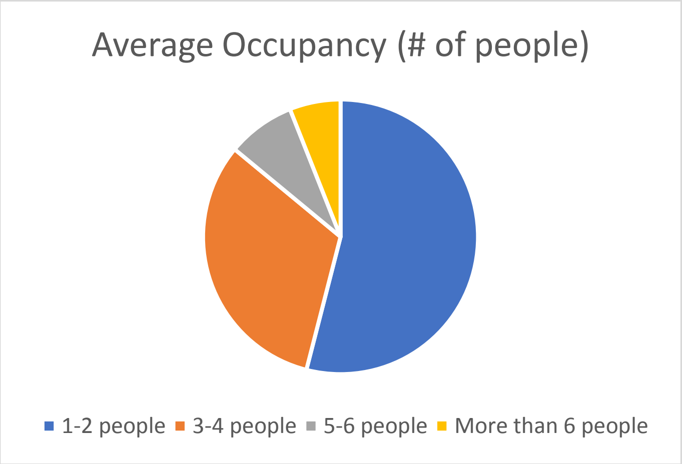

Figure 16. Average Occupancy of Properties in Lake Sunapee Watershed.

3.5 WATER QUALITY MODEL

This section provides results from the Lake Loading Response Model (LLRM) developed for Lake Sunapee. The LLRM is an Excel-based model developed by AECOM for use in New England and modified for New Hampshire lakes by incorporating New Hampshire land use TP export coefficients where available (CTDEP and ENSR, 2004). The model uses environmental data to develop an annual water and phosphorus loading budget for lakes and their tributaries. Surface water, ground water and direct precipitation are the major components of the water budget. Phosphorus loads expressed as both mass and concentration are estimated from all major sources in the watershed. Both water and phosphorus are routed through user set tributary basins to the lake. The tributary basin network can be linear or branched. The model incorporates data about watershed and sub-basin boundaries, land cover, point sources (if applicable), septic systems, waterfowl, rainfall, lake volume and surface area, and internal phosphorus loading. These data are combined with coefficients, attenuation factors, and equations from scientific literature on lakes, rivers, and nutrient cycles.

The following describes the process by which critical model inputs were determined for the Lake Sunapee Watershed using available resources and GIS analysis, and presents annual average predictions of water load, total phosphorus, chlorophyll-*a*, Secchi disk transparency, and algal bloom probability. The model can be used to identify current and future pollution sources, estimate pollution limits and water quality goals, and guide watershed protection and improvement projects.

3.5.1 Watershed and Subwatershed Delineations

Watershed and tributary drainage area (subwatershed) boundaries are needed to estimate water and phosphorus export to the downstream surface waterbody. Land cover types within each subwatershed determine the amount of water and phosphorus that are exported from each subwatershed (See Appendix A, Subwatershed Map 5).

3.5.2 Basin Divisions

Modeling the Lake Sunapee Watershed presents several challenges. The Lake Sunapee Watershed contains eight significant lakes and/or ponds (greater than 20 acres in size) in the watershed. Computationally, the upstream lakes were modeled first and then predicted water and phosphorus from each of these waterbodies was added to the Lake Sunapee model as a point source at the appropriate position in the watershed. A schematic of the watershed is provided in Figure 17. By modeling upstream lakes first, the phosphorus and water balance of each of the watershed lakes and ponds were calibrated to known water quality data. The correct water and phosphorus contribution from each upstream lake and pond to Lake Sunapee was used as input to the watershed model at the appropriate location in the Lake Sunapee Watershed.

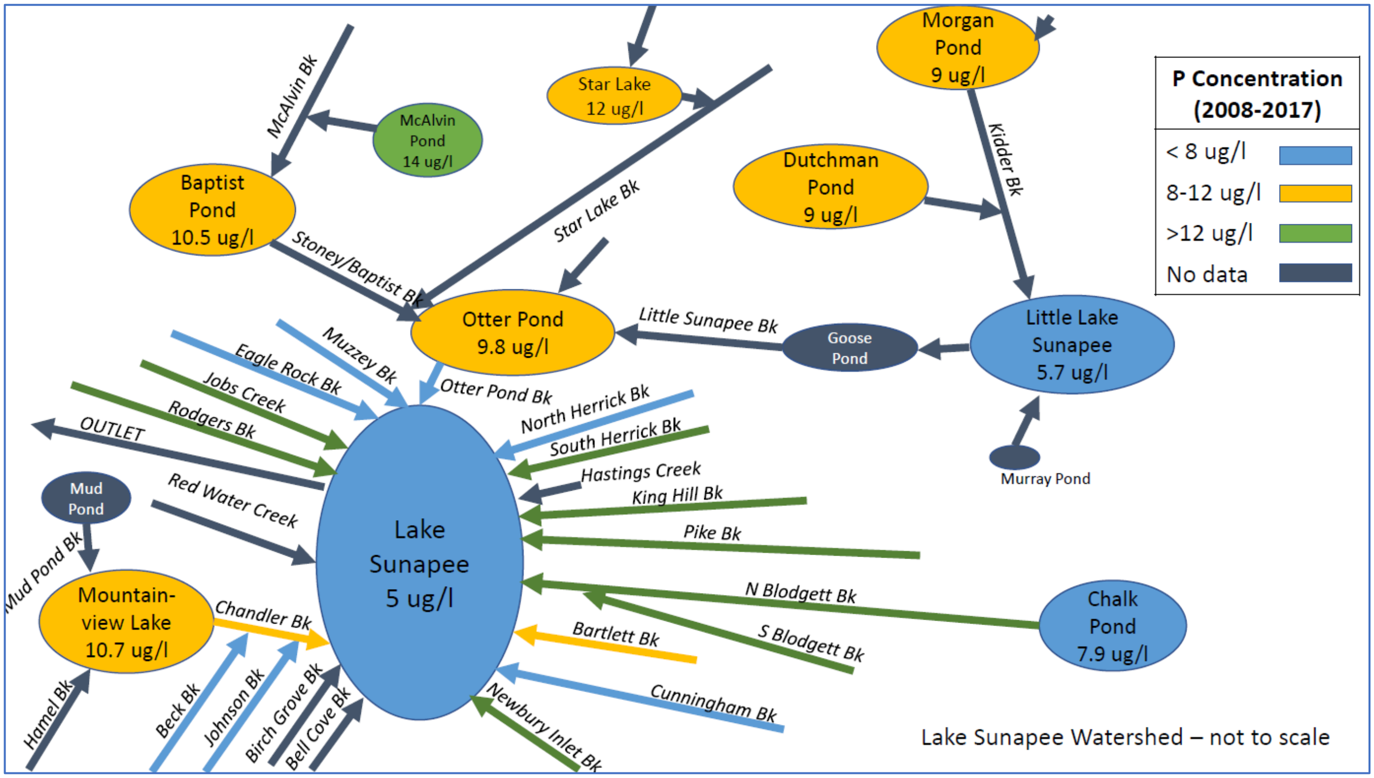

Figure 17. Schematic Representation of the Lake Sunapee Watershed.

Lakes and ponds typically function as phosphorus sinks in that a portion of the phosphorus that enters the lake or pond remains in the lake or pond through sedimentation and biological processes. To accurately simulate the process of phosphorus attenuation in upstream ponds, the Lake Sunapee Watershed was divided into nine models. These included: Baptist Pond, Star Lake, Morgan Pond, Dutchman Pond, Little Lake Sunapee, Otter Pond, Mountainview Lake, Chalk Pond and Lake Sunapee. Output from each upstream model is routed through the Lake Sunapee model (the terminal model) at the appropriate position in the Sunapee Watershed.

3.5.3 Land Cover Update

Land cover for the watershed was classified using a USGS Landsat 8 image from 2018. Based on the Land Cover Mapping Standards created by NH GRANIT, thirteen primary land cover classes were used that best represent dominant land features of the watershed. For more detail on land cover assessment methodology including land cover classes refer to Appendix C, Land Cover Methodology. Most of the subwatersheds are represented by a majority of forest cover that consists of intact or recently disturbed areas by timber harvesting or for other reasons (refer to Figure 18 on following page). Bartlett Brook, Bell Cove Brook, Birch Cove Brook, Dutchman Pond and Morgan Pond subwatersheds are the least disturbed by development. Subwatersheds having the most development (roads, building, maintained fields/open areas) are Hastings Creek, Herrick Cove North Brook, Rodgers Brook and Shoreland West.

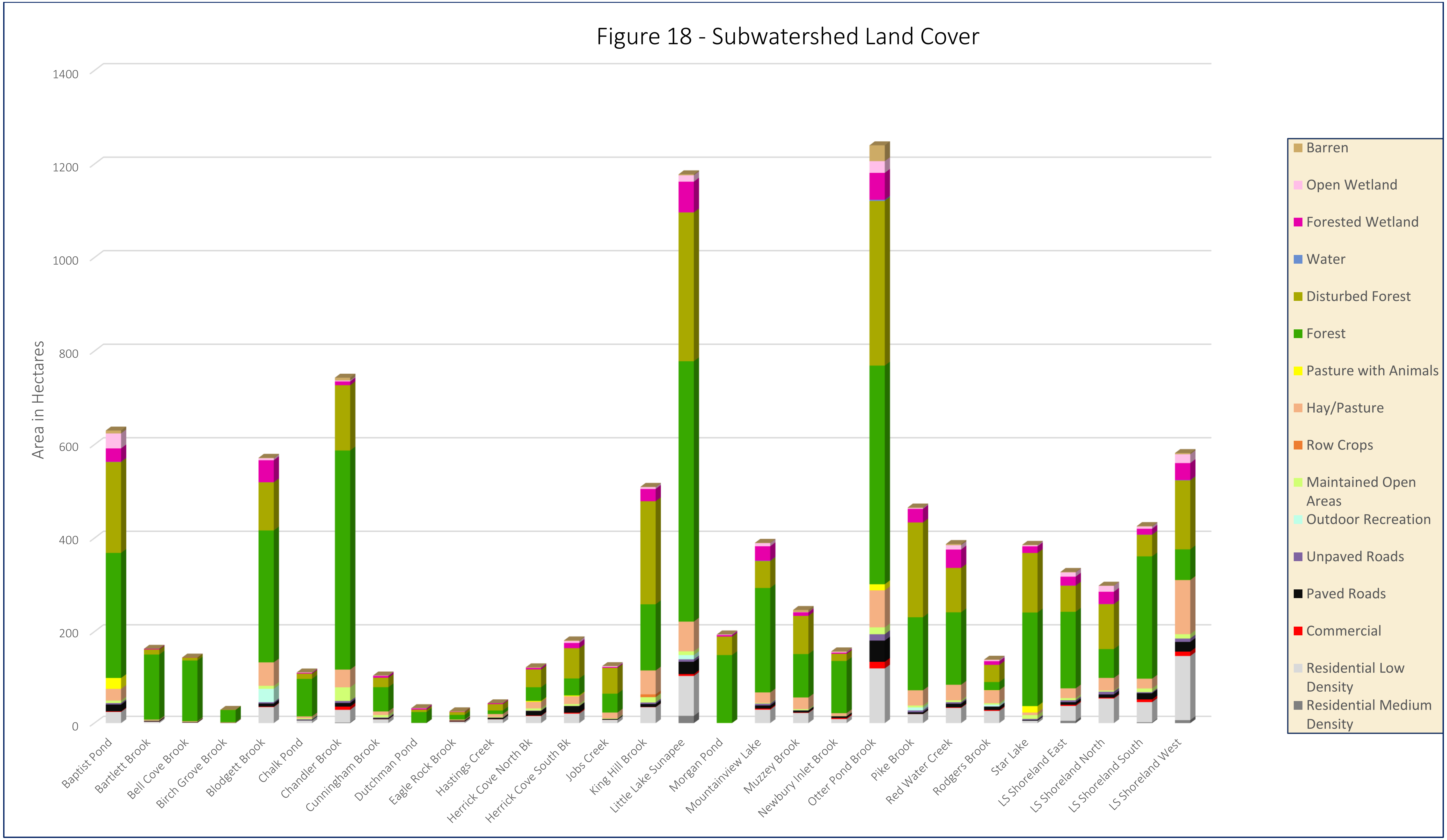
Figure 18 - Subwatershed Land Cover
Area in Hectares
0
200
400
600
800
1000
1200
1400
Baptist Pond
Bartlett Brook
Bell Cove Brook
Birch Grove Brook
Blodgett Brook
Chalk Pond
Chandler Brook
Cunningham Brook
Dutchman Pond
Eagle Rock Brook
Hastings Creek
Herrick Cove North Bk
Herrick Cove South Bk
Jobs Creek
King Hill Brook
Little Lake Sunapee
Morgan Pond
Mountainview Lake
Muzzey Brook
Newbury Inlet Brook
Otter Pond Brook
Pike Brook
Red Water Creek
Rodgers Brook
Star Lake
LS Shoreland East
LS Shoreland North
LS Shoreland South
LS Shoreland West
Barren
Open Wetland
Forested Wetland
Water
Disturbed Forest
Forest
Pasture with Animals
Hay/Pasture
Row Crops
Maintained Open Areas
Outdoor Recreation
Unpaved Roads
Paved Roads
Commercial
Residential Low Density
Residential Medium Density

Based on the land cover assessment, current conditions show that about half the watershed has been impacted by some form of land use activity (Figure 19). Accordingly, nearly 90% of the watershed runoff load to Lake Sunapee is from human impacted land uses (refer to Figure 20) that adds up to 723 kg/yr.

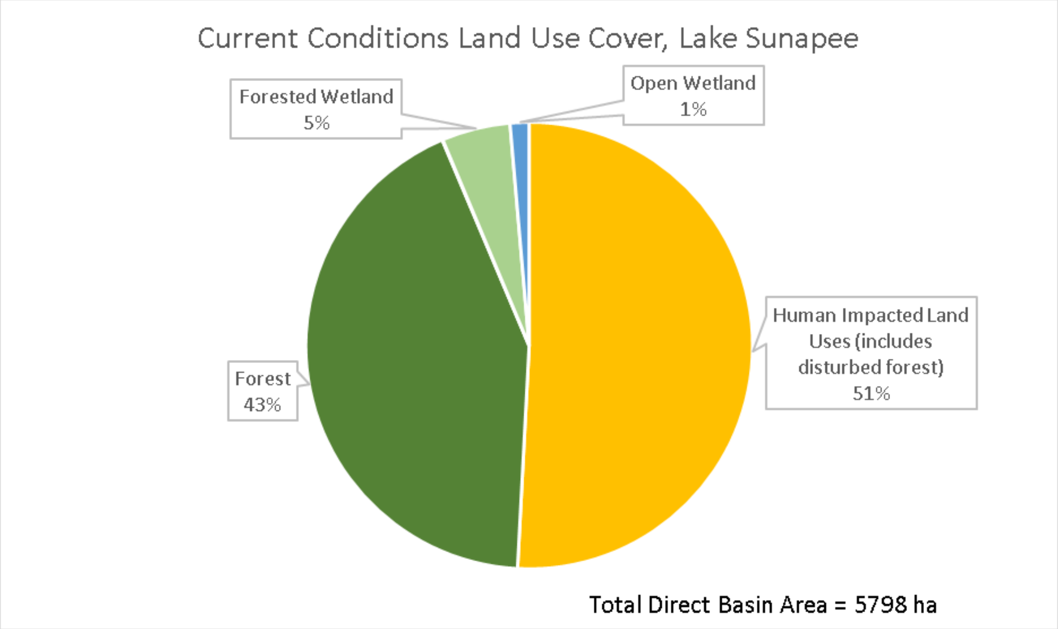

Figure 19. Current Land Cover Distribution for Watershed Drainage to Lake Sunapee (Note: Figure does not include land area above upstream lakes).

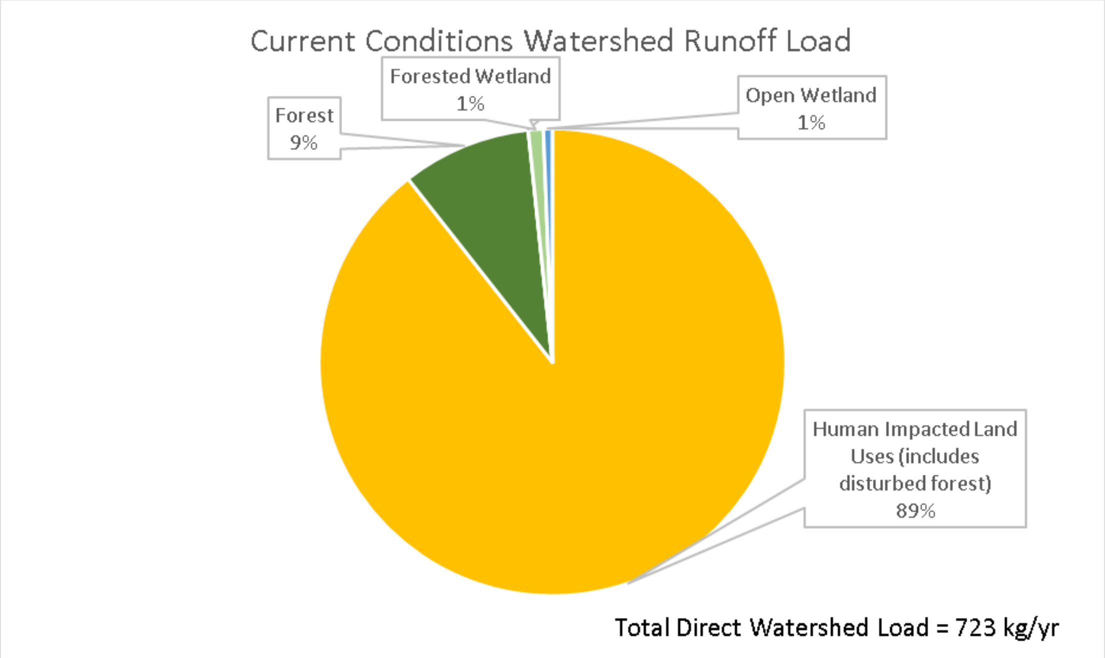

Figure 20. Current Estimated Watershed Load by Aggregated Land Cover Category for Watershed Drainage to Lake Sunapee (Note: Figure does not include loads to upstream lakes).

3.5.4 Other Major LLRM Inputs

The following presents a brief outline of other variable sources and assumptions input to the model. Refer to Limitations to the Model (Section 3.5.6) for further discussion.

- **United States climate data** from Newbury, NH was used to estimate annual precipitation on the watershed (1.21 m/yr) (https://www.usclimatedata.com/climate/newbury/new-hampshire/united-states/usnh0382). Annual discharge data from the USGS gage on the Sugar River (#01152500) for the period 2009-2018 were used to estimate the water yield for the watershed (1.62 cfsm).
- **Lake volume and area estimates** (surface area and perimeter lengths) were calculated using 2016 GRANIT LiDAR data. The mean depth came from NHDES VLAP reports except for Morgan Pond and Star Lake. The maximum depth for those waterbodies was acquired from the Boating USA app and used to calculate the mean depth (mean depth was estimated as 0.4 times the maximum depth). Lake Sunapee maximum depth was calculated from the 2008 Bathymetric Survey made possible by the Breidablik Fund.
- **Lakes in the greater Sunapee Watershed** were modeled independently from Lake Sunapee. Annual water volumes and phosphorus mass leaving these lakes were added to the next downstream model as a point source. In the upper part of the watershed, Morgan and Dutchman Ponds were added to Little Lake Sunapee. Baptist Pond, Star Lake and Little Lake Sunapee were added to Otter Pond. The output from the following lakes were added directly to the Lake Sunapee Model as point sources: Otter Pond, Mountainview Lake and Chalk Pond.
- **Septic system data** were estimated from existing primary dwelling buildings determined during the land cover analysis. These data were used to determine whether septic systems within 250 feet of lakes or adjacent wetlands were modern systems or older non-modern systems. It was assumed that modern systems captured 90% of the phosphorus that entered them while older systems only captured 80%. Each property with a septic system was classified by usage as a full-time residence or a part-time residence (i.e. seasonal). The phosphorus load to each system was calculated based on usage. While no formal septic system survey data were included in the model, a septic survey was conducted in the fall of 2019. For this effort, property records were searched for pertinent information such as date house built, date of most recent septic installation or upgrade, number of bedrooms, seasonal or year-round use, and distance of system to surface water. These results will be compared to assumed values for the model and if warranted, the model will be updated for the next revision.
- **Water quality data** were gathered from the NHDES Environmental Monitoring Database (EMD) and the LSPA. Data were screened for relevant site locations and water quality parameters (Secchi disk transparency, chlorophyll-*a*, total phosphorus, dissolved oxygen, and temperature). The model was calibrated using tributary and lake samples taken between 2009 and 2018 (or recent 10 years). Sites were only included if they were a close match to the outlet of a sub-basin used in the model. Data were summarized to obtain median water quality summaries for total

phosphorus, chlorophyll-*a*, and Secchi disk transparency. Water quality data were discussed in more detail in Section 3.2.1.

- **Waterfowl data** were determined using a standard estimate of 0.3 birds per hectare of lake surface area. Waterfowl can be a direct source of nutrients to lakes; however, if they are ingesting material from the lake and their waste returns to the lake, the net effect may be less than might otherwise be assumed; even so, the phosphorus excreted may be in a form that can be readily used by algae and plants and may be transported from the lake bottom to the surface waters where it is available for algal growth.
- **Internal loading** from anoxic release has not been widely documented in Lake Sunapee or in lakes and ponds in the watershed. It is possible that a degree of internal recycling occurs due to the transport of phosphorus from the sediments to the water column by the cyanobacteria *Gloeotrichia echinulata* however, rates of transfer are not currently available. Ongoing research in Lake Sunapee and elsewhere may allow estimation of this component of the nutrient budget in the future.

3.5.5 Calibration

Calibration is the process by which model estimations are brought into agreement with observed data and is an essential part of environmental modeling. Initial calibration trials focus on the input parameters with the greatest uncertainty. Changes are made within a plausible range of values, with site specific environmental conditions as a guide. In-stream phosphorus concentrations (2009-2018) from most tributaries to Lake Sunapee were available to be used as guideposts however, without streamflow information at the time of sampling, the utility of these data is limited. Flow data allows the calculation of loads which would allow a much more direct calibration of inputs of phosphorus from individual subwatersheds. Observed in-lake phosphorus concentrations (2009-2018) were given primacy during the calibration process, such that the ability of the model to accurately simulate annual average in-lake phosphorus concentrations was used as a leading indicator of acceptable model performance. Upstream models were calibrated first. The mean predicted TP concentration from the empirical models was compared to measured (observed) values. Input factors in the export portion of the model, such as export coefficients and attenuation, were adjusted to yield an acceptable agreement between measured and average predicted TP. Model estimates and monitoring data are presented in Table 11. Where there were sufficient current data, model estimates matched with field data reasonably well. Total phosphorus predictions were typically slightly higher than field data as would be expected given that model predictions are annual averages and field data are summer epilimnetic concentrations. Nurnberg (1996) shows summer epilimnetic concentrations as 14% lower than annual concentrations using a dataset of 82 dimictic lakes while Nurnberg (1998) shows a difference of 40% using a dataset of 127 stratified lakes. The target calibration TP concentration was 10-20% higher than the summer epilimnetic mean. This was achieved in all lakes with sufficient recent data except Dutchman Pond where the model predicted lower than the calibration target and Chalk Pond where the model predicted higher than the calibration target. Neither of these ponds represent major components of the Lake Sunapee nutrient budget (<2% collectively) so small deviations in predicted loads from them have little influence over the Lake Sunapee model estimates.

Table 11 - Predicted vs Measured Water Quality for Major Lakes & Ponds in the Lake Sunapee Watershed

	Total Phosphorus Load[1]	Total Phosphorus	Chlorophyll-*a*	Secchi Transparency	Probability of Algal Bloom
Scenario	(kg/yr)	(µg/l)	(µg/l)	(µg/l)	>10 µg/l (% of time)
Baptist Pond (modeled)	79.3	11.82	3.9	3.5	1.7
Baptist Pond (measured)(N)[2]	na	10.5 (19)	5.7 (19)	5.6 (19)	na
Chalk Pond (modeled)	16.5	11.92	4	3.4	1.8
Chalk Pond (measured)(N)	na	7.9(13)	3.5(13)	3.1 (12)	na
Dutchman Pond (modeled)	4.7	5.91	1.6	5.9	0
Dutchman Pond (measured)(N)	na	9.1(10)	2(10)	na	na
Lake Sunapee (modeled)	1,315	5.9	1.5	5.9	0
Lake Sunapee (measured)(N)	na	5.0(145)	1.6(144)	8.4(128)	0
Little Lake Sunapee (modeled)	164	6.79	1.9	5.3	0
Little Lake Sunapee (measured)(N)	na	5.7(10)	2.7(9)	4.2 (10)	na
Morgan Pond[3] (modeled)	10.2	3.64	0.7	8.5	0
Morgan Pond (measured)(N)	na	9(3)	6.4(2)	3.1 (2)	na
Mountainview Lake (modeled)	60.1	10.03	3.2	3.9	0.5
Mountainview Lake (measured)(N)	na	10.1(15)	3.8(16)	3.1 (14)	na
Otter Pond (modeled)	331.7	10.27	3.3	3.9	0.6
Otter Pond (measured)(N)	na	9.8(37)	3.5(37)	3.0 (37)	na
StarLake[4] (modeled)	35.6	6.98	2	5.2	0
Star Lake (measured)(N)	na	12.1(1)	na	3.7(1)	na

Notes:

[1] TP Load is from all sources including upstream watershed sources

[2] Measured data are from 2009-2018 unless noted (N=number of observations).

[3] Morgan Pond data from 1987-1996

[4] Star Lake data from 1984

Predicted TP in Lake Sunapee was intentionally higher to account for the seasonality of monitoring data as described above. Chlorophyll-*a* predictions were similar to monitoring data. Predicted Secchi transparency was > 2m lower than observed transparency. This discrepancy may be explained, in part, by LSPA's use of a view scope to measure Secchi transparency which typically results in deeper transparency observations. It is unlikely that view scopes were used in the lakes used to develop the TP-Secchi transparency relationship (Oglesby and Shaffner 1978) used in the LLRM. Continued water quality sampling and flow monitoring in the watershed can be designed to increase the confidence in model derived load estimates from individual subwatersheds and reduce some of the simplifying assumptions made during model calibration.

The following key calibration input parameter values and modeling assumptions were made:

- The **standard water yield** coefficient from the USGS gage on the Sugar River is 1.62 cubic ft/sq. mile.
- **Direct atmospheric deposition** phosphorus export coefficient was assumed to be 0.11 kg/ha/yr from Schloss et al. (2013) and represents a largely undeveloped watershed.
- Default **water and phosphorus attenuation factors** were used with exceptions as noted in Table 11. Water can be lost through evapotranspiration, recharge to deep groundwater, and recharge to wetlands, while phosphorus can be removed by infiltration, soil binding, best management practices or uptake processes. Experience from numerous New Hampshire watersheds suggest at least a 5% loss (95% passed through, default) of water in each subwatershed and a 10% loss (90% passed through) of phosphorus for each sub-basin. Larger water losses (<95% passed through) can be expected with lower gradient or wetland-dominated sub-basins. Additional infiltration, filtration, detention, and uptake of phosphorus results in lower phosphorus attenuation values, such as for sub-basins dominated by moderate/small ponds or wetlands (75%-85% passed through) or channel processes that favor uptake (85% passed through), depending on the gradient. Headwater systems were assumed to have a greater attenuation than higher order streams since flows are typically lower, giving more opportunity for infiltration, adsorption, and uptake.
- **In-lake phosphorus concentrations** were estimated by the average in-lake P concentration predicted by empirical model equations from Kirchner and Dillon (1975), Larsen and Mercier (1976), Jones and Bachman (1976), Reckhow (1977) and Nurnberg (1998). Vollenweider (1975) was excluded from the average as it consistently estimated in-lake P that was higher than the rest of the models.

3.5.6 Limitations to the Model

There are several limitations to the model; literature values and best professional judgement are used in place of measured data, where there are few or no data or data are not representative of annual average conditions. Acknowledging and understanding model limitations is critical to interpreting model results and applying any derived conclusions to management decisions. The model should be viewed as one of many tools available for lake and watershed management. Because the LLRM incorporates specific waterbody information and is flexible in applying new data inputs, it is a useful tool that predicts annual average in-lake total phosphorus concentrations with a high degree of confidence; however, model confidence can be further increased with more data (see proposed action item in Section 5.3.4). The following lists specific limitations to the model as it was applied to Lake Sunapee:

- **The model represents a static snapshot in time based on the best information available at the time of model execution.** Factors that influence water quality are dynamic and constantly evolving; thus, the model should be regularly updated when significant changes occur within the watershed and as new water quality and physical data are collected. In this respect, the model should only be considered up to date on the date of its release. Model results represent annual averages and are best used for planning level purposes and should only be used with full recognition of the model limitations and assumptions.
- **Limited phosphorus loading data were available.** Tributaries associated with most sub-watersheds had a great deal of concentration data but few flow data from which to calculate loads for model calibration. Continued data collection at existing sites coupled with flow data would make the dataset stronger and may further increase agreement between tributary observations and model estimates. More data are needed to effectively calibrate the model to known observations for some sub-basins. Until more data are available, we assumed that similar land cover coefficients and attenuation values exist across the entire Sunapee Watershed.
- **Nearly all of the in-lake monitoring data are from the open water season** and most are from the summer, a time when epilimnetic concentrations are typically lower than mean annual concentrations. The empirical models all predict mean annual TP concentrations assuming fully mixed spring overturn conditions.
- **Precipitation varies among years** and hence hydrologic loading will vary. This may greatly influence TP loads in any given year, given the importance of runoff to loading.
- **Upstream lakes** in the watershed were modeled as single subwatersheds primarily due to a lack of supporting tributary data. Many of the upstream lake watersheds could be split further into subwatersheds. This would allow greater insight into the sources of phosphorus to each of the upstream lakes but is not likely to change the Lake Sunapee model much as each upstream lake model was calibrated to data from its respective lake.
- **Septic system loading** was estimated based on literature values and enumeration of systems using GIS and remote sensing data. Literature values for daily water usage, phosphorus concentration output per person, and system phosphorus attenuation factors were used and may not reflect local watershed conditions. Septic data collected during the 2019 LSPA septic survey may allow a more robust estimation of septic influence on total phosphorus concentration in Lake Sunapee in the future.
- **Waterfowl counts were based on regional estimates.** In the future, a large bird (e.g., geese, ducks, etc.) census throughout the year would help improve the model loading estimates.
- **Land cover export coefficients were estimates.** Spatial analysis has innate limitations related to the resolution and timeliness of the underlying data. In places, local knowledge was used to ensure the land use distribution in the LLRM was reasonably accurate, but data layers were not 100%

verified on the ground. In addition, land uses were aggregated into classes which were then assigned export coefficients; variability in export within classes was not evaluated or expressed. While these coefficients may be accurate on a watershed or sub-watershed scale, they often do not represent conditions on individual parcels or parts of parcels within the greater land cover mapping unit. Refer to documentation within the LLRM spreadsheet for specific land cover coefficient citations.

3.5.7 Results

Current Conditions

As described above, the current conditions scenario was developed by calibrating the LLRM to mean observed conditions from 2009-2018 subject to the stated limitations of the model. The model results provide a reasonable accounting of sources and resulting in-lake concentrations on an annual basis. The model can be appropriately used for the planning purposes intended including evaluation of scenarios that might reduce or increase future loads. The model can be appropriately used to inform future decisions in terms of the influence of actions in the watershed on Lake Sunapee water quality.

Table 12 - Total phosphorus (TP) and Water Loading Summary by Source for Lake Sunapee Under Current Conditions

	Current (2019)		
Source	TP (kg/yr)	%	WATER (cubic meter/yr)
Atmospheric	184.9	14%	11,695,963
Internal	0	0%	0
Waterfowl	50	4%	0
Septic System	110.6	8%	102,798
Watershed Load	969.7	74%	61,332,858
Total Load to Lake:	**1,315.20**	**100%**	**73,131,619**

Water and total phosphorus load by source are presented in Table 12. The model predicts that approximately 74% of the total phosphorus load to Lake Sunapee originates in the watershed. This includes the proportion of the load that passes through lakes upstream of Lake Sunapee in the watershed. Atmospheric deposition accounts for 14% of the current load while septic systems and waterfowl account for 8% and 4% respectively of the total phosphorus load.

Table 13 - Predicted Water Quality Parameters Under Different Loading Scenarios for Lake Sunapee

	Total Phosphorus Load	Total Phosphorus	Chlorophyll-*a*	Secchi Transparency	Probability of Algal Bloom
Scenario	(kg/yr)	(µg/l)	(µg/l)	(m)	> 10 µg/l (% of time)
Natural Background	427	1.8	0.1	14.5	0
Current Conditions	1,315	5.9	1.5	5.9	0
10-year Buildout	1,511	6.8	1.9	5.3	0
Full Buildout	1,942	8.7	2.6	4.4	0.2

Current modeled results are presented in Table 13 (previous page). Under current conditions, Lake Sunapee has an estimated annual average total phosphorus concentration of 5.9 µg/l, a chlorophyll-*a* concentration of 1.5 µg/l and a Secchi transparency of 5.9 m. The likelihood of an algal bloom with a chlorophyll-*a* concentration of >10 µg/l is currently 0%.

Total watershed loading by subwatershed (not including contributions from upstream lakes and ponds) is presented in Figure 21. While this table does illustrate where the largest loads originate in the watershed, it is somewhat misleading as the larger watersheds typically have the largest loads. In order to normalize for watershed size, watershed loading by subwatershed is best shown on an areal basis to account for differences in the sizes of subwatersheds. Figure 22 shows areal loading in kg/ha for all the subwatersheds included in the model. These data are displayed spatially in Appendix A, Current Conditions Map 8. The darker green subwatersheds have the highest areal loading rates while the lightest green have the lowest areal loading rate.

Otter Pond is the largest watershed source of phosphorus to Lake Sunapee (Figure 21). This is not surprising as it is the largest subwatershed as well as supporting a substantial development. Many of the small upstream ponds show very small loads as the subwatersheds are small and largely forested. On a per hectare basis (areal) there is much less variability in watershed yield (Figure 22). What is clear is that the more densely developed subwatersheds such as all of the direct shoreline as well as Rogers, Hasting, North Herrick and South Herrick all show relatively high phosphorus yield per hectare while largely undeveloped subwatersheds like Morgan, Dutchman, Bartlett and Bell Cove show relatively low phosphorus yield per hectare.

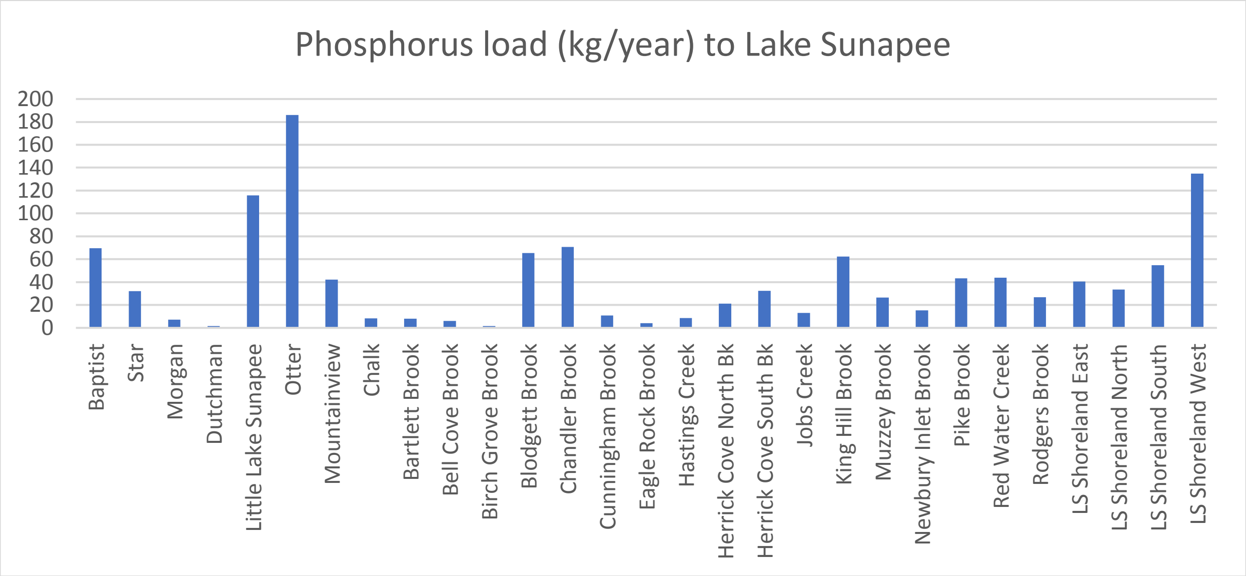

Figure 21. Phosphorus Load (kg/yr) by Subwatershed for the Lake Sunapee Watershed.

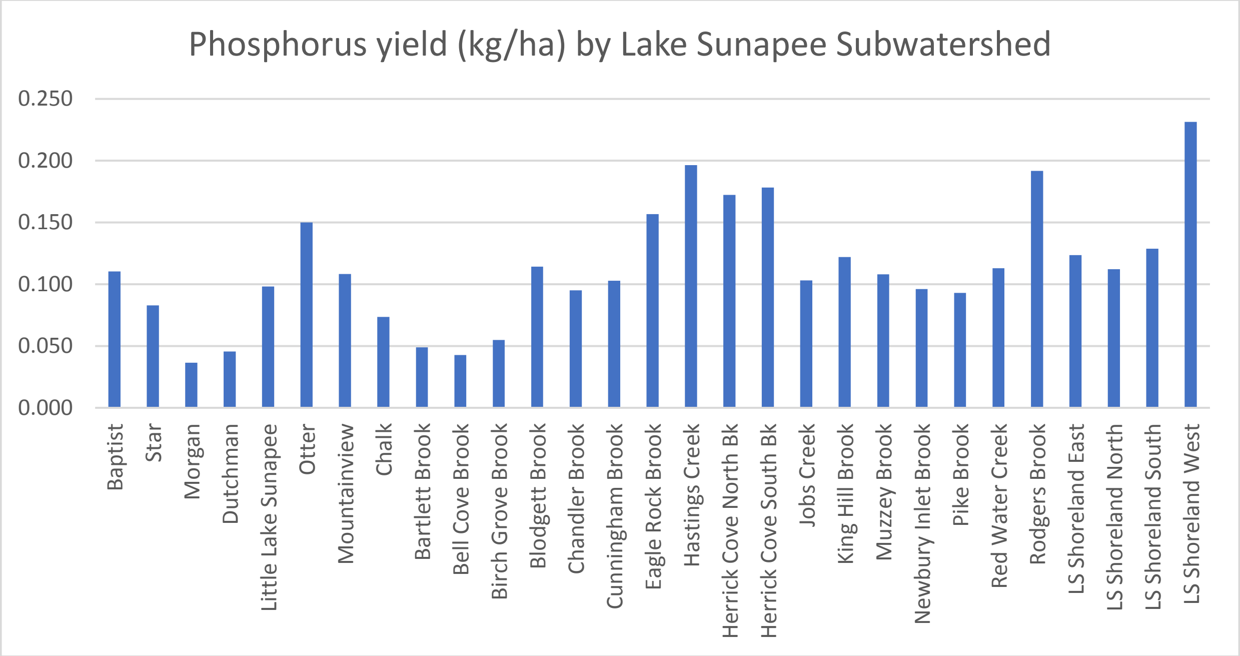

Figure 22. Phosphorus Yield (kg/ha) by Subwatershed for the Lake Sunapee Watershed.

Natural Background

This scenario is a representation of the best possible water quality for Lake Sunapee and was generated by converting all watershed land cover to forest and eliminating septic systems. Each upstream lake was modeled similarly. While it is not realistic to expect the entire watershed to revert to forest, this scenario provides an estimate of the best possible water quality for the lake. Under this scenario, the lake would have been expected to have total phosphorus concentrations approximately 4 µg/l lower than current conditions and continue to support a trophic classification of oligotrophic or very low productivity (Table 13, page 51). Water quality would be excellent under this scenario. Estimated watershed phosphorus yield by subwatershed for the natural background scenario is displayed in Figure 23 (page 55) and in Appendix A, Natural Background Map 9.

Buildout Scenarios

The primary goal of the buildout analysis was to reasonably predict building growth throughout the watershed, so that the associated land use adjustments can be utilized to predict water quality impacts to Lake Sunapee, at specific points in the future. Typically, buildout predictions can be based on 1) a specific time interval into the future (i.e. 10 years from the present) or 2) at a point in the future a certain degree of buildout will potentially occur (i.e. full buildout). Buildout incorporated existing zoning and town specific growth rates and excluded unbuildable areas (See Appendix A, Buildable and Unbuildable Areas Maps 10 & 11). This was described in detail in Section 3.3 above.

For this project, both 10-year and full buildout scenarios were modeled. A half-buildout scenario was also developed but not modeled. The 10-year buildout analysis was developed with the thought that this Plan would be revisited and updated 10 years following completion. The results of the 10-year and full buildout scenarios were used as input to the watershed model discussed below, facilitating a comparison of existing watershed conditions to the potential buildout scenarios, and an evaluation of impacts to lake water quality based on those specific changes in land use.

10-Year Buildout

The 10-year buildout scenario was developed to assess the impact of the potential development of the watershed under current zoning over the 10-year planning window for this plan. This scenario involved converting existing forested and agricultural land not currently in conservation to residential land subject to zoning constraints in each town within the Lake Sunapee Watershed based on historic growth rates and a 10-year time frame. This was designed as a worst-case scenario meaning that all building was conducted under conventional standards and no extraordinary BMPs were included nor was there an attempt to incorporate low impact development principles. Some level of best management practices can be expected for future development so the actual increases in loading might be lower than those projected. It should also be noted that development could also include more intensive uses with changes in zoning which would tend to increase the loading estimates.

Projections of Lake Sunapee water quality under the 10-year buildout scenario are presented in Table 13. Under this scenario, annual phosphorus loading would increase by nearly 200 kg resulting in a total phosphorus concentration increase of approximately 1 µg/L for Lake Sunapee. The chlorophyll-*a* concentration would also increase in the lake while transparency would decline by approximately 0.5 m. Results from this scenario as specified would result in a decline in water quality in Lake Sunapee. However, implementation of the plan described in this document coupled with careful development and redevelopment using best management practices and conservation principles should result in maintenance or improvement in current water quality. Estimated watershed phosphorus yield by subwatershed under the 10-yr buildout scenario is displayed in Figure 23 (page 55) and in Appendix A, 10-Year Buildout Map 12.

Full Watershed Buildout

The full buildout scenario was developed to assess the complete impact of the potential development of the watershed under current zoning. This scenario involved converting all existing forested and agricultural land not currently in conservation to residential land subject to zoning constraints in each town within the Lake Sunapee Watershed. As in the 10-year buildout scenario, it was assumed that all future building would retain similar characteristics as current building in the watershed and similar levels of best management practices. This was also designed as a worst-case scenario meaning that all building was conducted under conventional standards and no extraordinary BMPs were included nor was there an attempt to incorporate low impact development principles. In reality, some level of best management practices could be expected for future development so the actual increases in loading might be lower than those projected. It should also be noted that development could also include more intensive uses which would tend to increase the loading estimates.

Projections of Lake Sunapee water quality under the full buildout scenario are presented in Table 13. Under this scenario, lake phosphorus load would be expected to increase 50% relative to current levels resulting in an in-lake phosphorus concentration of 8.7 µg/L for Lake Sunapee. Chlorophyll-*a* concentrations are projected to increase significantly in the lake to 2.6 µg/L and the probability of algal bloom conditions greater than 10 µg/L would be 0.2 % of the time for Lake Sunapee. Secchi transparency would be reduced to 4.4 m. These projected concentrations would support a trophic classification of mesotrophic or a moderately productive lake. This is a scenario that would likely produce unacceptable water quality in Lake Sunapee for most stakeholders. It also highlights the need for aggressive reduction of existing sources over the lifespan of this plan to offset the phosphorus loading impact of inevitable future development as well as additional measures at the local level to ensure that future development is as low impact as possible. Estimated watershed phosphorus yield by subwatershed under full buildout is displayed in Figure 23 and in Appendix A, Full Buildout Map 13. When compared to current conditions, the rate of phosphorus export from nearly every subwatershed is increased. The only subwatersheds that show only modest increases relative to current conditions are those with little future land development potential as a function of steep slopes, wetlands, conserved land or land that is already developed.

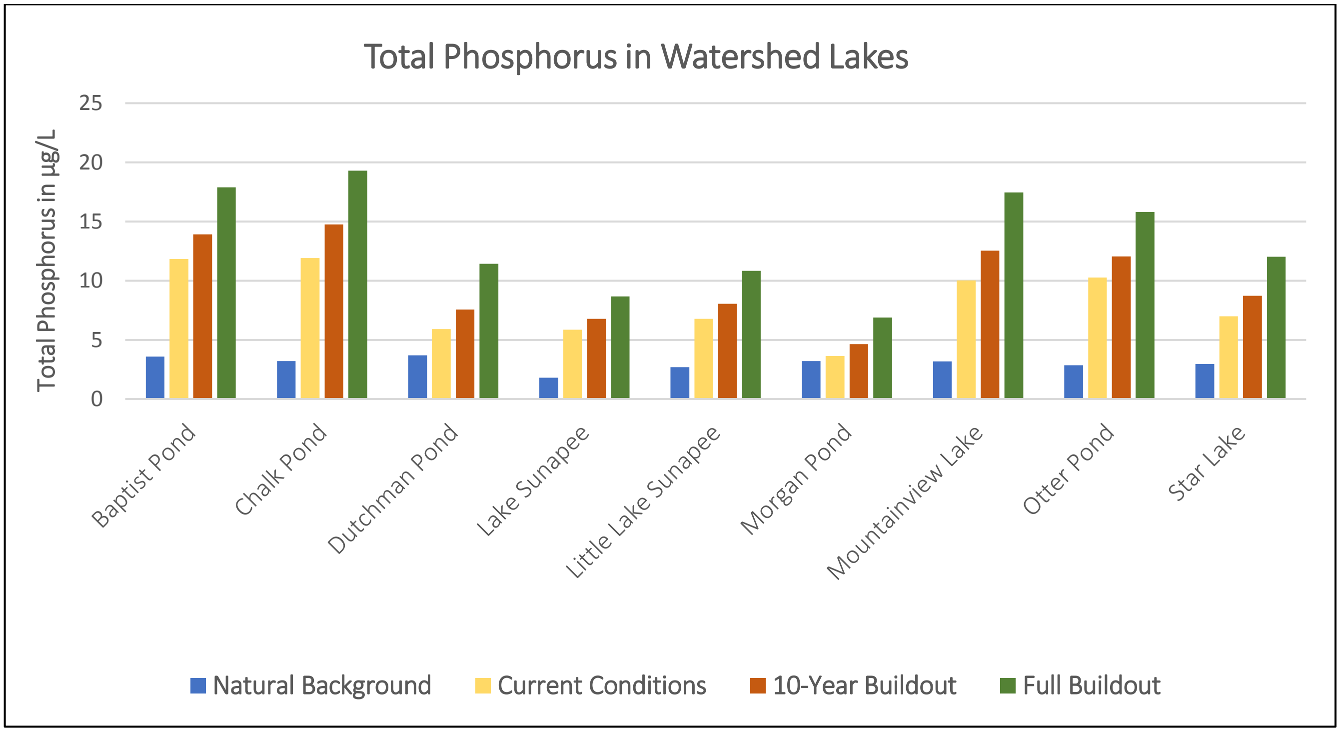

Figure 23. Comparison of In-lake TP Concentrations for Lake Sunapee and Watershed Lakes Under Four Scenarios.

3.6 WATERSHED STORMWATER SURVEY ASSESSMENT

3.6.1 Identification of Potential Stormwater Problem Areas

Prior to surveys performed in the field, the stormwater survey assessment began with 1) an inventory of existing and historical data relevant to known or suspected stormwater problem areas, 2) coordination with local residents and committee members to garner participation in the initial inventory of stormwater concerns, and 3) initial meetings with towns and project stakeholders.

Having been stewards of Lake Sunapee and its watershed since 1898, LSPA had an existing list of known stormwater problem areas, developed from communications with watershed residents and businesses over the last few decades. Additionally, during an initial public meeting presenting this Plan, the project team gave local residents and committee members 'homework', which included the opportunity to reply back to the team via email with known stormwater problem areas that they were aware of. Given the size of the watershed, these initial efforts alone generated a significant number of potential projects to be investigated during field surveys.

The project team then met with the towns that comprised the largest portions of the watershed, including New London, Sunapee, Newbury and Springfield (via phone). A meeting with NHDOT was also conducted, considering the amount of NH Department of Transportation (NHDOT) roadway and facilities within the watershed. These meetings provided an opportunity for LSPA, towns and NHDOT to 1) share maps, information and confirm known stormwater problem areas, 2) discover new problem areas based on each groups existing inventory of issues and gather information on existing capital improvement programs and schedules, and 3) to identify potential synergy between LSPA and future projects. Additional sites were added to the stormwater problem area list based on these meetings.

3.6.2 On the Ground Surveys

With a complete list of potential stormwater problem areas in hand, on the ground surveys began in October 2018. Two separate teams performed surveys over a two-day period on October 23 and 24, 2018. Additional surveys were performed in the spring and summer of 2019 to complete inspections of the initial list of stormwater problem areas, and to perform inspections at sites that were recently added to the list. Each public road in the watershed was driven to locate additional sites not identified during the initial screening meetings.

At each site, the project team collected data to assess existing conditions with respect to stormwater runoff and pollutant loadings, determine suitable BMPs to mitigate loadings, collect measurements to support conceptual BMP development, and collect general site information (photos, GPS coordinates, site ownership, land use type, etc.). A Watershed Survey Datasheet, which summarizes all the information collected was generated for each site. An example of one of these sheets is provided in Appendix G.

3.6.3 Data Processing and Prioritizations

A table describing proposed BMP projects is provided in Appendix H. The table includes a Project ID, project location, site name, drainage characteristics, an estimate of phosphorus generated from the drainage, estimated phosphorus load reductions based on the proposed BMP, and an estimate of design, permitting and construction cost for each project.

The Simple Method (Schueler 1987) was used to estimate annual pollutant loads based on sub-basin area, annual rainfall and pollutant concentration. Pollutant load reductions were calculated based on documented removal efficiencies for specific types of BMPs. Conceptual costs were developed as summarized in Section 5.6. The estimated cost of each project was then divided by the respective P load reduction estimate, to produce a cost per pound of phosphorus removed. A common metric for evaluating the cost effectiveness of a project, the cost per pound of phosphorus removed was used as one of the criteria to prioritize the list of BMP projects, discussed briefly below.

The BMP prioritization was performed by assigning numerical scores to each project relative to six criteria. These criteria were developed by the project team and are specific to the project and characteristics of the lake and watershed. The total scores were used to sort the projects by priority, with the highest score receiving top priority for implementation, and the lowest score having the lowest priority for implementation. The prioritization methodology is discussed in more detail in Appendix H along with a prioritized list of projects.

4. MANAGEMENT STRATEGIES

4.1 GOALS FOR LONG-TERM PROTECTION

Numerical water quality criteria for total phosphorus (TP) in oligotrophic lakes have been established by the State of New Hampshire (Section 3.1). For Lake Sunapee, an oligotrophic lake, the criterion is set at < 8 µg/L. This criterion is 60% higher than the current summer epilimnetic concentration of TP (5.0 µg/L- measured) and 35% higher than the current annual average TP concentration (5.9 µg/L- estimated with LLRM). By this criterion, Lake Sunapee is currently oligotrophic.

Best professional judgment of the project technical team, NHDES, and the steering committee were employed to give a range of options for a goal. The steering committee then selected a quantitative target TP loading that will protect water quality into the future.

Review of existing data and modeling of current conditions suggested that the current phosphorus concentrations in the lake would result in acceptable water quality going forward. This point is bolstered by the fact that water quality as measured by chlorophyll-*a* and TP has not changed appreciably in recent years. At present, the modeling projects a zero percent probability of a lake-wide algal bloom based on current nutrient levels. However, periodic water quality problems like the localized cyanobacteria blooms observed in recent years, evidence that nearshore water quality may be declining and the deficit of dissolved oxygen in the deep sections of the lake is worrying. It is acknowledged that continued development and loading as well as episodic large loading events have the