2. WATERSHED CHARACTERIZATION

2.1 LOCATION AND CLIMATE

The Lake Sunapee Watershed experiences seasonal temperature variations consistent with the temperate climate zone of the northeastern U.S. The warmest month of the year is July, with an average maximum temperature of 79 degrees Fahrenheit (°F), while the coldest month of the year is January, with an average minimum temperature of 8 °F (Figure 1) (US Climate Data, 2019).

The average annual precipitation is 47.6 inches (in), which includes an average snowfall amount of 61 inches in the Sunapee area. Precipitation is generally evenly distributed throughout the year, with a large part of the total annual runoff generated from spring snowmelt (Figure 1). Lake Sunapee is a dimictic lake meaning that the lake thermally stratifies in both the summer and winter (under ice cover) and mixes vertically twice per year in the spring and fall.

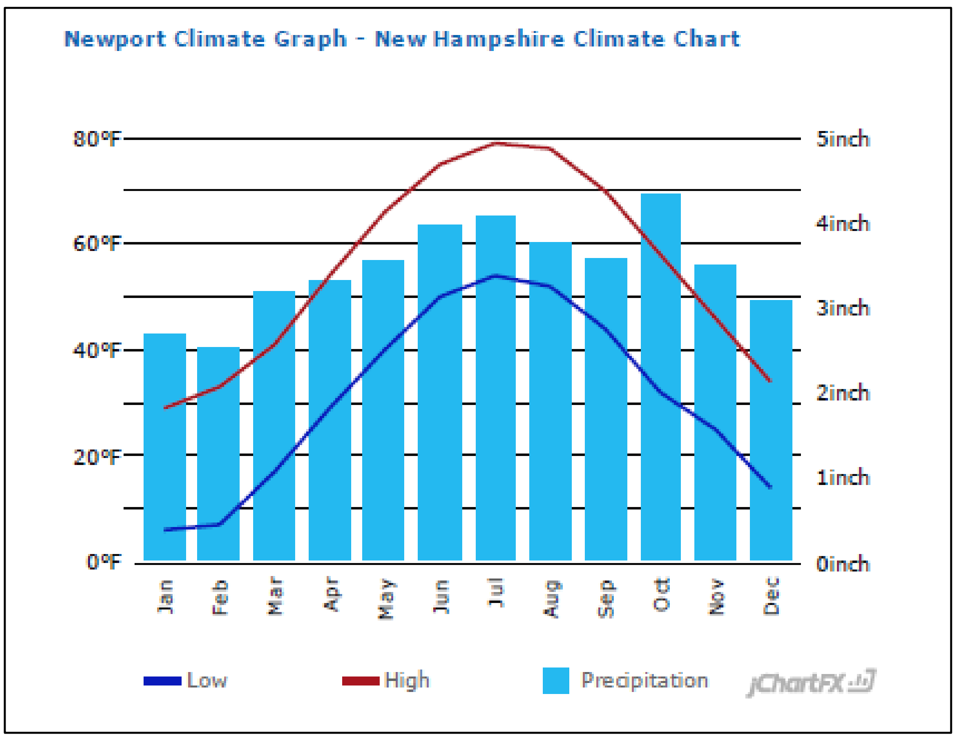

Figure 1. Temperature and Precipitation for Newport, NH (1981-2010) (US Climate Data, 2019).

Hydrologic changes are occurring throughout the northeastern United States and within the Sunapee Watershed [Dupigny-Giroux et al. 2018; Hayhoe et al. 2018]. These changes are most evident in the winter and spring seasons, where temperatures increases have led to advances in the timing of snowmelt and spring runoff by more than 10 days. Seasonal differences in temperatures have decreased as winter months have warmed three times faster than summer months, and the growing season has lengthened. Warmer winter temperatures have increased the fraction of precipitation that falls as rain instead of snow. Over the period 1958 to 2012, the amount of precipitation falling in the heaviest (highest 1%) precipitation events has increased 55% in the Northeastern U.S., including New Hampshire.

Historic weather data show that the climate of the Sunapee Lake Watershed is changing consistent with regional change. Temperature is increasing by 0.2 °F per decade (Figure 2). Precipitation is increasing by 1.19 inches per decade (Figure 3) and the duration of ice cover is decreasing (Figure 4) leading to a longer open water growing season.

Future conditions with warmer temperatures, more rainfall, more intense storms and a longer growing season are expected to increase phosphorus loading and be more favorable to cyanobacteria. Climate change, while a global issue should be accommodated in Lake Sunapee Watershed planning by reducing phosphorus loading further and accommodating increased runoff in any engineered solutions.

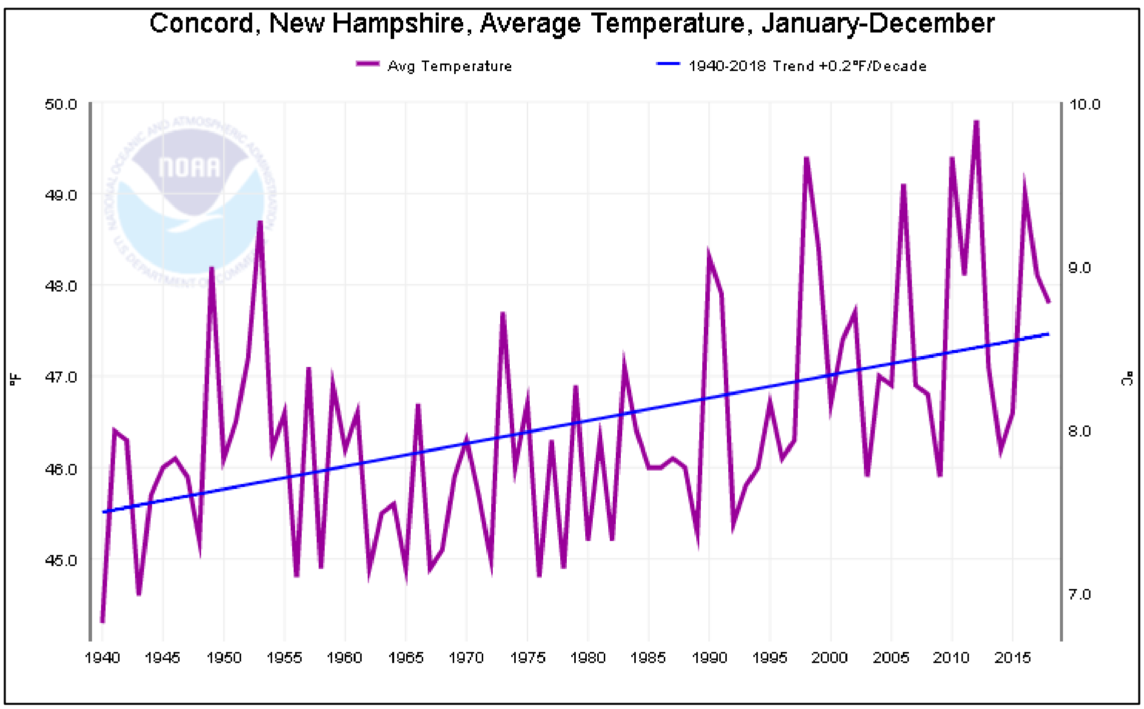

Figure 2. Average Annual Temperature at Concord, NH (National Oceanographic and Atmospheric Administration (NOAA) 2019)

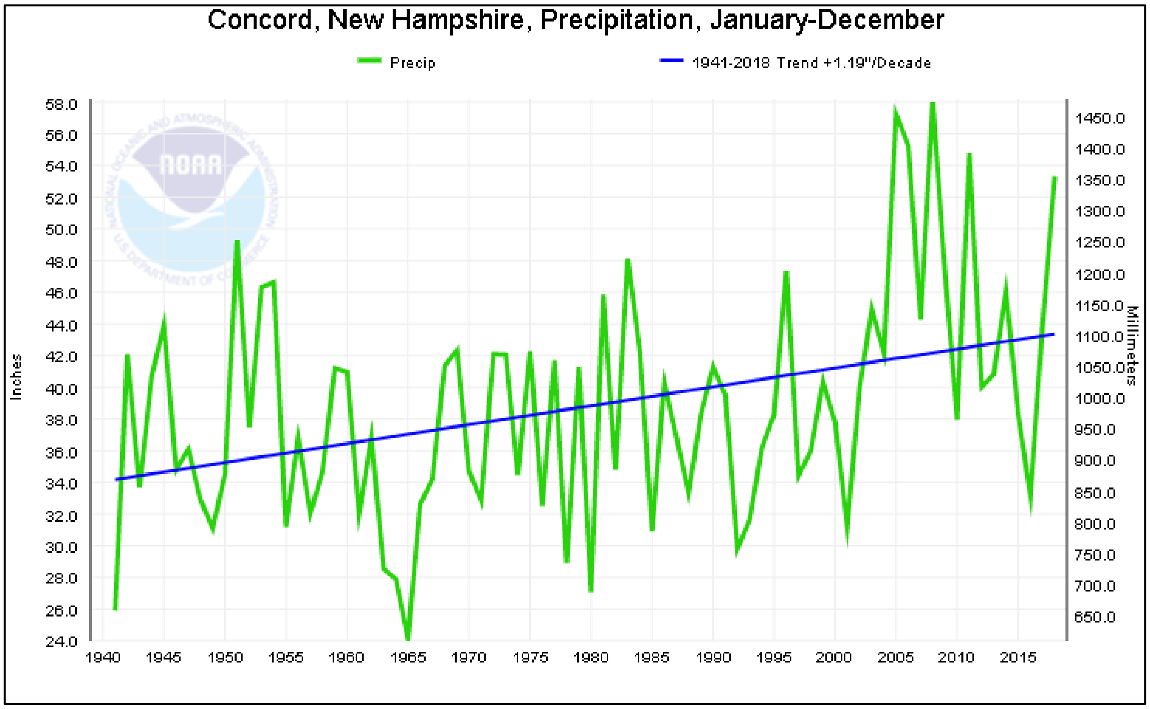

Figure 3. Monthly Average Precipitation at Concord, NH (National Oceanographic and Atmospheric Administration (NOAA) 2019)

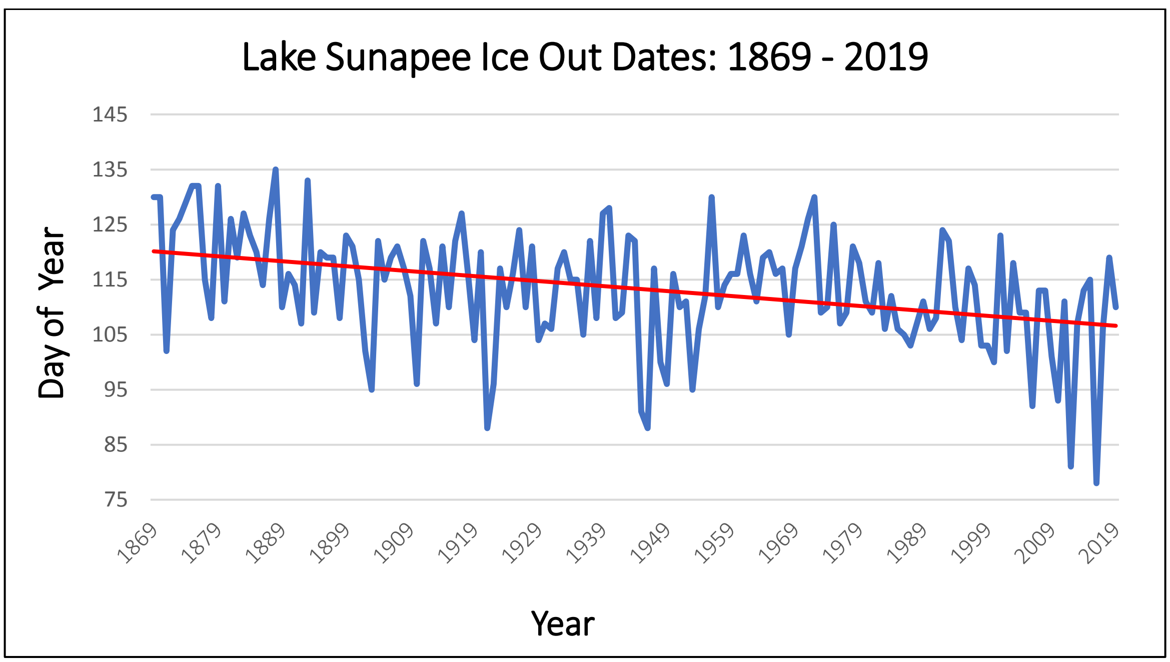

Figure 4. Ice Out Dates on Lake Sunapee from 1869-2019 (Ice out on Lake Sunapee is determined by the ability to navigate from one end of the lake to the other. The red line is a linear trendline. Source: LSPA unpublished data).

2.2 POPULATION, GROWTH TRENDS AND LAND USE

2.2.1 Population and Growth Trends

According to the New Hampshire Economic & Labor Market Information Bureau, the population in the six towns that lie within the Lake Sunapee Watershed totaled 14,057 in 2017 (NHES, 2020). The population for those same towns in 1960 was 4,365, indicating an increase of 9,692, or a percent increase of 222% from 1960 to 2017. The largest decennial percent change for all towns was the increase in population between 1970 and 1980, and the percent increases in towns during those years ranged from 31% in New London, to 89% in Newbury.

Typically, population trends are correlated with building and development. Section 3.3.2 provides information on historical building permits and their trends over time in the three largest towns within the watershed (note that building permit data was not obtained for Goshen, Springfield and Sutton). For the period between 1970 and 1980, the percent of building permits registered relative to the entire record of building permits for each town was 17.5%, 16.4 and 24.4% for New London, Newbury and Sunapee, respectively.

2.2.2 Land Cover

Watershed land cover is critical to watershed planning as both the amount and quality of the water flowing off the land to downstream waterbodies is directly affected by the activities on the land. In general, natural land covers such as forest and wetlands export less water and nutrients (phosphorus) than developed land cover such as roads, lawns, houses and commercial development. NH GRANIT land cover data, LiDAR and aerial photographs were used to determine certain land cover classifications, such as wetlands and forest. Selected land uses were confirmed on the ground during a watershed survey.

In total, 13 major land class categories were used to define all land cover within the watershed. In addition, two minor categories, medium residential (see Table 1) and pastures with animals, were added to further discriminate potentially important phosphorus loading areas within the watershed. This provided more realistic data for the modeling described in Section 3.5. Additionally, paved and unpaved road areas were defined using available length and width information sourced from NH GRANIT.

The dominant land cover for every subwatershed except Rodgers Brook was forest and disturbed forest. The location of most residential and commercial development is near roads and along lake/pond shorelines as can be seen in Appendix A, Land Cover Map 3. The densest areas of development (where impervious cover is highest) within the watershed are the commercial district of New London off Route 11, the western end of Georges Mills Cove, Sunapee Harbor, Newbury Harbor and Blodgett's Landing. There are also three active golf courses within the watershed; Twin Lake Villa on the shoreline of Little Lake Sunapee, Granliden within the Rodgers Brook subwatershed and Baker Hill within the Blodgett and Pike Brook subwatersheds. More information on land cover for each subwatershed is found in Section 3.5.3, Land Cover Update. More detailed land cover methodology can be found in Appendix C.

For the sake of consistency, the project team based land classes used for the land cover assessment on the NH Land Cover Mapping Standard. For more information about how the land cover assessment was done, refer to Section 3.5.3 (Land Cover Update) found in this plan. For class definitions refer to the 2020 WMP Classification Schema in Appendix C.

Table 1 - Medium Density Residential Areas in the Lake Sunapee Watershed

Subwatershed	Subdivision Name	Main Road Name	Area in Hectares[1]
Little Lake Sunapee	Fenwood	Fenwood Drive	3.5
Little Lake Sunapee	Great Pines	Spruce Lane	4.5
Little Lake Sunapee	Hilltop	Hilltop Place	8
Shoreland West	Indian Cave	Indian Cave Landing	6.5
Shoreland South	Edgemont	Edgemont Road	0.75
Shoreland South	North Peak Village	North Peak Village	1
Chandler Brook	North Peak Village	North Peak Village	1.25
Shoreland East	Blodgett's Landing	Blodgett's Landing Road	5

[1]Areas measured by LSPA using ArcGIS Pro software, May 2019

2.2.3 Protected and Public Lands

Conservation of land represents a unique opportunity in watershed planning to permanently protect land in a less developed state. In the northeast, undeveloped conserved land is often forest. Because of this, conserved lands often exhibit the lowest phosphorus export in a watershed. Approximately 8,414 acres, or 34% of the land in the Lake Sunapee watershed has some level of protection as either public or private conservation land (the total acreage excludes pond & lake area greater than 10 acres in size; see Appendix A, Conservation Land Map 4). It is important to note that easement agreements on conservation land often allows some use of the land to occur such as recreation, timber harvesting and agriculture. LSPA will pinpoint key parcels in these subwatersheds and work with local land conservation organizations (i.e. Ausbon Sargent Land Preservation Trust) to preserve them. See the Action Plan (Section 5.3) for more details.

2.3 PHYSICAL FEATURES

General Description

The Lake Sunapee Watershed is a medium-sized drainage basin in the Sugar River Watershed of the upper Connecticut Basin and is defined by the USGS as Hydrological Unit (HUC) 12 number 010801060402. The watershed spans approximately 12,072.5 hectares (29,832 acres) or 46.6 square miles and lies within Merrimack and Sullivan Counties and portions of six towns – Goshen, Newbury, New London, Springfield, Sunapee and Sutton (see Figure 5 and Table 2).

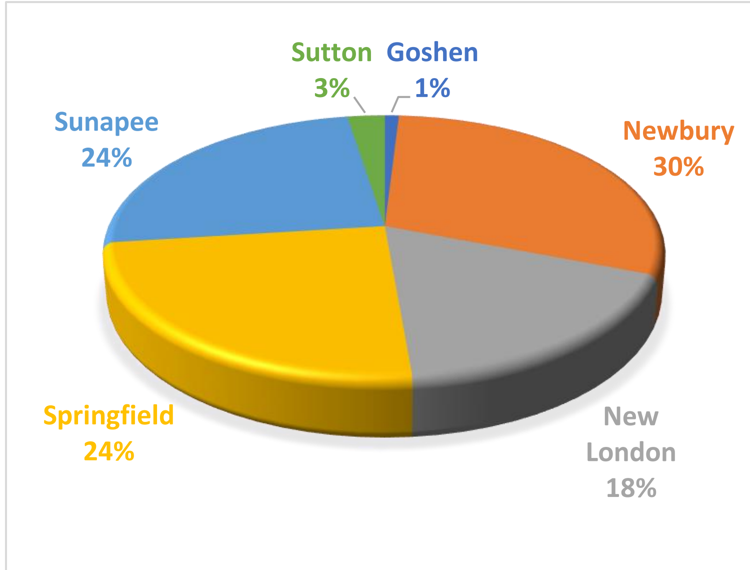

Figure 5. - Watershed Area in Each Town in the Lake Sunapee Watershed

The Lake Sunapee Watershed boundary was delineated using a digital elevation model (DEM) created from NH GRANIT 2016 LiDAR data. This provided a more accurate representation of the watershed due to the higher resolution created by the LiDAR data. Consequently, watershed, subwatershed, and waterbody boundary lines and surface areas did slightly change from the 2008 management plan. Before LiDAR, USGS 7.5-minute DEMs (30-meter resolution) were used to define the watershed and subwatershed boundaries and waterbody sizes were derived from the National Hydrography Dataset (NHD). It should be noted that watershed boundaries are not static and can change due to factors such as road and other development that can alter drainage patterns.

Table 2 - Municipality Surface Area Within the Lake Sunapee Watershed

Municipality	Area in Hectares	Area in Acres	% of Watershed Area
Goshen	115.0	284.2	1
Newbury	3,615.6	8,934.2	30
New London	2,141.4	5,291.6	17.7
Springfield	2,939.6	7,263.9	24.3
Sunapee	2,956.6	7,305.9	24.5
Sutton	304.3	751.9	2.5

2.3.1 Waterbodies, Subwatersheds and Streams

There are 13 named lakes and ponds in the watershed of varying size, shape and depth as listed in Table 3 and viewed in Appendix A, Subwatersheds Map 5. Lake Sunapee, whose shores are largely developed with both year-round and seasonal residential development, is the largest waterbody with Murray Pond being the smallest.

Table 3 - Waterbody Statistics

	Surface Area[1]		Maximum Depth		Mean Depth[2]		Volume		Perimeter[1]	
Waterbody Name	Hectares	Acres	Meters	Feet	Meters	Feet	Cubic Meters	Acre-feet	Kilometers	Miles
Baptist Pond	34.9	86.2	7.5	24.6	2.4	7.9	837,622	679	4.2	2.6
Chalk Pond	9.7	23.9	3.6	11.8	2	6.6	193,382	157	2.1	1.3
Dutchman Pond	12.4	30.8	3	9.8	1.9	6.2	236,546	192	1.9	1.2
Goose Hole Pond[4]	6.9	17.2							1.6	1
Lake Sunapee[3]	1,681.3	4,155	34.1	112	11.4	37.4	191,672,442	155,391	58.7	36.4
Little Lake Sunapee	198.8	491.3	13.3	43.6	4.4	14.4	8,747,386	7,092	11.9	7.4
McAlvin Pond[4]	4.2	10.4							0.9	0.6
Morgan Pond	21.6	53.3	2.6	8.5	1	3.4	224,401	182	3.5	2.2
Mountainview Lake	47.4	117.3	6.7	22	4.1	13.5	1,945,442	1,577	5.1	3.2
Murray Pond[4]	1.4	3.3							0.7	0.4
Mud Pond[4]	3.8	9.5							1	0.6
Otter Pond	76.4	188.7	7.6	24.9	4	13.1	3,054,947	2,477	6	3.7
Star Lake	27.8	68.7	5.4	17.7	2.2	7.1	600,227	487	3.7	2.3

NOTES:

[1]Surface areas and perimeter lengths calculated using 2016 GRANIT LiDAR data.

[2]Mean depth source from NHDES VLAP reports except for Morgan Pond and Star Lake where maximum depth, acquired from the Boating USA App, was used to calculate mean depth (mean depth was estimated as 0.4 times the maximum depth).

[3]Lake Sunapee max depth is calculated from the 2008 Bathymetric Survey made possible by the Breidablik Fund.

[4]Maximum depth of Goose Hole, McAlvin, Murray and Mud ponds not known.

There are 29 defined subwatersheds for perennial streams or waterbodies within the watershed as listed in Table 4. Goose Hole Pond, McAlvin Pond, Murray Pond and Mud Pond are all relatively small with few data to describe them. They were not explicitly split out in the data analysis or modeling effort (Section 3.5) but are incorporated in the analysis as a part of the watershed of the next downstream lake or pond. Additionally, shoreland drainage of Lake Sunapee was divided into four distinct areas, identified as Shoreland North, South, East and West (see Appendix A, Subwatersheds Map 5).

Table 4 - Lake Sunapee Subwatersheds				
		Surface Area[1]		% of Watershed
Name	#	Hectares	Acres	
Baptist Pond	1	630	1,557	6.3
Bartlett Brook	2	163	404	1.6
Bell Cove Brook	3	144	357	1.4
Birch Grove Brook	4	29	72	0.3
Blodgett Brook	5	572	1,413	5.7
Chalk Pond	6	112	276	1.1
Chandler Brook	7	743	1,837	7.5
Cunningham Brook	8	105	259	1.1
Dutchman Pond	9	33	81	0.3
Eagle Rock Brook	10	26	65	0.3
Hastings Creek	11	44	108	0.4
Herrick Cove North Brook	12	123	304	1.2
Herrick Cove South Brook	13	181	448	1.8
Jobs Creek	14	125	310	1.3
King Hill Brook	15	510	1,260	5.1
Little Lake Sunapee	16	1,178	2,911	11.8
Morgan Pond	17	194	480	1.9
Mountainview Lake	18	390	964	3.9
Muzzey Brook	19	247	609	2.5
Newbury Inlet Brook	20	158	390	1.6
Otter Pond	21	1,218	3,011	12.2
Pike Brook	22	466	1,151	4.7
Red Water Creek	23	388	958	3.9
Rodgers Brook	24	140	345	1.4
Shoreland East	25	328	810	3.3
Shoreland North	26	320	791	3.2
Shoreland South	27	426	1,053	4.3
Shoreland West	28	582	1,438	5.8
Star Lake	29	386	953	3.9

NOTES:
[1]Totals do not include upstream ponds or lakes except for Goose Hole, McAlvin, Mud and Murray Ponds which were not explicitly modeled in Section 3.5.

There are 27 named streams and brooks in the watershed (see Appendix A, Major Brooks Map 6), Major Brooks in the Lake Sunapee Watershed). Nineteen of them drain directly into Lake Sunapee.

2.3.2 Topography

Terrain within the watershed ranges from steep slopes (greater than 25%), to rolling terrain. Elevations range from 2,743 feet at the summit of Mount Sunapee to just under 1,093 feet at the Lake Sunapee outflow at the Sugar River in Sunapee. The land surface in the Sunapee drainage basin (watershed) slopes moderately to relatively steeply to the lake from all sides. These slopes are steepest along the southern and western sides of the lake. The slope of the land surface is controlled largely by the underlying bedrock in the region.

2.3.3 Wetlands, Soils and Geology

Wetlands, as identified in the 1991 National Wetland Inventory, represent a relatively small portion of the watershed. Excluding the 13 named lakes and ponds, about 1,030 acres or 3.5% of the watershed is comprised of palustrine (freshwater) wetlands dispersed throughout the watershed. Wetland locations are shown in Appendix A, Land Cover Map 3. A total of 290 wetland units, excluding the 13 named waterbodies have been identified in the watershed.

A total of 2,738 acres are considered steep soils averaging 15% or greater in slope as determined through soils surveys prepared by the Natural Resource and Conservation Service and the 2019 Buildout Analysis for this plan. This represents 9.2% of the watershed.

According to Thompson et al. (1990), the bedrock that underlies Lake Sunapee's drainage basin is composed primarily of Devonian & Cretaceous igneous rocks (granite, granodiorite, quartz monzonite and related rocks). Thompson's map also indicates that a portion of the northeastern and southwestern part of the drainage basin is underlain by Silurian and Devonian metasedimentary rocks (metapelites, metaturbites, quartzites and conglomerates). The bedrock slopes in Lake Sunapee's drainage basin are covered by a thin layer of relatively sandy glacial till (Soil Conservation Service, 1965 & 1988 as cited in Schloss, 1989). The soils formed in the glacial till on the hillsides and mountain slopes in the lake's drainage basin are classified by the Soil Conservation Service (1988) as "deep, gently sloping to very steep, well drained and somewhat excessively drained, loamy and sandy soils of the Monadnock-Marlow-Hermon series". These soils are very strongly acidic and are described by the Soil Conservation Service, 1965 (as cited in Schloss, 1989) as having "good drainage for septic tank systems."

2.3.4 Lake Morphology

Lake Sunapee is relatively long and narrow with a length to width ratio of about 4 to 1 and a watershed to lake area ratio of 6 to 1. The lake is approximately 8 miles long and from 0.5 to 2.5 miles wide (east to west), covering 6.5 square miles. The maximum depth, as determined from the 2008 Bathymetric Study funded by the Breidablik Fund, is 112 feet. It is the sixth largest lake in New Hampshire with a surface area of 4,155 acres and has about 36 miles of shoreline. Being relatively deep, the lake thermally stratifies during the warmer months. There are 11 islands on the lake, the largest one known as Great Island.

2.4 AQUATIC BIOLOGY

Aquatic biology has the potential to significantly influence water quality in lakes, particularly in low-nutrient lakes such as Sunapee. Currently, Lake Sunapee is actively monitored for invasive aquatic plants and animals which can displace native species and impair recreational and aquatic life uses. Variable milfoil (*Myriophyllum heterophyllum),* a problem in many northeast lakes was discovered in at least two locations years ago and eliminated by LSPA and NHDES. Continued vigilance and rapid action have kept invasive aquatic plants and animals from establishing a presence in the lake.

The fish community of Lake Sunapee, like many New Hampshire lakes, is not static. It includes a stocked apex predator (landlocked salmon) in addition to the introduced species largemouth bass, smallmouth bass and recently, rock bass. Native bullhead, chain pickerel, lake trout, smelt, yellow perch and others are also present. Rainbow trout, although not stocked directly, were stocked in upstream lakes (Little Lake Sunapee in 2016) and are likely present in Lake Sunapee. The Sunapee trout is thought to be extinct in Lake Sunapee.

Through predation, the fish community can cause cascading effects through the food web that result in changes in algal growth and nutrient cycling (Carpenter et al. 1986). For example, in Lake Sunapee, trophic effects might explain a partial disconnect between concentrations of chlorophyll-*a* observed relative to phosphorus concentrations in some years. Current research on the Lake Sunapee food web may yield additional insights that may allow some of the trophic interactions to be quantified and may help explain some of the variability in water quality from season-to-season and year-to-year.

Other potential indirect trophic effects on water quality in Lake Sunapee could be related to the loss of deep oxygen causing salmonid fish (landlocked salmon) to concentrate in the shallower layers of the lake than they prefer, resulting in food chain effects on planktivorous fish (smelt and young of other species), zooplankton and algae. The recent introduction of new species like rock bass may also have effects on the food chain. Further understanding of these potential biological interactions in Lake Sunapee may help guide management in the future. Research on the influence biological interactions may have on water quality is presented in Section 5.3.2.

THERE ARE NO REASONABLE SCENARIOS WHERE ADDITIONAL PHOSPHORUS INPUT TO LAKE SUNAPEE WILL IMPROVE LONG-TERM WATER QUALITY.

Regardless of the influence of the aquatic community on water quality, the influence of phosphorus on water quality remains critical to designated use support. There are no reasonable scenarios where additional phosphorus input to Lake Sunapee will improve long-term water quality and future support of designated uses.