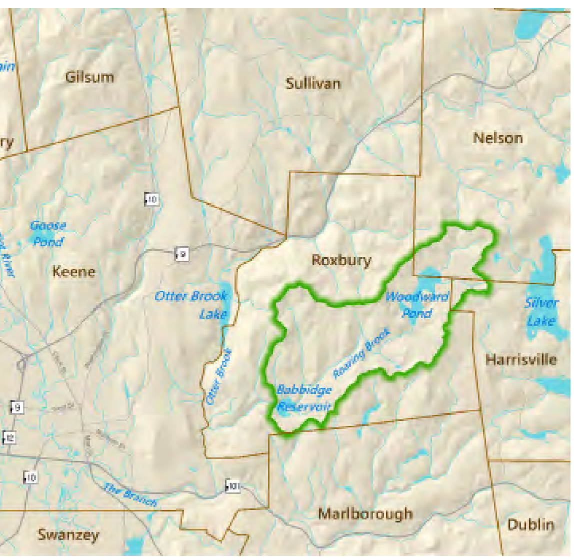
City of Keene
December 2018

Final Technical Report

Roaring Brook Watershed Management Plan



IN ASSOCIATION WITH:

New England Forestry Consultants, Inc.

DK Water Resource Consulting, LLC

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List of Acronyms & Abbreviations

AC	Acres
BD-FT	Board-Feet
BMP	Best Management Practices
DO	Dissolved Oxygen
DPW	Department of Public Works
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GPM	Gallons per Minute
GPS	Global Positioning System
HA	Hectares
LLRM	Load-Lake Response Model
MGD	Million Gallons per Day
NEWWA	New England Water Works Association
NHDES	New Hampshire Department of Environmental Services
NHDOT	New Hampshire Department of Transportation
NHFGD	New Hampshire Fish and Game Department
NHNHB	New Hampshire Natural Heritage Bureau
NRCS	Natural Resource Conservation Service
NWI	National Wetlands Inventory
RSSC	Ridge Skippers Snowmobile Club
SWPA	Source Water Protection Area
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
USACOE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey

Glossary

Anoxic

Areas of surface waters or groundwater that are depleted of dissolved oxygen.

Aquifer

An underground porous, water-bearing geological formation.

Base Flow

Stream discharge derived from groundwater sources as differentiated from surface runoff.

Bathymetry

The measurement of water depth at various places in a body of water.

Board-Feet

The board-foot is a unit of measure for the volume of timber or lumber. It is the volume of a one-foot length of a board one foot wide and one inch thick.

Disinfection Byproducts

Disinfection byproducts are chemical, organic and inorganic substances that can form during a reaction of a disinfectant with naturally present organic matter in the water.

Emergent

Rooted below a body of water or in an area that is periodically submerged but extending above.

Eutrophication

The process of waterbodies being enriched by excessive nutrient concentrations such as phosphorus or nitrogen, resulting in high productivity.

GIS (Geographic Information System)

A computer-based mapping and information management system tied to geographic data.

Hydrology
The study of a watershed's behavior during and after a rainstorm. A hydrologic analysis determines the amount of rainfall that will stay within a watershed - absorbed by the soil, trapped in puddles, etc. - and the rate at which the remaining amount of rainfall will reach the stream.

Impoundment
A body of water formed by a dam or other feature that collects and confines water in or as if in a reservoir

Lentic
Ecology of, relating to, or inhabiting still water.

Limnology/Limnological
Relating to the biological, chemical, and physical features of lakes and other bodies of fresh water.

Oligotrophic
A lake or other body of water characterized by extremely low nutrient concentrations such as nitrogen and phosphorous, resulting very moderate productivity. Such lakes are often deep, with sandy bottoms and very limited plant growth, but with high dissolved-oxygen levels. Oligotrophic waterbodies represent the early stages in the life cycle of a lake.

Palustrine
Inland, nontidal wetlands characterized by the presence of trees, shrubs, and emergent vegetation (vegetation that is rooted below water but grows above the surface). Palustrine wetlands range from permanently saturated or flooded land to land that is wet only seasonally.

Riparian
The interface between land and a river or stream.

Secchi Transparency/Secchi Disk
A measure of the water clarity or turbidity of a waterbody, or the instrument used to measure this parameter. A Secchi disk is mounted on line and lowered into the water column. The depth at which the disk is no longer visible is taken as a measure of the transparency of the water.

Silviculture
The practice of controlling the establishment, growth, composition, health, and quality of forests to meet diverse needs and values.

Stumpage
The price a private firm pays for the right to harvest timber from a given land base, paid to the current owner of the land.

Thermal Stratification

A change in the temperature at different depths in the lake, due to the change in water's density with temperature.

Thermocline

A steep temperature gradient in a body of water such as a lake, marked by a layer above and below which the water is at different temperatures.

Tributary

A stream that flows into a larger stream or body of water at a confluence.

Trophic State

A description of the various productivity levels of waterbodies. Waterbodies are classified by three trophic levels (listed from most productive to least): eutrophic, mesotrophic, and oligotrophic.

Turbidity

The suspension of sediment in water; water that is clouded, muddy, dull, or polluted.

Watershed

A land area that drains into a lake, stream or river. Also called "basins," watersheds vary in size. Larger ones can be divided into sub-watersheds or sub-basins.

1

Introduction

1.1 Purpose of this Study

For more than 100 years, the Roaring Brook Watershed has provided drinking water for the City of Keene. The water it supplies is among Keene's most valuable public resources. While the Keene Department of Public Works (DPW) oversees the property according to State regulations that prohibit activity in the watershed, there is no formal management plan in place. Therefore, this study has been conducted to provide information needed to develop a comprehensive management plan for the property.

This study includes an inventory of the natural features of the watershed, an evaluation of the riparian characteristics of Roaring Brook and the limnological characteristics of Woodward Pond and Babbidge Reservoir, an inventory of timber and other natural resources on City-owned land, and consideration of the current and potential public use of the land. The study applies science and land management policies to develop a strategy that protects and enhances the water supply while maximizing the value of the property to the public.

1.2 Watershed and Property Description

The Roaring Brook Watershed above the Babbidge Reservoir outlet is approximately 3,157 acres in total. The majority of the watershed lies within Roxbury, although the watershed encompasses portions of Nelson, Harrisville and a small portion of Marlborough. Based on corrected statewide tax parcel mapping, the City owns approximately 2,643 acres of land, approximately 1,965 acres of which lies within the watershed.[1] See **Figure 1-1** and **Table 1-1**.

Table 1-1. Roaring Brook Watershed and Keene Ownership, by Town

Municipality	Roaring Brook Watershed[1] (Acres)	Keene Ownership[2] (Acres)	Keene Ownership In Roaring Brook Watershed[2] (Acres)
Roxbury	2,609	2,456	1,793
Nelson	459	148	148
Harrisville	87	25	23
Marlborough	2	5	1
Total	3,157	2,634	1,965

Note:
1 From VHB watershed delineation.
2 Parcel areas in this table are from VHB analysis of refined parcel mapping. These figures may differ from tax records.

In developing the data shown in **Table 1-1**, draft parcel boundaries were developed from NH GRANIT, including the NH Parcel Mosaic data layer (February 2017) and the NH Conservation/Public Lands data layer.[2] Paper copies of historical property maps and surveys on file at the Keene Department of Public Works were also compiled and reviewed. During review of the parcel data, discrepancies among the various sources were noted. Additionally, field work conducted as part of this study found that the condition of the boundary lines for the perimeter of the property was generally poor. Few sections of well blazed and marked lines were encountered.

To resolve these mapping issues, field data was collected in an attempt to better map the parcel boundaries. This included the use of autonomous hand-held GPS receivers to map features such as stone walls, property corners, and blaze marks. These data were collected without the aid of post-processing or differential corrections. The accuracy of the resulting GPS data ranges from approximately 3 to 30 feet and therefore is not survey quality, but the data did allow correction of parcel boundaries appropriate for a watershed study. The resulting corrected parcel boundaries were used as the basis for all subsequent field work and analysis presented in this study. However, a survey of the property is recommended to fully determine the actual extent of City ownership (See Chapter 6 for a summary of recommendations).

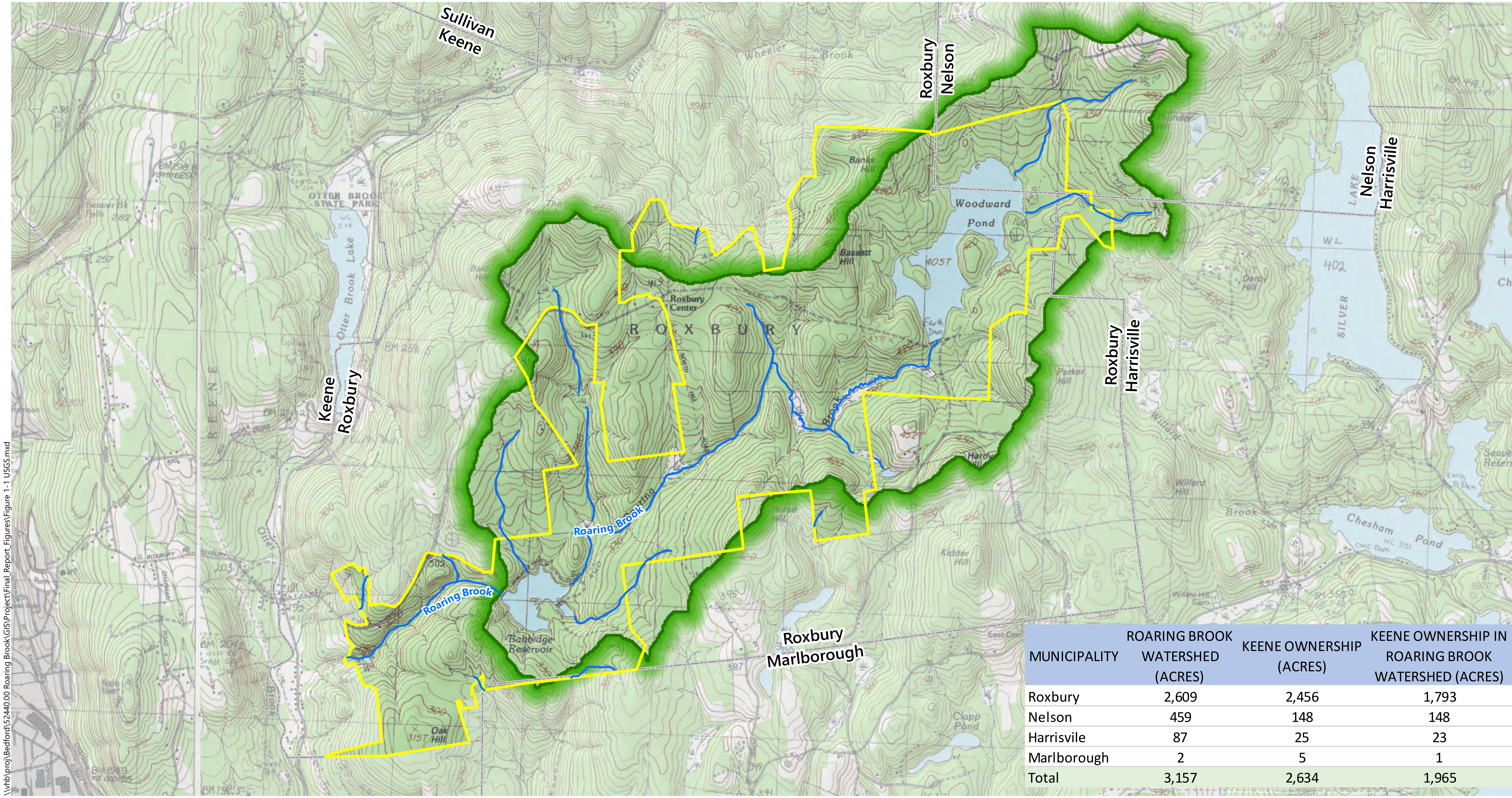
The watershed is mostly forested, and the landscape is dominated by rolling hills (*e.g.*, Banks, Bassett, Horse, and Oak Hills). A deep valley containing Roaring Brook runs the length of the property, sloping southeast, interlaced with several narrow tributary valleys with some limited wetland complexes. The forest overstory is dominated by

▼

1 Statewide parcel mapping was obtained from GRANIT, the statewide GIS database, and was updated based on GPS-mapped field evidence during this study. The resulting parcel map indicates that the City owns approximately 2,643 acres of land in total. However, this estimate is based on provisional parcel boundaries and may not reflect the true acreage of ownership.

2 https://granitweb.sr.unh.edu, NH Conservation/Public Lands at 1:24,000 Scale, NH Statewide Parcel Mosaic, accessed February 2017.

FIGURE 1-1



MUNICIPALITY	ROARING BROOK WATERSHED (ACRES)	KEENE OWNERSHIP (ACRES)	KEENE OWNERSHIP IN ROARING BROOK WATERSHED (ACRES)
Roxbury	2,609	2,456	1,793
Nelson	459	148	148
Harrisvile	87	25	23
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\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 1-1 USGS.mxd

0 1250 2500 5000 Feet

Keene-Owned Lands (Updated Boundary)
Roaring Brook Watershed (Above Babbidge Dam)
Town Boundary
Intermittent and Perennial Streams

Roaring Brook Watershed Management Plan

Roaring Brook Watershed

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

red oak *(Quercus rubra)* and white pine *(Pinus strobus)*, and it includes patches of hemlock *(Tsuga canadensis)* and, in the steeper ravines, occasional red spruce *(Picea rubens)*. The riparian zones around Babbidge Reservoir and Woodward Pond, as well as the heights around Horse Hill, are highlighted in the New Hampshire Fish & Game Department's (NHFGD) 2015 Wildlife Action Plan (WAP) as some of the highest ranked habitat in the State. (See Section 2.5 for a discussion of wildlife habitat in the watershed.)

1.3 Woodward and Babbidge Ponds

Water is stored in two impounded reservoirs – the first created by the Woodward Pond Dam, the second by the Babbidge Reservoir Dam. Woodward Pond (or Woodward Reservoir) is approximately 166 acres in size and stores approximately 490 million gallons of freshwater in the northwestern portion of the property. Water from the Woodward Pond flows into Babbidge Reservoir (or Babbidge Pond) in the southeastern portion of the property, which is approximately 40 acres and stores about 145 million gallons.[3] **Table 1-2** provides data on the size of each of these impoundments, as well as their expected flushing rates based on hydrological characteristics. Woodward Pond is larger in size, but has a small watershed compared to that of the smaller Babbidge Reservoir. (The Babbidge watershed includes the Woodward watershed.) As a result, the relative flushing rates of the two reservoirs are much different. Babbidge flushes much more rapidly than Woodward, and as a result would be expected to respond much more quickly to changes in the quality of water entering the reservoir.

Table 1-2. Physical Characteristics of Roaring Brook Reservoirs

Waterbody/Basin	Size (ac/ha)	Direct Watershed Area (ac/ha)	Total Watershed Area (ac/ha)	Ave Flushing Rate (flushings/yr)
Woodward Pond	166/67	986/399	986/399	1.5
Babbidge Reservoir	40/16	2,011/814	3,157/1279[1]	10.5

Notes:
1 Includes Woodward watershed and reservoir surface area

The water from Babbidge Reservoir flows via ductile iron pipe to the City's Water Treatment Facility on Roxbury Street. There, it is filtered and disinfected prior to being delivered into the public water distribution system.

The watershed is an essential resource to the City of Keene, both now and for the future. It supplies much of the community's current 2.7 million gpd water demand. About 2 million gpd is withdrawn from Babbidge Reservoir, with the balance

[3] Storage volumes are from Weston & Sampson Engineers (1989).

supplied by four groundwater wells located within the City limits. While the City has adequate water supply currently, preservation and potential increase of safe yield from existing supplies is warranted. As the City and region continues to grow, managing the community's water resources becomes increasingly important. Protecting both the quantity and quality of this water is essential to the community.

2

Natural Resources

2.1 Introduction

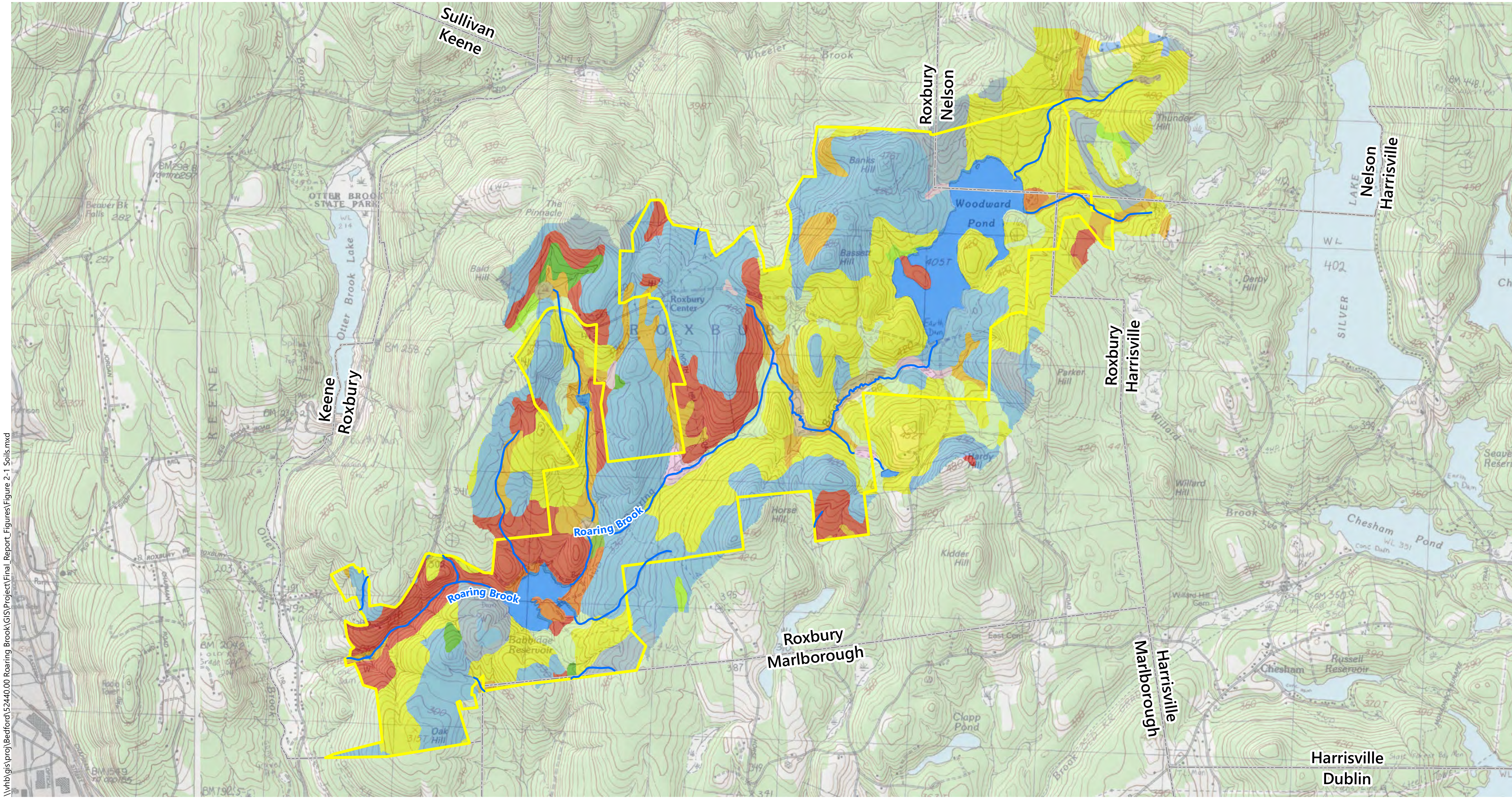
The following is a description of various natural resources that are located within the Roaring Brook Watershed, including information regarding soils, wetlands, groundwater, conservation lands, wildlife habitat, and rare species.

2.2 Soils

Soil types within the Roaring Brook Watershed vary from smaller areas of poorly drained soils within wetland areas or along streams to larger areas of well drained upland soils. **Figure 2-1** depicts soil types based on mapping completed by the Natural Resource Conservation Service (NRCS) in the Cheshire County Soil Survey, and related data is summarized in **Table 2-1**. Note that this mapping was performed on a county-wide basis with relatively limited soil sampling; no new soils sampling was conducted as part of this watershed study. Therefore, the map does not show small areas of contrasting soils that occur within the map units.

Based on the county soil data, the most common soil type within the Roaring Brook Watershed is *Tunbridge-Berkshire* soils and *Marlow fine sandy loam*. *Tunbridge-Berkshire* soils are typically stony, well-drained soils that occur on level to very steep upland areas. These soils are commonly found at the crest of hillsides or along the plains of glaciated uplands, and are usually represented in oblong, irregular shapes on the soils map. *Marlow fine sandy loam* soils are well drained soils and largely occur within wooded areas on rounded hills or side slopes. These areas typically cover an area between 5 and 40 acres in size. *Berkshire and Monadnock* soils also occur within a large portion of the watershed, and are well drained, extremely stony soils commonly found along steep hillsides or mountainous areas. A small amount of *Chocorua mucky peat* occurs along Roaring Brook, within the central portion of the watershed; this soil is classified as a very poorly drained soil. These soils occur in depressional areas associated with lake outwash plains and glacial till uplands. *Lyme and Moosilauke* soils

FIGURE 2-1



\\vhb\gis\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 2-1 Soils.mxd

0 1250 2500 5000 Feet

Keene Owned Land (Updated Boundary)
Roaring Brook Watershed (Above Babbidge Dam)
Town Boundary
Intermittent and Perennial Streams

NRCS Soils (Type)
- Berkshire and Monadnock soils
- Colton loamy fine sand
- Lyme and Moosilauke soils
- Chocorua mucky peat
- Ossipee mucky peat
- Marlow fine sandy loam
- Peru fine sandy loam
- Pillsbury fine sandy loam
- Sunapee fine sandy loam
- Sheepscot sandy loam
- Tunbridge-Berkshire complex
- Tunbridge-Lyman
- Water

Roaring Brook Watershed Management Plan

Soil Resources

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

are commonly occurring poorly drained soils within the watershed that are very stony and occur in depressional areas. The parent material of *Lyme and Moosilauke* soils are till and glacial drift.

Table 2-1. Soil Types within the Roaring Brook Watershed

Soil Series Name	Drainage Class	All Keene-Owned Land (acres)	Keene-Owned Land In Watershed (acres)
Tunbridge-Berkshire	Well drained	879	572
Marlow fine sandy loam	Well drained	735	655
Berkshire and Monadnock	Well drained	354	175
Peru fine sandy loam	Moderately well drained	134	132
Lyme and Moosilauke soils	Poorly drained	117	107
Tunbridge-Lyman	Well drained	100	45
Lyman-Tunbridge	Somewhat excessively	33	
Colton loamy fine sand	Excessively drained	31	31
Chocorua mucky peat	Very poorly drained	30	30
Ossipee mucky peat	Very poorly drained	27	27
Sunapee fine sandy loam	Moderately well drained	8	1
Sheepscot sandy loam	Moderately well drained	4	4
Pillsbury fine sandy loam	Poorly drained	4	4
Monadnock fine sandy loam	Well drained	0	6
	Total	2,634	1,965

Note:
Totals include 177 acres of surface waters.

The predominance of well drained and sandy soils on the property contributes to the recharge of Woodward Pond and Babbidge Reservoir, improving the supply of water within the watershed. The poorly and very poorly drained soils also help to protect water quality; the high organic content of these soils tends to trap potential contaminants that might otherwise enter the water supply.

2.3 Wetlands

According to the Natural Wetland Inventory (NWI) and limited field observations conducted during this study, several open water, forested, scrub-shrub, and emergent wetlands occur along Roaring Brook and associated tributaries. These significant wetlands include swamp and marsh areas, and cover approximately 8.6% of the City-owned property, or about 226 acres. This total is likely an underestimate of the total wetlands on the parcel, since it is derived primarily from interpretation of aerial photography; it is likely that additional wetland areas could be identified on the parcel if a field-based wetland delineation were to be conducted. However, because of the large size of the parcel and the level of effort required to delineate wetlands to site-specific standards, field delineation of the entire parcel is not recommended at this time. This would likely require 20-30 days of field work and is unlikely to yield new information commensurate with this level of effort. Rather, the City should field delineate wetlands in limited areas as required to support future site-specific projects (e.g., dam or road maintenance projects).

GIS data was developed and field inspection by boat and on foot were performed in 2017 to review major wetland systems within the portion of the Roaring Brook watershed owned by the City of Keene. **Table 2-2** provides a list of wetland types that are within the Keene-owned portion of the watershed, including their Cowardin classification, and **Figure 2-2** depicts their distribution. The largest wetland systems are Babbidge Reservoir and Woodward Pond themselves, but other freshwater systems also exist within the watershed.

Table 2-2. Wetlands within Keene-Owned Portions of the Roaring Brook Watershed

Cowardin Classification	Cowardin Classification Definition	All Keene-Owned Parcels (acres)	Keene-Owned Land In Watershed (acres)
L1UBH	Lacustrine, Limnetic, Unconsolidated Bottom, Permanently Floded	170	170
PSS1E	Palustrine, Scrub Shrub, Broad-Leaved Deciduous, Seasonally Flooded/Saturated	18	18
PSS1Eb	Palustrine, Scrub Shrub, Broad-Leaved Decidusou, Seasonally Flooded/Saturated, beaver	10	10
PEM1E	Palustrine, Emergent, Persistent, Seasonally Flooded/Saturated	8	8
PFO1E	Palustrine, Forested, Broad-Leaved Deciduous, Seasonally Flooded/Saturated	5	5

PFO1Eb	Palustrine, Forested, Broad-Leaved Deciduous, Seasonally Flooded/Saturated, beaver	4	2
PUBH	Palustrine, Unconsolidated Bottom, Permanently Flooded	3	2
PEM1Eb	Palustrine, Emergent, Persistent, Seasonally Flooded/Saturated, beaver	2	2
PEM1Fb	Palustrine, Emergent, Persistent, Semipermanently Flooded, beaver	2	2
PFO4/1Eb	Palustrine Forested, Needle-Leaved Evergreen/Broad-Leaved Deciduous, Seasonally Flooded/Saturated, beaver	2	2
PFO4E	Palustrine, Forested, Needle-Leaved Evergreen, Seasonally Flooded/Saturated	2	2
	Total	226	226

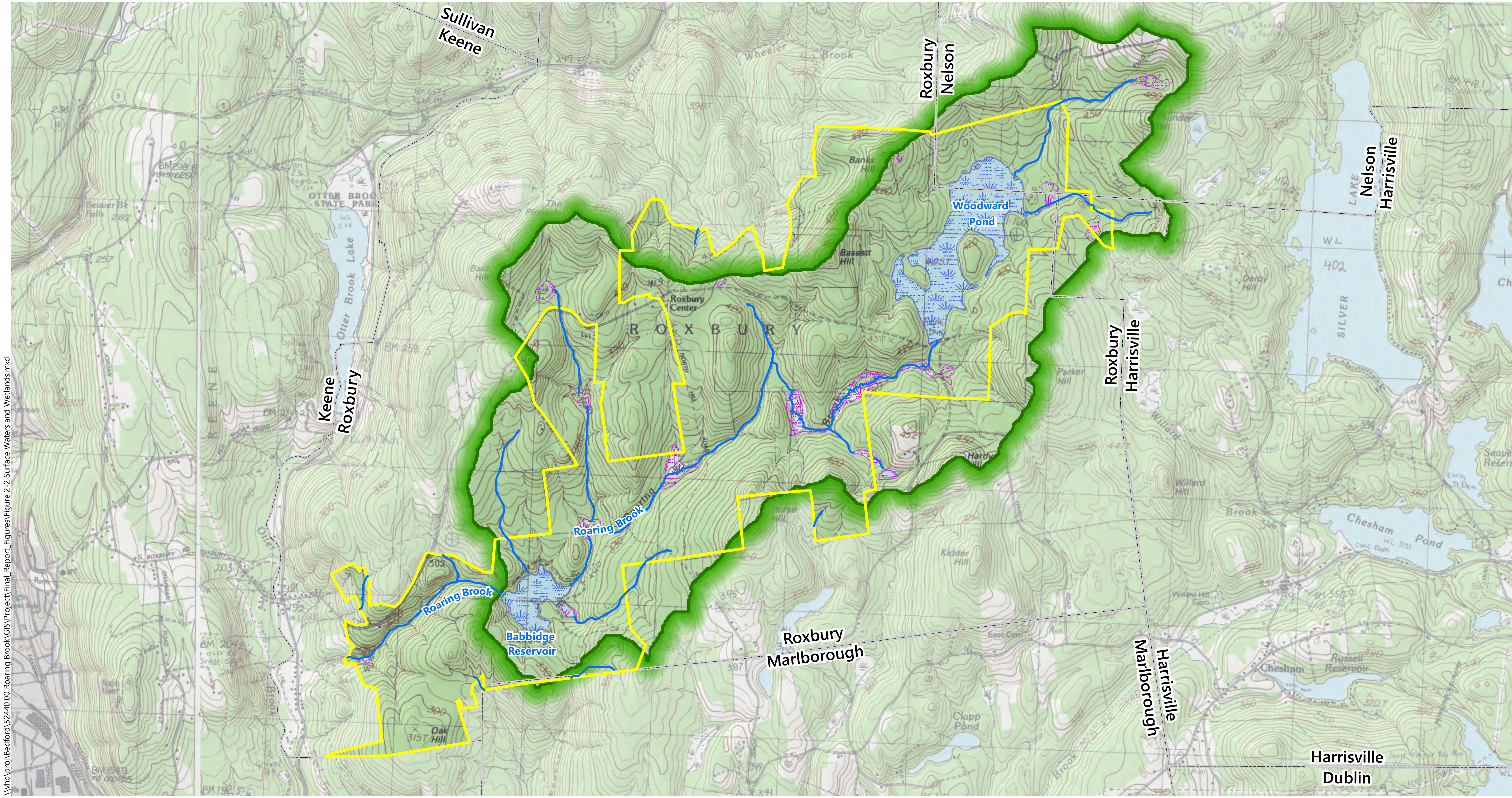
Note:
Data from VHB analysis of data provided by the US Fish and Wildlife Service, National Wetlands Inventory.

Descriptions are provided below for each of the three general categories of terrestrial wetlands within the study area. A discussion of the surface waters within the watershed (i.e., Woodward Pond and Babbidge Reservoir) are provided in Chapters 1 and 5.

Forested Wetlands (PFO)

Freshwater wetlands with at least 30% tree areal coverage are classified as PFO. Deciduous forested swamps in the study area are generally seasonally saturated and occur in isolated depressions or within the floodplain of the river. Dominant vegetation in the deciduous forested swamps typically consists of red maple (*Acer rubrum*) and white ash (*Fraxinus americana*) overstory with common winterberry (*Ilex verticillata*) and highbush blueberry (*Vaccinium corymbosum*) in the shrub layer. Cinnamon fern (*Osmunda cinnamomea*), jewelweed (*Impatiens capensis*), sensitive fern (*Osmunda sensibilis*), royal fern (*Osmunda regalis*), poison ivy (*Toxicodendron radicans*), skunk cabbage (*Symplocarpus foetidus*), and sphagnum moss (*Sphagnum* sp.) provide herbaceous ground cover.

Mixed deciduous/coniferous forested swamps typically occur in seasonally flooded pit and mound topography, consisting of saturated loamy/sandy/gravelly soils in topographic depressions. Dominant vegetation in the mixed deciduous/coniferous forested swamp consists of red maple, white pine, eastern hemlock (*Tsuga canadensis*), American elm (*Ulmus americana*), white ash, and yellow birch (*Betula alleghaniensis*) in the tree canopy; northern arrow-wood (*Viburnum recognitum*), highbush blueberry, and nannyberry in the shrub layer; and cinnamon fern, sensitive fern, skunk cabbage, goldthread (*Coptis groenlandica*), poison ivy, and sphagnum moss in the herbaceous layer.



\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 2-2 Surface Waters and Wetlands.mxd

0 1250 2500 5000 Feet

Keene Owned Land (Updated Boundary)
Roaring Brook Watershed (Above Babbidge Dam)
Town Boundary

NWI Wetland (Type)
Lacustrine
Palustrine
Intermittent and Perennial Streams

Roaring Brook Watershed Management Plan

Surface Waters and Wetlands

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

Shrub Wetlands (PSS)

Freshwater wetlands with less than 30% tree areal coverage and greater than 30% shrub aerial coverage are classified as PSS. Shrub wetlands also include wetlands where trees and shrubs, individually, cover less than 30% of an area, but in combination provide 30% or more areal coverage.

Shrub wetlands within the study area generally occur as seasonally flooded, densely vegetated, fringing habitats bordering forested and emergent wetlands and along the edges of Roaring Brook and its small tributary drainages. Field verification confirmed that shrub wetlands typically consist of northern arrow-wood, highbush blueberry, silky dogwood (*Cornus amomum*), speckled alder (*Alnus rugosa*), honeysuckle (*Lonicera* spp.), and occasional multiflora rose (*Rosa multiflora*), with skunk cabbage, sensitive fern, cinnamon fern, and poison ivy in the herbaceous layer.

Emergent Wetlands (PEM)

Emergent wetlands are freshwater wetlands (marshes and wet meadows) with a tree and shrub coverage of less than 30% of the area, but where the total cover of emergent vegetation in the wetland is 30% or greater. Freshwater marshes are seasonally flooded wetlands commonly saturated at or near the surface when not flooded, and are dominated by grasses or grass like plants. Freshwater wet meadows are seldom flooded wetlands that are saturated throughout the growing season, and are dominated by herbaceous vegetation.

In the Keene-owned portion of the watershed, freshwater emergent marshes exist as small inclusions within larger scrub-shrub and forested units, and typically created or influenced by beaver activity. These areas are dominated by broad-leaf and narrow leaf cattail (*Typha latifolia* and *T. angustifolia*), wool grass (*Scirpus cyperinus*), spike rush (*Eleocharis* spp.), shallow and pointed broom sedges (*Carex lurida* and *C. scoparia*), soft rush (*Juncus effusus*), three-square sedge (*Scirpus americanus*), and sphagnum moss. American elderberry (*Sambucus canadensis*), swamp milkweed (*Asclepias incarnata*), and Joe-pye-weed (*Eupatorium* sp.) are also found in some emergent marsh areas. Notable exotic invasive species, such as common reed (*Phragmites australis*) or purple loosestrife (*Lythrum salicaria*), were not observed in emergent wetlands, which indicated a high degree of ecological integrity and reflects their relatively high degree of geographic isolation. (See Section 2.7 for more information on invasive species in the watershed.)

The preservation of the wetlands within the watershed is important because they improve water quality supplied to downstream environments in several ways. By spreading out and slowing down flows they reduce erosion and prevent sediment being transported downstream where it might affect the ecology and productivity of the reservoirs. When healthy, wetland soils and vegetation capture, process and store nutrients and contaminants, and if the wetlands are undisturbed, the release of potential stressors such as sediments, nutrients, acids and metals from the soil can be prevented. Healthy wetlands can assist in removing harmful bacteria, and wetlands can also be important in the management of stormwater from off site by improving the removal of nutrients, suspended material and pathogens from water prior to its return to the environment.

2.4 Groundwater Resources

Aquifer Conditions

The water supply resource within the Roaring Brook Watershed derives primarily from the two surface impoundments of Roaring Brook. Additionally, the watershed is underlaid by a bedrock-till formation (like most of the region). Bedrock-till aquifers are made up of different rock types and are covered by till, a residual glacial mix of rocks, sand, silt and clay, where water occurs in the fractures and faults of the underlying bedrock. Bedrock-till aquifers typically have low yields, but are capable of supporting enough water for single family homes or small businesses, as is the case for a number of the residences in the watershed.

Stratified drift aquifers occur in valleys and comprise layered deposits of sand, gravel, silt and clay laid down thousands of years ago by glacial meltwaters. Water yields of millions of gallons per day are possible wherever deep saturated deposits of porous sand and gravel are found. No such stratified drift aquifers are located within the Roaring Brook Watershed due to the geology of the watershed, which consists mainly of steep hills and shallow bedrock. As shown in **Figure 2-3**, the nearest stratified drift deposit is located along Otter Brook to the west (downstream) of the Roaring Brook Watershed.

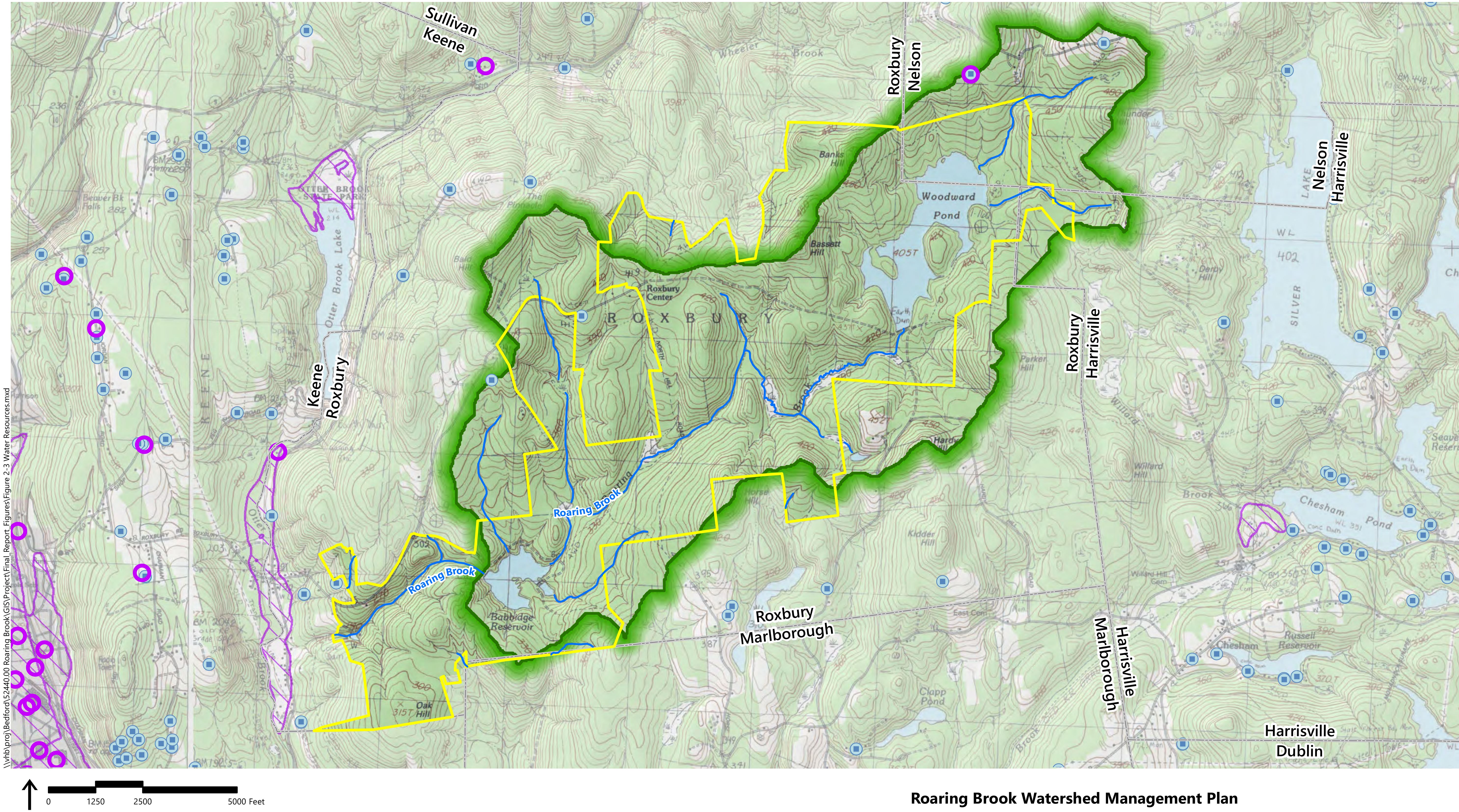
Wells

Based on a review of data provided by the NH Geological Survey, several private wells are located within the Roaring Brook Watershed, although none of these wells are located on City-owned land. These wells include private wells along Middletown Road, Apple Hill Road, and Lead Mine Road, as well as wells just outside the watershed, including along Davis Road, Horse Hill Road, Dillingham Road, and Pell Road. Because the NHDES database includes only wells installed since 1984, it is likely that additional private wells are located within and adjacent to the watershed.

Potential Contamination Sources

To identify potential sources of contamination, a review of the NHDES OneStop database was conducted. This database contains information on known above-ground and underground storage tanks, automobile salvage yards, hazardous waste generators, solid waste facilities, and active and former soil and groundwater

FIGURE 2-3



\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 2-3 Water Resources.mxd

Keene Owned Land (Updated Boundary)
Roaring Brook Watershed (Above Babbidge Dam)
Town Boundary
Intermittent and Perennial Streams
Public and Private Wells
Remediation Site
Stratified Drift Aquifer

Roaring Brook Watershed Management Plan

Groundwater Resources

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT, NHDES OneStop remediation sites.[4] Given the remote character of the watershed, only one such site was found to occur within the Roaring Brook Watershed. An inactive (closed) NHDES remediation site is located along Apple Hill Road, where there was a discharge of kerosene at a residential home in 1997 near the home's private well (NHDES Site Number 199703039). This discharge was contained and remediated in accordance with NHDES requirements and poses no current threat to the Roaring Brook water supply.

2.5 Wildlife Habitat

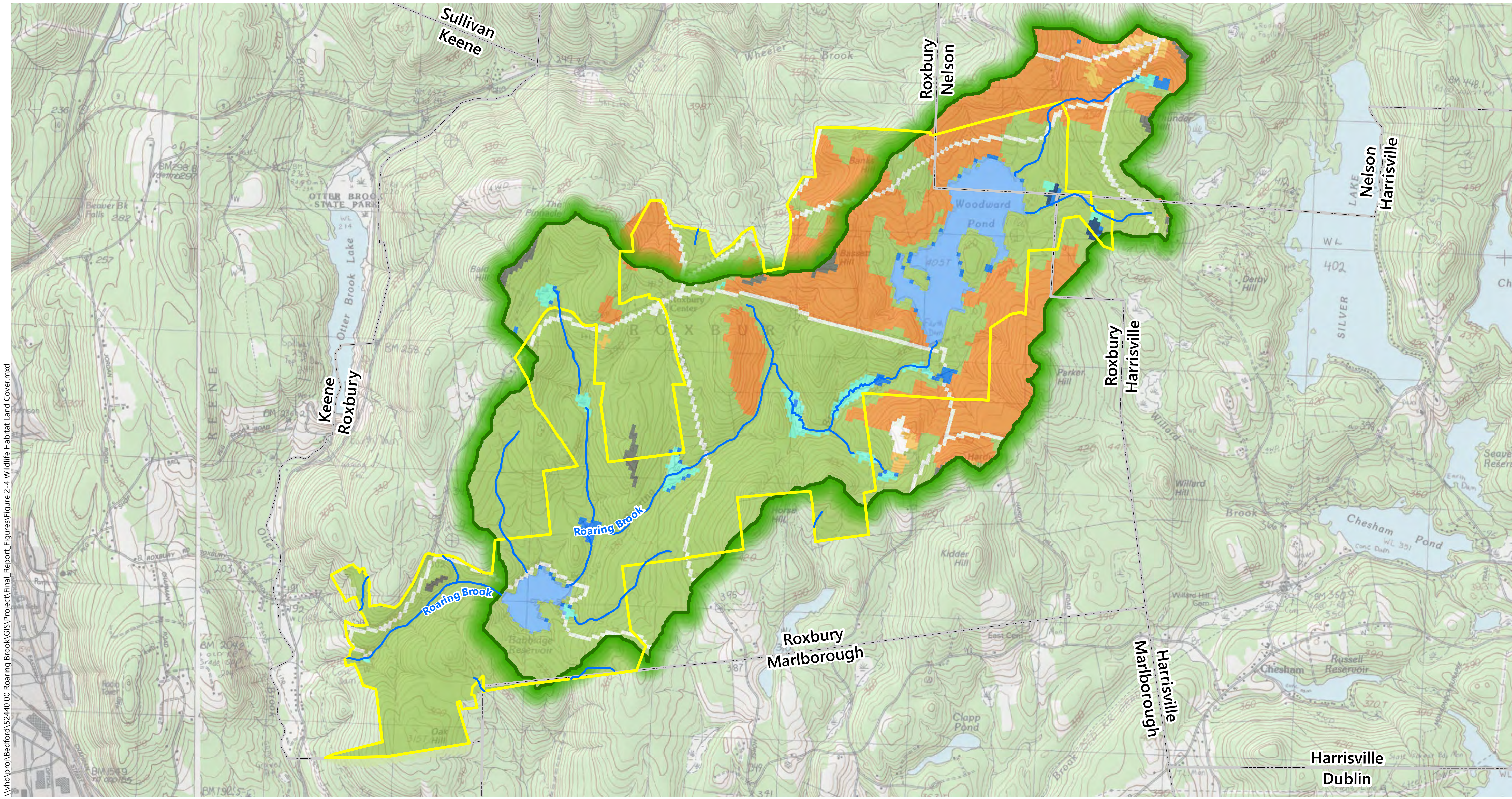
The NH Fish and Game Department has compiled Wildlife Habitat Land Cover data, which predict wildlife habitat types throughout the state to be used as a conservation tool to maintain critical wildlife habitats. **Figure 2-4** shows the main habitat types within the study area identified by the NHFGD's WAP. The majority of the Roaring Brook Watershed is mapped by NHFGD as Hemlock-Hardwood-Pine, with a lesser amount of Northern Hardwood-Conifer located mainly around Woodward Pond. A description of these habitats is provided below:

- <u>Hemlock-Hardwood-Pine:</u> This common habitat type covers approximately 50% of New Hampshire and largely occurs below 1,500 feet in elevation. A hemlock-hardwood-pine forest is considered a transitional forest community between hardwood conifer forests in higher elevations and oak pine forests in lower elevations. This habitat type has varying soil types but is typically composed of dry, sandy soils with dominant tree species of red oak and white pine, often transitioning to a dominance of hemlock and beech. Other tree species less commonly found within these forests include sugar maple, white ash, red spruce, witch hazel, black birch, and black cherry. Common herb species include starflower, wild sarsaparilla, and Canada mayflower. Notable wildlife species found within this habitat include cerulean warbler, eastern pipistrelle, bobcat, goshawk, and black bear.

- <u>Northern Hardwood-Conifer:</u> This habitat type is found between 1,400 and 2,500 feet in elevation. Approximately 20% of New Hampshire is composed of this habitat type, which is found mainly in central and northern New Hampshire. These forests are commonly harvested through forestry practices. Common species found in this habitat include hemlock and red spruce mixed with birches, northern hardwoods, balsam fir, and white pine. Small patches of sugar maple forests and beech and hemlock forests occur within this habitat type. This habitat supports very diverse species including 42 mammals, 73 birds, 8 reptiles, and 14 amphibians.

[4] NHDES data is available to registered users at https://www4.des.state.nh.us/onestopdatamapper/onestopmapper.aspx

FIGURE 2-4



0 1250 2500 5000 Feet

Keene-Owned Lands (Updated Boundary)
Roaring Brook Watershed (Above Babbidge Dam)
Town Boundary
Intermittent and Perennial Streams

NHF&G Wildlife Action Plan (WAP) Habitat
Grassland
Hemlock-hardwood-pine
NLCD Developed or Barren
Northern hardwood-conifer
Northern swamp
Open water
Peatland
Rocky ridge
Temperate swamp
Wet meadow/shrub wetland

Roaring Brook Watershed Management Plan

Wildlife Habitat Land Cover

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT, NHFGD WAP

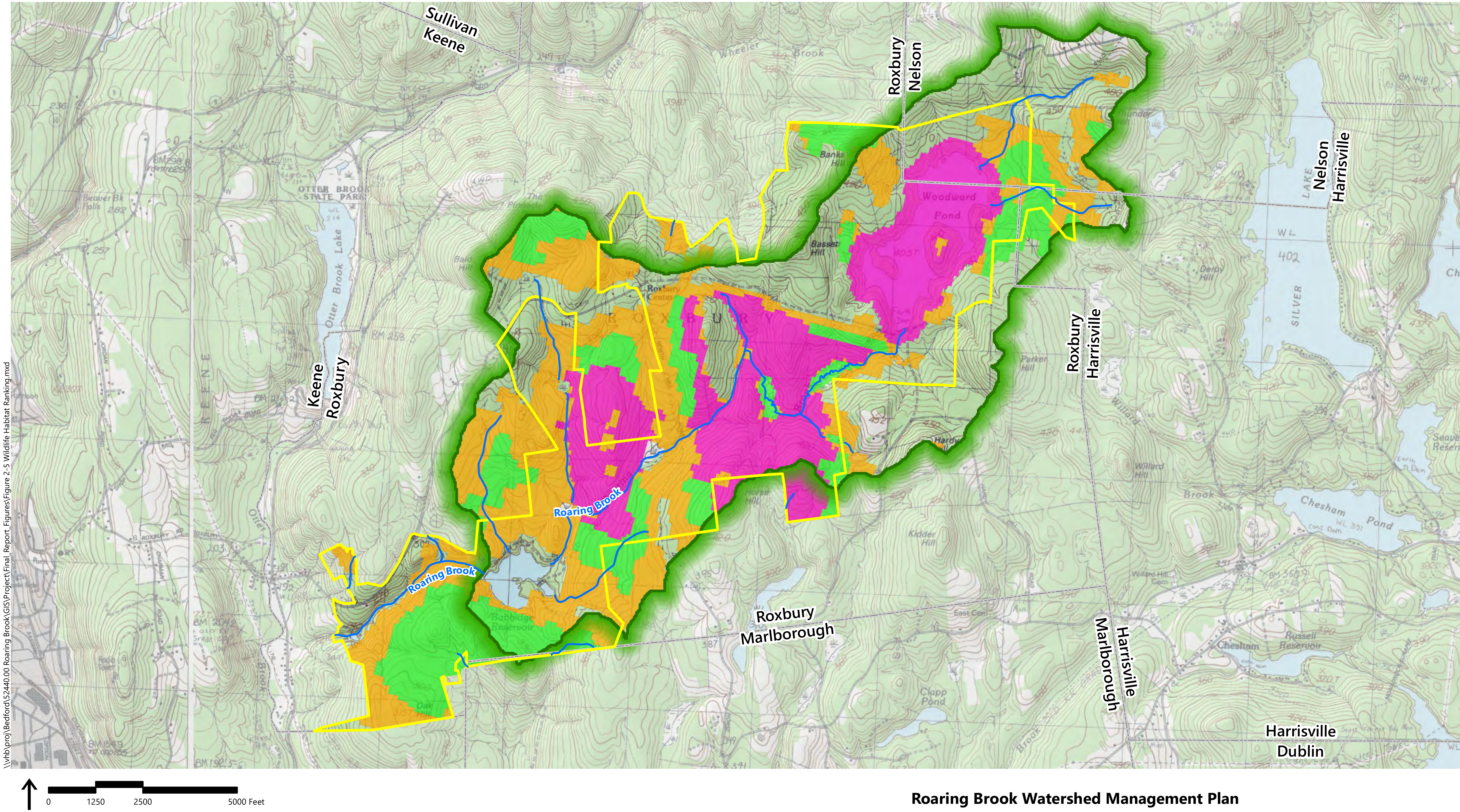
In addition to habitat types, the NHFGD has identified ranked habitat tiers within the state of New Hampshire. **Figure 2-5**, shows the locations of habitat tiers identified within the study area. This ranking system identifies terrestrial and wetland wildlife habitats within the state that are in the best condition to meet the needs of wildlife. These ranked habitats are considered especially important for species of greatest conservation need, which the NHFGD identified by consulting the state endangered and threatened species list, a wide variety of data sources, and knowledgeable experts.

The NHFGD habitat tiers were created using biological data, landscape data, and human influence information. This information was drawn from previously collected data by the NHFGD, the NH Natural Heritage Bureau (NHB), the Nature Conservancy, and the University of Massachusetts-Amherst, along with statewide Geographic Information Systems (GIS) data and others. This data was then analyzed and manipulated to create the habitat tiers.

Habitat tiers are separated into three tier rankings, which are 1) Top Ranked Habitat in the State, 2) Top Ranked Habitat in Biological Region, and 3) Supporting Landscape. The first tier, Top Ranked Habitat in the State, include the top 15% habitat areas, which include known critical habitats of state-listed species and all known alpine, dune, saltmarsh, and rocky shore habitats. The state was then divided into regions to designate the top 30% of each habitat type within each region, thus creating the second tier, Top Ranked Habitat in Biological Region. This tier provides each region of the state with a more balanced approach at identifying important habitat areas. The remaining top 50% habitat areas are designated to the Supporting Landscape tiers, as well as large continuous tracts of forestland.

Within the Roaring Brook Watershed are mapped areas of Tier 1, 2 and 3 habitat areas. Areas ranked as Tier 1 encompass Woodward Pond and upland habitat within the center of the watershed around Roaring Brook. Woodward Pond in particular is likely mapped as a Tier 1 habitat due to the presence of loons on the pond.

The presence of high-value wildlife habitat within the watershed does not directly contribute to protecting the quantity and quality of water. The availability of a healthy wildlife population is generally viewed as an ancillary benefit of maintenance of the watershed as a single unfragmented block of undeveloped land. However, the presence of certain species such as beaver and waterfowl can contribute to the occurrence of coliform bacteria within the raw water supply. The existing Keene drinking water treatment system removes these bacteria, however, such that risk to public health is protected. And, a plan for the future monitoring of potential microbial contamination is a recommendation of this watershed management plan. (See Section 5.2.2 for further discussion.)



Keene-Owned Lands (Updated Boundary)
Roaring Brook Watershed (Above Babbidge Dam)
Town Boundary
Intermittent and Perennial Streams

Wildlife Habitat Ranking
Tier 1 - Highest Ranked Habitat in NH
Tier 2 - Highest Ranked Habitat in Biological
Tier 3 - Supporting Landscapes

Roaring Brook Watershed Management Plan

Wildlife Habitat Ranking

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT, NHFGD WAP

\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 2-5 Wildlife Habitat Ranking.mxd

2.6 Threatened and Endangered Species

A search for the occurrence of rare plant, animal, or natural communities within the vicinity of the Roaring Brook Watershed was completed using NHB's DataCheck tool which provides information on the present, past, or probable existence of rare, threatened, or endangered species for improved land use planning and environmental impact assessment. The DataCheck tool reports such plant species, natural communities, invertebrate species, and vertebrate species that occur within a one-mile buffer of the project area.

The NHB report obtained for the City-owned portion of the Roaring Brook Watershed indicates one population of tracked species – a population of loons (*Gavia immer*) occurs along the north side of Woodward Pond. Loons are protected by state law (RSA 212-A, the NH Endangered Species Conservation Act). Loons are listed as a state-threatened species under this statute, and have been identified by the NHFGD as one of 169 "Species of Greatest Conservation Need" in the state. Species of Greatest Conservation Need are those which are declining in number, or which are limited to smaller patches of habitat, or are imperiled by specific threats.

The loon nesting site on Woodward Pond was first observed by scientists from the Loon Preservation Committee (LPC) on May 17, 2000. The LPC monitors the nesting site each year and works with the City of Keene to manage the water levels of Woodward Pond, since the pond is dam controlled. Three chicks were observed by City staff (Ben Crowder, personal communication); adult loons were observed frequently on Woodward Pond during field work conducted as part of this study in 2017, and the nest is assumed to be active at this time.

Like the high-value wildlife habitat found within the watershed, the presence of loons on the City-owned property does not directly contribute to water quantity or quality. However, their presence is an indicator of the high ecological integrity of the watershed.

2.7 Invasive Species

Invasive species are presently not a problem on Keene-owned portion of the watershed. The limited public access, remote nature of the tract, and its heavily timbered landscape, as well as abutting ownerships, appear to be effective at preventing the encroachment of invasive species.

No aquatic invasive species were observed during this study. However, very scattered, isolated occurrences of barberry (*Berberis thunbergii)* were observed during forest inventory field work. Its presence is not substantially different from other occurrences on land in southern New Hampshire, and it is not a particularly aggressive invasive species. Monitoring is the best short-term course of action; the cost of eradication is likely much more than any benefit.

Risk of invasive species introduction is associated with site disturbance that exposes mineral soil and the use of equipment or vehicles that may be contaminated with seeds, spores, or vegetative matter from other sites. Because preventing the establishment of invasive species is much more effective and less costly than eradication, the City should adopt practices to limit the potential their potential introduction. For example, the NH Department of Transportation (NHDOT) has developed Best Management Practices for Roadside Invasive Plants, which could serve as a basis for these practices.[5]

Control of invasive species, while not directly related to water quality or quantity, will help maintain the overall ecological health of the watershed and contribute indirectly to the sustainability of the system.

2.8 Conservation Lands

Many of the parcels located in the Roaring Brook Watershed have been placed under a conservation easement (refer to **Figure 2-6** and **Table 2-3**) by private landowners. A large network of adjoining conserved parcels is located within the Town of Roxbury and adjoining towns. Additionally, the Otter Brook State Park is located along the border of Roxbury and Keene, west (outside) of the Roaring Brook Watershed. The table below lists parcels under conservation that are located within the Roaring Brook Watershed (not including the City-owned parcels).

Table 2-3. Conservation Parcels Located Within the Roaring Brook Watershed[1]

Parcel Name	Easement Holder/Owner	Parcel Size (acres)	Within Watershed (acres)	Town
Hartshorne	Harris Center for Conservation	103	40	Nelson
Thunder Hill	Monadnock Conservancy	129	82	Nelson
Lightning Hill	Monadnock Conservancy	145	18	Nelson
5B Farm	Monadnock Conservancy	59	1	Nelson
BB&N	Harris Center for Conservation	94	19	Nelson
BB&N	Harris Center for Conservation	93	13	Harrisville
Earnest Henry Taves Trust	Society for the Protection of NH Forests	24	24	Roxbury
Earnest Henry Taves Trust	Society for the Protection of NH Forests	57	57	Roxbury
Parker Hill Forest	Monadnock Conservancy	89	7	Roxbury
Earnest Henry Taves Trust	Society for the Protection of NH Forests	85	37	Roxbury

▼

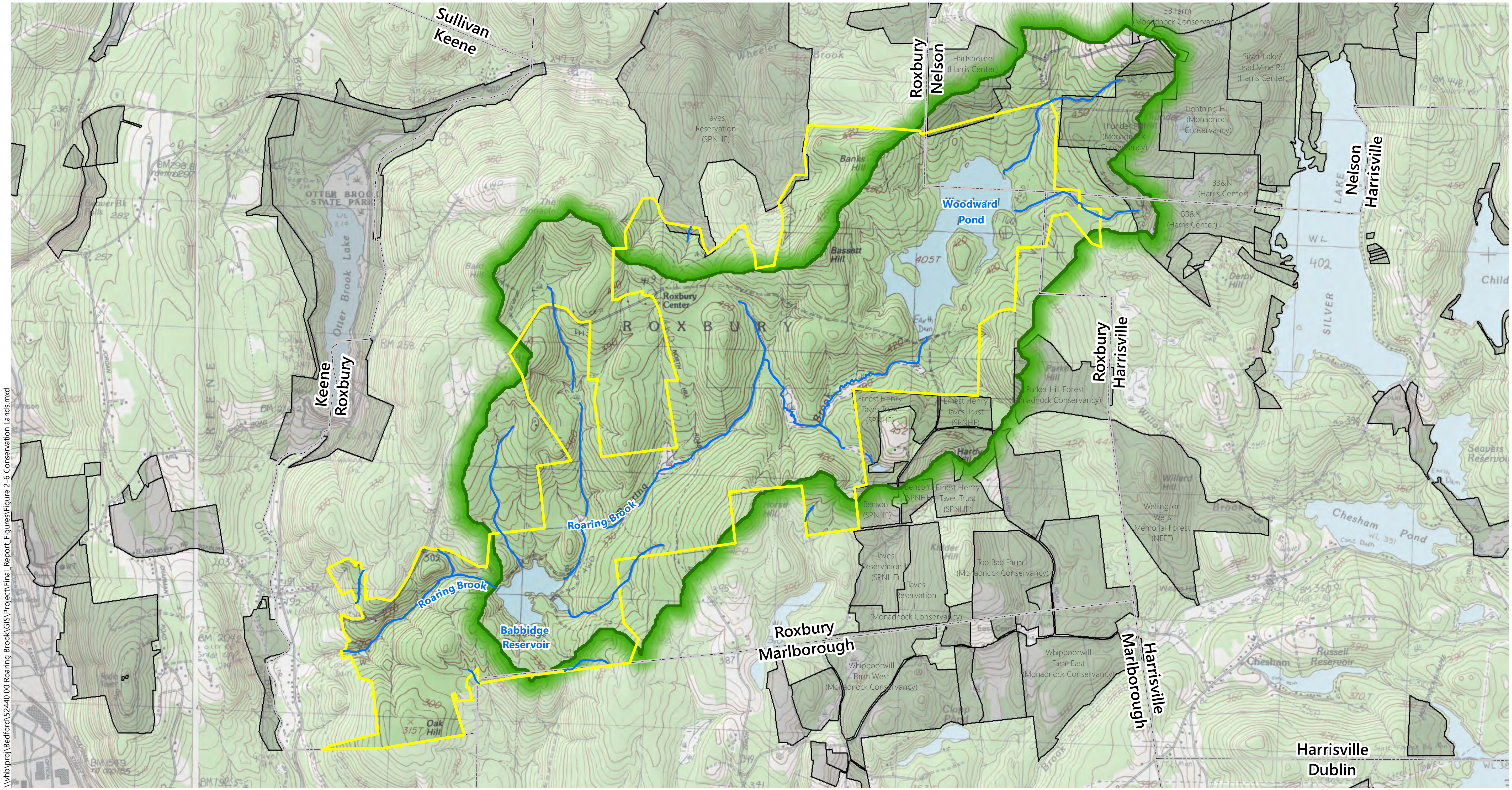
5 The NHDOT has published relevant information at https://www.nh.gov/dot/org/projectdevelopment/environment/units/program-management/invasivespecies.htm

Parcel Name	Easement Holder/Owner	Parcel Size (acres)	Within Watershed (acres)	Town
Benson	Society for the Protection of NH Forests	26	3	Roxbury
Benson	Society for the Protection of NH Forests	14	1	Roxbury
	TOTAL	918	302	

Note:
1 Data from NH GRANIT. Parcel sizes are approximate. Most parcels are only partially located within the watershed.

Of the total 3,157-acre watershed, the City of Keene owns 1,965 acres, approximately 302 acres are currently in conservation easements or owned by a conservation agency, and the remaining 890 acres are owned by private interests, with no known conservation restrictions. The relatively high proportion of undeveloped and protected land within the watershed (approximately 72 percent) is a major factor in preserving water quality within the watershed. (See Chapter 5 for a detailed discussion of observed water quality.)

FIGURE 2-6



\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 2-6 Conservation Lands.mxd

0 1250 2500 5000 Feet

- Keene Owned Land (Updated Boundary)
- Roaring Brook Watershed (Above Babbidge Dam)
- Conservation/Public Land (GRANIT 2009)
- Town Boundary
- Intermittent and Perennial Streams

Roaring Brook Watershed Management Plan

Conservation Lands

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

3

Land Use, Access, and Infrastructure

3.1 Introduction

The Roaring Brook watershed is primarily undeveloped, and human activity within the area is limited to residential development on parcels abutting the City-owned potion of the watershed.

However, prior to its use as a water supply, the land was home to a number of farms and residences, and used for pasture, crops, and woodlots. Cellar holes and stone walls are a testament to this past use. Stone quarrying also occurred in at least two areas on the property. A number of roads were built during this period, and the status and use of these rights-of-way for recreation and other purposes has been an issue of concern for the management and protection of the water supply.

This section discusses the current policies that prohibits access to the watershed, describes the roads located on the City-owned land, and considers issues related to public access, recreation, and security concerns.

3.2 Regulations Applicable to the Roaring Brook Watershed

3.2.1 State Rules (Env-Dw 902.18)

To establish reasonable watershed management practices that protect the quality of drinking water from the Roaring Brook watershed, the NH Department of Environmental Services (NHDES) adopted regulations that prohibit certain activities and establish penalties for violations. These regulations (NH Administrative Rule Env-Dw 902.18) are excerpted below, and the corresponding statutory authorities (the

NH Safe Drinking Water Act, RSA 485:23 and RSA 485:24) are contained in **Appendix A**.

Env-Dw 902.18 Protection of the Purity of Woodward Pond, Roaring Brook, Babbidge Reservoir and Their Watershed.

(a) The purpose of this section is to protect the purity of the water of Woodward Pond, Roaring Brook, and Babbidge Reservoir, which constitute the principal drinking water supply for the city of Keene.

(b) This section shall apply within the Woodward Pond, Roaring Brook, and Babbidge Reservoir watershed above the dam that is located at approximate latitude 42° 56′ 02″, longitude 72° 13′ 15″, in the towns of:

(1) Harrisville;
(2) Marlborough;
(3) Nelson; and
(4) Roxbury.

(c) Any person violating this section shall, in accordance with RSA 485:26, be guilty of a misdemeanor if a natural person or guilty of a felony if any other person.

(d) In accordance with RSA 485:24, the health officers and the boards of health of the towns of Harrisville, Marlborough, Nelson, and Roxbury and their duly authorized agents, and the city council of the city of Keene and its duly authorized agents, may act as agents of the department for the enforcement of this section in cooperation with the department.

(e) Where any provision of this section is in conflict with local ordinances, the provision that is more protective of the surface water shall apply.

(f) Any deviations from this section shall be by written consent of the department, in accordance with Env-Dw 902.05. The provisions of this section shall not apply to employees of the city of Keene engaged in the performance of necessary duties for the protection and control of said waters.

(g) In addition to any prohibitions adopted by local ordinance, the prohibitions that apply in the Woodward Pond, Roaring Brook, and Babbidge Reservoir watershed described in (b), above, shall be as follows:

(1) A person shall not build, continue, or maintain any buildings or structures of any kind in which humans reside or in which animals or fowl are kept within 75 feet of the high water mark of Woodward Pond, Roaring Brook, or Babbidge Reservoir or any inlet thereof or tributary thereto;

(2) A person shall not allow any wastes or water that has been used for washing or cleansing of materials, persons, or food to run into said pond, brook, or reservoir or any inlet thereof or tributary thereto;

(3) A person shall not throw or deposit any dead animal or fish or parts thereof, food, perishable or decayable material, manure, or human wastes into said pond, brook, or reservoir or any inlet thereof or tributary thereto, or leave or allow any such materials to remain on the surface of the ground where there is any likelihood of wash or contamination therefrom reaching said pond, brook or reservoir or any inlet thereof or tributary thereto;

(4) A person shall not throw any sawdust, or allow any sawdust to fall, into said pond, brook, or reservoir or any inlet thereof or tributary thereto;

(5) A person shall not boat, bathe, swim, trap, fish, hunt, camp, park trailers, or carry on any activity of a recreational or other nature, including but not limited to lumber operations, in or near the waters of said pond, brook, or reservoir and, above the reservoir dams, any tributary thereto; and

(6) A person shall not throw, deposit, or allow to remain upon the ice of the waters of said pond, brook, or reservoir or any inlet thereof or tributary thereto, any matter, waste, or materials such as are described in (2), (3), and (4), above.

(h) The city of Keene shall post a summary of the prohibitions contained in (g), above, at all public access locations where persons might reasonably be expected to access Woodward Pond, Roaring Brook, Babbidge Reservoir and their tributaries. This posted summary may also contain any prohibitions enacted by local ordinance.

3.2.2 Municipal Ordinances

While state law allows for local ordinances to protect water supply, no community within the watershed has adopted any regulation specific to the protection of Roaring Brook or its tributaries or reservoirs. However, all of the municipalities have adopted zoning ordinances which regulate aspects of land use within the watershed, as discussed below.[6]

Roxbury

Given that more than 80% of the watershed lies within Roxbury, its approach to land use regulations is particularly relevant. Roxbury first adopted a zoning ordinance in 1972, and last amended their regulations in 2008. The entire watershed lies within the "Rural Residential and Agricultural District." Among other requirements, this ordinance requires new building lots in this zone to be at least five acres per dwelling unit, which promotes low-density development. (See Chapter 5 for a discussion of the potential impact of land use on water quality.) The ordinance also prohibits septic

[6] Because the watershed contains a very small amount of land in Marlborough (approximately 2 acres in total), that community's ordinances are not reviewed here.

facilities within seventy-five (75) feet from the edge of a public water body or permanent stream, and prohibits development on slopes exceeding 25%.

Nelson

Nelson adopted its zoning ordinance in 2004 and has amended the ordinance several times. The zoning ordinance designates two districts: the Rural-Residential District, and the Lake District. The Lake District consists of all land from the shoreline of each lake or pond, including Woodward Pond, to a distance of 600 feet from the shoreline of each respective lake or pond. Although the Lake District encompasses a portion of the watershed, all land within this district is currently owned by the City of Keene. The Rural-Residential District comprises all remaining land not included in the Lake District. The ordinance limits new lots to a minimum of two acres. Nelson ordinances also contain language that limits the location of sewage effluent leaching fields, requiring that they be located more than 100 feet of the normal bank of any year-round stream or of any pond. Additional provisions allow the town to regulate types of pollution to land, air and water that are a result of activity or negligence including the burning of toxic substances, or the release of contaminants such as oil or gasoline into the ground or water.

Harrisville

Harrisville has adopted a comprehensive Master Plan, and adopted progressive Zoning and Subdivision Ordinances. The Planning Board reviews and approves specific land development plans through the subdivision process. The small portion of the watershed that lies within Harrisville is within the "Residential & Agricultural District," which requires a minimum lot size of two acres. Portions of the watershed also lie within one or more of several overlay districts, including a Wetlands Conservation District, and are subject to an ordinance regulating development on steep slopes, which limits certain activities on slopes of ten percent or greater. The Harrisville ordinances allow cluster development (by Special Exception) and conservation subdivisions within the Residential & Agricultural Districts, which would tend to reduce the intensity and impact of land development and related pollutant loading issues.

3.2.3 Recommendations Related to Land Use Regulations

Review of existing land use regulations related to the Roaring Brook watershed indicates that current regulations are adequate to protect water quality and quantity. No specific actions are recommended at this time.

3.3 Roads & Public Access

3.3.1 Road Inventory

To develop an accurate inventory of the roadway network within the watershed, a base map was compiled from various sources, beginning with the "NH Public Roads" dataset developed and maintained by the NH Department of Transportation, Bureau of Planning & Community Assistance and made available via the NH GRANIT GIS database.[7] This statewide dataset contains the location of state, local and selected private roads and their associated attributes, including road names.

Because the NHDOT dataset has limitations, particularly related to historical Class VI roads, we conducted an extensive assessment to verify the information. This included review of the following:

- Historical and modern maps and documents provided by the City, the Town of Roxbury, and the NH State Archives;
- State laws and policies regarding "Public Highways";
- Interviews with Roxbury officials; and
- Records of road discontinuances through Town of Roxbury Annual Reports dating to 1939.

Field work was conducted on foot and by vehicle using GPS to verify the location of the roadways, and several adjustments were made to reflect roadway alignments and conditions on the ground.

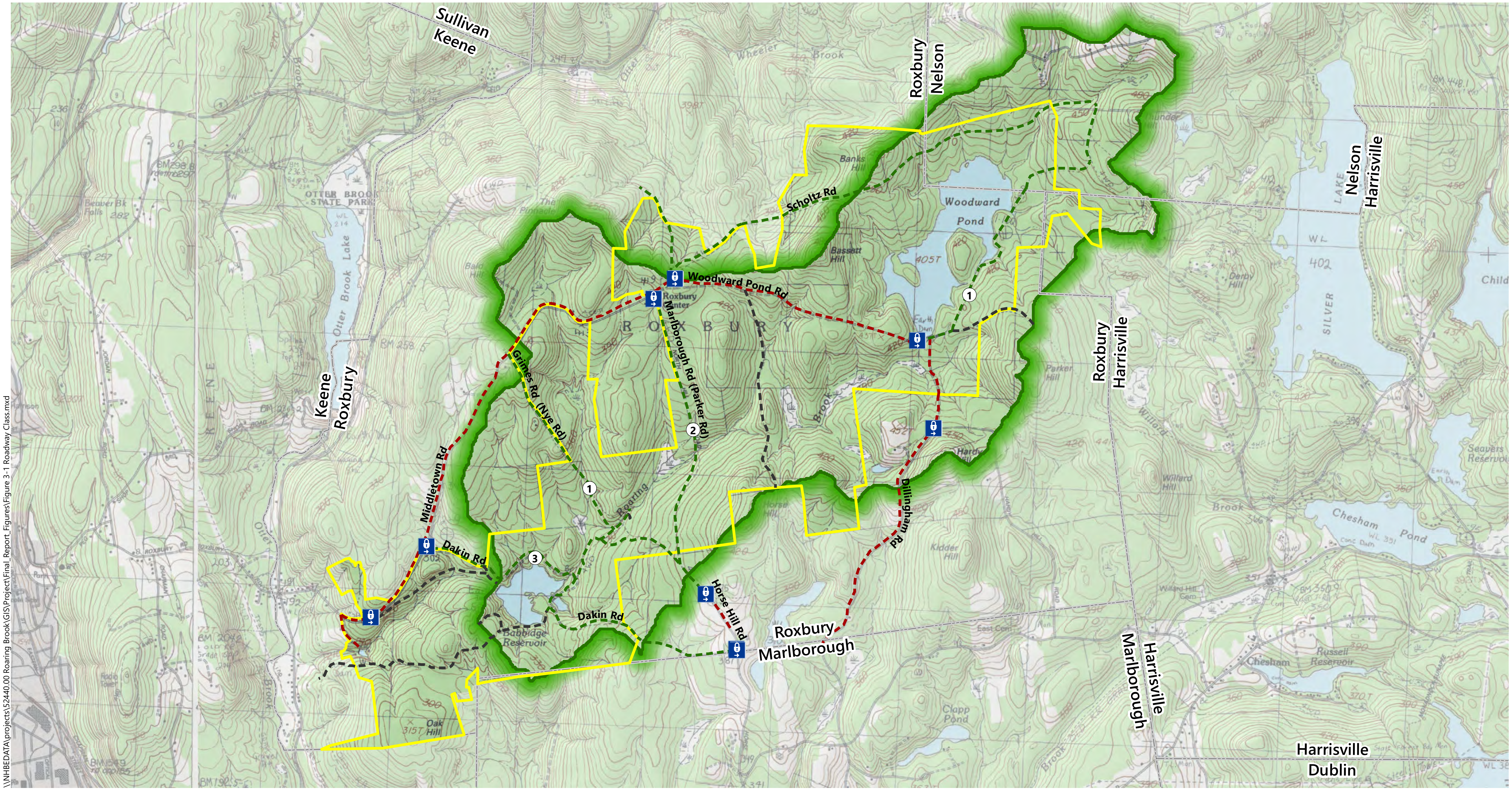
The resulting road map is presented in **Figure 3-1**, which depicts the accurate locations of the roads, along with their legislative classification, and the location of gates on certain Class VI roads (see discussion below). The inventory identified approximately 17 miles of roads and paths within the watershed.

Access to the City-owned property is from Middletown Road and Dillingham Road which are both Class V roads, maintained by the Town of Roxbury. Additionally, these two roads connect to a network of smaller unpaved, unmaintained Class VI roads that bisect the watershed, including Dakin Road, Grimes Road, Marlborough Road, Woodward Pond Road, and Scholtz Road.[8] Gates have been installed and are maintained by the City at most points where these Class VI roads enter the watershed.

[7] NH Public Roads, http://www.granit.unh.edu/data/search?dset=roads_dot/nh, NHDOT 2nd quarter 2017 dataset (June 30, 2017)

[8] Several of these roads have alternative names or spellings on various modern and historical maps and records. For example, Marlborough Road is named "Parker Road" in the NHDOT dataset, and often called "Marlboro Road" on older maps. Grimes Road is also named "Nye Road" on some historic maps and records.

FIGURE 3-1



0 1250 2500 5000 Feet

Keene-Owned Lands (Updated Boundary)

Roaring Brook Watershed (Above Babbidge Dam)

Town Boundary

Gate Location

Legislative Classification

Class V

Class VI

Unclassified/Unknown

Documented Road Discontinuances

1. From Woodward Pond Dam to the Nelson Line, and Grimes Road from the Marlboro Road to the Middletown Road, subject to gates and bars (1939)
2. Marlborough Road from the residence of Charles Yardley to Roaring Book (1976)
3. Dakin Road, subject to gates and bars (1971)

Roaring Brook Watershed Management Plan

Roadways and Trails

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

\\NHBEDATA\projects\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 3-1 Roadway Class.mxd

Middletown Road runs along the west side of the property until it terminates at Roxbury Center, where it provides a connection to Woodward Pond Road, Scholtz Road, and Davis Road. It also connects to Dakin Road, the principal access point to Babbidge Reservoir, and to Grimes and Marlborough Roads.

Dillingham Road approaches from the southeast side of the property. This is the principal access to the Woodward Pond Dam, via Woodward Pond Road. Access to the property on the southeast is also provided via Horse Hill Road, which connects to Dakin Road, Grimes Road, and Marlborough Road.

In addition to these main roads, several smaller unpaved roads and paths are also present on the property. These smaller roads and paths do not appear on modern or historic maps and represent private roads constructed by landowners prior to acquisition of the land by the City for water supply.

3.3.2 Road Classification and Public Access

A key issue for proper management of the water supply is limitation of access and activity in the watershed to reduce the risk of contamination. The City-owned land within the watershed, while owned by a public entity, is managed for a specific use and it is appropriate to prohibit public access to the property. However, the presence of the historic road network within the watershed provides the public with rights-of-way through the property.

To better understand this issue, this section reviews the basic laws and policies related to public roads, and provides a specific discussion of actions taken by the Town of Roxbury to discontinue certain road segments. A full review of the specific legal status of these roads is beyond the scope of this study, but we provide a summary of information related to their classification and management.[9,10]

NH Highway Law

State law relating to roads and public rights-of-way is contained at NH RSA 229, Highway System in the State, which defines a "public highway" as follows:

> *"Highways are only such as are laid out in the mode prescribed therefor by statute, or roads which have been constructed for or are currently used for motor vehicle, bicycle, or pedestrian public travel over land which has been conveyed to a city or town or to the state by deed of a fee or easement interest, or roads which have been dedicated to the public use and accepted by the city or town in which such roads are*

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9 Much of the background information summarized below is presented in more detail in a publication of the NH Municipal Association, *A Hard Road to Travel: New Hampshire Law of Local Highways, Streets, and Trails*, 2015.

10 This watershed management report does not intend to provide any legal opinion or interpretation regarding the status of any public highway within the watershed, but rather summarizes the findings of research conducted to understand their location and current management practices.

> *located, or roads which have been used as such for public travel, other than travel to and from a toll bridge or ferry, for 20 years prior to January 1, 1968, and shall include the bridges thereon. Highway does not include any bridge, trail, or path intended for use by off highway recreational vehicles, as defined in RSA 215-A:1, or snowmobiles, as defined in RSA 215-C:1."* [RSA 229:1]

Research at the NH State Archives did not identify any documents clearly relating to the formal layout of any of the roads within the watershed. However, since their basic alignments are referenced in historical maps and documents, they are presumed to be public highways by way of "prescriptive use," the legal doctrine that refers to actual use for public travel for at least 20 years prior to January 1, 1968, if not actual layout.

Highway Classification System

The highway system in New Hampshire is broken down into seven distinct classes, known as *Class I, II, III, III-a, IV, V* and *VI*. Class I, II and III highways are state highways, controlled and maintained by the NHDOT, with certain exceptions. Class IV, V and VI highways are local highways, managed by the municipalities. Because the roads in the watershed are all either Class V or Class VI, the discussion below is limited to these classes.

Class V Roads

Class V roads consist of all traveled highways, other than Class IV, that the town or city has the duty to maintain regularly. The law does not define size, use, engineering, or construction standards for Class V highways, and they can be small gravel roads or multi-lane paved streets. The defining characteristic of a Class V road is whether a town or city has a duty to maintain the road *and does, in fact, maintain it*. Court decisions have indicated that a highway must be both *traveled and maintained* to be a Class V highway; the fact that a road is used frequently by hunters, loggers or fishermen does not make it Class V, absent town maintenance (NHMA, 2015). This may be relevant to the status of Woodward Pond Road, as discussed further below.

Class VI Roads

Class VI roads consist of "all other existing public ways." Class VI roads include all local highways discontinued subject to gates and bars and all highways that have not been maintained and repaired by the town in suitable condition for travel for five successive years or more. In 1925, all non-maintained public highways were classified as Class VI. Class VI roads are full public highways in all aspects except maintenance, and a municipality has the same regulatory authority over Class VI roads that it has over Class V roads (NHMA, 2015).

Discontinuation of Roads

RSA 229:5, VII provides that a Class IV or V highway may become Class VI in one of two ways:

- A vote of the legislative body (*i.e.*, town meeting in the case of Roxbury) to discontinue it "subject to gates and bars" pursuant to RSA 231:45; or
- The failure to maintain it "in suitable condition for travel thereon for five successive years or more."

Discontinuation does not mean that the subject road is no longer a public highway. Rather, it means that the town no longer has the duty to maintain the road, and that landowners may erect gates and bars to control, but not prevent, public access.

Where a town has not maintained and repaired a Class V road for five years, it may revert to Class VI status whether or not the road is actually passable or used by the public. Although a road that has not been maintained and repaired may be traveled, it does not become a Class V highway. Resumption of maintenance of a Class VI highway can affect its classification status; a Class V road that attains Class VI status because of a lapse of maintenance will revert to Class V status again if the town has maintained it for at least five consecutive years. The maintenance and repair must be "regular" and "on more than a seasonal basis" so that the road is in "suitable condition for year-round travel" (NHMA, 2015).

Class VI Roads are Subject to Gates and Bars

Class VI highways may be deemed "subject to gates and bars," but any gates and bars must be capable of being opened and closed by users of the road. The term "gates and bars" is not defined by state law, but the term historically refers to an owner's right to enclose the property for their own benefit. The owner may require public travelers to open and close the gates or bars as a condition to travel. The selectmen are authorized to regulate the structures to assure public use.

Class V and VI Roads can be Reclassified to Trails

NH RSA 231-A allows for the reclassification of any Class V or VI highway to Class A or Class B trails by vote of the local legislative body. The statute includes provisions which protect the rights of land owners where the road is the sole access to any land. Trails differ from public highways in that, while they provide public right-of-way, they are subject to public trail use restrictions. They do not have the status of a publicly approved street and cannot be used as a vehicular access for any new building or structure, or for the expansion, enlargement, or increased intensity of use of any existing building or structure. They can be used to provide access for such nondevelopment uses as agriculture and forestry, or for access to any building or structure existing prior to its designation as a trail. Like Class VI roads, the municipality does not bear responsibility for maintaining a Class A or B trail.

Records Related to Road Classification in the Watershed

To gather information on town actions related to watershed road classifications, a review of available Roxbury Town Reports dating to 1939 was conducted with the assistance of Mr. James Rousmaniere, Roxbury Selectman, and Mr. Ken Buffum, Roxbury Road Agent. These Town Reports contain record of at least six town votes related to the classification of watershed roads, as presented in **Table 3-1**.

This information, taken together with data from the NH State Archives and the NHDOT dataset, suggests that all the roads within the watershed are Class VI, and therefore subject to gates and bars, except for Middletown Road, Dillingham Road, and portions of Woodward Pond Road.

Woodward Pond Road

A portion of Woodward Pond Road is currently classified as a Class V road, however, the eastern portion from the dam to the Nelson Line is Class VI, based on a town vote conducted in 1939. Votes in 1951 and 1956 affirm the Town's intent to manage the remaining portion of the road as a Class V Highway. The Keene DPW actively maintains the portion of the road from Dillingham Road to the dam site, and Mr. Ken Buffum has indicated that the portion west of the dam to Middletown Road has been periodically graded, but is not maintained in winter (Ken Buffum, Roxbury Road Agent, personal communication, August 16, 2017).

Table 3-1. Key Roxbury Town Votes Related to the Classification of Roads

Year	Warrant Article	Warrant Article Language	Result
1939		*To discontinue subject to gates and bars…the road from Woodward Pond Dam to the Nelson Line…(and) the Grimes Road from the Marlboro Road…to the Middletown Road*	Seconded and Carried
1951	Art. 11	*To discontinue Dakin Road and Woodward Pond Road*	Vote in Negative
1956	Art. 12	*The Town shall not close any portion of Woodward Pond Road from the old church to Dillingham Road.*	Vote in Affirmative
1971	Art. 17	*To see if the Town will vote to the closing of Dakin Road, subject to gates and bars*	Motion Carried
1976	Art. 20	*To close a portion of the Marlborough Road from the residence of Charles Yardley to Roaring Book*[1]	Motion Carried
1984	Art. 18	*To give the City of Keene permission to install gates on a) Horse Hill Road from the residence of Allen Laplante to the Middletown Road, b) Dakin Road from the Middletown Road to Horse Hill Road*	Motion Not Carried

Note:
1 Review of current and historic maps was unable to identify the location of the Yardley residence.

Grimes Road

Based on the town vote in 1939, the portion of Grimes Road on City-owned property was formally discontinued to Class VI. The Roxbury road agent reports that the town does not maintain this road (Ken Buffum, Roxbury Road Agent, personal communication, August 16, 2017).

Dakin Road

Dakin Road was considered for discontinuation by the town in 1951 and 1971. While the discontinuance was defeated in 1951, the vote in 1971 effected the discontinuance of the entire road, subject to gates and bars. Accordingly, the town does not maintain this road. However, the Keene DPW has maintained the portion of this road to Babbidge Reservoir to enable the operation and maintenance of the dam and reservoir.

Marlborough Road

The Town of Roxbury voted to close a portion of the Marlborough Road "from the residence of Charles Yardley to Roaring Brook" at its annual town meeting in 1976. Review of historical maps could not identify the location of the Yardley property, but based on town maps, it can be inferred that the portion of the road closed by the town vote extends from Middletown Road to Roaring Brook. Because the town warrant article specified that this road was "closed" and not discontinued subject to gates and bars, this section of the road may no longer be a public highway. And, because the remaining portion of the road has not been maintained by the Town for a period of greater than five years, its remaining length is assumed to have reverted to Class VI.

Other Roads and Paths

Several other woods roads and paths were identified on the property. These include a roadway extending from the western portion of Woodward Pond Road, near Roxbury Center, southward to Horse Hill. This section of road is sometimes known as the "Cross Watershed Path." Another roadway of note extends from the abandoned railroad grade parallel to Branch Road on the west side of the watershed to Babbidge Reservoir. These roads are not referenced in the documents reviewed as part of this study. Further research may reveal that they should be considered public highways under state law, but their lack of documentation suggests that they are more likely to be private roads constructed by previous landowners to access farms, timber stands, or quarry operations. Accordingly, their status is treated as "unclassified" or "unknown."

Existing Gates and Bars

A total of eight gates or fences were identified on or adjacent to watershed roads. Their locations are shown in **Figure 3-1**. These include several gates installed and maintained by the City of Keene, including at the following locations:

- The western end of Woodward Pond Road, near Roxbury Center;
- The western end of Marlborough Road, near Roxbury Center;
- The western end of Dakin Road, near its intersection with Middletown Road;
- The eastern end of Dakin Road, at Horse Hill Road; and
- At Dillingham Road, near Woodward Pond Road.

Other fences or gates are located at the City-owned chlorination plant, and at Woodward Pond Dam.

Several of these gates were installed in 1997, following coordination between the City of Keene and the Town of Roxbury. (See **Appendix B** for a copy of correspondence related to these gates.)

3.3.3 Road Condition Assessment

In addition to locating road alignments on the property and conducting research on their classification, this study included a basic inventory of culverts and bridges along the roads, and a preliminary visual assessment of road condition.

The road condition assessment used a modified version of the gravel road rating system developed by Walker (2002), which uses a simplified 5-point rating scale. The rating system reflects the major factors that affect the performance of the roadway, including roadway crown, drainage, and adequacy of the gravel layer. Observations on surface distresses such as wash-boarding, loose rock, and dust were made. Areas where roadway erosion impacted water quality were of particular note. (See Chapter 5 for a discussion of how roadways potentially affect water quality in the watershed.)

Table 3-2 outlines the rating categories with the typical distress and necessary maintenance or rehabilitation procedures. The roadway may not have all types of distress at any particular time, and may have one or two of the individual deficiencies.

Table 3-2. Road Condition Assessment Ratings

Rating	Interpretation	Maintenance Needs
Excellent	A newly constructed road. Excellent crown, drainage, and gravel layer.	Little or no maintenance needed.
Good	Recently regraded with good crown and drainage and adequate gravel layer.	Routine maintenance needed.
Fair	Needs regrading or ditch construction or maintenance; some erosion noted.	Regrading (reworking) necessary to maintain. Needs some ditch improvement and culvert maintenance. Some areas may need additional gravel.

Poor	Needs additional aggregate or major drainage maintenance; substantial erosion noted.	Needs additional new aggregate. Major ditch construction end culvert maintenance also required.
Failed	Not passable; significant erosion noted.	Road is partially or totally impassable. Needs complete rebuilding and/or new culverts.

The resulting assessment conditions are presented in **Figure 3-2** and summarized in **Table 3-3**.

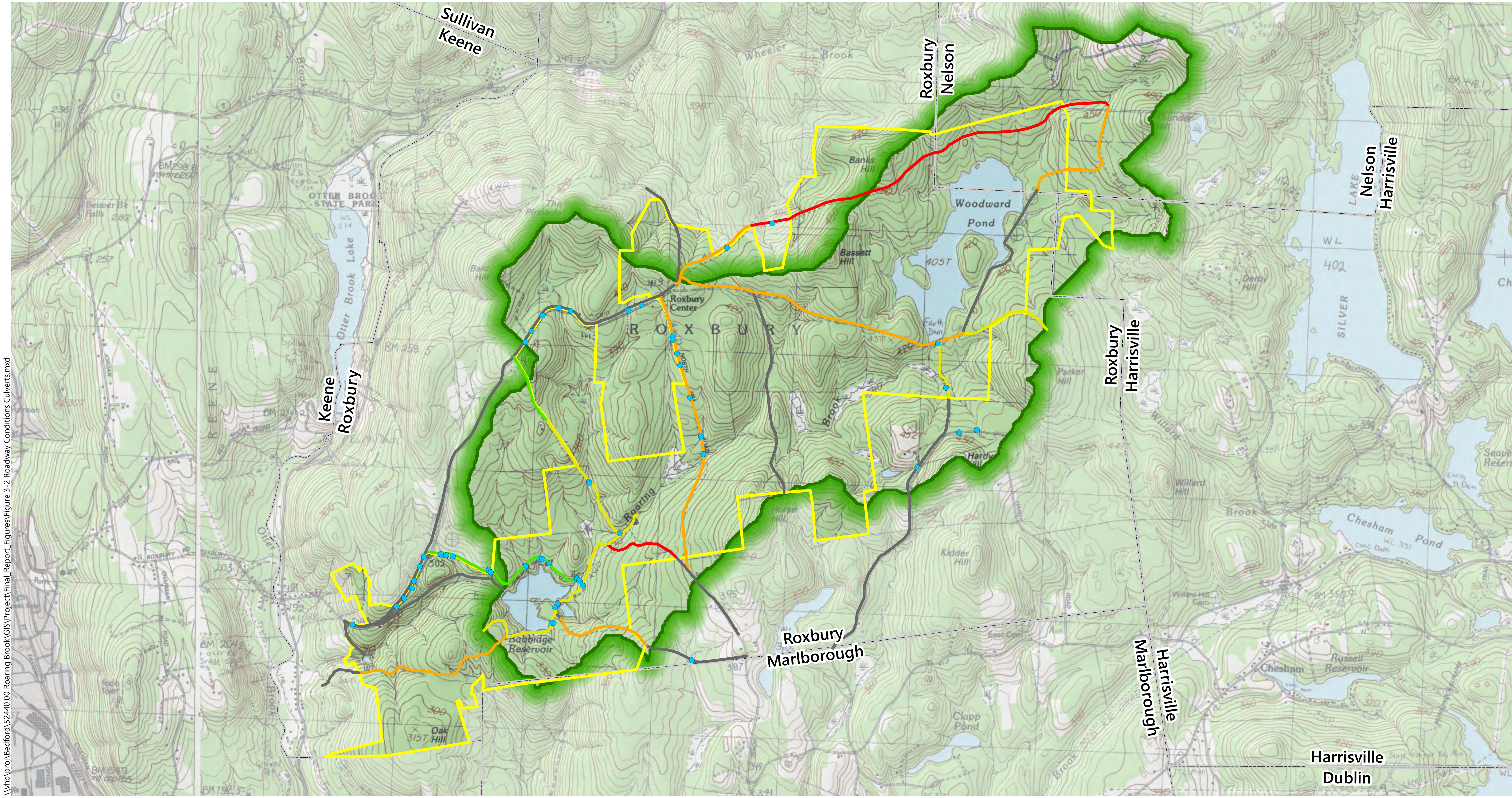
Based on this preliminary assessment, approximately 1.5 miles of the almost 17 miles of roads and paths within the watershed were rated "good." These sections are limited to portions of Dakin Road and Grimes Road where regular maintenance has been performed by the City or a private land-owner.

Table 3-3. Summary of Road Condition Assessment

Road	Classification	Condition	Length(ft)	Culverts/ Bridges
Dakin Road	VI	Good	4,876	13
		Fair	1,080	1
		Poor	2,821	0
Grimes Road	VI	Good	1,827	0
		Fair	3,575	3
		Poor	-	0
Woodward Pond Road	V(only)	Good	-	0
		Fair	1,519	1
		Poor	6,929	1
Scholtz Road	VI	Good	-	0
		Fair	-	0
		Poor	4,546	1
		Failed	10,063	1
Marlborough Road	VI	Good	-	0
		Fair	-	0
		Poor	7,307	6
Unclassified/ Unnamed Roads	Unclassified	Good	-	0
		Fair	7,663	3
		Poor	6,491	0
		Failed	2,030	0
		Not Rated	27,316	1

The Keene DPW has performed maintenance on sections of Dakin Road and Woodward Pond Road to maintain access to dam infrastructure. The City reports that this road repair work involves placement of approximately four loads of gravel and involves less than two days labor each year. The total direct cost of this work has been

FIGURE 3-2



\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 3-2 Roadway Conditions Culverts.mxd

0 1250 2500 5000 Feet

- Keene-Owned Lands (Updated Boundary)
- Roaring Brook Watershed (Above Babbidge Dam)
- Town Boundary
- Culvert Location

Roadway Condition

- Good
- Fair
- Poor
- Failed
- Not Rated

Roaring Brook Watershed Management Plan

Roadway Condition & Culverts

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

less than $2,000 annually (Aaron Costa, Keene DPW, personal communication, March 19, 2018).

Additional road repair is planned to occur during reconstruction of both dams, which should address outstanding issues on these sections of roads.

3.3.4 Recommendations Related to Roads

The following actions related to the existing road and trail system are recommended:

Review Status of Roadway Classifications: The City, working with the Town of Roxbury, should review the current understanding of the classification of the various roads and trails within the watershed. As needed, the City and Town should consider discontinuing or reclassifying certain roads or portions of certain roads. This could include re-designate sections of class VI roads where this would be appropriate. (Also see recommendations related to access and security in Section 3.5 below.)

Roadway Maintenance: The City should develop a program to stabilize portions of the road network on the property. The objective of this program should be to address areas of severe and moderate erosion, especially in areas found to be in failed or poor condition. This program should not seek to expand these roads, but rather to ensure that erosion is fully managed and to install appropriate stream crossings (culverts or small spans) to reduce sediment loads to watershed tributaries. (See Section 5.5.2 for a discussion of the predicted water quality benefits of such a program.)

3.4 Recreational Use of the City-Owned Property

Even though public access is prohibited and the property is posted against trespassing, the property has natural and scenic value that makes it attractive for persons seeking an outdoor recreational experience. Natural characteristics that make this property unique include remote, isolated bodies of water which provide value to waterfowl and other wildlife, historic cellar holes and associated stone walls, and historic quarry locations.

Securing the boundary of the watershed is difficult, and occasional recreational use of the property occurs in violation of the current policies regarding access to the property. In fact, recreational activity, including occasional unauthorized all-terrain vehicle use around Babbidge Reservoir, seems to have increased in recent years, raising concerns.

Fieldwork occurred during hunting season and encounters with or evidence of use by hunters was frequent. Other uses observed included cross country skiing, ATV use (limited, but particularly prevalent along Scholtz Road), hiking, geo-caching and skating (very limited). Except for erosion and damage at Scholtz Road and portion of Grimes Road, no significant evidence of abuse from these activities was noted, nor were instances of dumping or timber trespass.

Access to the property by snowmobiles is prevalent. While the property is not part of the official state snowmobile trail system, a number of trail signs indicate that regional snowmobile clubs maintain trails within the watershed. These clubs include the Ridge Skippers Snowmobile Club (RSSC), based on Sullivan, NH, whose trail map depicts routes on the City-owned property including portions of Woodward Pond Road, Scholtz Road, Marlborough Road, and Dakin Road. The RSSC maintains a parking area for snowmobilers at Otter Brook Park from which these routes can be accessed. Snowmobile use and related trail construction has been an issue of concern in the adjacent Taves Reserve, a conservation property managed by the Society for the Protection of NH Forests.[11]

Managing recreational use of public water supply lands has been a challenge for other water supplies in New Hampshire and the northeast. The Massabesic Watershed, for example, employs two full time and two part time patrol officers, yet finds that much of the recreational use of its property involves activities that pose a risk to the water supply (John O'Neil, Watershed Forester, Manchester Water Works, personal communication, August 23, 2017.)

These issues include droppings from dogs and horses, evidence of persons or dogs swimming in reservoirs, hikers that leave trash on the property, unauthorized trail construction, and unauthorized hunting, including instances where injured animals were not tracked and eventually expired in an area where the decaying carcass was in contact with surface water. These activities can increase erosion into reservoirs and tributary streams, and increase the risk of pathogens or contaminants from gasoline-powered engines entering the water supply.

Issues such as these have lead the New England Water Works Association (NEWWA) to adopt a policy that, while recognizing legally existing recreational uses on or adjacent to water supply sources, opposes legislation or any administrative action that would permit or require the opening of domestic water supply reservoirs and adjacent lands to increased recreational use.[12]

[11] See Roxbury Selectmen meeting notes dated December 27, 2016 for a discussion of Forest Society concerns regarding use of motorized vehicles on the Taves Reserve.

[12] New England Water Works Association, Inc., Water Resources Committee, *Resolution & Policy Concerning Recreational Use of Public Water Supplies,* Final Revised Policy, December 20, 2006. See **Appendix G**.

3.4.1 Recommendations Related to Recreational Use

Given the problems experience by other water suppliers in the northeast, as reflected in the NEWWA policy, expansion of recreational use of the property is not recommended. The City should consider additional measures to limit access to the property which could damage roads or increase risks to the reservoirs. These recommendations are outlined in Section 3.5 below.

3.5 Access and Security

To help protect the water supply reservoirs, the City has gated and posted most road access points to the watershed, except for a few locations. (See discussion in Section 3.2.2.) The City has also installed security cameras in at least two locations, including at the Dakin Road and Woodward Pond Road intersections with Middletown Road.

Figure 3-3 provides an inventory of observed signs and gates, including signage associated with third-party recreational use of the property (*i.e.*, snowmobile clubs) and adjacent landowner postings.

Significant considerations related to watershed security include the following:

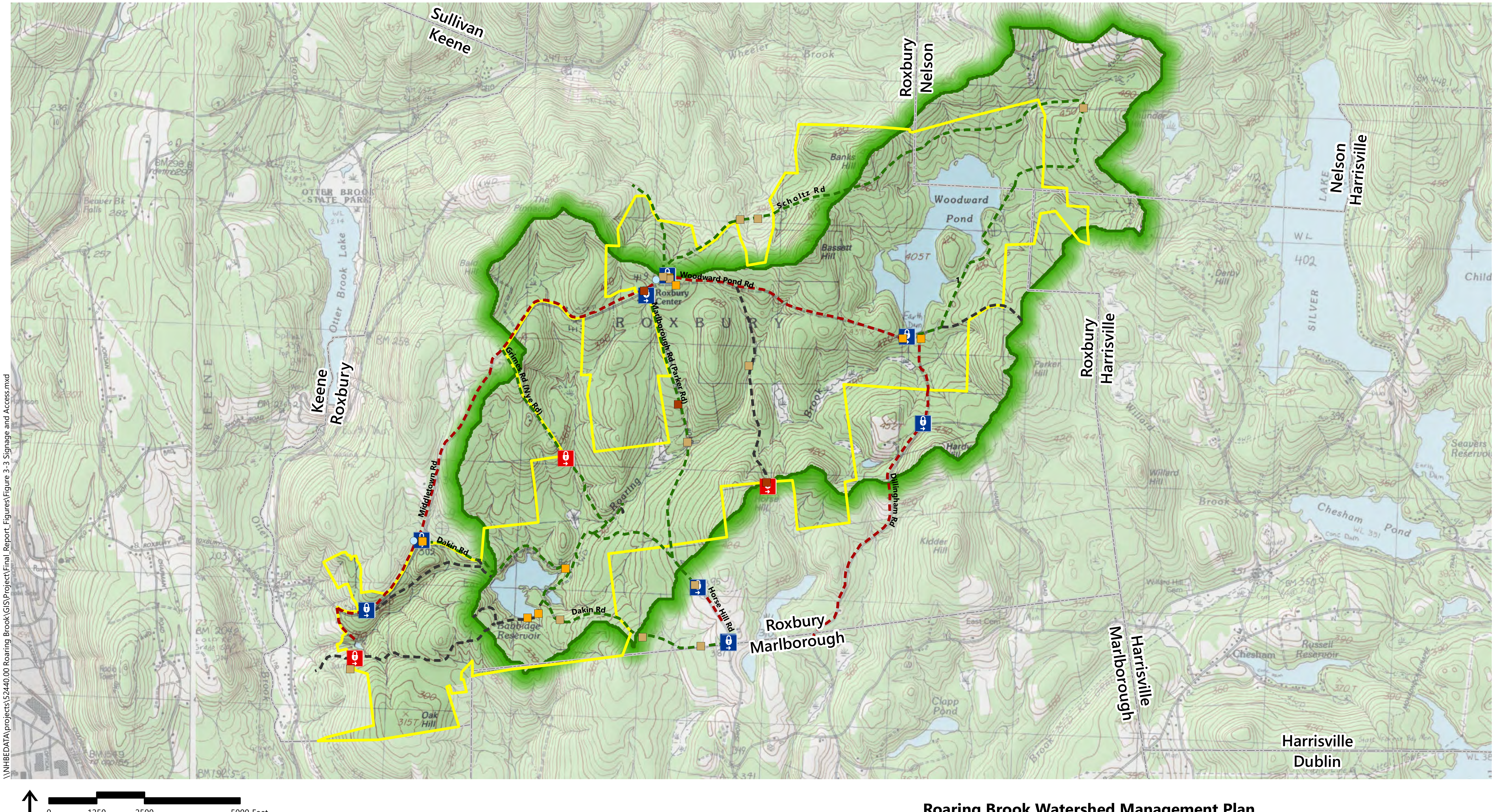
- The existing security practices consist of random patrols by the Roxbury Police Department and the presence of Keene DPW staff during monitoring and maintenance activity, with some perimeter signage, entry gates, and security camera systems.

- Boundary markings and perimeter signage is absent or lacking along most of the property.

- Due to the size of the property (more than 18.5 miles of boundary perimeter), securing the perimeter with fencing would be costly and adversely affect the rural nature of the area. As a result, access points are unlimited.

- Based on the size of the property and the relatively low amount of illicit activity observed, full time active patrols of the property would be cost prohibitive and not justified.

- A lack of fencing and other measures at the Woodward Pond and Babbidge Reservoir Dams creates a risk of damage to this important infrastructure and presents a liability issue for the City.



Roaring Brook Watershed Management Plan

Signage and Access

Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

The City of Keene has a good relationship with the Town of Roxbury, where much of the city-owned property is located. Because Keene lacks enforcement authority in its neighboring town, the City has relied primarily on Roxbury to monitor and patrol activity in the watershed, using funding from the State of New Hampshire. This funding has expired in recent years, however, and Roxbury patrols have since ceased. The City has developed an inter-municipal agreement with Roxbury to renew these patrols, with the intent to rely primarily on public education rather than an enforcement approach. As preliminarily proposed, Keene would compensate Roxbury police staff for 10 hours of patrols per month.

3.5.1 Recommendations Related to Access and Security

In addition to the resumption of regular patrols of the watershed, the following potential improvements to security practices should be considered:

- **Additional Signage/Gates:** While the most prominent road access points are currently controlled, access to the property from Class VI or private roads is uncontrolled at certain locations. **Figure 3-3** shows the location of three recommended additional gates:
  - **Southern Access Point:** At the southwest boundary of the City-owned property, where an unclassified road provides access to Babbidge Reservoir and Dakin Road. Field observations indicate that this road is used by ATVs, which have caused some erosion and road damage. Because this road is likely a private way, prohibition of public access at this location is likely justified. Any new gate at this location should be capable of blocking ATV access while still allowing access to authorized persons, especially as needed to maintain an airport beacon in this vicinity.
  - **Grimes Road:** A portion of Grimes Road is used to access a private residence, and no gates are present on this road currently. Grimes Road was discontinued, subject to gates and bars, in 1939. Therefore, an additional gate on this road is warranted. The location of the gate should avoid interference with access to the private residence.
  - **Horse Hill:** An unclassified road accesses the City-owned property near the height-of-land at Horse Hill. Evidence of recreational access was observed, including excessive erosion at the locations of intermittent tributaries along this road. The location is at the border of the City-owned property with a private conservation parcel, which has been posted. A small gate was previously in place in this location (presumably placed by others), but has fallen into disrepair and has

been removed. Because this road is likely a private way, prohibition of public access at this location is likely justified.

- **Additional Perimeter Signage:** Boundary markings and perimeter signage is absent or lacking along most of the property. Additional signage along the boundary of the City-owned property would be useful to notify the public that the property and limit prohibited activity.

- **Targeted Security at Key Infrastructure:** Currently, limited fencing at the Babbidge and Woodward Dams allows the public to access these structures. Keene DPW staff report that previous unauthorized access to Babbidge Dam created damage to the earthen dam, and evidence of vandalism is present on structures at these locations. Due to the importance of these dams and the liability involved, additional security measures including secure fencing of these vulnerable points should be installed.

- **Education and Awareness:** Any additional security measures should be accompanied by an outreach program that engages stakeholders. The target audience for this program should include Roxbury municipal officials, Roxbury residents, and other stakeholders including abutting landowners and regional recreational clubs such as the RSSC.

- **Additional Inspection Vehicle to Monitor the Watershed:** While the City has vehicles available for operations on the watershed property, these vehicles cannot access most of the watershed property because most roads and trails are not safely accessible to most cars and trucks. An all-terrain vehicle (utility side-by-side) should be acquired by the City to allow staff to access all portions of the watershed. This would allow for efficient regular monitoring of the property and help to ensure its proper management.

4

Forest Management

4.1 Introduction

As member of the project team conducting this study, New England Forestry Consultants conducted an inventory of the timber resource on the Keene-owned portion of the Roaring Brook watershed.[13] This chapter discusses some of the benefits of forest management, reports the results of the timber inventory, presents a summary of the potential for harvesting timber from the property, and discusses issues that would need to be considered in planning a timber harvest. Chapter 5 provides an analysis of the potential water quality effects of harvesting timber from the City-owned parcels.

4.2 Timber Harvest Considerations

A properly planned and executed timber harvest could provide a variety of benefits, including revenue to the City, an increased yield of water, and a more diverse and healthy stand of trees and wildlife. However, land management activities, particularly timber harvesting activities, have both positive and negative aspects that must be considered. A discussion of these aspects of land management follows.

4.2.1 Silviculture

Silvicultural methods that are typically used to regenerate trees, including clearcutting, leaving seed trees, shelterwoods, or selective harvest, typically increase water yield relative to unmanaged forests when properly timed to coincide with favorable weather and carefully applied to the species and soil conditions.

[13] Mr. Dennis D. McKenney, NH Licensed Professional Forest #61, Licensed Land Surveyor #691 supervised the forest management component of this study.

Water supply watersheds in the northeast are typically managed to favor hardwood species over softwood species, since crown cover of softwoods can limit the amount of precipitation reaching the forest floor. Thus, a timber management plan that removes softwood cover can reasonably be expected to increase water supply yields. This benefit would only occur as long as the forest is actively managed; succession of the forest to a softwood dominant cover type would eventually decrease yields. The magnitude of this benefit cannot be precisely defined at this level of study, but it is expected that it would be relatively minor and temporary unless a permanent, long-term timber management plan is adopted.

4.2.2 Landscape Diversity and Health

The promotion of a healthy and diverse landscape can be achieved via an active, continuous (not sporadic) forest management program including harvests and regular intervals. The timber inventory on the Keene-owned parcels indicates that virtually the entire tract is currently a landscape of mature or over-mature timber. Almost no areas of sapling or seedling age class were observed during fieldwork. In fact, the youngest trees observed were associated with the last episodes of harvesting that occurred about 35 to 40 years ago. A more balanced age class distribution would add diversity, reduce the level of over-maturity in the aging white pine stands to improve overall health and encourage a wider variety of wildlife species.

4.2.3 Wildlife Management

Wildlife management is readily incorporated with an active forest management program. Many native species of birds and wildlife are present on the land. Signs of black bear, beaver, bobcat, coyotes, deer, grouse, turkeys and waterfowl were regularly encountered. Much of the timber inventory fieldwork occurred during the hunting season for white tail deer; the land is popular among deer hunters. Occasionally, a portable tree stand was observed. Routine practices during a timber harvest can include reserving active den and nest trees or trees having such potential, releasing old apple trees so they receive full sunlight, maintaining log landings in open, grassy cover by annual mowing, and managing the red oak resource to produce acorns for wildlife as well a seed source.

4.2.4 Forest Heath

Issues surrounding forest health is typical of the region, and therefore no action is presently recommended. Few trees damaged by lightning strikes were noted and some scattered white pine stems may be infected with blister rust, however neither problem is unusual. Affected stems could be removed during harvest, however, lightning struck stems have significant wildlife value greater than any monetary value. White ash will be at higher risk in the next 20 years to an invasive beetle, the

Emerald Ash Borer. Since the infestation is fatal within several years, pre-emptive salvage during any harvest is warranted. Gypsy moth is a risk to red oak, but the best strategy for protection is to maintain vigorous trees in well stocked but not overstocked stands.

Scattered mortality due to over-maturity was observed, which is common on most properties in New Hampshire. These stems have significant wildlife value and are identified on the diameter distribution graphs as "cull" trees. Rarely, other stems have been damaged by felling and skidding during earlier harvests in the late 1970's. Unhealthy or over-mature trees are more susceptible to rot than are immature, healthy, vigorously growing trees. Proper forest management should seek to harvest mature and unhealthy timber prior to excessive damage from rot, and to salvage those trees already infected or otherwise damaged.

White pine blister rust and the white pine weevil are typically the most damaging agents affecting white pine growing in southern New Hampshire. Blister rust is a fatal disease which causes the trunk to become spindle-shaped and pitch soaked. Sections above the canker die quickly once the canker encircles the stem. At one time, the alternate host of the disease, *Ribes* sp., was eradicated by State of New Hampshire forestry personnel, but this practice is now abandoned. While effective, most control today is limited to the harvesting of infected stems. Weevil damage and blister rust were observed occasionally but are not beyond typical expectations.

Damage from the white pine weevil is caused by an insect which lays its eggs in the topmost shoot of the tree and the larvae then burrow through the stem and emerge as adults to continue the life cycle. The larvae kill the stem and the limbs below turn upward to become the new top. This creates the "dog leg" character visible in many pines. The severity of the defect depends on the frequency of the attack, the intensity of competition from surrounding stems, and the age of the tree. Dense stands force the new tops to quickly turn upward and limit damage and small young stems show less defect as they increase in size. Stems subject to frequent attacks, called "cabbage pines" by foresters and lumbermen, often have multiple tops and can be so crooked as to be unmerchantable for anything except wood chips. Infected trees should be harvested whenever possible to minimize the owner's economic losses. Since damage from the white pine weevil cannot be easily controlled, improvement harvests will remove badly weevilled or infected trees with the purpose of upgrading stand quality and vigor and salvaging stems before decay renders them worthless for forest products.

Emerald Ash Borer (EAB) is an invasive pest now present in NH and recently confirmed in towns as near as Mont Vernon. Control in forest stands is not economically practical although effective controls are available for shade and ornamental trees. Mortality within a few years after attack is certain for any infested tree. Pre-emptive salvage is recommended when ash is present within any harvest area to minimize economic loss to the owner and to eliminate the risk of the tree as a hazard.

4.2.5 Summary of Timber Harvesting Benefits and Issues

Several factors that account for the benefits and disadvantages of timber harvesting are related to biological, economic, social, and silvicultural factors. The following table briefly identifies some of the benefits and disadvantages, real or perceived, associated with active forest management including commercial harvesting.

Table 4-3. Summary of Timber Harvesting Benefits and Impacts

Category	Benefit	Impact
Ecological	Can add to diversity of species both commercial and noncommercial; can add diversity of species, game and non-game; can be used to control diseases and pests, can be used to reduce risk of wildfire.	May have negative effects on some species of vegetation and wildlife; effects can be of short or long duration; elimination of wildfires can be detrimental to some species and certain wildlife.
Economic	Timber is a financial asset that can generate income for the use of the landowner; harvesting generates tax revenue for the municipality from which the timber is harvested; locally sourced and harvested timber supports the region's economic infrastructure.	Timber harvesting can impact other amenities that may have economic value such as aesthetics, perceived negative impact to wildlife; risk to water quality.
Silvicultural	Harvesting promotes the growth and regeneration of younger, vigorous trees.	Some regeneration methods are aesthetically unappealing and too drastic, too rapid a change. Large blocks of forest can be reserved from harvest and left for management as wilderness.
Social	Well managed forests provide a variety of benefits to all people: wood, water, wildlife and recreation.	If land is perceived to be too unique and valuable for management as commercial forest land, harvesting should be excluded.
Water Quality & Yield	Harvesting can be a useful tool for the management of increased water yield.	Timber harvesting operations, if not properly managed, can impact water quality. Low impact techniques can mitigate this risk.

4.3 Harvesting in Watershed Management Areas

Active Forest Management practices require the routine use of Best Management Practices (BMP's). A specific guidance document, *Good Forestry in the Granite State*, offers data on the legal and recommended buffers along riparian areas like those found on the City's watershed. Further, NH RSA 227-J (basal area) and RSA 482-A (wetlands) guide all harvests, whether within protected watersheds or not. Another excellent guidance document is found in the *Forestry Handbook, 2nd Edition* (Karl F.

Wenger, Ed.). Section 12 of the *Forestry Handbook* is dedicated to Forest Hydrology and Watershed Management, and particularly informative in this section is *Table 2*, "Potential Impacts of Forest Practices and Utilization upon Stream Quantity and Quality," including detailed explanations of the potential impacts. This section explains that timber harvesting can increase the quantity of water in streamflow and reservoir storage but may result in increased sedimentation, nutrient concentration and warmer stream temperatures. These impacts can be minimized with the use of BMP's such as buffer strips and the protection of the stream channel. Softwood stands decrease water yield; hardwood stands result in increased yield. Any increase in yield diminishes as the forest re-grows. Virtually all of the City's land can be considered as mature stands of hardwood (predominantly oak) and the softwood stands (predominantly white pine). Hemlock is almost exclusively found on the wetter soils and in the immediate riparian buffer.

An analysis of the potential impacts to water quality within Woodward Pond and Babbidge Reservoir is provided in Chapter 5 of this report.

4.4 Past Land Use and Timber Harvests on the Property

During the pre-Civil War years, the Roaring Brook Watershed and surrounding land was used for pasture, crops, and woodlots. Cellar holes, old road, and stone walls are a testament to this. In fact, much of the watershed was cleared for conversion to agriculture in the late 1700's and early 1800's. This use was abandoned in the late 19th century, and the area was reclaimed by trees.

Evidence of former harvesting, forest fires, and widespread quarrying of granite bedrock or glacial erratics was observed during survey of the property. The interest in an active forest management program within the Roaring Brook Watershed is at least 75 to 80 years old. Historic maps have been found dating to the 1930's which were developed for forest management purposes; interestingly, these maps refer to Woodward Pond by its former name of "Echo Lake."

The most recent timber harvesting activity dates to the late 1970's and early 1980's when extensive but careful selective harvesting of white pine *(Pinus strobus)* took place (refer to **Appendix C**, 1970's Harvest Map). This timber harvesting work covered 50% or more of the watershed and in some cases was located adjacent to the reservoirs, Roaring Brook, and associated tributaries. The youngest trees within the watershed, now 35-40 years old, are associated with these harvests. Based on field review of the current property, these harvests appear to have been well supervised and skillfully executed.

4.5 Timber Inventory Results

A timber inventory using 1/10-acre circular plots arranged in a grid pattern was completed in the fall of 2016 and winter of 2017. A map depicting the various stand types is presented in **Figure 4-1**, and a summary of the inventory by land cover types is provided in **Table 4-1**.

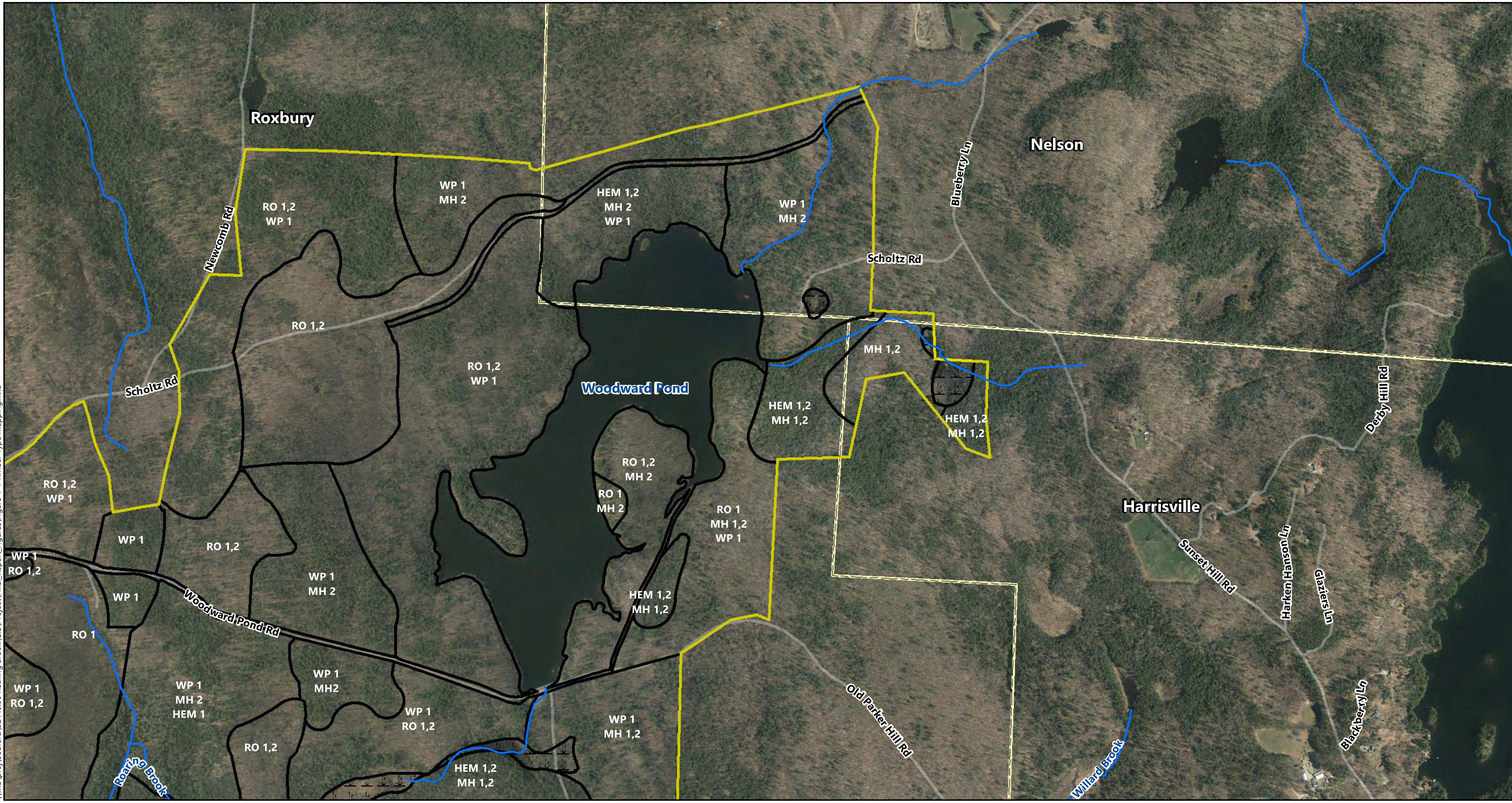
Table 4-1. Timber Inventory

Type	# of plots	Acres +/-
Wetland	5	26
Reservoirs	32	166
Forest Land	474	2,455
Total	511	2,647

Data gathered at the forest land plots included counts of all trees 11” DBH (diameter breast height) and larger, as well as observations on smaller trees suitable for pulpwood, merchantable height, allowance for defect, cull or snag trees. The tree data was analyzed to generate volume estimates by size, species and product using the forest management software “ForestMetrix.” Mapping data was compiled using GPS and GIS software to produce a series of timber type maps. (See **Figure 4-1**.)

An estimate of the total volume and value of each tree species is provided in **Table 4-2,** which shows that the dominant timber species is red oak. (Additional detailed data is provided in **Appendix C**.) In fact, the property holds an exceptional volume of high value red oak (almost 11 million board feet), which is currently the most valuable hardwood species in New Hampshire; the southwest corner of New Hampshire is a known source of quality red oak. However, much of the white pine (the second most prevalent species) is unacceptable growing stock - they are of poor form due to many branches or crooked stems, they show signs of over-maturity in the form of reduced crown ratios, or they display signs of serious internal defect. All these defects result from over-maturity.

FIGURE 4-1



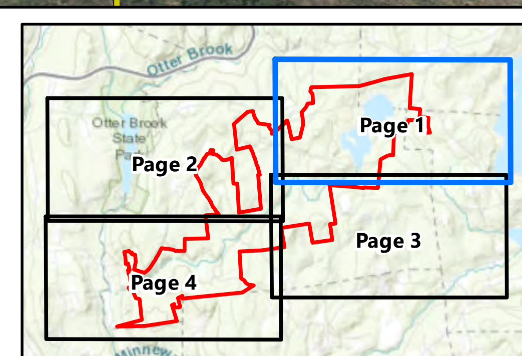
\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 4-1 Timber Type Mapping.mxd

0 500 1000 2000 Feet

- Keene-Owned Lands (Updated Boundary)
- Timber Type Area
- Wetland
- Town Boundary
- Intermittent and Perennial Streams
- NHDOT Road

Timber Type Area Label Key

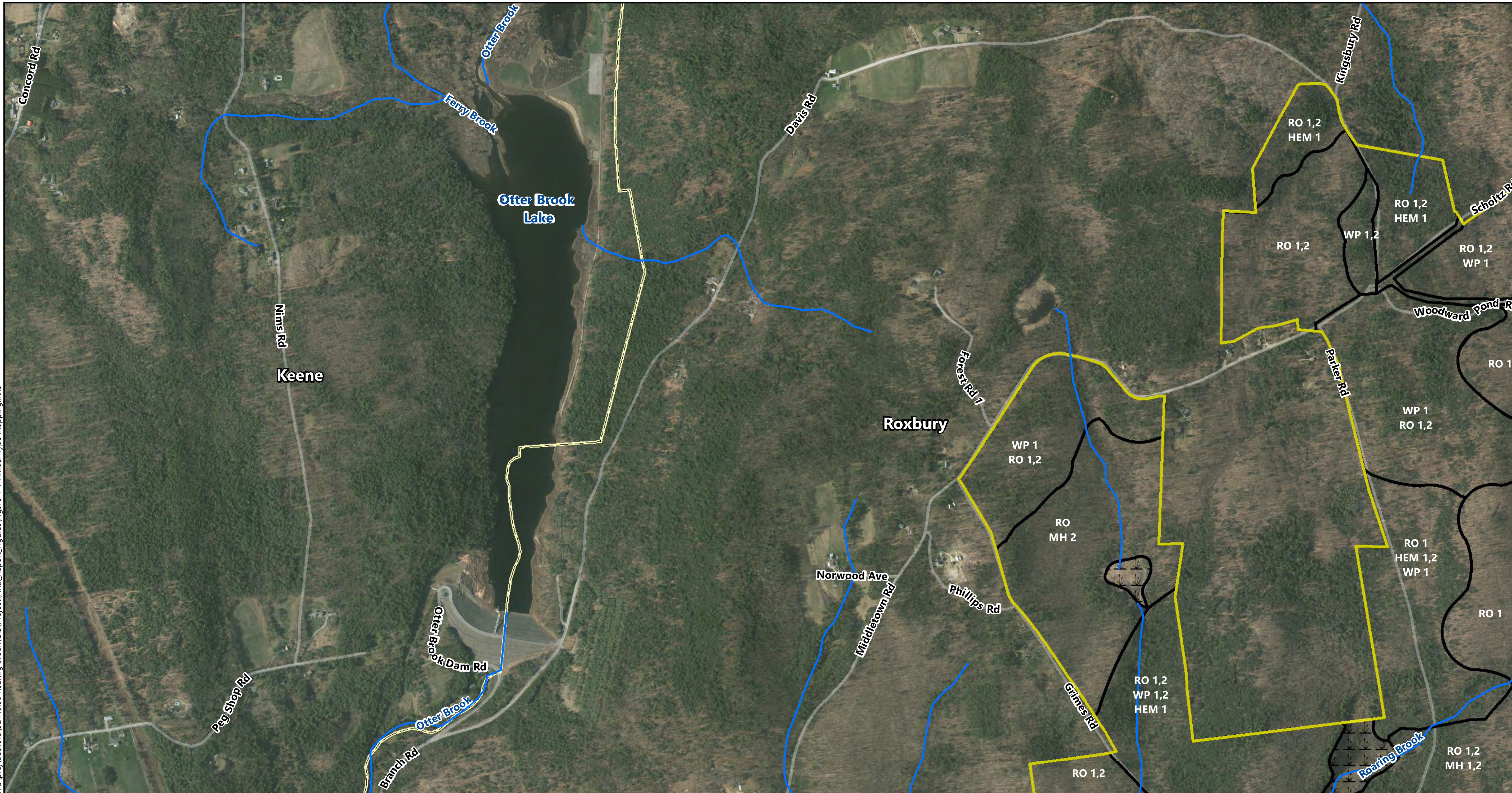
Tree Species:	Tree Size:
HEM: Hemlock	1: Sawtimber, 12'' DBH+
WP: White Pine	2: Poletimber, 6-11'' DBH
MH: Mixed Hardwood	3: Saplings, 1-5'' DBH
RO: Red Oak	



Roaring Brook Watershed Management Plan

Timber Type Mapping
Page 1 of 4
Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

FIGURE 4-1



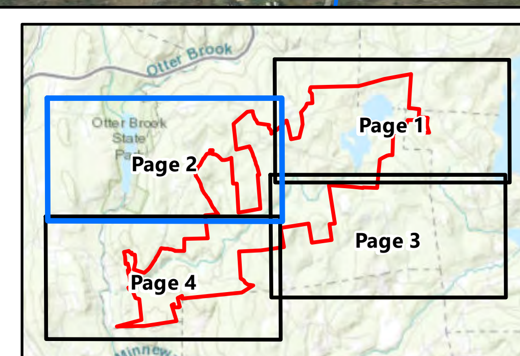
\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 4-1 Timber Type Mapping.mxd

0 500 1000 2000 Feet

- Keene-Owned Lands (Updated Boundary)
- Timber Type Area
- Wetland
- Town Boundary
- Intermittent and Perennial Streams
- NHDOT Road

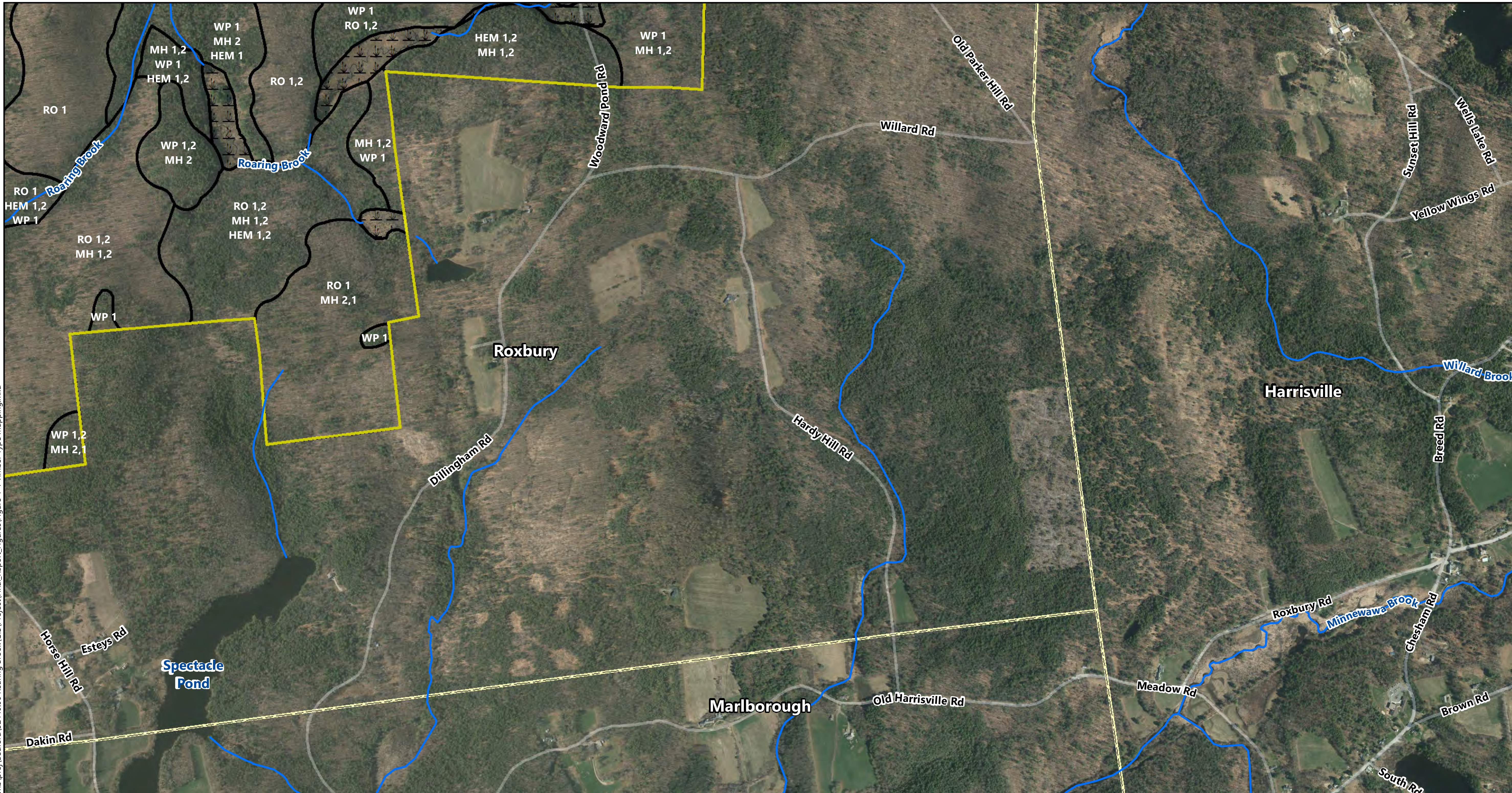
Timber Type Area Label Key

Tree Species:	Tree Size:
HEM: Hemlock	1: Sawtimber, 12'' DBH+
WP: White Pine	2: Poletimber, 6-11'' DBH
MH: Mixed Hardwood	3: Saplings, 1-5'' DBH
RO: Red Oak	



Roaring Brook Watershed Management Plan

Timber Type Mapping
Page 2 of 4
Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT



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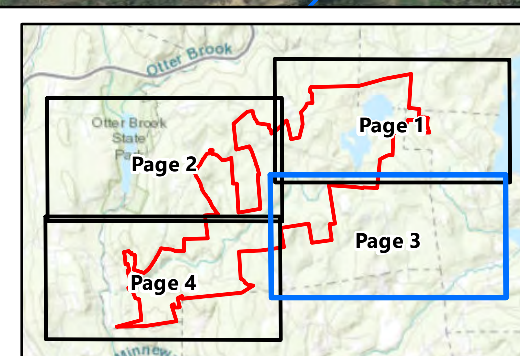
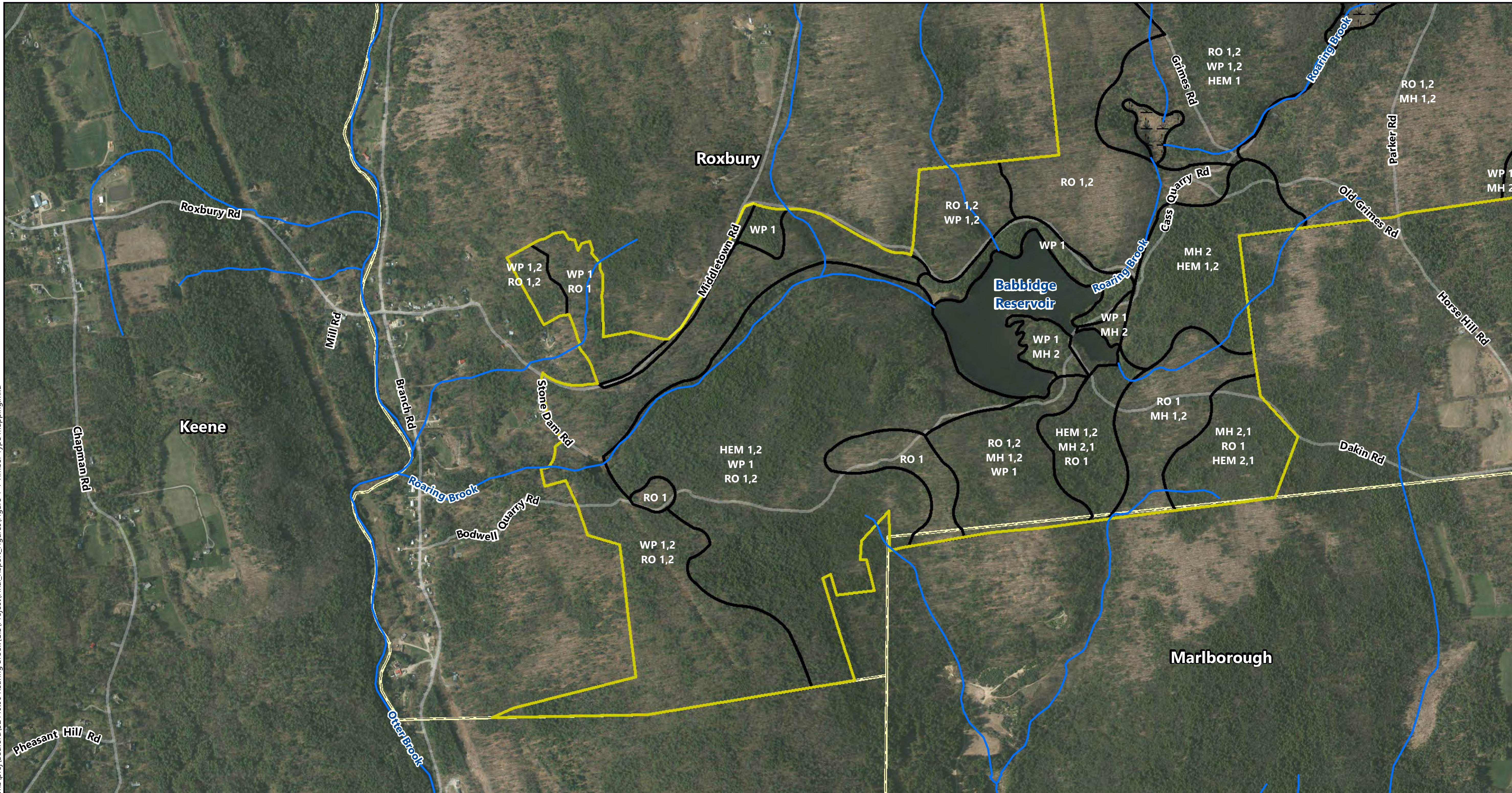


Roaring Brook Watershed Management Plan

Timber Type Mapping
Page 3 of 4
Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

FIGURE 4-1



\\vhb\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 4-1 Timber Type Mapping.mxd

0 500 1000 2000 Feet

Keene-Owned Lands (Updated Boundary)
Timber Type Area
Wetland
Town Boundary
Intermittent and Perennial Streams
NHDOT Road

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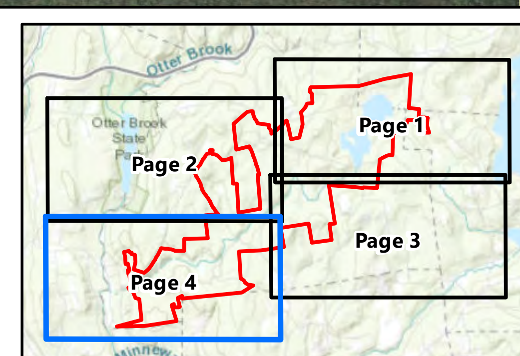


Roaring Brook Watershed Management Plan

Timber Type Mapping
Page 4 of 4
Source: USGS Stream Stats, VHB, NEFCO, NHGRANIT

Table 4-2. Timber Inventory – Volume and Value Estimates, by Species[1]

Species	Bd-Ft/Acre[2]	Total MBF[3]	$/MBF	Estimated Value[4]	% Value
Northern Red Oak	4,412	10,832	$450	$4,874,270	72.8%
White Pine	3,823	9,387	$145	$1,361,067	20.3%
Red Maple	324	796	$180	$143,279	2.1%
Hemlock	727	1,785	$60	$107,098	1.6%
White Ash	129	316	$250	$78,999	1.2%
Yellow Birch	73	179	$250	$44,772	0.7%
Sugar Maple	87	215	$200	$42,961	0.6%
Black Cherry	27	65	$200	$13,036	0.2%
Red Spruce	53	131	$90	$11,770	0.2%
Red Pine	32	79	$60	$4,760	0.1%
White Birch	18	45	$100	$4,512	0.1%
Beech	42	103	$40	$4,134	0.1%
Black Birch	4	11	$250	$2,740	0.0%
Total	9,753	23,944		$6,693,399	

Notes:
1 Data from New England Forestry Consultants, 2017.
2 Bd-Ft = Board-Feet, a measure of the volume of timber.
3 MBF = Million board-feet.
4 The estimated value represents all of the standing timber on the site, and would be realized only through an intensive liquidation harvest. See Section 4.4 for a discussion of the potential value of a reasonable harvest scenario.

4.6 Potential Timber Harvest

New England Forestry Consultants' assessment estimates that the total timber on the Keene-owned property is almost 24 million board-feet, with a total value of $6.7 million. However, a reasonable timber management plan must consider long-term forest management principles, the quality and accessibility of the various timber stands on the property, as well as account for aesthetic setbacks to nearby roadways and water quality buffers to Woodward Pond, Babbidge Reservoir, Roaring Brook, and other streams and wetlands. Based on these considerations, New England Forestry Consultants estimates that the timber potentially available for harvest is approximately 13 million board-feet, with a value of approximately $3.3 million. (See **Appendix C, Table IV**.) This harvest would likely be staged over a period of 15 years, generating an average of $221,000 per year. This estimate is based on recent timber market conditions and is subject to change.

Current and future trends in markets for our local forest products often vary considerably by product and species. Sawlog markets for red oak and white pine, the predominant species by volume on the tract, are presently strong, but markets for low quality pallet grade, roundwood pulp or whole tree chips are weak. Markets for quality sawlogs should remain strong for the foreseeable future, but the trend for trees of pulpwood or lower quality are of concern. Strong markets for these low value trees are critical for silvicultural reasons. So, harvest activities, if authorized, should be planned to coincide with strong markets for low quality timber.

Harvests, when and if authorized, should prioritize the harvest of over-mature white pine and, to the extent markets allow, pulpwood of all species. The goal would be to capture the value of over-mature saw timber stems sooner rather than later and remove pulpwood simultaneously. Red oak stands, which predominate on the landscape, should also be judiciously thinned to remove mature trees. Equally as important, thin or immature stems should be left to foster more rapid growth.

The tables and charts included in **Appendix C** provide detailed information about the volume and value of timber by species and product for the property as a whole. The property is well stocked with quality sawtimber and growing stock, particularly white pine and red oak. The tables show the percentage breakdown by species of acceptable and unacceptable trees. Acceptable trees are deemed capable of becoming or presently are high value sawlogs; unacceptable trees are those suitable only for pulpwood, firewood or chips irrespective of their present or future size. This tract is adequately stocked with acceptable growing stock of species well suited for growth on the existing soil types and should respond well to management. In fact, red oak and white pine, the region's most economically valuable hardwood and softwood, dominate all other species by all important metrics—basal area, trees per acre, size and volume. Together they represent over 84% of the standing sawtimber volume and 93% of the sawtimber value. See **Appendix C, Table V** for the specific metrics for the data by species on a per acre basis.

However, much of the white pine is graded as "unacceptable" growing stock. Generally, these trees are over-mature or show signs of significant defect resulting from crowding and intense competition from other trees. **Appendix C, Chart I** provides a breakdown of trees per acre by species to illustrate the percentage in categories like acceptable versus unacceptable growing stock, cull trees and snags. While much of the white pine is of low quality, the reverse is true for the red oak.

Appendix C, Table III breaks down the sawtimber volume not only by species but by diameter as well. Over 55% of the sawtimber volume is found in trees 19" DBH or larger; this volume is predominantly large white pine and red oak. About 33% of the volume is in found in the 15-18" DBH group. Timber harvesting should not be directed solely at trees of a certain size or even a certain species. The data illustrates that the tract is heavily stocked with mature sawtimber, and that no harvesting has occurred for about 40 years. The lack of timber harvesting on the parcel is resulting in a decline in the vigor of the white pine as well as the red oak, and lost opportunities for revenue from responsible forest management as well as wildlife and increased water yield.

High volumes of pulpwood are also present and shown in terms of tons per acre for softwood and hardwood; top wood is also included. Present markets for pulpwood and chips are weak but still exist. These markets are vital for the removal of unacceptable growing stock as a source of modest revenue. Silviculturally, they are critical to improving species composition, upgrading stand quality, and creating conditions favorable to the regeneration of desired species. Every effort should be made to use these markets to maximum silvicultural advantage.

Stumpage values shown by species or product are based on recent, comparable sales of standing timber marketed and supervised by the Monadnock Office of New England Forestry Consultants, Inc. and close to the Roaring Brook watershed. **Appendix C, Table IV** presents estimates by species and for roundwood products. These are, for lack of a better term, identified as a timber liquidation value. This is not to suggest, condone, or in any way recommend "liquidation" as a management option but rather to identify and quantify the economic value represented by the timber resource for discussion purposes. **Appendix C, Chart II** is a more visual representation of the volume and value by species that clearly illustrates the dominance of white pine and red oak sawtimber.

Per acre data by species is given in **Appendix C, Table V** for the various species. Again, it illustrates the dominance of red oak and white pine by metrics such as basal area, trees per acre. Of note are the large QMD—quadratic mean diameter—values for red oak and white pine at 17" and 20", respectively. The red oak and white pine found on this land are large and mature. Volume per acre is well above the average volume for similar land in southern New Hampshire.

5

Water Quality

5.1 Introduction

Current and potential future water quality impacts linked to both human activities (*e.g*., land development, timber harvesting, roads) and natural occurring events (*e.g*., increased storm intensity, natural eutrophication processes) were assessed particularly with respect to parameters which affect eutrophication (nutrients and algae).[14] These parameters, related to algal growth, are indicators of substances that may interfere with the disinfection process and can lead to additional releases of disinfection byproducts (DBPs) which would, in turn, affect drinking water quality.

Although Total Organic Carbon (TOC) and turbidity levels in the City's source water have generally been low, existing data does show occasional turbidity spikes. These are likely related to storm events that occurred prior to the monitoring events.

Occasional episodic disturbances or even prolonged incremental changes in water quality can ultimately affect water treatment quality and quantity and the production of disinfection byproducts. Preserving excellent water quality through appropriate watershed protection measures is fiscally prudent since it avoids expenditures on treatment upgrades.

Algae growth in the supply reservoirs fueled by nutrients from the watershed can directly affect TOC levels in the water supply. Managing water quality will be important in the future, since the predicted effects of climate change, such as higher water temperatures, longer growing season and lower flushing rates due to prolonged droughts, have the potential to increase the magnitude and duration of elevated algal growth in the reservoirs. Some of the manifestations of climate change in the northeast include more frequent, intense storms resulting in increased runoff and streambank erosion, increased soil temperatures and shorter frozen ground periods.

▼

14 Eutrophication is the process of waterbodies being enriched by excessive nutrient concentrations such as phosphorus or nitrogen, resulting in high productivity. Eutrophication adversely impacts water quality.

Climate change may also result in major changes to the forest health from invasive species, loss of native species, drought, disease or insect infestations. A healthy forest throughout the watershed is essential to the protection of water quality. Forest is by far the dominant land cover and not only provides exceptional water and nutrient retention it also armors the landscape reducing the potential for water quality issues to arise from many of the manifestations of climate change. Detrimental changes in the forest have the potential to increase the delivery of nutrients to the reservoirs from the watershed as the potential for the forest to absorb them is reduced.

In addition to issues related to increased TOC and the formation of disinfection byproducts, nutrient enrichment can increase the risk for cyanobacteria (blue-green algae) blooms. Many cyanobacteria species can produce toxins which can be problematic in drinking water.

Managing the watershed in a manner that anticipates current and future risks is essential. To this end, identifying factors or changes in the watershed that could trigger algal production in Woodward and Babbidge reservoirs is critical. Therefore, as part of this study, changes in nutrient loading and the reservoir's potential response to some of these factors was evaluated and are discussed further below. A monitoring plan is proposed for the future that will provide data to evaluate trends in water quality and to identify episodes of poor or declining water quality should they occur.

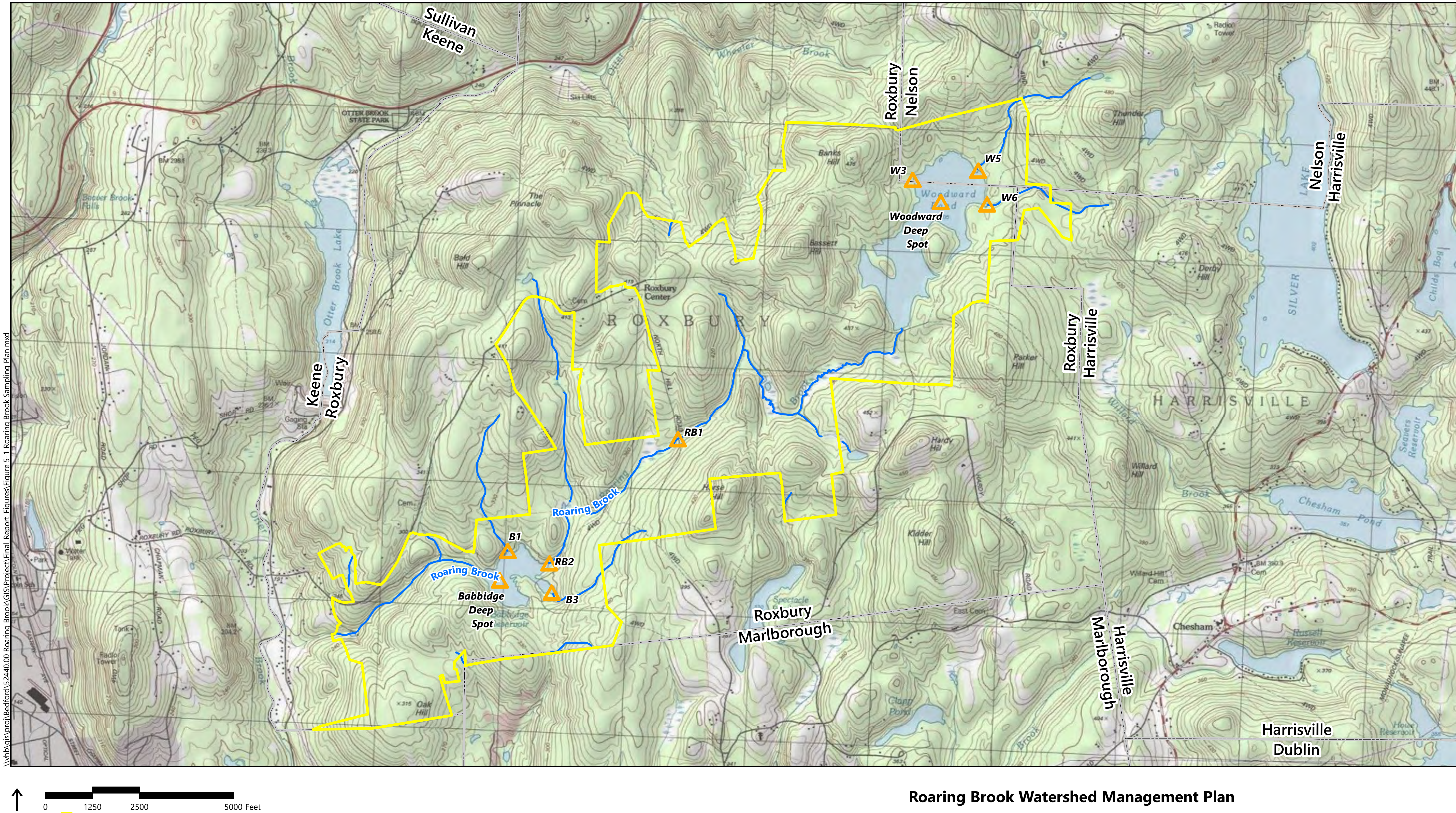
5.2 Water Quality Monitoring

Water quality monitoring was conducted in the Roaring Brook watershed by the project team on four occasions in 2016-2017. Sampling station locations from the 2016-2017 sampling program are shown in **Figure 5-1**. An initial sampling event was conducted in the fall of 2016 as a part of a reconnaissance survey of the watershed. More comprehensive testing in the reservoirs and the tributaries was conducted during three events in 2017. Data collected by the NH Department of Environmental Services (NHDES) in Babbidge Reservoir in 2016 and 2017 as a part of the trophic survey program was used to augment the data collected by the project team. All sampling was completed in accordance with an approved monitoring plan dated June 23, 2017. (See **Appendix D**.)

5.2.1 Trophic Parameters

A summary of water quality parameters related to trophic state is provided in **Table 5-1**.[15] A full table of water quality data, including those collected by NHDES, is

[15] Trophic state is a description of the various productivity levels of waterbodies. Waterbodies are classified by three trophic levels (listed from most productive to least): eutrophic, mesotrophic, and oligotrophic. Oligotrophic waters have the best quality for drinking water supplies.



Roaring Brook Watershed Management Plan

Sampling Locations

Source: USGS Stream Stats, VHB, NHGRANIT

\\vhb\gis\proj\Bedford\52440.00 Roaring Brook\GIS\Project\Final_Report_Figures\Figure 5-1 Roaring Brook Sampling Plan.mxd presented in **Appendix E**. Profile data are presented in **Appendix E, Figures E-1** through **E-6.** The profile graphs depict how temperature and dissolved oxygen vary with depth. Both temperature and dissolved oxygen concentrations decrease with depth, with the most pronounced effect occurring near the pond bottom (approximately 9 meters in Woodward Pond and 8 meters in Babbidge Reservoir). These graphs indicate the amount of thermal stratification present in the waterbodies during the sampling events; a pronounced thermocline can be observed in the graphs for most of the sampling events.

Table 5-1. Summary of Trophic Parameter Results in the Roaring Brook Watershed (2016-2017 mean values)

Station	Depth[1]	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Chlorophyll *a* (µg/L)	Secchi Transparency (meters)[2]	Total Nitrogen (µg/L)	TN/TP ratio (calculated)
Babbidge Deep Spot	Core	6.0	1.4	2.5	5.2	399	54
Babbidge Deep Spot	Hypo	9.5				799	69
Woodward Deep Spot	Core	5.9	<1	2.3	5.9	506	31
Woodward Deep Spot	Hypo	9.6				898	75
W-3	0	3.1					
W-5	0	6.6					
W-6	0	21.4					
RB-1	0	5.1					
RB-2	0	5.9					
B-1	0	4.5					
B-3	0	8.0					

Note:

1 The "Core" sample is a composite sample of the epilimnion, the region of the water column that receives the most solar radiation, is warmest and most often has the highest levels of biological productivity. The "Hypo" sample represents the hypolimnion which is the dense, bottom layer of water in a thermally-stratified lake. A "0" depth indicates a surface sample from tributaries to the reservoirs.

2 Secchi transparency is a measure of water transparency or turbidity in bodies of water, determined by using a Secchi disk.

Algae are fueled by nutrients (primarily phosphorus) and reproduce mainly through cell division, although resting cysts are an important mechanism for surviving unfavorable periods. When growth conditions are ideal (warm, lighted, nutrient-rich waters), algae multiply rapidly and reach very high densities (blooms) in a matter of weeks. As these cells sink out of the lighted portion of the water column, they consume more oxygen than they produce through photosynthesis. Eventually the cells die and consume more oxygen as they decompose. The result can be depressed oxygen concentrations in the deeper portions of a reservoir. In the most extreme case, all of the oxygen is consumed in the deeper water. Under those conditions, termed *anoxia*, phosphorus previously deposited in the sediments can be released back into the water column potentially fueling further blooms.

Currently, low phosphorus concentrations in both Woodward and Babbidge Reservoirs are not particularly favorable for algal growth. Phosphorus concentrations observed in both reservoirs were well below New Hampshire criteria for oligotrophic (low nutrient) lakes. The calculated nitrogen to phosphorus ratio suggests that both reservoirs are highly phosphorus limited. This emphasizes the need to control phosphorus as part of the watershed management plan as the best way to control algal growth and prevent eutrophication of the reservoirs. Chlorophyll *a* data from the reservoirs supports that contention and Secchi transparency is relatively high. Phosphorus concentrations in the deeper waters of the reservoirs are somewhat higher than those observed in the surface waters but are not high enough to suggest widescale release of phosphorus from the sediments. Furthermore, the deep-water areas of both reservoirs are relatively small, restricting the area that could contribute to phosphorus release under anaerobic conditions.

Oxygen and temperature profiles show that the reservoirs do stratify to some degree and this stratification persists into September. Dissolved oxygen concentrations are depressed in the deeper waters during this stratification, but waters only become or approach anoxia (no oxygen) within a meter or two of the bottom. As stated above, based on the bathymetry of the reservoirs, areas this deep are very small. As a result, the potentially negative effects of low oxygen on reservoir water quality are likely small at this time. If the anoxic area expands (which would be more likely with increases in phosphorus), potential impacts on water quality would become a larger concern.These concerns might include iron and manganese release from the sediments to the water column or phosphorus release from the sediments under anoxic conditions. This potential phosphorus release may fuel further algal growth which would depress dissolved oxygen concentrations further in a positive feedback loop.

5.2.2 Microbiological Parameters

Microbiological parameters collected as a part of the field program provide indicators of possible pathogen sources in the watershed. These could include wildlife, waterfowl, livestock, pets, or human sources. Means of these values are summarized in **Table 5-2**. All results are presented in **Appendix E**. In general, numbers of indicator organisms were low - however, the standards for total coliform and *E. coli* in drinking water are 0/100 ml. The presence of any of these organisms is a concern however, they are effectively removed by the treatment process and are not seen in the finished water. Despite elevated counts at several tributary stations, a non-natural source could not be determined. It is likely that these values can be attributed to wildlife (*e.g.*, beaver) and waterfowl sources. Further investigation and monitoring upstream of the confluence of these tributaries is necessary to definitively identify the likely sources. The monitoring plan presented in **Appendix F** presents procedures to further confirm the presence of pathogens and tracing sources upstream from the point of detection. Mitigation of the sources, once determined, can be accomplished if they are determined to be anthropogenic or from domestic animals however, mitigation may be difficult if the source is determined to be wildlife.

At this point, beaver control (which is a long term and continuous process, if undertaken) probably isn't justified based on these water quality results. If intact, the beaver ponds provide the opportunity for nutrients and solids to settle before they get to the reservoirs. However, if significant flooding of property or the significant loss of trees either through beaver harvest or flood-related mortality from future higher water levels becomes a concern, beaver control should be considered. If beaver dams are large and unstable and are at risk of catastrophic failure, partial removal or installation of beaver pipes would be justified.

Table 5-2. Mean values of microbiological parameters in the Roaring Brook watershed in 2017.

Station	Depth	Fecal coliform (#/100 ml)	Total coliform (#/100 ml)	*E. coli* (#/100 ml)
Babbidge Deep Spot	0	5	96	8
Woodward Deep Spot	0	3	125	3
W-3	0	4	587	14
W-5	0	102	1108	152
W-6	0	35	1414	574
RB-1	0	5	810	10
RB-2	0	14	877	13
B-1	0	4	688	9
B-3	0	8	439	5

5.2.3 Other Drinking Water Parameters

Samples were analyzed for a suite of typical drinking water parameters in 2017. Mean values are presented in **Table 5-3,** and additional results are presented in **Appendix E**. These values were well within drinking water standards. Both iron and manganese (which can impact aesthetics of finished water) were relatively low. Slightly elevated iron values in the deeper waters of Babbidge are likely related to the loss of oxygen near the bottom and subsequent dissolution of sediment iron. Total organic carbon values were highest in tributary W-6 which is a fairly small tributary high in the watershed.

Table 5-3. Mean Values of Other Drinking Water Parameters in the Roaring Brook Watershed, 2017.

Station	Depth[1]	Nitrate + Nitite-N	Turbidity	Total Organic Carbon	Iron	Mn
Babbidge Deep Spot	Core	ND	0.4	4.0	0.2	0.0
Babbidge Deep Spot	Hypo				0.5	0.1
Woodward Deep Spot	Core	ND	0.3	3.8	0.1	0.0
Woodward Deep Spot	Hypo				0.1	0.1
W-3	0		0.1	2.8		
W-5	0		1.1	3.1		
W-6	0		0.6	8.0		
RB-1	0		0.1	3.6		
RB-2	0		0.2	4.1		
B-1	0		0.0	3.4		
B-3	0		0.1	5.9		

Note:
1 See explanation in Note 1 of Table 5-1.

5.3 Watershed and Reservoir Modeling

The project team estimated existing nutrient loads to Babbidge and Woodward reservoirs using well established nutrient load-lake response modeling (LLRM) techniques. The LLRM model is a linked watershed loading/lake response model that has been applied to over 50 lakes and watersheds in New Hampshire. To help establish baseline conditions and calibrate the model, discrete water quality samples and limnological measurements were performed during three sampling events and at critical times in the summer months. Samples were collected in the reservoirs and tributaries as described above. Complete sampling results are presented in **Appendix E**. The trophic related parameters used to calibrate the water quality model are presented in **Table 5-1** above. The model results were then used to evaluate scenarios that might produce a measurable change in algal production within the reservoirs. The modeling effort analyzed three scenarios:

- Build-out under current zoning,
- Potential effects of a staged multi-year timber harvest,
- Effects of a road maintenance program.

5.3.1 LLRM Model of Current Conditions

Current water and total phosphorus (TP) loading was assessed using the LLRM methodology, which is a land use export/lake response model developed for use in

New England and modified for New Hampshire lakes by incorporating New Hampshire land use TP export coefficients when available.

The direct and indirect nonpoint sources of water and TP to the Roaring Brook reservoirs include:

- Atmospheric deposition (direct precipitation to the reservoirs)
- Surface water base flow (dry weather tributary flows, including any groundwater seepage into streams from groundwater)
- Stormwater runoff (runoff draining to tributaries or directly to the ponds)
- Waterfowl (direct input from resident and migrating birds)
- Direct groundwater inputs

5.3.2 Hydrologic Inputs and Water Loading

Calculating TP loads to the Roaring Brook reservoirs requires estimation of the sources of water to the reservoirs. The three primary sources of water are: 1) atmospheric direct precipitation; 2) runoff, which includes all overland flow to the tributaries and direct drainage to the reservoirs; and 3) baseflow, which includes all precipitation that infiltrates and is then subsequently released to surface water in the tributaries or directly to the reservoirs (*i.e.*, groundwater). Baseflow is roughly analogous to dry weather flows in streams and direct groundwater discharge to the reservoirs. The annual water budget is broken down into its components in **Table 5-4**.

- **Precipitation** - Mean annual precipitation was assumed to be representative of a typical hydrologic period for the watershed. The annual precipitation value was derived from Streamstats (https://water.usgs.gov/osw/streamstats /new_hampshire.html). For the Roaring Brook Reservoirs watersheds, 1.08 m (42.5 in) of annual precipitation was used.

- **Runoff** - For each land use category, annual runoff was calculated by multiplying mean annual precipitation by basin area and a land use specific runoff fraction. The runoff fraction represents the portion of rainfall converted to overland flow. This was compared to the standard water yield for this area.

- **Baseflow** - The baseflow was calculated in a manner like that used for runoff. However, a baseflow fraction was used in place of a runoff fraction for each land use. The baseflow fraction represents the portion of rainfall converted to baseflow.

The hydrologic budget was calibrated to a representative standard water yield for New England (Sopper and Lull, 1970; Higgins and Colonell, 1970), verified by assessment of yield from various New England USGS flow gauging stations.

Table 5-4. Roaring Brook Reservoirs Annual Water Budget as Estimated Using LLRM[1]

Water Budget	Woodward	Babbidge
	m^3/yr	m^3/yr
Atmospheric	724,821	166,935
Watershed Runoff	803,009	1,488,808
Watershed Baseflow	1,542,369	5,504,003[1]
Total	3,070,200	7,159,746

Note:
1 Includes discharge from Woodward Pond.

5.3.3 Nutrient Inputs

Land Use Export

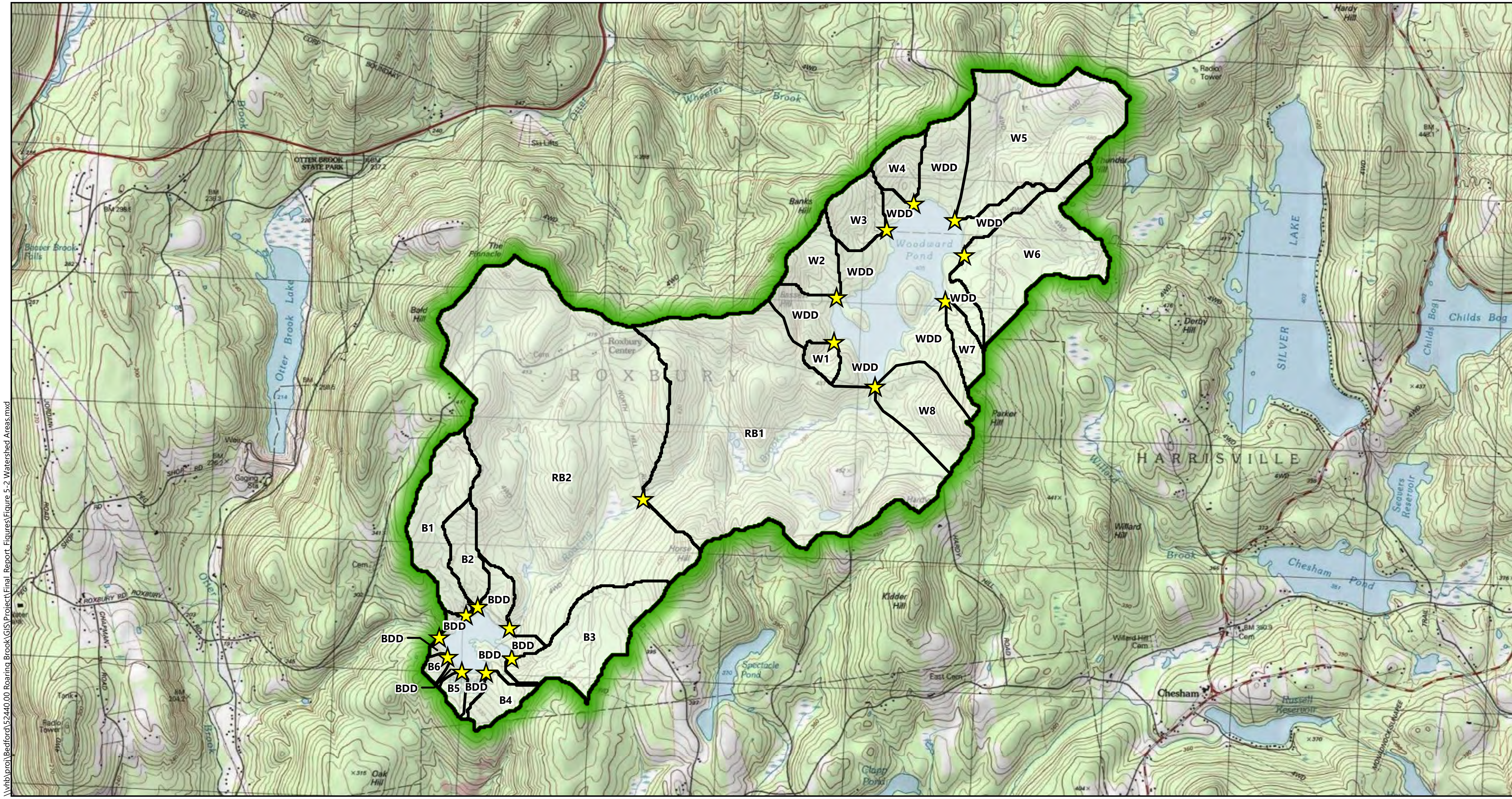
In developing the LLRM, the Roaring Brook watershed was divided into 18 sub-basins, as shown in **Figure 5-2**, each with their own characteristics**,** using a GIS database developed for this project. Land uses within the watershed were determined using GIS data (New Hampshire GRANIT 2017) and ground-truthing (when appropriate). Watershed land use is summarized in **Table 5-5**. The TP load for the watershed was calculated using export coefficients for each land use type. The watershed loading was adjusted based upon proximity to the reservoirs, soil type, presence of wetlands, and attenuation provided by natural features for water or nutrient export mitigation. The watershed load (baseflow and runoff) was combined with direct loads (atmospheric and waterfowl) to calculate TP loading. Because Woodward Pond is in the watershed for Babbidge, the modeled outflow concentration from Woodward is modeled as a point source to a subwatershed of Babbidge (RB 1). The generated loads to the reservoirs were then input into a series of empirical models that provided predictions of in-reservoir TP concentrations, chlorophyll *a* concentrations, algal bloom frequency, and water clarity.

Atmospheric Deposition

Nutrient inputs from atmospheric deposition were estimated based on TP coefficients for direct precipitation. The atmospheric load of 0.11 kg/ha/y includes both the mass of TP in rainfall and the mass in dryfall (*i.e.*, the delivery of nutrients from dry air). The coefficient was then multiplied by the reservoir areas (ha) to calculate an annual atmospheric deposition TP load.

Waterfowl

Total phosphorus load from waterfowl was estimated using a TP export coefficient and an estimate of annual mean waterfowl population. It was estimated that on average twenty waterfowl reside on Woodward Pond and five on Babbidge



0 1250 2500 5000 Feet

Roaring Brook Watershed (Above Babbidge Dam)

Sub-Watershed

Watershed Origin Point

Roaring Brook Watershed Management Plan

Watershed Delineation

Source: USGS Stream Stats, VHB, NHGRANIT

Reservoir. Waterfowl were assumed to be present for half of the year. The TP export coefficients used for waterfowl was 0.56 kg/waterfowl/y. Waterfowl loadings of nutrients are small relative to watershed loads.

Table 5-5. Land Use by Reservoir Watershed

Land Use	Woodward Pond		Babbidge Reservoir	
	ha	Percentage	ha	Percentage
Residential/Commercial/Industrial	3.1	0.8%	6.9	0.8%
Low Density Industrial	0.7	0.2%	0.0	0.0%
Hay/Pasture	10.3	2.6%	8.4	1.0%
Beech/Oak	161.5	40.5%	343.6	42.2%
Paper Birch/Aspen	12.6	3.2%	38.9	4.8%
Other Hardwoods	74.4	18.7%	65.0	8.0%
White/Red Pine	4.5	1.1%	21.4	2.6%
Spruce/Fir	5.0	1.3%	6.0	0.7%
Hemlock	6.6	1.7%	27.2	3.3%
Mixed Forest	100.6	25.2%	273.6	33.6%
Open Water	12.5	3.1%	6.2	0.8%
Forested Wetland	0.6	0.2%	0.0	0.0%
Open Wetland	1.1	0.3%	11.2	1.4%
Other Cleared	2.1	0.5%	0.0	0.0%
Roads	3.0	0.8%	5.2	0.6%
Total Area	399	100%	814[1]	100%

Note:
1 Does not include area of Woodward watershed

Internal Loading

Because the reservoirs do not show evidence of phosphorus accumulation in deeper waters during stratification, internal loading was not expected be a major TP source at this time and was not included in the model.

5.3.4 Phosphorus Loading Assessment Summary

The overall watershed of the Roaring Brook watershed consists of a mixture of rural, agricultural, and low density residential uses. Because of their relatively high nutrient export coefficients, the developed areas of the watershed tend to yield a larger portion of the nutrient load to the reservoirs. TP loads were estimated based on runoff and groundwater land use export coefficients. The TP loads were then attenuated based on natural features to match tributary monitoring data. Loads from the watershed as well as direct sources were then used to predict in-pond concentrations of TP, chlorophyll *a*, Secchi disk transparency, and algal bloom probability. The estimated load and in-reservoir predictions were then compared to in-reservoir concentrations from recent monitoring. The attenuation factors were used as calibration tools to achieve a close agreement between predicted in-reservoir TP and observed mean/median TP. However, perfect agreement between modeled concentrations and monitoring data were not expected as monitoring data are limited to one season, which may or may not have been representative of long term average conditions in the reservoirs. The estimated existing TP loads to each of the reservoirs by category are presented in **Table 5-6** and in detail in **Figures 5-3** and **5-4**.

Loading from the watershed was overwhelmingly the largest source of phosphorus to each of the reservoirs. The forest land cover yields the largest portion of the load but is overwhelmingly the largest percentage of the land cover. Roads and developed portions of the watershed make up a relatively small proportion of the watershed land cover but contribute disproportionately to the phosphorus load.

Table 5-6. Roaring Brook Reservoirs Modeled TP Loading Summary

Inputs	Reservoir TP loading			
	Woodward		Babbidge	
	(kg/y)	% of total	(kg/y)	% of total
Atmospheric	7.4	19	1.7	3
Internal	0.0	0	0.0	0
Waterfowl	5.6	14	1.4	3
Watershed Load	25.9	67	51.9[1]	94
Total	38.9	100	55.0	100

Note:
1 Includes load discharged from Woodward Pond

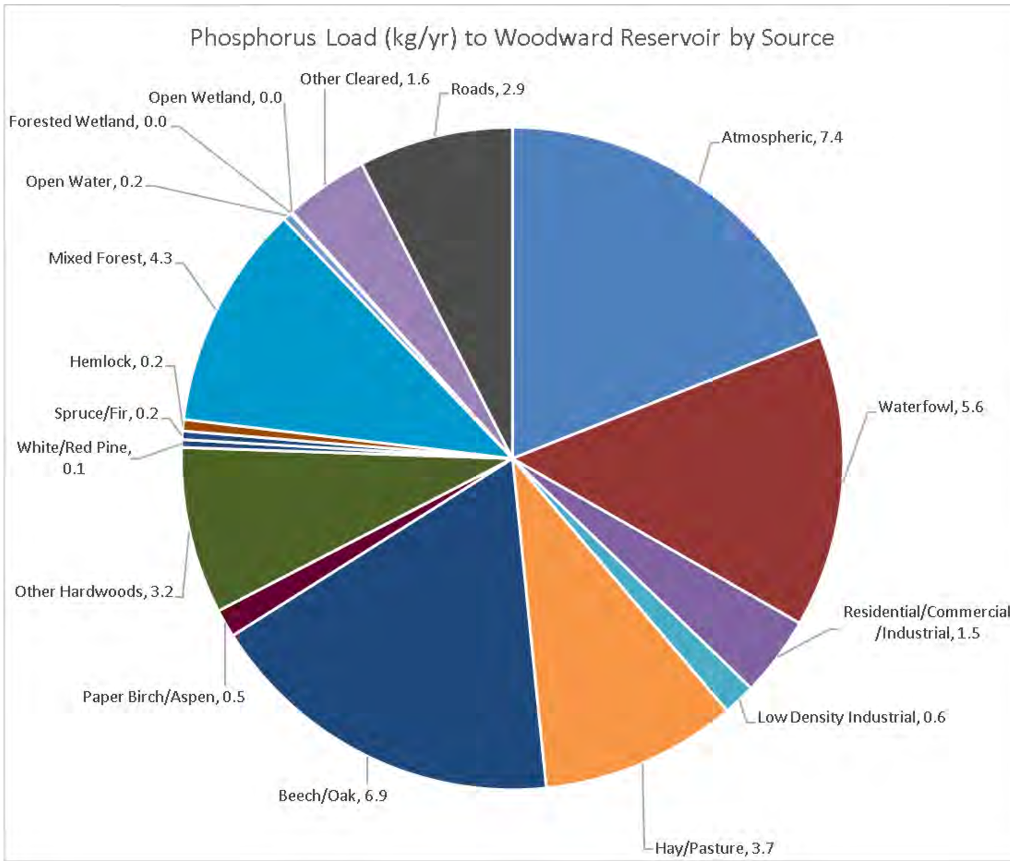
5.3.5 Phosphorus Loading Assessment Limitations

While the analysis presented above provides a reasonable accounting of sources of TP loading to the Roaring Brook Reservoirs, there are limitations to the analysis:

- 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.
- 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 model 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.
- TP export coefficients as well as runoff/baseflow exports were representative but also had limitations as they were not calculated for the study water body, but rather are regional estimates.

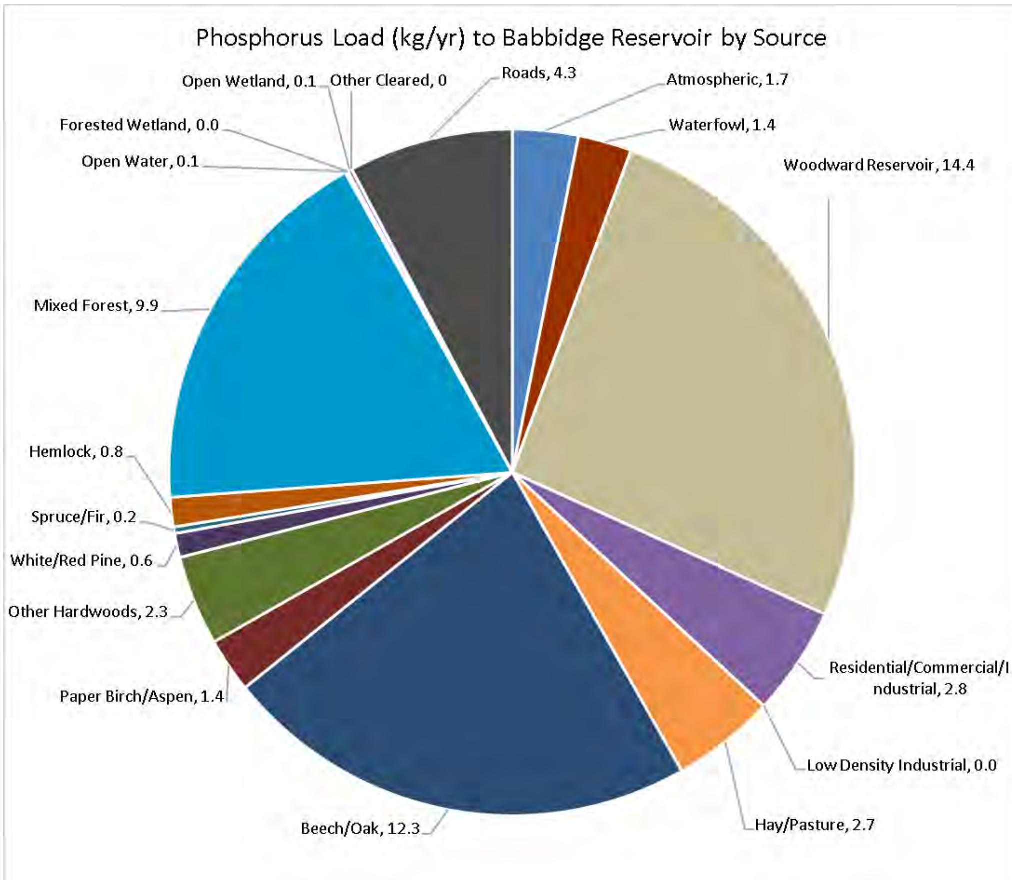
- Water quality data for the Roaring Brook watershed are limited to one full year with sparse data in one additional year, restricting calibration of the model.

Figure 5-3. Sources of Phosphorus to Woodward Pond



Note: Total load is 38.9 kg/yr.

Figure 5-4. Sources of Phosphorus to Babbidge Reservoir



Note: Total load is 55.0 kg/yr.

5.4 Reservoir Response to Current Phosphorus Loads

TP load outputs from the LLRM Methodology were used to predict in-lake TP concentrations using empirical models. The models include: Kirchner-Dillon (1975), Vollenweider (1975), Reckhow (1977), Larsen-Mercier (1976), Jones-Bachmann (1976) and Nurnberg (1998) for TP. These empirical models estimate TP from system features, such as depth and detention time of the waterbody. The load generated from the export portion of LLRM was used in these equations to predict in-reservoir TP. The mean predicted TP concentrations from these 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. Because these empirical models account for a degree of TP loss to the lake sediments, the in-reservoir concentrations predicted by the empirical models are lower than those predicted by a straight mass-balance where the mass of TP entering each reservoir is equal to the mass exiting each reservoir without any retention. Also, the empirical models are based on relationships derived from many other lakes and reservoirs. As such, they may not apply accurately to any one reservoir, but provide an approximation of predicted in-pond TP concentrations and a reasonable estimate of the direction and magnitude of change that might be expected if loading is altered. These empirical modeling results and mean field data are presented in **Table 5-7**.

In general, predicted nutrient concentration match field data for the Roaring Brook reservoirs (**Table 5-7**). Because freshwater systems are most frequently limited by phosphorus (field data confirms this is the case for the Roaring Brook reservoirs), calibration focused on matching predicted phosphorus with field data. In both reservoirs, the model somewhat under-predicts chlorophyll *a* levels but the predicted Secchi transparency is very close to observed in both reservoirs. Algal blooms with chlorophyll *a* concentrations greater than 10 µg/l are predicted 0.0% of the time in both reservoirs under current conditions. This matches the observations of Keene Department of Public Works staff persons responsible for managing the watershed; no algal blooms in either reservoir have been observed.

Table 5-7. Predicted and Measured Water Quality Parameters in Roaring Brook Reservoirs Under Current Conditions

Water Quality Parameter	Woodward Pond	Babbidge Reservoir
Predicted TP (µg/l)	6.1	6.1
Measured TP (2016-17) (µg/l)	5.9	6.0
Predicted Chlorophyll *a* (µg/l)	1.6	1.6
Measured Chlorophyll *a* (µg/l)	2.3	2.5
Predicted Secchi transparency (m)	5.7	5.7
Measured Secchi transparency (m)	5.9	5.2
Predicted probability of bloom (chl *a* > 10 µg/l) (% of time)	0.0%	0.0%

The TP loads estimated using the LLRM methodology translates to annual predicted mean in-reservoir TP concentrations of 6.1 µg/l for both reservoirs. These concentrations are very low and should not fuel substantial algal and plant growth. Transparency values should also remain high in both reservoirs if phosphorus concentrations remain low. The model should be updated to reflect current data every 5 years using data to be collected as a part of the monitoring program proposed in this plan.

5.5 Loading Scenarios & Land Management Strategies

To understand how various land management strategies could improve or impact water quality in Woodward Pond and Babbidge Reservoir, the LLRM model was used to evaluate four scenarios:

- A natural background scenario (representing the best possible water quality for the reservoirs);
- A road management program aimed at managing watershed roads to address some of the issues discussed in Chapter 3;
- A simulated 15-year staged forest harvest (based on a potential timber harvest program as discussed in Chapter 4); and
- A buildout of land within the watershed currently not owned by the City of Keene.

The modelling results can be used to better understand how each of these scenarios could affect water quality, whether beneficial or detrimental. This information, in turn, can help prioritize management actions designed to protect the watershed as a public resource.

The results of these models are presented in **Tables 5-8** and **5-9**, and are discussed in detail in the sections that follow.

Table 5-8. Predicted Water Quality Parameters Under Different Loading Scenarios for Woodward Pond

Scenario	Total Phosphorus Load (kg/yr)	Total Phosphorus (µg/l)	Chlorophyll *a* (µg/l)	Secchi Transparency (m)	Probability of Algal Bloom[1] (%)
Natural Background	29.5	4.6	1.1	7.1	0.0
Current Conditions	38.9	6.1	1.6	5.7	0.0
Road Management	38.7	6.1	1.6	5.8	0.0
Forest Harvest - Year 5	63.3	9.7	3.0	4.0	0.4
Forest Harvest - Year 10	42.3	6.6	1.8	5.4	0.0
Forest Harvest - Year 15	39.2	6.2	1.6	5.7	0.0
Forest Harvest - Year 20	39.2	6.2	1.6	5.7	0.0
Buildout	123.4	19.5	7.3	2.4	18.9

Note:
1 The probability of an algal bloom is the percentage of time where chlorophyll *a* is predicted to be greater than 10 µg/l.

5.5.1 Natural Background

This scenario is a representation of the best possible water quality for the Roaring Brook reservoirs and was generated by converting all watershed land use to forest.

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 reservoirs. Under this scenario, the reservoirs would have been expected to have total phosphorus concentrations approximately 1.5 μg/l lower than current conditions and continue to support a trophic classification of oligotrophic or very low productivity (**Tables 5-8** and **5-9**). Water quality would be excellent under this scenario.

Table 5-9. Predicted Water Quality Parameters Under Different Loading Scenarios for Babbidge Reservoir

Scenario	Total Phosphorus Load (kg/yr)	Total Phosphorus (μg/l)	Chlorophyll *a* (μg/l)	Secchi Transparency (m)	Probability of Algal Bloom[1] (%)
Natural Background	42.9	4.8	1.1	6.9	0.0
Current Conditions	55.0	6.1	1.6	5.7	0.0
Road Management	54.6	6.1	1.6	5.8	0.0
Forest Harvest - Year 5	73.5	8.1	2.4	4.7	0.1
Forest Harvest - Year 10	81.5	9.0	2.7	4.3	0.2
Forest Harvest - Year 15	87.0	9.5	3.0	4.1	0.4
Forest Harvest - Year 20	56.0	6.2	1.7	5.7	0.0
Woodward Watershed Buildout Only	85.8	9.6	3.0	4.1	0.4
Entire Watershed Buildout	203.6	22.9	8.9	2.1	31.4

Note:
1 The probability of an algal bloom is the percentage of time where chlorophyll *a* is predicted to be greater than 10 μg/l.

5.5.2 Road Management

As discussed in Chapter 3, the Roaring Brook watershed contains a number of Class V and Class VI roads, as well as unclassified paths. Some of these roadways are in very poor or failed condition; such road surfaces deliver a higher phosphorus load than forested areas due to greater runoff volumes and sediment transport. During recent watershed surveys, several roadway segments were observed to have eroded gullies within or along the side of the road where runoff was discharged directly to the nearby stream crossings. In some cases, culverts that conveyed tributaries beneath roads were damaged or were lacking, enabling vehicles to pass directly through the stream. This can result in short-term spikes in turbidity and nutrient loading due to the soil disturbance.

The amount of phosphorus contributed from roads depends a great deal on the erodibility of gravel surface due to steep slopes, soil types and the stormwater management controls. Roads with channelized flow due to eroded gullies that drain directly into streams have potential to contribute relatively high phosphorus loads compared to stable, well-maintained roads that produce sheet flow to the roadway edge. The rate at which sediment and associated phosphorus is delivered to tributaries and downstream reservoirs can have substantial effects on the loading from road surfaces.

In developing annual phosphorus load estimates from existing gravel roads within the watershed using the land use export model, a typical average annual load estimate of 1.0 kg/ha/year was used across the watershed. This average loading rate reflects observations made during road inventory field work which found that approximately 50% of the existing road surfaces were in a stable condition while the remaining 50% were observed to be experiencing some degree of erosion or culvert washout condition.

Efforts to restore and stabilize degraded or eroded roadway segments would result in lower phosphorus loads. Restoration efforts could include road regrading to eliminate gullies, establishing a crown on roads to allow runoff to disperse into nearby wooded areas and replacing culverts at stream crossings where culverts have been washed away.

Roads are the phosphorus source most easily managed on Keene-owned lands in the watershed. Road management can be expected to reduce phosphorous loads by as much as 20 to 65% for each road segment, depending on the BMPs employed.[16] Higher removal efficiencies are generally associated with BMPs that capture and infiltrate stormwater while the lower removal efficiencies are generally associated with stabilized flow-through BMPs such as grassed swales and level spreaders. For purposes of this analysis, we assumed a conservative 30% removal efficiency for future road restoration / maintenance activities that were assumed to occur on 50% of the estimated road area within the watershed.

Based on these assumptions, the road maintenance activity could result in a load reduction of approximately 0.2 kg/yr in Woodward Pond and 0.4 kg/yr in Babbidge Reservoir. The reductions, while modest on an annual average basis, would also make the roads more resilient to future extreme events.

5.5.3 Forest Management

A forest harvest scenario was developed to assess the reservoir water quality implications of a timber harvest on City-owned land. This model is based on the timber management considerations discussed in Chapter 4, which were incorporated into the modeling scenario as follows:

- Timber would be harvested from the whole watershed (except for buffers described below) over a 15-year period.
- Each harvested area, including temporary logging roads and landings, would recover within 5 years such that nutrient export would return to levels existing prior to harvest.

▼

16 The UNH Stormwater Center (2011) presented a summary of treatment efficiencies for similar roads in a study conducted in the Province Lake watershed in Wakefield, NH.

- Phosphorus export from harvest to recovery is linear.
- Softwood stands would be harvested early in the harvest.
- Hardwood stands would be harvested in later years.
- 70% of the softwoods and 50% of the hardwoods would be harvested in each stand.
- Class VI roads would be upgraded to Class V to support access and transportation.
- Each year's cut would require construction/grading to install 0.5 hectare (1.25 acres) landing and 1.5 hectares (3.75 acres) of new roads, assumed to be restored within 5 years after the harvest.
- The area to be harvested over 15 years is 996 hectares (2,462 acres), less buffers around water resources.
- No cut buffers were established within 300 feet from Roaring Brook and reservoirs.
- No-cut buffers were established within 100 feet from wetlands and streams other than Roaring Brook.
- Between 20 and 40 hectares (50-100 acres) were assumed to be harvested each year. In most years between 30 and 40 ha (75 to 100 acres) were assumed to be harvested.

For modeling purposes, the harvest schedule was developed based on guidance (Chapter 4) that recommends prioritization of softwood harvesting. The harvest schedule used in the simulation is found in **Table 5-10**. The model assumed that the harvest would generally proceed from upstream to downstream by subwatershed, and also assumed that adjacent subwatersheds were harvested together to keep the harvest units contiguous. Because RB1 and RB2 are the largest subwatersheds, harvesting within these areas would occur over a period of multiple years. Early year harvests in those subwatersheds correspond to softwood harvesting.

It should be noted that there are numerous possible harvest schedules. However, it is likely that alternative schedules, while resulting in potentially different timing of projected phosphorus and chlorophyll *a* concentrations in the reservoirs, would yield a similar maximum change if the alternative harvest is completed on a 15-year schedule. The area assumed to be cut in each year of our simulation was variable and dependent on the area of softwoods or hardwoods available in each subwatershed. Care was taken to keep harvest blocks in each year adjacent.

Results of the harvest scenario simulation are presented in **Figures 5-5** and **5-6**. The simulations predict increases in phosphorus and chlorophyll *a* and reductions in transparency in both reservoirs. A critical phosphorus concentration of 7.2 µg/l is shown on **Figures 5-5** and **5-6**. This number should be considered a maximum phosphorus value for the reservoirs to remain below the NH low nutrient or oligotrophic criteria (8 µg/l) with a 10% margin of safety. The harvest impact period is shorter in Woodward as the timing of harvest in the Woodward watershed is in the early years of the simulation. Because Woodward drains to Babbidge, projected changes to Woodward result in changes in Babbidge. In later years of the timber harvest scenario, harvest is restricted to subwatersheds downstream of Woodward, so Woodward recovers while water quality impacts are still projected for Babbidge.

The results indicate that timber harvesting increases the probability of algal blooms in each reservoir to a non-zero value, indicating some risk to water quality. This non-zero probability is predicted to be greatest (0.4% of the time, which represents an algal bloom approximately 1.4 days in a typical year) in Woodward Pond in Year 5, and in Babbidge in Year 15. The risk of an algal bloom persists for longer in Babbidge than Woodward due to the size of the Babbidge watershed.

We note that the model results are based on standard forestry practices. It is possible that a harvest using very low impact techniques could result in a lower impact on the reservoirs, while a poorly managed harvest could result in greater risk to the reservoirs.

Table 5-10. Year(s) of Harvest for each Roaring Brook Subwatershed (From Start of Harvest Period)

Subwatershed	Year(s) of Harvest
W1	3
W2	3
W3	3
W4	4
W5	4
W6	4
W7	5
W8	5
WDD	6
B1	14
B2	14
B3	14
B4	15
B5	15
B6	15
BDD	15
RB1	1,7,8,9,10
RB2	2,11,12,13

Figure 5-5. Predicted Trophic Parameters, Woodward Pond, 15-Year Forest Harvest

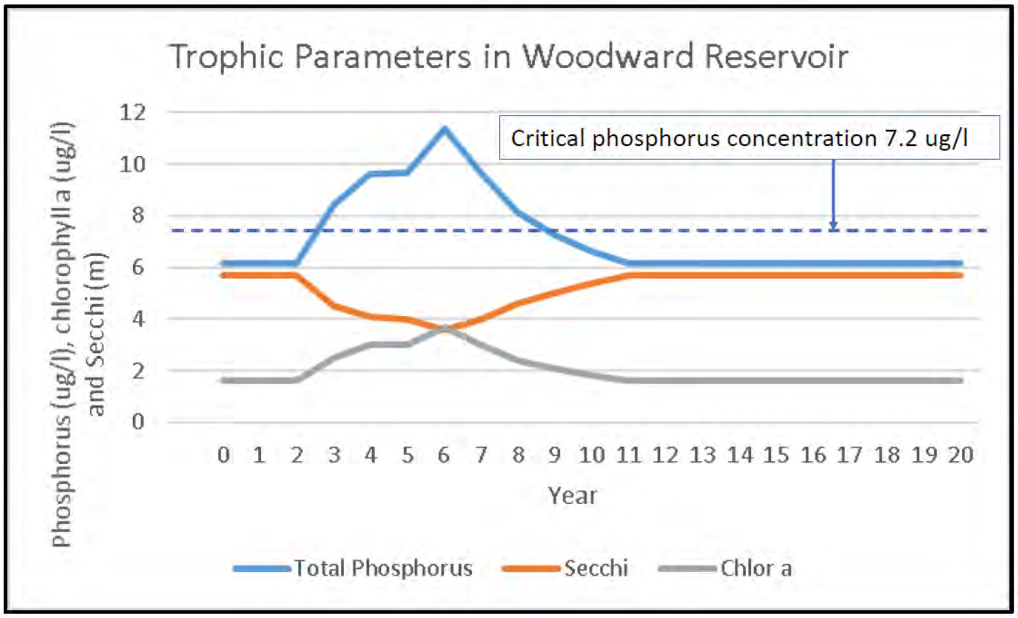
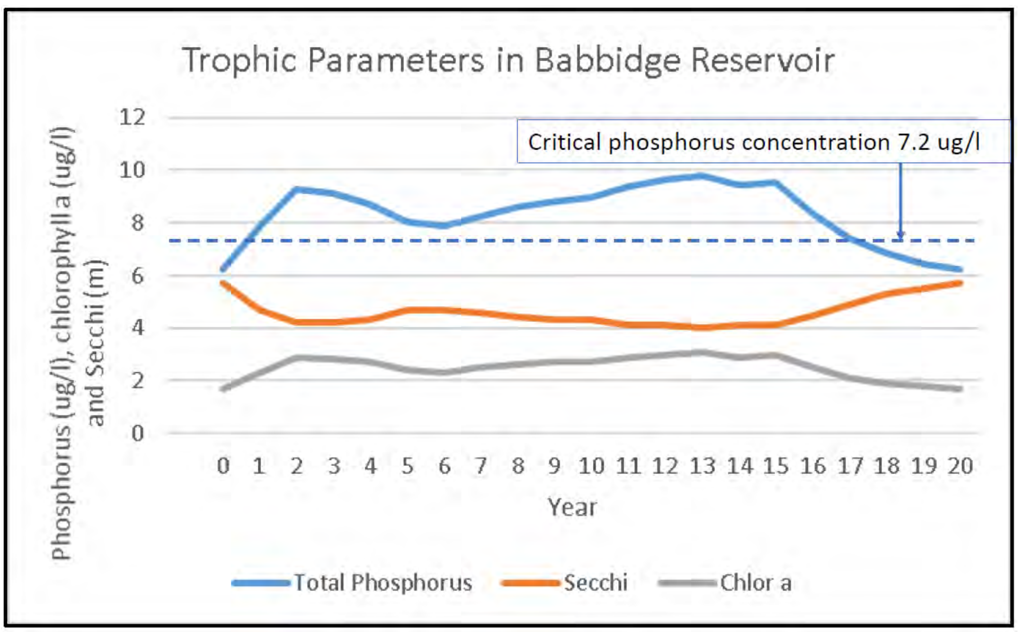


Figure 5-6. Predicted Trophic Parameters, Babbidge Reservoir, 15-Year Forest Harvest



5.5.4 Watershed Buildout

Nutrient loading from developed land is greater than forest land, and increased development and urbanization is associated with water quality degradation. Therefore, a model of the potential effects of land development on privately-owned lands within the Roaring Brook watershed was generated to assess the potential risk associated with future development. This "build out" scenario involved the following:

- Identification of all land within the Roaring Brook watershed that is not currently owned by the City or within a conservation easement, using the GIS database built for this project.
- Converting existing undeveloped forested and agricultural land not currently owned by the city or in conservation to low-density residential land use as is allowed under current zoning.
- Land conversion excluded wetlands and surface waters as well as areas of high slope (greater than 25%) but included parcels with insufficient road frontage (assuming that additional roads could be built to serve these areas).
- We assumed that future residential development would occur in a pattern and intensity like existing development within the watershed.
- We also assumed that future development would have similar levels of best management practices; future development would employ conventional approaches with no extraordinary BMPs or low impact development principles.

Projections of reservoir water quality under the watershed buildout scenario are presented in **Tables 5-8** and **5-9.** Under this scenario, reservoir phosphorus concentrations would be expected to increase three to four times relative to current levels to 19.5 μg/L for Woodward Pond and 22.9 μg/L for Babbidge. Chlorophyll *a* concentrations would increase significantly in both reservoirs and the probability of algal bloom conditions greater than 10 μg/L would be 18.9% of the time for Woodward and 31.4% of the time for Babbidge. Clearly, this scenario would result in unacceptable water quality in the Roaring Brook Reservoirs.

To determine the relative importance of Woodward Reservoir and its watershed to Babbidge water quality a scenario is presented in **Table 5-9,** which evaluates the impact of buildout of just the Woodward watershed on water quality in Babbidge. Because Woodward provides such a significant portion of the load to Babbidge, development of available land within the Woodward Pond sub-basin would result in an approximately 50% increase in the amount of phosphorus in Babbidge Reservoir. This scenario illustrates the potential effects on water quality even if only a portion of the Roaring Brook watershed is developed and highlights the value of considering additional land conservation.

These results suggest that the primary threat to water quality in the Roaring Brook watershed would be future land development on the portions of the watershed that are not under city ownership or subject to conservation easements. While the City's ownership and management of a large portion of the watershed has resulted in excellent water quality within the ponds, a substantial risk of future water quality degradation could result if substantial development within the non-conserved portion of the watershed occurs. This risk can be mitigated by employing improved best management practices for future development that reduce nutrient export from developed parcels, so the actual increases in loading might be lower than those projected. These management practices could include measures such as low impact development requirements for new projects or limitations on the density of development. However, more intensive land uses could also occur as allowed by current regulations, which would increase the loading estimates and associated risk of water quality impacts.

6

Discussion & Recommendations

6.1 Introduction

This section summarizes the major findings of the Roaring Brook watershed assessment, discusses recommended actions, and discusses potential revenue sources that could be used to fund future watershed work. A summary of the recommended actions with costs is provided in Table 6-1.

6.2 Water Quality

Key Findings

Water quality sampling demonstrates that Woodward Pond and Babbidge Reservoir are oligotrophic, and provide an excellent source of high water quality drinking water.

Currently, low phosphorus concentrations in both Woodward and Babbidge Reservoirs are not particularly favorable for algal growth. Phosphorus concentrations observed in both reservoirs are well below the New Hampshire criteria for oligotrophic (low nutrient) lakes. The calculated nitrogen to phosphorus ratio suggests that both reservoirs are highly phosphorus limited.

This emphasizes the need to control phosphorus as part of the watershed management plan as the best way to control algal growth and prevent eutrophication of the reservoirs. Chlorophyll *a* data from the reservoirs supports that contention, and Secchi transparency is relatively high. Phosphorus concentrations in the deeper waters of the reservoirs are somewhat higher than those observed in the surface waters but are not high enough to suggest widescale release of phosphorus from the sediments. Furthermore, the deep-water areas of both reservoirs are relatively small, restricting the area that could contribute to phosphorus release under anaerobic conditions.

Table 6-1. Summary of Recommended Actions with Preliminary Costs

Recommendation	Initial Cost	Annual Cost	Priority	Comment
The City should develop and implement a long-term water quality monitoring program.	$12,300	$22,000	High	Detailed water quality monitoring plan with cost estimate provided in Appendix F.
Preservation of additional lands within the watershed should be considered.	$15,000-$25,000	TBD	Medium	Cost of this program is dependent on the number of acres to be acquired and the type of acquisition (fee simple vs. easement). Because these factors are currently unknown, a total cost cannot be determined at this time. The initial cost is to develop identified specific target parcels, with support from a licensed surveyor and city legal staff.
The City should address erosion and sedimentation caused by recreational use of roads.	-	$2,000-$5,000	High	Costs assume that City staff would conduct maintenance, and annual costs are based on typical annual costs provided by the City.
The City should consider development of a forest management plan which would address harvesting timber from a portion of the watershed.	$15,000-$20,000	$200,000 - $250,000 (revenue)	Medium	Initial cost assumes professional forester to develop harvest plan. This recommendation is revenue positive once harvest begins.
The City should develop a long-term stewardship and monitoring program to be conducted on an annual basis to monitor and protect water quality and natural resources.	$18,000-$22,000	$1,500	Medium	Initial cost assumes consultant assistance to develop the stewardship and monitoring plan. Annual costs assume monitoring and update to plan conducted by City staff.
The City should commission a detailed survey of the property.	$15,000-$30,000	-	High	One time cost to develop the survey. Cost will be dependent on specifications.
The City should review the status of roadway classifications and consider petitioning for further discontinuances or re-classifications.	$2,500	-	High	One time costs to finalize research and for legal support if a petition is to be developed.

The City should take additional steps to monitor and secure the property.				
Signage/Gates at three uncontrolled access points	$4,500	-	High	Install vehicle barriers at Southern Access (near Oak Hill) and at Grimes Road and Horse Hill Road.
Additional watershed signage	$4,000	-	Medium	Assumes up to 200 signs along property boundary, installed.
Targeted Security at Key Infrastructure	$35,000-$79,000	-	High	Assumes approximately 1,200 LF of fencing, with access gates at $29-$66/LF, depending on final specification.
Additional Inspection Vehicle to Monitor the Watershed	$8,000-$12,000	$400	High	Cost to purchase a new side-by-side utility vehicle to allow watershed monitoring and operations.
The City should work with the Town of Roxbury and other stakeholders to improve education and awareness of the sensitivity and value of the watershed.	$500	-	High	Task would involve coordination time for City staff and production of printed materials.

Note: All costs are preliminary planning level estimates and subject to change as the specific implementation of the recommended action is further defined.

The primary threat to a continued high-quality water supply is potential future development of the watershed.

Of the total 3,157-acre watershed, the City of Keene owns 1,965 acres, with an additional 302 acres currently in conservation easements or owned by a conservation agency, and the remaining 890 acres are owned by private interests, with no known conservation restrictions. Thus, while approximately 72% of the watershed is protected, the remaining 28% could be developed in the future.

While water supply lands can accommodate low-impact development, modeling conducted as part of this study shows that a realistic build-out of the watershed could increase reservoir phosphorus concentrations by as much as three to four times current levels (19.5 μg/L for Woodward Pond and 22.9 μg/L for Babbidge Reservoir). Chlorophyll *a* concentrations would increase significantly in both reservoirs and the probability of algal bloom conditions greater than 10 μg/L would be 18.9% of the time for Woodward Pond and 31.4% of the time for Babbidge Reservoir. Under this scenario, algal blooms could occur within Babbidge Reservoir more than 100 days per year. Clearly, this scenario would result in unacceptable water quality in the Roaring Brook reservoirs and adversely impact the City's ability to supply water to its residents.

Additional risks to water quality include the potential for erosion from roads, and the potential for introduction of contamination or pathogens by recreational or illicit access to the property.

Recommendation Related to Water Quality

The City should develop and implement a long-term water quality monitoring program.

Based on the model results and baseline data collection, the project team recommends a long-term water quality monitoring program geared toward providing early detection of water quality changes, including nutrient monitoring, pathogen monitoring, and monitoring for cyanobacteria. The monitoring program should include recommended thresholds or action levels for both visual inspections and the collection of water quality data at critical areas. A future monitoring plan for the reservoirs, including a detailed cost estimate, is presented in **Appendix F**.

Preservation of additional lands within the watershed should be considered.

The absence of development on City-owned and abutting lands has created conditions favorable to excellent water quality. Permanent preservation of the remaining lands within the watershed would help to ensure continued high quality of this resource and mitigate the risk of future water quality degradation. The City should explore the potential for protecting additional lands, either through fee simple ownership, or through the acquisition of conservation easements. Partnerships with the Town of Roxbury or conservation organizations such as the Monadnock Conservancy or the Forest Society may be able to facilitate this program. (See below for potential funding opportunities.)

The City should address erosion and sedimentation caused by recreational use of roads.

Inventory and assessment of roads within the watershed indicates that current road conditions account for a minor, but disproportionate, amount of nutrient pollutant loading. This results primarily from recreational vehicles operating in a manner that creates erosion, particularly where culverts or bridges are lacking at tributaries to Roaring Brook. Notable unstable areas occur along Scholtz Road, Woodward Pond Road, Grimes Road, and a few other locations within the watershed. Water quality modeling indicates that addressing these eroded areas would have some benefit. This program should be limited in scope and should not require significant construction; a benefit would be derived by addressing a relatively small number of areas where substantial and active on-going erosion at watercourses is currently occurring. The objective of this program should be to address areas of severe and moderate erosion, especially in areas found to be in failed or poor condition. This program should not seek to expand these roads, but rather to ensure that erosion is fully managed and to install appropriate stream crossings (culverts or small spans) to reduce sediment loads to watershed tributaries.

6.3 Natural Resource Management

Key Findings

The City-owned land contains an exceptional timber resource, but the lack of a forest management plan has impacted its quality and value.

A timber inventory conducted as part of this study found that the property holds an exceptional volume of high value red oak (almost 11 million board feet), which is currently the most valuable hardwood species in New Hampshire. The property also holds a large volume of white pine. However, much of the white pine is unacceptable growing stock - they are of poor form due to many branches or crooked stems, they show signs of over-maturity in the form of reduced crown ratios, or they display signs of serious internal defect. This reflects the fact that the property lacks a timber management plan; timber has not been harvested from the property since the 1980s.

New England Forestry Consultants’ assessment estimates that the total timber on the Keene-owned property is almost 24 million board-feet, with a total value of $6.7 million. Of this total, New England Forestry Consultants estimates that the timber potentially available for harvest is approximately 13 million board-feet, with a value of approximately $3.3 million. This harvest would likely be staged over a period of 15 years, generating an average of $221,000 per year. This estimate is based on recent timber market conditions, and is subject to change.

As discussed elsewhere in this report, timber harvesting can help increase watershed yield (water quantity), but also presents risks to water quality that need to be carefully considered and managed.

The Roaring Brook watershed has very high ecological integrity.

Ecological resources within the watershed have a very high degree of integrity and value. The property contains a large block of unfragmented habitat that is ranked among the most valuable wildlife habitat in the state. The presence of a loon nesting site on Woodward Pond is notable. Invasive species are presently not a problem on the Keene-owned portion of the watershed. The limited public access, remote nature of the tract and its heavily timbered landscape, as well as conservation of abutting parcels, have preserved the ecological integrity of the forest and provide valuable habitat.

Recommendation Related to Natural Resource Management

The City should consider development of a forest management plan which would address harvesting timber from a portion of the watershed.

Forest management can provide benefits resulting from careful stewardship of watershed land: opportunities to increase water yield, generation of significant income (potentially $3.3 million), and benefits to the region's wildlife. A reasonable timber management plan would consider long-term forest management principles, the quality and accessibility of the various timber stands on the property, and account for aesthetic setbacks to nearby roadways and water quality buffers to Woodward Pond, Babbidge Reservoir, Roaring Brook, and other streams and wetlands.

The management plan must also balance the potential for water quality impacts; the water quality model developed as part of this study indicates that timber harvesting increases the probability of algal blooms in each reservoir to a non-zero value, indicating some risk to water quality. This non-zero probability is predicted to be greatest (0.4% of the time, which represents an algal bloom approximately 1.4 days in a typical year) in Woodward Pond in Year 5, and in Babbidge in Year 15. It is possible that a harvest using very low impact techniques could result in a lower impact on the reservoirs, while a poorly managed harvest could result in greater risk to the reservoirs.

The City should develop a long-term stewardship and monitoring program to be conducted on an annual basis to monitor and protect water quality and natural resources.

A stewardship and monitoring plan would provide a means for organized and systematic monitoring of the property. The plan should describe how the land is to be managed, who will be responsible for annual monitoring, how monitoring will be conducted including frequency, what data will be collected, and how observed problems or issues would be addressed. Annual monitoring by City staff could be conducted in conjunction with the Keene and/or Roxbury Conservation Commissions. The stewardship plan should also consider management of the notable natural resources on the property, including the loon population. Because preventing the establishment of invasive species is much more effective and costly than eradication, the City could use the stewardship plan to adopt practices to limit the potential their potential introduction.

This stewardship plan should develop policies for the management of wildlife. For example, if significant flooding of property or the significant loss of trees either through beaver harvest or flood-related mortality from future higher water levels becomes a concern, beaver control should be considered. If beaver dams are large and unstable and are at risk of catastrophic failure, partial removal or installation of beaver pipes would be justified.

6.4 Security & Public Access

Key Findings

Prohibition of public access to the watershed is important to protecting water quality.

Activity within the watershed creates a risk of water quality impacts from introduction of pathogens or contaminants into the reservoirs, whether through accidents, unintentional actions, or deliberate or negligent activity. The surface water treatment facility managed by the City can greatly reduce, but not completely eliminate, contaminants and pathogenic organisms. Thus, prohibiting public access and use of the City-owned property by posting it against trespass and ensuring compliance with this policy is an appropriate and reasonable measure to mitigate the risk to the water supply. The fact that the property is bisected by several Class VI roads (*i.e.*, public highways), however, introduces conflicts with this strategy.

While access points to the City-owned parcels are reasonably well controlled, its boundaries in general are not well marked.

Gates and signage are present at most of the entrances to the property, alerting the public to the restrictions in place to protect water quality. However, field work conducted as part of this study found that the condition of the boundary lines for the perimeter of the property was generally poor. Few sections of well blazed and marked lines were encountered, and relatively few signs exist along the perimeter of the property.

Recommendations Related to Access and Security

The City should commission a detailed survey of the property.

It is recommended that the City conduct a detailed property survey to better locate the property boundaries. This work would allow verification of the preliminary findings contained in this report regarding the status of public highways, and should include blazing and painting of the boundaries, with installation of witnesses on all corners for the entire perimeter (approximately 18.5 miles and 114+ corners), to clearly mark the property. Lines and corners clearly marked by blazing and painting the lines and witness trees at corners minimize the risk of boundary disputes in the future or a timber trespass resulting from confusion as to the location of the boundary. And, installation of signs along the boundary will help to educate the public about the sensitive resources present within the watershed.

The City should review the status of roadway classifications and consider petitioning for further discontinuances or re-classifications.

The City, working with the Town of Roxbury, should review the current understanding of the classification of the various roads and trails within the watershed. As needed, the City and Town should consider discontinuing or reclassifying certain roads or portions of certain roads. This could include re-designate sections of class VI roads where this would be appropriate.

The City should take additional steps to monitor and secure the property.

In addition to the resumption of regular patrols of the watershed, the following potential improvements to security practices should be considered:

- **Additional Signage/Gates:** While the most prominent road access points are currently controlled, access to the property from Class VI or private roads is not complete. Additional signage and gates should be considered at a minimum of three locations:
    - **Southern Access Point:** At the southwest boundary of the City-owned property, where an unclassified road provides access to Babbidge Reservoir and Dakin Road. Field observations indicate that this road is used by ATVs, which have caused some erosion and road damage. Because this road is likely a private way, prohibition of public access at this location is likely justified. Any new gate at this location should be capable of blocking ATV access while still

allowing access to authorized persons, especially as needed to maintain an airport beacon in this vicinity.

- **Grimes Road:** A portion of Grimes Road is used to access a private residence, and no gates are present on this road currently. Grimes Road was discontinued, subject to gates and bars, in 1939. Therefore, an additional gate on this road is warranted. The location of the gate should avoid interference with access to the private residence.

- **Horse Hill:** An unclassified road accesses the City-owned property near the height-of-land at Horse Hill. Evidence of recreational access was observed, including excessive erosion at the locations of intermittent tributaries along this road. The location is at the border of the City-owned property with a private conservation parcel, which has been posted. A small gate was previously in place in this location (presumably placed by others), but has fallen into disrepair and has been removed. Because this road is likely a private way, prohibition of public access at this location is likely justified.

- **Additional Perimeter Signage:** Boundary markings and perimeter signage is absent or lacking along most of the property. Additional signage along the boundary of the City-owned property would be useful to notify the public that the property and limit prohibited activity.

- **Targeted Security at Key Infrastructure:** Currently, limited fencing at the Babbidge and Woodward Dams allows the public to access these structures. Keene DPW staff report that previous unauthorized access to Babbidge Dam created damage to the earthen dam, and evidence of vandalism is present on structures at these locations. Due to the importance of these dams and the liability involved, additional security measures including secure fencing of these vulnerable points should be installed.

- **Additional Inspection Vehicle to Monitor the Watershed:** While the City has vehicles available for operations on the watershed property, these vehicles cannot access most of the watershed property because most roads and trails are not safely accessible to most cars and trucks. An all-terrain vehicle (utility side-by-side) should be acquired by the City to allow staff to access all portions of the watershed. This would allow for efficient regular monitoring of the property and help to ensure its proper management.

The City should work with the Town of Roxbury and other stakeholders to improve education and awareness of the sensitivity and value of the watershed.

The City has taken measures, in accordance with the NHDES rules regulating activity within the watershed, to prohibit public access to the watershed. Maintenance of the current practices is warranted. In addition, the City should develop a program, in consultation with Roxbury and other stakeholders, to further educate the public. Any additional security measures should be accompanied by an outreach program that broadly engages stakeholders. The target audience for this program should include Roxbury municipal officials, Roxbury residents, and other stakeholders including abutting landowners and regional recreational clubs such as the RSSC.

6.5 Potential Revenue Opportunities

Potential opportunities to generate funding for watershed management activities are outlined below.

Timber Harvesting

As discussed elsewhere, harvesting of timber could generate an estimated $3.3 million over the course of a 15-year period, or about $221,000 per year. This substantial revenue opportunity would more than offset the costs of watershed management activities.

NHDES Local Source Protection Grants

NHDES administers the Local Source Water Protection Grant program, which provides money to develop and implement programs to protect existing sources of public drinking water.[17] The grant award for any one project cannot be more than $20,000. However, applicants can submit applications for multiple projects in the same grant year. Local match funds are not required, but are considered during application scoring. These grant funds can be applied to several activities, including:

Planning: Grants can be used to identify appropriate protection measures, such as educational programs, programs to ensure implementation of BMPs, local land use regulations, groundwater reclassification, adoption of source water protection rules under the provisions of RSA 485:23, and planning for land acquisition.

Implementation: Grants can be used to implement protection and security measures in source water protection areas. Grants can be used to prioritize lands for conservation but cannot be used to purchase lands or easements. Grants can be used for land transaction costs associated with permanent protection of Source Water Protection Area (SWPA), such as: performing land surveys as a precursor to land acquisition, associated legal and transaction costs (including required stewardship fees in accordance with a conservation organization's written policy regarding such fees), title opinion, attorney fees, baseline documentation, and stewardship plans.

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[17] See https://www.des.nh.gov/organization/divisions/water/dwgb/dwspp/index.htm for more information on NHDES grant opportunities.

Grants can also be used for source sustainability (*e.g.*, preserving groundwater recharge) and "consumption-side" water conservation (*e.g.*, community-based social marketing, customer audits, low-flow fixtures) but not for projects eligible for loans under the Drinking Water State Revolving Fund, such as "system-side" conservation (*e.g.*, leak detection, system audits, and metering).

Security: Grants can be used to implement security measures, as long as the project protects the source itself. This can include fencing around wells or intakes. The fencing can include other buildings as well, as long as the source is part of the fenced-in area. Gates for well and intake access roads are eligible, along with access control for those areas. Alarms, signs, cameras, locks, and lights for sources are also eligible. Applications for security implementation projects should include a detailed cost breakdown identifying components that will protect sources and those that will protect other portions of the water system. Grants cannot be used to implement security measures unless the source is directly protected as a result of the project.

NHDES Water Supply Land Protection Grants

Funding assistance to acquire land or obtain easements is available from the Water Supply Land Conservation Grant Program. New Hampshire municipalities and non-profit 501(c)(3) organizations having water supply or land conservation as a principal mission are eligible to apply. The land must be within a SWPA for an existing, proposed, or future water supply and it must be from a willing seller. The amount of funding varies each year, and the program is competitive. NHDES normally provides 25% of total project costs. Match sources can include donated land or easements that also lie within the SWPA, public funds, donated transaction expenses, or private funds. Grants issued from 2003 through 2014 have averaged about $170,000 per project.[18]

NH Drinking Water and Groundwater Trust Fund

The NH Drinking Water and Groundwater Trust Fund is another grant available through NHDES. This grant, established under RSA 485-F, is available for various kinds of water supply projects including those that protect water supply land. Funds for the grant came from a lawsuit won by the State of New Hampshire regarding negative impacts from gasoline additive manufacturers on the state's groundwater and drinking water resources. A commission of nineteen (19) diverse and qualified members decide how the funds should be disbursed on a quarterly basis. The commission also monitors the projects being completed under the grant. Grants that have been awarded over the last two years ranged from $10,000 to $2,500,000.

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[18] NH Department of Environmental Services. 2014. Water Supply Land Protection Grant Program – Sixth Report. June 2012 – July 2014.

Drinking Water and Groundwater Trust Fund grants are available to municipalities or municipality-owned water utilities, as well as privately owned water utilities associated with public water supplies. Projects involving contaminated soil or groundwater are not eligible for this grant; however, projects involving contaminated surface waters can still apply. Applicants for projects including land preservation are encouraged to provide matching funds. Each project is evaluated against selection criteria and established funding qualifications.

7

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Appendices A through G

Appendix A

NH Safe Drinking Water Act, RSA 485:23 and RSA 485:24

TITLE L
WATER MANAGEMENT AND PROTECTION

CHAPTER 485
NEW HAMPSHIRE SAFE DRINKING WATER ACT

Water Pollution Control

Section 485:23

485:23 Petition to Protect Water Supplies. –
I. Whenever any board of water commissioners, local board of health, local health officer or 10 or more citizens of any town or city have reason to believe that a public water or ice supply is being contaminated or is in danger of contamination, and that the local regulations are not sufficient or effective to prevent such pollution, they may petition the department to investigate the case, and to adopt rules under RSA 541-A as the department may deem necessary for the protection of the said supply against any pollution that in its judgment would endanger the public health. Citizens petitioning under this section shall designate a signatory of the petition as the person to whom the department shall send its response.
II. Whenever any board of water commissioners, local board of health, or other owner of a public water supply has reason to believe that a public water supply is in danger of being contaminated or is otherwise threatened and that an emergency condition exists such that a petition pursuant to paragraph I to the department and the adoption of rules would not adequately protect the water supply, the board or owner may petition the governor to declare a state of emergency for the public water supply. At the request of the governor, the department shall consult with the owner of the water supply and make a recommendation as to emergency protections that may be necessary. If the governor declares a state of emergency for a public water supply, those additional protections that the governor deems necessary shall be effective immediately and for the duration of the emergency. The declaration of a state of emergency for a public water supply shall not exceed 6 months. The governor may renew the declaration one time for up to 6 additional months upon further request by the original petitioner. At such time as any of the emergency protections are to become permanent, the department shall initiate rulemaking in accordance with RSA 485:24. Any protections in the governor's declaration shall be enforced in the same manner as rules adopted pursuant to RSA 485:24 or RSA 485:25 with violations of the protections subject to RSA 485:4 and RSA 485:58.

Source. 1989, 339:1. 1996, 228:106. 2002, 141:1, eff. May 13, 2002.

TITLE L
WATER MANAGEMENT AND PROTECTION

CHAPTER 485
NEW HAMPSHIRE SAFE DRINKING WATER ACT

Water Pollution Control

Section 485:24

485:24 Investigations; Rules. –
I. The department shall respond in writing to a petition filed under RSA 485:23, I, after due investigation, but not later than 30 days after receipt of the petition, informing the petitioners of the department's intended action. In response to a petition, or upon its own motion, the department shall adopt such rules under RSA 541-A as it may deem best to protect the water or ice supply against any dangerous contamination. If requested by the department, the local board of water commissioners, the local board of health, or the local health officer, shall enforce such rules in cooperation with the department.
II. In the case of water supplies any part of which may be outside the town or city concerned, the health officer of such town or city may act as an agent of the department for the enforcement of these rules when so designated by the department. The department may empower the board of water commissioners, local board of health, or local health officer and their agents of the affected municipality to enforce rules adopted under the provisions of this section.

Source. 1989, 339:1. 1996, 228:106. 2002, 141:2, eff. May. 13, 2002.

Appendix B

Correspondence between Keene and Roxbury

RCD 4/11/97

TOWN OF ROXBURY
OFFICE OF THE SELECTMEN
MIDDLE TOWN ROAD
R.F.D. KEENE, NEW HAMPSHIRE 03431
TELEPHONE: 352-4903

4/9/97

To Curt Blumquist
KEENE WATERWORKS

On Sep. 9, 1996 the town of Roxbury adopted R.S.A.s 236:38 through 236:47 which give the Selectmen the athourity to post and also gate roads to protect them from damage.

You certainly have our permission to erect 3 gates; two on Woodward Pond Road and one Horse Hill Rd.

Our Fire Chief Dick Donohue be will be happy to show you where to put the gates. Also we obviously will need keys.

Peter Stubbles[?] - Head Selectman
Roxbury.

City of Keene

580 Main Street New Hampshire 03431-4037

August 12, 1997

Mr. Peter Stuhlsatz, Chairman
Board of Selectmen
Town of Roxbury
Middletown Road, RR 4
Roxbury, NH 03431

RE: City of Keene Watershed Gate Locations

Dear Mr. Stuhlsatz:

Since receiving your letter of April 9, 1997, the Public Works Department has been reviewing locations to erect three (3) gates on various roads that access the City of Keene public water supply watershed. Attached is a map of the proposed locations for the gates. The Water Division has marked out these locations on the road for your review. If you would like to visit the sites with Department personnel, please contact Mike Stankovich, Deputy Director/ Utilities Manager, at 357-9836, Ext. 11. He is coordinating the project for me. Please determine the number of keys needed for the gates and to whom they are to be distributed.

Last fall, the Selectmen asked about any rules that may exist on permitted activities on the waters of Babbidge and Woodward Reservoirs. I have attached a copy of New Hampshire Department of Environmental Services (NHDES) Administrative Rule Env-WS-386, concerning surface water protection rules. If you have any questions concerning this information, please feel free to contact me at 352-6550. I look forward to hearing from you regarding the gates.

Sincerely,

Kürt Blomquist, P.E.
Public Works Director

c: Alfred Merrifield, Assistant City Manger/Health Director
Michael Stankovich, Deputy Director/Utilities Manager
Richard Donahue, Fire Chief, Town of Roxbury – Branch Rd RR4 Roxb 03431

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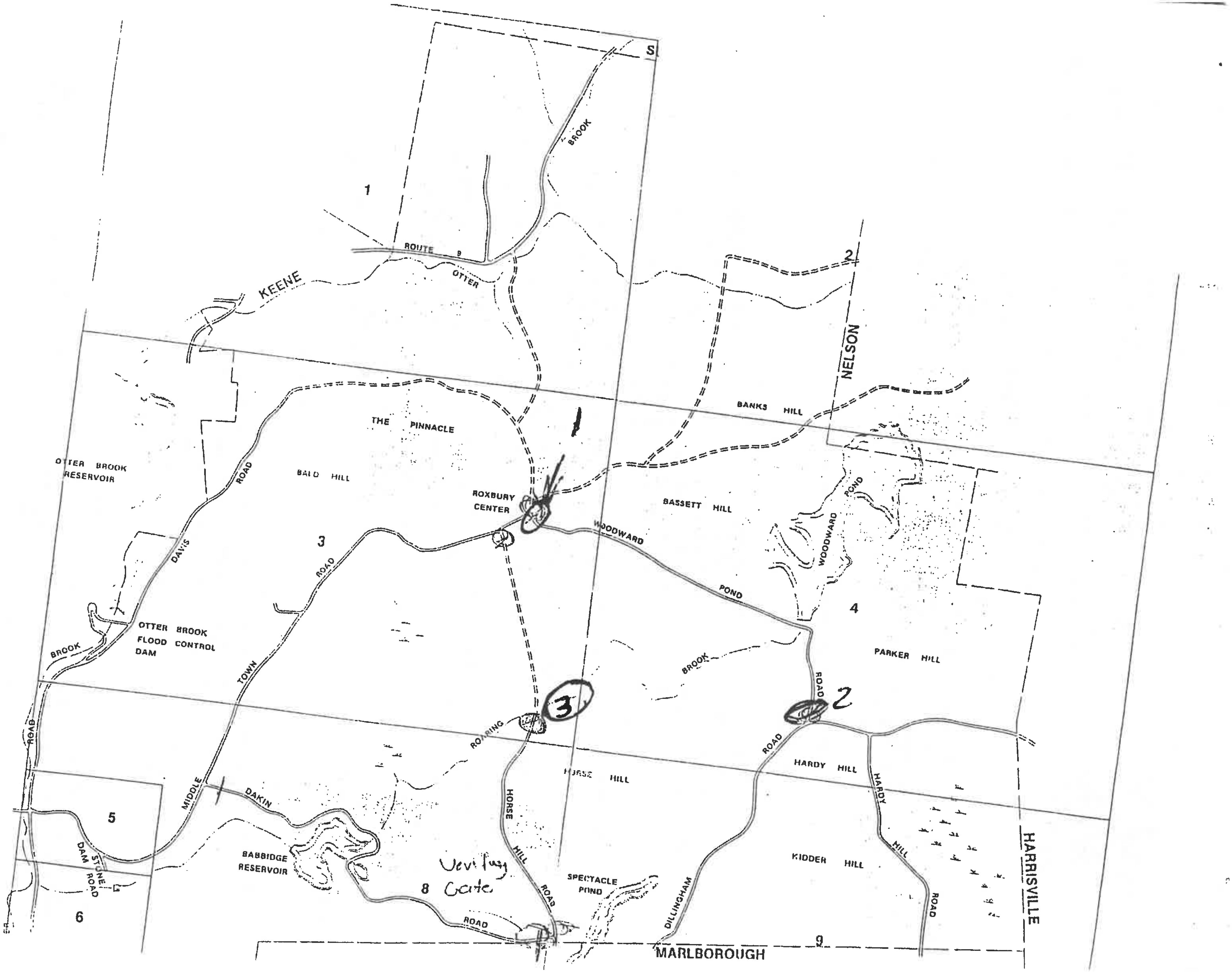
Phone

Mayor 357-9804 • Manager 357-9804 • Accounting 352-1013 • Airport 357-9835 • Assessor 352-2125 • Attorney 357-9806
Building Maintenance 357-9844 • City Clerk 352-0133 • Equipment Garage 357-9831 • Fire 357-9861 • Health 352-5440 • Human Resources 357-9858
Human Services 357-9809 • Information Management Services 357-9802 • Inspections 352-5440 • Juvenile Conference Committee 357-9810
Landfill & Recycle/Transfer Station 352-5739 • Parks & Recreation 357-9829 • Planning 352-5474 • Police 357-9815 • Public Works 352-6550
Purchasing 357-9800 Tax Collector 357-9801 • Water Treatment Facility 357-8483 • Wastewater Treatment Plant 357-9836 • Water & Sewer 352-3239

FAX

Airport 357-9853 • City Hall 357-9847 • Fire 358-3420 • Landfill & Recycle/Transfer Station 352-8325 • Library 352-1101 • Police 357-9823
Public Works 357-9848 • Wastewater Treatment Plant 357-9854

Area Code 603


KEENE
NELSON
HARRISVILLE
MARLBOROUGH
ROUTE 9
OTTER BROOK
BANKS HILL
THE PINNACLE
BALD HILL
BASSETT HILL
ROXBURY CENTER
WOODWARD POND ROAD
WOODWARD POND
PARKER HILL
OTTER BROOK RESERVOIR
DAVIS ROAD
TOWN ROAD
OTTER BROOK FLOOD CONTROL DAM
BROOK ROAD
BROOK
ROARING BROOK
HORSE HILL
HORSE HILL ROAD
HARDY HILL
HARDY HILL ROAD
KIDDER HILL
DILLINGHAM ROAD
MIDDLE DAKIN ROAD
BABBIDGE RESERVOIR
SPECTACLE POND
STONE DAM ROAD
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PART Env-Ws 386 RULES FOR PROTECTING THE PURITY OF REGULATED WATERSHEDS

Statutory Authority: RSA 485:23 and RSA 485:24

Env-Ws 386.01 Purpose. The purpose of these rules is to recognize the importance of those surface water supplies that are used as sources of public water supply and to provide methods for reasonable watershed management so as to maintain high levels of water quality.

Env-Ws 386.02 Applicability to Regulate Watersheds. These rules apply only to the particular watershed identified in the introductory paragraph(s) of each section. The rules in Env-Ws 386.01 through Env-Ws 386.04 apply to Env-Ws 386.10 through Env-Ws 386.68.

Env-Ws 386.03 Restriction of Activities Beyond The Setback From Streams and Shorelines.

(a) Many of the watershed rules in Env-Ws 386.10 through Env-Ws 386.68 restrict activity beyond the shoreline setback if such activity, in the division's judgement, would endanger water quality.

(b) Criteria for determining that an activity beyond the shoreline setback can endanger water quality shall be:

(1) Type of contaminant;

(2) Amount of contaminant generated by the activity;

(3) Persistence of the contaminant;

(4) Distance from the contaminant locus to water supply intake; and

(5) Application of best management practice (BMP) or best available treatment (BAT).

Env-Ws 386.04 Waivers.

(a) A waiver of a restriction in any one watershed may be sought.

(b) Such waiver shall be evaluated as follows:

(1) All requests for waivers shall be submitted to the division.

(2) Each request for a waiver and determination of essential compliance shall include the following information:

a. A specific reference to the paragraph of the section for which a waiver is being sought;

b. A full explanation of why a waiver is necessary and demonstration of hardship caused if the rule is adhered to;

c. A full explanation of the alternatives for which a waiver is sought, with backup supporting data; and

d. A full explanation of how the granting of the waiver is consistent with the intent of RSA 485:24 and RSA 485:25 and would have a just result.

(3) The division shall approve a request for waiver upon finding that:

a. The proposal shall be at least equivalent to the specific requirement contained in the rule; or

b. If the proposal was not equivalent to the requirement contained in the rule, it shall be adequate to ensure that the intent of RSA 485:24 and RSA 485:25 is met.

(c) No waiver shall be granted which, in the judgement of the division, contravenes the intent of the rules.

(d) Waivers granted in writing as part of the approval, shall expire with the approval and shall be transferrable with the approval.

(e) The applicant shall complete a formal waiver request which contains all of the above requirements. The owner shall co-sign and acknowledge agreement and consent to all waiver requests.

Env-Ws 386.05 through Env-Ws 386.09 RESERVED.

Env-Ws 386.36 Protection of the Purity of Woodward Pond, Roaring Brook, Babbidge Reservoir and Their Watershed.

(a) The purpose of this rule is to protect the purity of water of Woodward Pond, Roaring Brook, Babbidge Reservoir and Stone Dam Reservoir which is the principle drinking water supply for the city of Keene.

(b) This section shall be effective within the Woodward Pond, Roaring Brook, Babbidge Reservoir and watershed above the dam which is located at approximate latitude 42°56'00", longitude 72°13'15", in the towns of:

(1) Harrisville;
(1) Marlborough;
(2) Nelson; and
(2) Roxbury.

(c) Any person violating these rules shall, in accordance with RSA 485:26, be guilty of a misdemeanor if a natural person or guilty of a felony if any other person.

(d) Under the provisions of RSA 485:24, the city of Keene and its agents may enter at reasonable times any land or property within the drainage areas associated with the tributaries to the public water supply in the towns of Harrisville, Marlborough, Nelson and Roxbury for the purpose of investigating watershed sanitation and other sources of potential water contamination.

(e) Where any provision of these rules is in conflict with state law or other local ordinances, the more stringent provision shall apply. These rules shall not amend or alter any federal or state law or rule or local ordinance or rule.

(f) Any deviations from these rules shall be by written consent of the division and the city of Keene, in accordance with Env-Ws 386.04. These provisions shall not apply to employees of the city of Keene engaged in the performance of necessary duties for the protection and control of said pond.

(g) The city of Keene shall post a summary of the prohibitions contained in (h) below at all public access locations where persons might reasonably be expected to access Woodward Pond, Roaring Brook, Babbidge Reservoir and or its tributaries. This posted summary may also contain any prohibitions enacted by local ordinance.

(h) These restrictions shall include:

(1) A person shall not build, continue or maintain any buildings or structures of

any kind in which humans reside or in which animals or fowl are kept, within 75 feet, of the high water mark of Woodward Pond, Roaring Brook, Babbidge Reservoir, or within, 75 feet of any stream tributary thereto;

(2) A person shall not permit any wastes or water that has been used for either washing or cleansing of materials, persons, or food to run into said pond or into any inlet or tributary thereto;

(3) A person shall not throw or deposit any dead animal, fish or parts thereof, food or any article perishable or decayable, or any excreta either human or animal, into said waters, or leave or permit any such wastes to remain on the surface of the ground where there is any likelihood of wash or contamination there from reaching said ponds, brooks or reservoirs or any inlet or tributary thereto;

(4) A person shall not throw any sawdust, or allow any sawdust to fall, into said waters or into any inlet or tributary thereto;

(5) A person shall not boat, bathe, swim, trap, fish, hunt, camp, park trailers or carry on any activity of a recreational or other nature, including but not limited to lumber operations in or near the waters of Woodward Pond, Roaring Brook, Babbidge Reservoir and, above the reservoir dams and the streams tributary thereto; and

(6) A person shall not throw, deposit or allow to remain upon the ice of the waters of said waters pond, or upon that of any inlet thereof, or of any stream tributary thereto, any matter, waste, or materials such as are described in (2), (3) and (4) above.

Appendix C

Timber Harvesting Data

Table III

Diameter Distribution of Sawtimber Volume by Species City of Keene "Roxbury" Watershed February 2017

Volume (Sawtimber)	DBH (inches)											% of Total
Species	12	13	14	15	16	17	18	19	20	21	20"+	Tract Total	volume
aspen			-		-							-	
beech	6,569	8,510	11,248	13,397	48,196	-	15,419		-		-	**103,338**	**0.4%**
black birch	3,822		5,154		1,984							**10,960**	**0.0%**
black cherry	3,034		5,058	5,110	11,836	11,091	7,710		21,343			**65,181**	**0.3%**
hemlock	121,851	7,335	222,472	68,312	333,803	79,478	345,811	68,932	145,784	71,653	319,542	**1,784,974**	**7.5%**
northern red oak	325,324	188,855	1,128,484	642,968	1,536,010	700,849	1,584,795	327,207	1,284,253	398,592	2,714,374	**10,831,711**	**45.2%**
red maple	44,217	4,263	140,075	55,846	202,554	79,310	95,628	-	79,190		94,911	**795,996**	**3.3%**
red pine	14,054	3,667			61,606							**79,327**	**0.3%**
red spruce	34,531		11,602	6,779		12,941	14,784		23,576		26,567	**130,780**	**0.5%**
sugar maple	15,169	2,132	34,441	5,110	44,898	13,569	36,459	16,748	-	17,900	28,381	**214,806**	**0.9%**
white ash	12,637		59,284	23,778	44,743	48,064	25,696	16,748	47,125	18,070	19,851	**315,996**	**1.3%**
white birch	6,067		11,961	5,110	9,341	-	12,643	-				**45,122**	**0.2%**
white pine	114,743	36,319	228,318	195,051	425,729	174,095	828,715	286,263	965,292	363,391	5,768,756	**9,386,672**	**39.2%**
yellow birch	16,674	4,263	31,912	22,108	21,650	17,876	38,340	17,385	8,878			**179,087**	**0.7%**
Tract Total	**718,692**	**255,345**	**1,890,009**	**1,043,568**	**2,742,349**	**1,137,273**	**3,006,001**	**733,285**	**2,575,442**	**869,605**	**8,972,382**	**23,943,951**	**100%**
% of total volume	**3%**	**1%**	**8%**	**4%**	**11%**	**5%**	**13%**	**3%**	**11%**	**4%**	**37%**	**100%**	
cumulative total	**3%**	**4%**	**12%**	**16%**	**28%**	**33%**	**45%**	**48%**	**59%**	**63%**	**100%**		
DBH Group	**Small 12-14" DBH**			**Medium 15-18" DBH**				**Large 19"+DBH**					
Group % of Total Volume	**12%**			**33%**				**55%**					

Table IV

Harvest Income Projections, 2017-2032

City of Keene "Roxbury" Watershed February 2017

DBH Group	Small, 12-14" DBH	Medium, 15-18" DBH	Large 19"= DBH	Total
Hardwood	2,069,154	5,382,086	5,110,958	12,562,198
Softwood	794,891	2,547,105	8,039,756	11,381,753
Total	2,864,045	7,929,191	13,150,714	23,943,951
	Percent of Volume Proposed for Harvest by Group			
Hardwood	20%	30%	60%	
Softwood	70%	70%	70%	
	Estimated Volume, BD FT			Total
Hardwood	413,831	1,614,626	3,066,575	5,095,031
Softwood	556,424	1,782,974	5,627,829	7,967,227
	970,255	3,397,599	8,694,404	13,062,258
% of total sawtimber volume	4%	14%	36%	55%
	2017 Stumpage Price (blended for all species); $/mbf			
Hardwood	$400.00	$440.00	$460.00	
Softwood	$130.00	$130.00	$130.00	
	Estimated Harvest Value			Total
DBH Group	Small, 12-14" DBH	Medium, 15-18" DBH	Large 19"= DBH	
Hardwood	$165,532	$710,435	$1,410,624	$2,286,592
Softwood	$72,335	$231,787	$731,618	$1,035,740

Estimated Harvest Income, 2017-2032 $3,322,332

Percent of Total Sawtimber Value 50%

Estimated Income per Year, 2017-2032 $221,489

Table V

Per Acre Data by Species
City of Keene "Roxbury" Watershed
February 2017

Stand: 1: 2,455 acres							
Species	Basal Area	Trees/ Acre	QMD	Tons/ Acre	Total Tons	Bd Ft/ Acre	Total MBF
northern red oak	39	25	17	41.7	102,392	4,412	10,832
white pine	24	11	20	29.9	73,428	3,823	9,387
hemlock	8	5	16	7.8	19,105	727	1,785
red maple	5	4	16	4.2	10,228	324	796
sugar maple	2	1	17	1.4	3,558	87	215
white ash	1	1	16	1.2	3,012	129	316
yellow birch	1	1	15	0.8	1,878	73	179
beech	1	1	16	0.8	2,057	42	103
white birch	1	0	15	0.5	1,177	18	45
red spruce	0	0	15	0.4	969	53	131
black birch	0	0	13	0.3	643	4	11
black cherry	0	0	16	0.3	670	27	65
red pine	0	0	14	0.2	582	32	79
aspen	0	0	15	0.1	155	-	-
Stand Total	**83**	**50**	**17**	**89.6**	**219,854**	**9,753**	**23,944**

Table VI

Sampling Statistics CI 90%
City of Keene "Roxbury" Watershed
February 2017

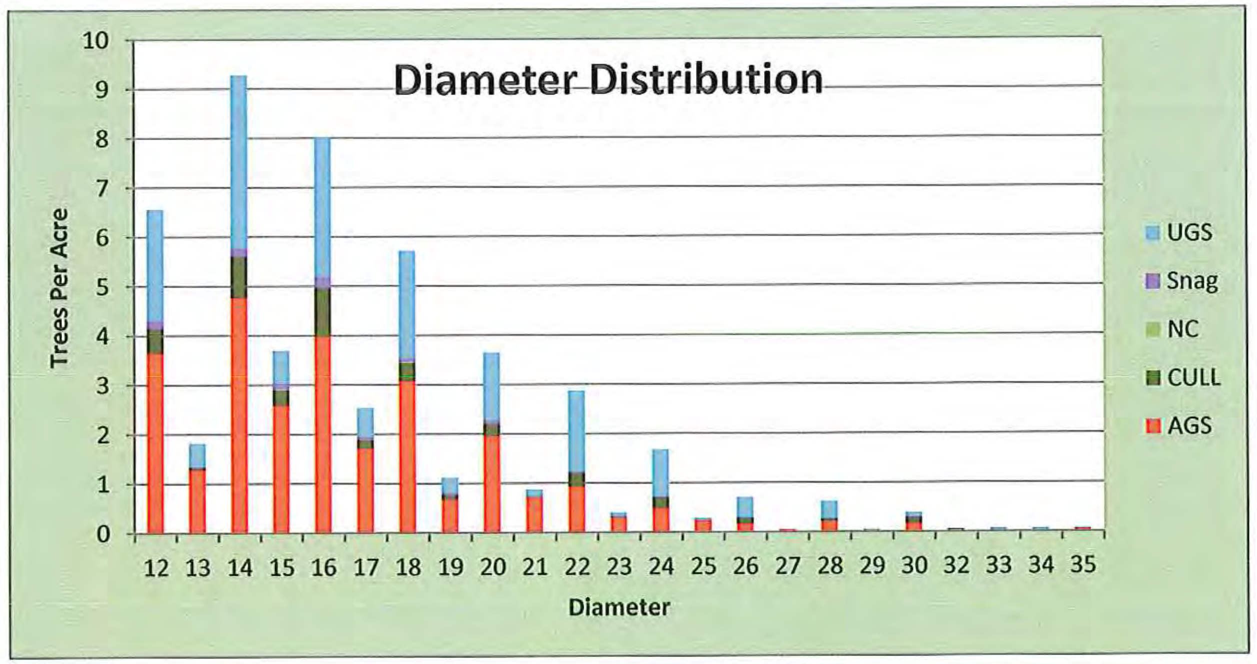
Tract					
Tract Acres:	2455		# Points	474	
Sampling Statistics					
Conf. Level: 90%	**All Saw (BF)**		**All Tons products**	**All volume Tons**	**BA**
Mean	9,753.1		14.5	89.6	82.6
Standard Error	356.5		0.7	2.7	2.1
CI Lower	9,165.5		13.2	85.0	79.1
CI Upper	10,340.8		15.7	94.1	86.0
% Sampling Error	6.0%		8.4%	5.0%	4.2%

Species Composition	Basal Area		TPA	QMD
	Total		Total	
northern red oak	39	47.1%	25	16.8
white pine	24	29.5%	11	19.8
hemlock	8	9.1%	5	16.2
red maple	5	5.9%	4	15.9
sugar maple	2	1.8%	1	17.3
white ash	1	1.7%	1	15.9
yellow birch	1	1.2%	1	14.9
beech	1	1.1%	1	15.9
white birch	1	0.7%	0	15.2
red spruce	0	0.5%	0	14.8
black birch	0	0.4%	0	13.4
black cherry	0	0.4%	0	15.8
red pine	0	0.3%	0	14.2
aspen	0	0.1%	0	14.7
Tract Total	**83**	**100.0%**	**50**	**17.3**

Table VI

Sampling Statistics CI 90%
City of Keene "Roxbury" Watershed
February 2017

Tract



Volume Summary	All Saw (BF)		All Tons products		All volume Tons	
	Acre	Stand	Acre	Stand	Acre	Stand
northern red oak	4,412	10,831,711	6.3	15,549.2	41.7	102,392.0
white pine	3,823	9,386,672	1.8	4,371.2	29.9	73,428.0
hemlock	727	1,784,974	2.5	6,045.4	7.8	19,105.2
red maple	324	795,996	1.6	3,839.5	4.2	10,228.2
sugar maple	87	214,806	0.7	1,831.6	1.4	3,558.0
white ash	129	315,996	0.2	478.3	1.2	3,011.8
beech	42	103,338	0.5	1,230.7	0.8	2,057.4
yellow birch	73	179,087	0.2	437.4	0.8	1,877.5
white birch	18	45,122	0.3	805.4	0.5	1,177.4
red spruce	53	130,780	0.0	20.8	0.4	969.0
black cherry	27	65,181	0.1	148.7	0.3	670.2
black birch	4	10,960	0.2	555.1	0.3	642.8
red pine	32	79,327	0.0	6.8	0.2	581.9
aspen	-	-	0.1	155.2	0.1	155.2
Tract Total	**9,753**	**23,943,951**	**14.5**	**35,475.2**	**89.6**	**219,854.4**

Table VII

	Harvest Income Projections, 2017-2032			
	City of Keene "Roxbury" Watershed		February 2017	
DBH Group	Small, 12-14" DBH	Medium, 15-18" DBH	Large 19"= DBH	Total
Hardwood	2,069,154	5,382,086	5,110,958	12,562,198
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Total	2,864,045	7,929,191	13,150,714	23,943,951
	Percent of Volume Proposed for Harvest by Group			
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Hardwood	413,831	1,614,626	3,066,575	5,095,031
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	970,255	3,397,599	8,694,404	13,062,258
% of total sawtimber volume	4%	14%	36%	55%
	2017 Stumpage Price (blended for all species); $/mbf			
Hardwood	$400.00	$440.00	$460.00	
Softwood	$130.00	$130.00	$130.00	
	Estimated Harvest Value			Total
DBH Group	Small, 12-14" DBH	Medium, 15-18" DBH	Large 19"= DBH	
Hardwood	$165,532	$710,435	$1,410,624	$2,286,592
Softwood	$72,335	$231,787	$731,618	$1,035,740
			Estimated Harvest Income, 2017-2032	**$3,322,332**
			Percent of Total Sawtimber Value	**50%**
			Estimated Income per Year, 2017-2032	**$221,489**

Table VIII

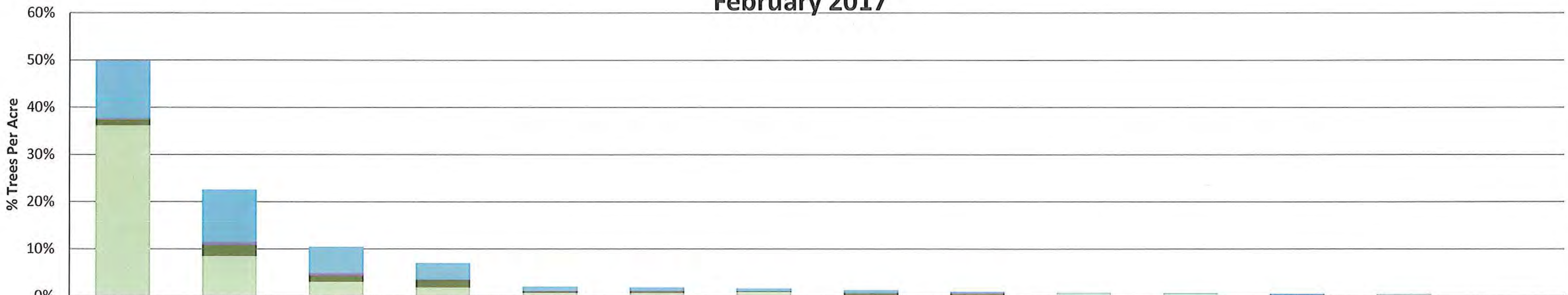
City of Keene, NH Watershed Lands by Town

No.	Town	Map	Lot	2016 Assessed Value	Taxed Y/N	2016 Tax Bill	Acres	Assessed Value/Acre
1	Harrisville	70	37	$ 40,900	N	~	22.00	$ 1,859
2	Nelson	408	18	$ 188,100	Y	$ 3,704	135.00	$ 1,393
3	Roxbury	103	5	$ 1,600	PILOT	$80,000+/- annual payment in lieu of taxes, 2,305 acres	0.90	$ 1,778
4	Roxbury	403	4	$ 142,100	PILOT		120.97	$ 1,175
5	Roxbury	403	6	$ 60,500	PILOT		29.73	$ 2,035
6	Roxbury	403	7	$ 322,200	PILOT		275.05	$ 1,171
7	Roxbury	403	8	$ 272,600	PILOT		138.40	$ 1,970
8	Roxbury	403	24	$ 73,500	PILOT		42.12	$ 1,745
9	Roxbury	403	25	$ 177,200	PILOT		172.76	$ 1,026
10	Roxbury	403	26	$ 186,100	PILOT		187.93	$ 990
11	Roxbury	403	27	$ 99,900	PILOT		69.59	$ 1,436
12	Roxbury	404	9	$ 49,200	PILOT		18.96	$ 2,595
13	Roxbury	404	10	$ 38,600	PILOT		9.31	$ 4,146
14	Roxbury	404	11	$ 140,200	PILOT		111.23	$ 1,260
15	Roxbury	404	17	$ 255,500	PILOT		221.38	$ 1,154
16	Roxbury	404	31	$ 40,700	PILOT		0.79	$ 51,519
17	Roxbury	404	37	$ 96,400	PILOT		60.80	$ 1,586
18	Roxbury	404	37-1	$ 32,200	PILOT		2.56	$ 12,578
19	Roxbury	405	9	$ 87,600.00	PILOT		15.50	$ 5,652
20	Roxbury	405	16	$ 208,400.00	PILOT		235.00	$ 887
21	Roxbury	405	17	$ 142,000.00	PILOT		119.45	$ 1,189
22	Roxbury	405	22	$ 567,500.00	PILOT		472.80	$ 1,200
				Estimate of Taxes Paid		$83,704	2,462.23	Total Acreage as per Town Records
				Per Acre Tax		$ 34	2,647.00	Estimated Area as per NEFCo Fieldwork
							185	acreage differential +/-, 7.5% +/-

Stands::StandTextName

TPA

Chart I
Trees per Acre Composition by Species
City of Keene 'Roxbury' Watershed
February 2017

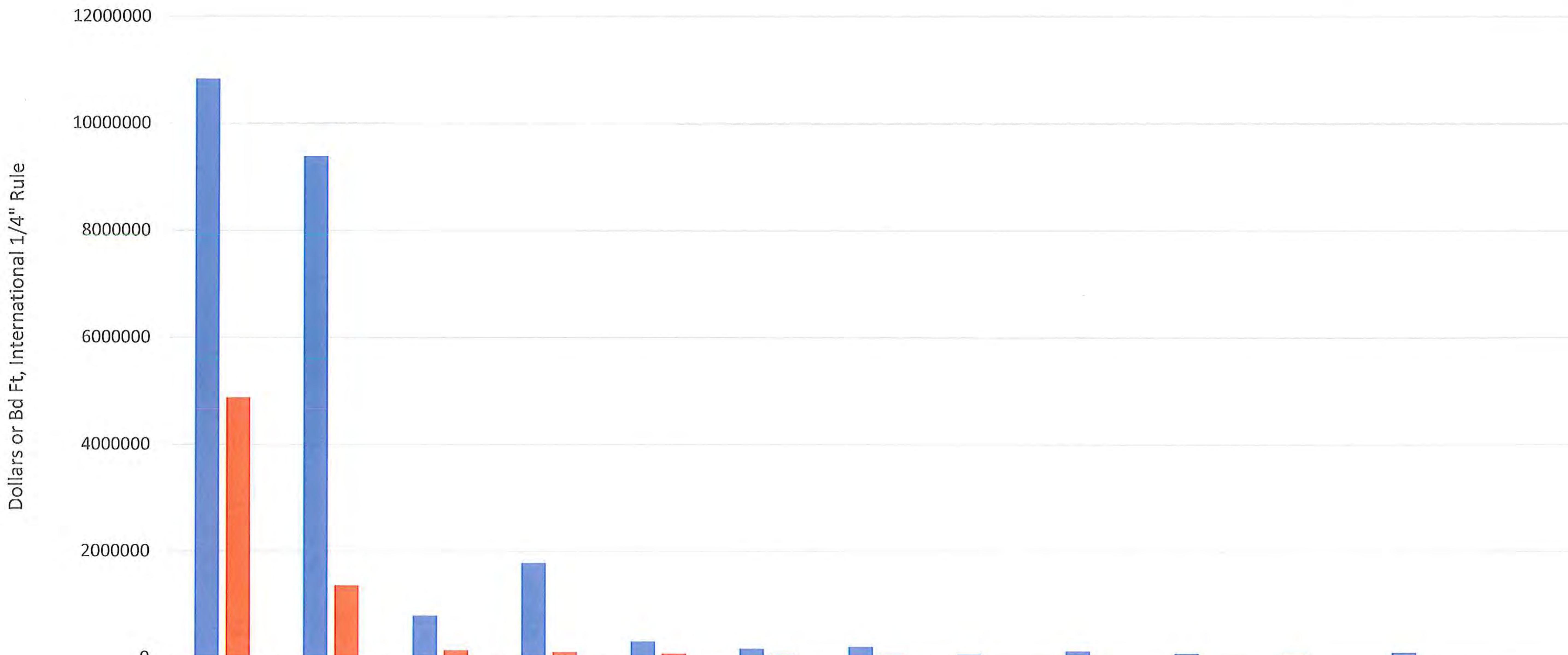


	northern red oak	white pine	hemlock	red maple	white ash	sugar maple	yellow birch	beech	white birch	black birch	red spruce	black cherry	red pine	aspen
UGS	12%	11%	6%	4%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%
Snag	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CULL	1%	2%	1%	2%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%
AGS	36%	8%	3%	2%	1%	1%	1%	0%	0%	1%	1%	0%	0%	0%

Species

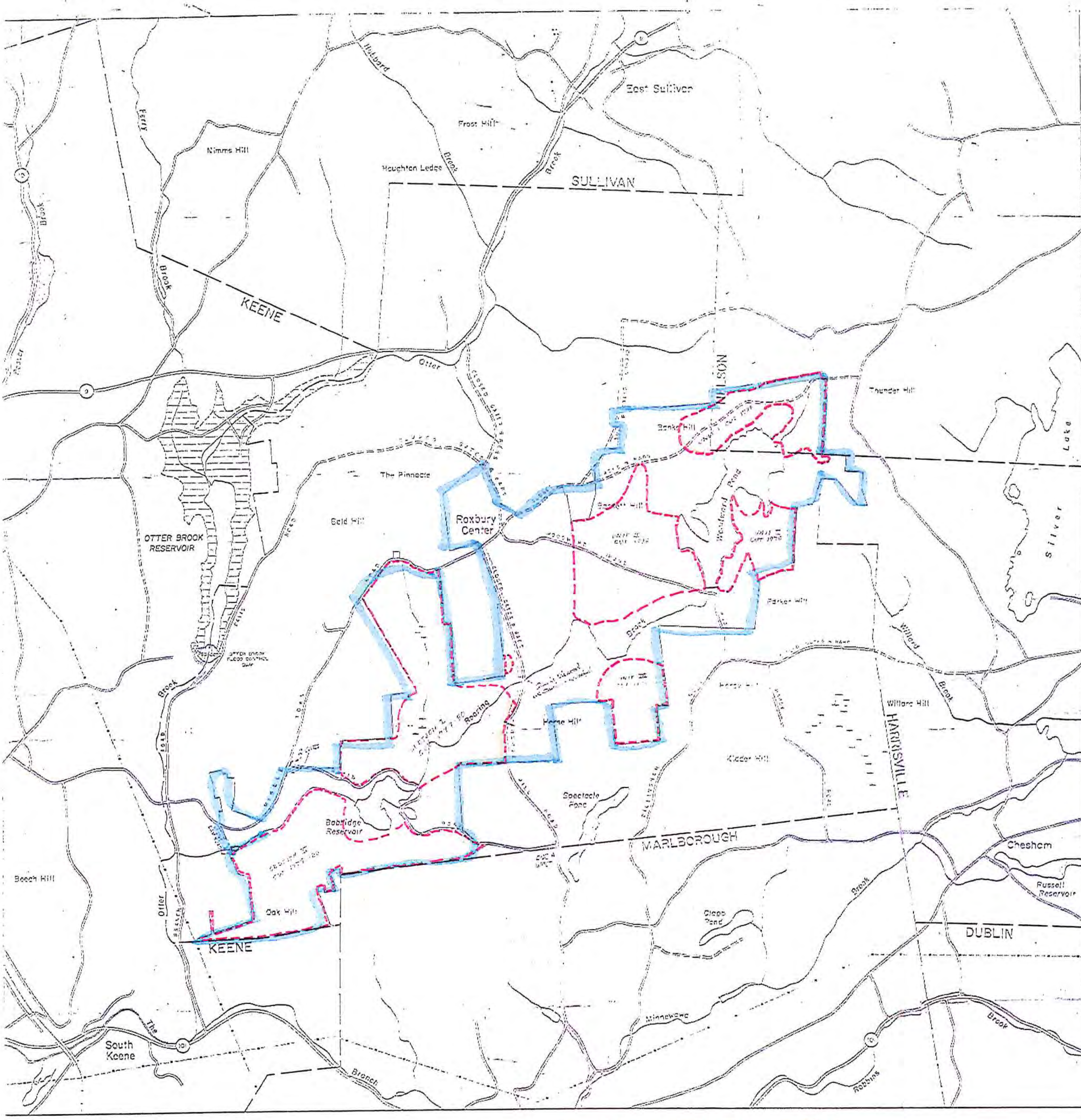
Species

Chart II
City of Keene 'Roxbury' Watershed 2,455 Forested Acres
Sawtimber Volume and Value by Species as of February 2017



	Northern Red Oak	White Pine	Red Maple	Hemlock	White Ash	Yellow Birch	Sugar Maple	Black Cherry	Red Spruce	Red Pine	White Birch	Beech	Black Birch
Bd Ft Volume	10,831,711	9,386,672	795,996	1,784,974	315,996	179,087	214,806	65,181	130,780	79,327	45,122	103,338	10,960
Estimated Value	$4,874,270	$1,361,067	$143,279	$107,098	$78,999	$44,772	$42,961	$13,036	$11,770	$4,760	$4,512	$4,134	$2,740

Bd Ft Volume   Estimated Value



WATERSHED PROPERTY BOUNDARY

- - - - HARVEST BOUNDARY 1978-1980

STATE OF NEW HAMPSHIRE
DEPARTMENT OF RESOURCES AND ECONOMIC DEVELOPMENT

TOWN OF ROXBURY, N. H.

1970'S HARVEST MAP

SOURCE:
WM P. HOUSE COLLECTION
CHESHIRE COUNTY
REGISTRY OF DEEDS

ddm FEB'17

Appendix D

Water Quality Sampling Plan

Roaring Brook Water Quality Sampling Plan for:

The Roaring Brook Watershed Plan

City of Keene, New Hampshire

June 23, 2017

Prepared by:

DK Water Resource Consulting LLC
45 Red Brook Circle
Wolfeboro, NH 03894

and

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Two Bedford Farms Drive, Suite 200
Bedford, NH 03110

Contents

I. Background

The City's interest in maintaining high quality water in its surface water supply is well understood given the rising costs to install and maintain advanced treatment at the Water Treatment facility. Current and potential future water quality threats linked to both human activities and natural occurring events (i.e. increased storm intensity, natural eutrophication processes) can be evaluated using data collected through this monitoring plan. Historic data collected by Keene suggests periodic increased total organic carbon (TOC) and turbidity. These parameters can interfere with the disinfection process and can lead to additional releases of disinfection byproducts (DBP's). Although TOC and turbidity levels in the City's source water have generally been low, existing data does show occasional turbidity spikes with two of the highest readings in the last five years occurring this past year in August and November. These are likely related to moderate intense storm events that occurred during each of these months.

Occasional episodic disturbances or even prolonged incremental changes in water quality can ultimately affect water treatment effectiveness and the production of disinfection byproducts. Preserving excellent water quality through appropriate watershed protection measures is not only fiscally prudent as it could avoid costly treatment upgrades but enables the City to provide safe and aesthetically pleasing water to its customers which is essential to a sustainable program.

Recent research suggests that climate change could increase future TOC levels. Algae growth in the supply reservoirs fueled by nutrients from the watershed can directly affect TOC levels in the water supply. Higher water temperatures, longer growing season and lower flushing rates due to prolonged droughts have the potential to increase the magnitude and duration of elevated algal growth in the reservoirs. More frequent, intense storms resulting in increased runoff and streambank erosion, increased soil temperatures, shorter frozen ground periods as well as major changes in the forest stand due to climate change, wind, ice storms, disease or insect infestations also have the potential to increase the delivery of nutrients to the reservoirs from the watershed. Maintaining a healthy forest to minimize the vulnerability to these threats will be a primary focus in the watershed plan. In addition to issues related to increased TOC and the formation of disinfection byproducts, nutrient enrichment can increase the risk for cyanobacteria (blue-green algae) blooms. Many cyanobacteria species have the ability to produce toxins, obviously not a desired situation for a drinking water resource.

A comprehensive monitoring program will allow detection of trends in parameters of concern before concentrations reach critical levels. This will allow the water utility to either adapt treatment processes and/or increase levels of watershed protection to keep water quality high.

II. Sampling Plan

Collection of high quality water quality monitoring data in conjunction with a program such as this serves several purposes. First, collection of water quality data allows tabulation of accurate loading estimates from the watershed and accurate modeling of reservoir concentrations. Second, collection of data allows identification of and ranking of sources to characterize loading and to inform the selection of appropriate structural and non-structural BMPs to address the identified problems. Finally, a water quality sampling program allows evaluation of effectiveness of existing and future control measures. This will allow the water utility to be adaptively managed into the future and designs and strategies to be modified as-needed based on real-world performance data.

Sampling will be conducted by a combination of contractors and/or city employees. Water quality sampling is proposed for specific locations in the Woodward and Babbidge reservoirs and watersheds. Sampling will be conducted in accordance with the University of New Hampshire Lakes Lay Monitoring Program protocols (UNH 2016). The sampling will be conducted for two purposes. First it will be used to screen or confirm existing water quality problems that may be addressed through changes in management and second it will be used to calibrate a water quality model of the Woodward/Babbidge system. Samples will be analyzed for a variety of water quality parameters as discussed below. Because many of the parameters of concern are related to nutrient enrichment, an increased focus will be placed on parameters related to algal growth (nutrients) in addition to the traditional parameters used to evaluate treatment of the finished water.

The New Hampshire Department of Environmental Services (NHDES) is currently evaluating Babbidge Reservoir as a part of the Trophic Survey program. This program includes collection of water quality parameters with an emphasis on those related to trophic state (nutrients, chlorophyll a, dissolved oxygen etc.). This program started in August of 2016 with one sampling event and incudes upcoming sampling events in July of 2017 and June of 2018. Sampling dates in this monitoring plans were chosen to not overlap with the NHDES program to avoid duplication of effort.

A. Sampling Design

Tributary sampling will be conducted over the next growing season beginning in spring 2017 and continuing through the fall. Sampling target three (3) separate precipitation events roughly coinciding with spring, summer and fall depending on precipitation patterns. Sample analyses will be performed by City of Keene or the UNH LLMP lab in Durham. This sampling is expected to be shore based with grab sample collection. Locations are described in Table 1 and depicted in Figure 1.

In reservoir monitoring will occur in the deep spot of each reservoir on three occasions. Samples will be collected on one of these occasions by NHDES (July 2017). Other sampling times will include early spring (after ice-out), late summer/early fall and late fall (after turnover). One of the lake sampling events (July 2017) in Babbidge Reservoir will be conducted by NHDES as a part of its Lake Trophic Survey. NHDES will also collect samples in June of 2018 to complete their assessment of Babbidge Reservoir. Data from the 2018 event as well as sampling conducted by NHDES in August 2016 can be used to assess the variability of water quality in Babbidge Reservoir.

The monitoring consists of runoff sampling at seven (7) tributary locations (Figure 1) and one (1) in-reservoir sampling station in each reservoir. Each sampling event will include a duplicate sample collected at a randomly chosen location.

Three separate precipitation events will be targeted for the tributary runoff sampling These events targets include spring runoff, mid-summer and late summer early fall. Results of the sampling will be summarized in a technical memorandum, highlighting any discernable trends or differences and will be used to calibrate the water quality model being constructed as a part of this project. A proposed sampling schedule is provided in Table 2.

Table 1. Proposed Sampling Location Descriptions

Sampling ID #	Location Description
W-3	Northwest tributary to Woodward Reservoir
W-5	Northeast tributary to Woodward Reservoir
W-6	East Tributary to Woodward Reservoir
Woodward Reservoir	Deep Spot
RB-1	Roaring Brook at North Hill Road
RB-2	Roaring Brook at Babbidge Reservoir
B-1	Northwest tributary to Babbidge Reservoir
B-3	East tributary to Babbidge Reservoir
Babbidge Reservoir	Deep Spot

Table 2. Baseline Sampling Schedule

Target Period	Target Conditions	Location
Within 2 weeks of ice out	Spring turnover-well mixed	Reservoir stations
Spring	Pre leaf-out spring runoff	Tributary stations
July	Mid-summer stratification	Reservoir Stations
Summer	Summer rain event	Tributary Stations
Late summer/early fall	Maximum stratification prior to fall turnover	Reservoir Stations
Late summer/early fall	Fall runoff event	Tributary Stations

B. Baseline Sampling

Nine (9) sites will be monitored as part of this project in 2017: These stations are shown on Figure 1. Sampling parameters are described in Table 3. These include 7 stream locations and two reservoir locations. Samples will be collected in accordance with the latest UNH LLMP QAPP protocols (UNH 2016) which are summarized below.

Tributary sampling events will occur during 2017 during runoff events. Since flow in many of the small tributaries is primarily storm related, sampling will occur as soon as practicable after a rainfall of at least 0.25 inches or a period of snowmelt. Three (3) baseline sampling events will be conducted. One event will occur in spring prior to leaf-out. The second event will occur in the mid-summer and the third event will occur in the mid-fall. Parameters to be analyzed in tributary water samples are presented in Table 3.

Reservoir sampling will occur on a similar schedule to tributary sampling and may coincide with the tributary events if conditions allow. Samples will be collected on three occasions: within a few weeks of ice out, in mid-summer and in mid to late September, prior to lake turnover. It is expected that the July 2017 sample in Babbidge will be collected by NHDES as a part of their Lake Trophic surveys. If the reservoir is stratified, both an epilimnetic core and a deep sample will be collected from each reservoir. Detail on sampling methods is provided below.

Figure 1. Monitoring locations for Roaring Brook watershed.

Table 3: List of Parameters for the Roaring Brook Watershed Monitoring Program with lab responsibility.

Laboratory Parameter	Field Parameter
Reservoir Stations	
UNH Laboratory	
Chlorophyll a (chlor a) (surface layer only)	Temperature (T)
Dissolved color	Dissolved Oxygen (DO)
Total phosphorus as P (TP)	pH
Soluble reactive phosphorus as P (SRP)	Secchi transparency
TN/TP ratio (calculated)	Specific Conductance
Nitrite plus nitrate as N (NO2 + NO3)	Turbidity
Organic nitrogen (ON calculated)	
Total nitrogen as N (TN calculated)	
City of Keene Laboratory	
Iron	
Manganese	
Ammonia as N	
Total Kjehldahl Nitrogen (TKN)	
Total organic carbon as C (TOC)	
Total coliform (surface layer only)	
Fecal coliform (surface layer only)	
Escherichia coli (E. coli) (surface layer only)	
Tributary Stations	
UNH Laboratory	Temperature (T)
Total phosphorus as P (TP)	Dissolved Oxygen (DO)
City of Keene Laboratory	pH
Total organic carbon as C (TOC)	Specific Conductance
Total coliform	Turbidity
Fecal coliform	
Escherichia coli	

C. Future Monitoring Recommendations – Cyanobacteria and Hydrology

Monitoring of the Roaring Brook watershed should be continued beyond the conduct of this watershed plan however, the intensity of the monitoring effort is dependent on the findings. The minimal plan, consistent with other water utilities with surface water supplies should include a combination of parameters designed to assist with treatability of the raw water and parameters to measure trophic state or the relative fertility of the reservoirs. Increases in the concentrations of parameters related to trophic state may lead to more serious long-term ramifications for the water supply including increases or changes in treatment, the presence of harmful algal blooms, depression of oxygen at depth in the reservoirs and a more favorable environment for invasive aquatic species, particularly plants.

A final future monitoring plan will be presented as a part of the final watershed plan for Roaring Brook. This monitoring plan will incorporate the baseline data information to be collected in 2017. It is expected that this program will include a minimum of two sampling events per year and a subset of the parameters evaluated during the baseline survey in 2017. Specific details on parameters, methods and timing will be included.

Cyanobacteria related parameters should be added to the list of monitoring program once equipment and training of staff have been completed. Protocols would follow those listed in the Quality Assurance Program Plan (QAPP) for the Cyanobacteria Monitoring Collaborative Program (USEPA 2017). Specifically, protocols for the BloomWatch (Tier 1), Cyanoscope (Tier 2) and Cyanomonitoring (Tier 3) would be followed at reservoir stations during regularly scheduled monitoring events or if raw water results of observations suggest a bloom is in progress.

In addition to routine monitoring, consideration should be given to installing staff gages in the major tributary streams and establishing stage discharge curves for these gages. This will allow flow to be estimated during future monitoring events.

D. Sampling Protocol

This project Standard Operating Procedure (SOP) defines the procedures for the collection of water samples from a shore based station and an in-lake station.

The collection of water samples is limited to the parameters described in Table 3.

D.1 Health and Safety Considerations

Daily safety briefs are to be conducted at the start of each sampling event before any work commences. These daily briefs are to be facilitated by the sampling coordinator or his/her designee to discuss the day's events and any potential health risk areas covering every aspect of the work to be completed. Weather conditions are often part of these discussions. Everyone on the field team has the authority to stop work if an unsafe condition is perceived and not resume work until the conditions are fully remedied.

D.2 Equipment and Materials

The equipment list in Table 4 contains materials which may be needed in carrying out the procedures contained in this monitoring plan. Not all equipment listed below may be necessary for a specific activity. Additional equipment may be required, pending field conditions.

D.3 Sample Collection Procedures

Sample collection information will be recorded at the time of collection using either standardized forms, a field logbook, or a combination. This information will include, but not be limited to, the station ID, time and date of sample collection, the sampler's name, and any pertinent observations on weather, rainfall, presence of wildlife or waterfowl and other circumstances potentially relevant to water quality. A sample data sheet is provided in Appendix A.

Table 4. Sampling Equipment List

Water sample containers.
Sample Bottle Labels
Sample collection forms (Appendix A)
Field logbook (optional)
Dipper with long handle
Chain of Custody forms (Appendix B)
YSI multiparameter water quality meter (or equivalent) equipped with Dissolved Oxygen, Temperature and Specific Conductance sensors.
Turbidity meter
Integrating tube sampler
Alpha Bottle (or equivalent)
Boat and boat related safety equipment
Anchor and line
Depth sounder (optional)

Sample bottles are labeled in the field with waterbody name/town, sample location, sample date, sample time, and the collector's initials. Sampling procedures will follow the University of New Hampshire Lakes Lay Monitoring Program protocols (UNH 2016). Those protocols are summarized below but the original reference should be consulted for detailed field procedures.

If collecting a sample from a culvert: 1) Direct fill bottles from culvert outlet taking care to not disturb and collect sediment from the bottom of the culvert. If the culvert is submerged or partially submerged, collect samples as far up inside the pipe as possible to avoid collecting water from the receiving water body. This may require the use of a dipper on a pole at some stations. Rinse dipper three times with sample water at the point of collection then collect sample. Pre labeled sample bottles should be filled directly from the dipper. 2) Samples should be stored on ice in the dark.

If collecting samples from an open channel: 1) Direct fill bottles at the station or use a dipper to collect sample from the main portion of the flow. Rinse dipper three times with sample water at the point of collection then collect sample. Take care not to disturb sediments in the channel upstream of the sample collection location. Pre-labeled sample bottles should be filled directly from the dipper. 2) Samples should be stored on ice in the dark.

In-lake sampling will consist of field measurements of Secchi depth transparency and pH as well as performing temperature/dissolved oxygen/specific conductance profiles at the deep spot locations in the each reservoir. Water quality samples will be collected at these two deep stations. If the temperature profile indicates that the reservoir is stratified (greater than 4 °C difference between surface and bottom temperatures), samples will be drawn by a core of the epilimnion (thermocline defined as a greater than 1°C drop in temperature for a 1 meter change in depth).

All samples should be placed on ice in the dark and delivered to the laboratory in Keene, NH within 6 hours of sample collection to meet the holding time for pathogens. Samples to be analyzed by UNH should be preserved and delivered to the lab within the prescribed holding time. Samples should be accompanied with standard Chain of Custody forms (Appendix B).

III. References

United States Environmental Protection Agency. 2017. Quality Assurance Program Plan (QAPP) for the Cyanobacteria Monitoring Collaborative Program. Office of Measurement and Evaluation, North Chelmsford, Ma.

University of New Hampshire. 2016. Quality Assurance Project Plan for Water Quality Monitoring and Lake Surveys. New Hampshire Center for Freshwater Biology and Lakes Lay Monitoring Program.

Appendix A

Field Sheet

Roaring Brook Field Monitoring Form

Note: Form adapted from NHDES VLAP form

Lake Name: ______________________ Town: ______________________

Field Monitors: ______________________ Date Sampled: ______________________

______________________ Time Sampled: ______________________

______________________ Bottom Depth at deep spot: ______ m

WEATHER CONDITIONS *(Circle one for each):*

Cloud Cover	Air Temperature	Wind Conditions	Water Surface	Lake Level
Clear	<40° cold	Calm	Calm	High
Hazy	41°-60° cool	Breezy	Ripples	Normal
Partly cloudy	61°-80° warm	Strong	Small waves	Low
Overcast	>80° hot	Gusty	Moderate waves	
			White Caps	

PRECIPITATION CONDITIONS *(Check off all that apply):*

Rain while sampling:____ Rain previous 24 hrs:____ Rain previous 48 hrs:____ Rain previous 72 hrs:____

Indicate how much rain: ______________ OR No rain for past ______ days

TRIBUTARY SAMPLES COLLECTED *One large white and one small brown (contains acid) at each station.* ***Optional:*** *one small white (E. coli). List the station name, stream flow and conditions at time of sampling. Check off appropriate column for samples collected.*

Station Name	Stream Flow Conditions and Observations (Dry, Stagnant, Low, Moderate, High)	Large White Bottle (total suspended solids)	Sm. Brown Bottle (phosphorus)	Sm. White Bottle (*E. coli*)

NEW SAMPLING LOCATION:

Did you sample at a new location this sampling event? (Circle one) **YES** **NO**

If "Yes", provide a map with station location and complete a station identification form for each new sampling station and submit with samples.

Contact the VLAP Coordinator for a station identification form or print out a form from the DES website at: http://des.nh.gov/organization/divisions/water/wmb/sampling.htm

If you do not have a station identification form, provide the following information:

Station Name: ______________________________________

Type of Station *(specify in-lake (near shore), tributary)*: ______________________

Station Location: *(Please provide one of the following):*

1. Latitude/Longitude Coordinates: GPS coordinates: __________ °N Lat __________ °W Long

Specify make and model of GPS: ______________________

2. Include a map indicating the approximate location of station and station name.

FIELD OBSERVATIONS *(Please note any watershed observations, areas of erosion and sedimentation, recent storms/droughts, algal blooms, suspicious looking plants, wildlife observed, sampling problems, equipment problems, and areas of concern):*

Appendix B

Chain of Custody Form

CHAIN OF CUSTODY RECORD

STANDARD

Page__1___Of___1___

CLIENT NAME:	PROJECT:
ADDRESS:	PHONE: FAX: EMAIL:
PROJECT MANAGER	SAMPLER

ANALYSES REQUESTED

SPECIAL HANDLING

- Same Day Rush 150%
- 24 Hour Rush 100%
- 48-72 Hour Rush 75%
- 4 - 5 Day Rush 30%
- Rush Extractions 50%
- 10 - 15 Business Days
- QA/QC Data Package

Charges will apply for weekends/holidays

Method of Shipment

ID# (For lab Use Only)	DATE SAMPLED	TIME SAMPLED	SMPL TYPE	SAMPLE IDENTIFICATION/SITE LOCATION	# OF CONT											COMMENTS

RELINQUISHED BY	DATE / TIME	RECEIVED BY
RELINQUISHED BY	DATE / TIME	RECEIVED BY
RELINQUISHED BY	DATE / TIME	RECEIVED BY

SAMPLE CONDITION:

Actual Temperature:

Received On Ice	Y / N
Preserved	Y / N
Evidence Seals Present	Y / N
Container Attacked	Y / N
Preserved at Lab	Y / N

SAMPLE TYPE CODE:
AQ=Aqueous
NA = Non Aqueous
SL = Sludge
DW = Drinking Water
WW = Waste Water
RW = Rain Water
GW = Ground Water
SO = Soil
SD = Sediment
OL = Oil
OT = Other Matrix

SPECIAL REQUIREMENTS / BILLING INFORMATION

COC version 042707

Appendix E

Water Quality Data

Appendix E: Roaring Brook Water Quality Data (2016-2017)

Standards/Criteria				Total Phosphorus	Soluble Reactive Phosphorus	Chlorophyll *a*	Secchi Transparency	Nitrate + Nitite-N	Total Nitrogen -N	Total Kjehldahl Nitrogen	Ammonia	Organic Nitrogen (calculated)[1]	TN/TP ratio (calculated)	pH	Dissolved Oxygen	Temperature	Specific Conductance	Dissolved color	Turbidity	Total Organic Carbon	Iron	Mn	Fecal coliform	Total coliform	E coli
				µg/l	µg/l	µg/l	m	mg/l	mg/l	mg/l	mg/l	mg/l			mg/l	°C	mS/cm	PCU	NTU	mg/l	mg/l	mg/l	#/100ml	#/100ml	#/100ml
Drinking water MCL[2]								10																0	0
Acute Aquatic Life Criteria														6.5-8.0			2.755								
Chronic Aquatic Life Criteria														6.5-8.0			0.835				1				
Oligotrophic criteria				<8		<3.3																			
Sampling Date	**Sampling Group**	**Station**	**Depth of sample (m)**																						
3/22/2016	NHDES	Babbidge Deep Spot	2	9.6		2.28	5.7	ND	ND					5.8			0.00212	15	0.5						
3/22/2016	NHDES	Babbidge Deep Spot	6	8.8		3.36		ND	ND					5.9			0.00217	15	0.5						
8/16/2016	NHDES	Babbidge Deep Spot	1.5	<5.0				ND	ND					6.4			0.00206	27		3.3					
8/16/2016	NHDES	Babbidge Deep Spot	core(0-6)			4.02	5.7																		
10/21/2016	VHB/DK/Keene	Babbidge Dam	0	8																					
10/21/2016	VHB/DK/Keene	Woodward Dam	0	3.8																					
10/21/2016	VHB/DK/Keene	RB-2	0	4.5																					
4/27/2017	VHB/DK/Keene	Babbidge Deep Spot	0												profile	profile	profile						<1	51	<1
4/27/2017	VHB/DK/Keene	Babbidge Deep Spot	core (0-7)	5.8	<1.0	1.3	5.4		<0.100	0.36	0.17	0.19		5.9	profile	profile	profile	16.7	0.3	4.6	0.13	0.019			
4/27/2017	VHB/DK/Keene	Woodward Deep Spot	0												profile	profile	profile						<1	28	<1
4/27/2017	VHB/DK/Keene	Woodward Deep Spot	core (0-8)	5.2	<1.0	1.6	6.8		<0.100	0.53	<0.06	0.50		6.7	profile	profile	profile	13.2	0.3	3.6	0.09	0.014			
4/27/2017	VHB/DK/Keene	W-3	0	2.1										5.5	10	6.8	0.0179		0	2.9			<1	>2420	<1
4/27/2017	VHB/DK/Keene	W-5	0	4.3										6.6	11.1	8.8	0.0298		0.2	2.8			<1	387	1
4/27/2017	VHB/DK/Keene	W-6	0	10.3										5.7	10.1	9.9	0.0175		0.1	6.4			<1	1414	<1
4/27/2017	VHB/DK/Keene	RB-1	0	4.2										6.3					0	3.7			4.1	1203	2
4/27/2017	VHB/DK/Keene	RB-2	0	3.8										6.1	10.6	11.5	0.0214		0.2	4			2	1300	1
4/27/2017	VHB/DK/Keene	B-1	0	4.3										5.6	10.9	8.9	0.0305		0	4			<1	921	<1
4/27/2017	VHB/DK/Keene	B-3	0	4.4										4.9	11.9	6.5	0.0206		0	4.7			<1	411	<1
7/11/2017	NHDES	Babbidge Deep Spot	2	7.52				ND						6.29			0.01987	30							
7/11/2017	NHDES	Babbidge Deep Spot	core (0-5)			1.62	5.3																		
7/14/2017	VHB/DK/Keene	Babbidge Deep Spot	0												profile	profile	profile						6.3	39	8
7/14/2017	VHB/DK/Keene	Babbidge Deep Spot	core (0-3)	7.4	1.5	2.2	4.4	<0.05	0.399	0.25	0.16	0.09	54	6.1	profile	profile	profile	33.3	0.5	3.8	0.18	0.024			
7/14/2017	VHB/DK/Keene	Babbidge Deep Spot	7	11.5					0.799	0.23	0.11	0.12	69		profile	profile	profile				0.46	0.089			
7/14/2017	VHB/DK/Keene	Woodward Deep Spot	0												profile	profile	profile						3.1	76	4
7/14/2017	VHB/DK/Keene	Woodward Deep Spot	core (0-4)	6.9	<1.0	3.2	5.3	<0.05	0.212	0.29	0.06	0.23	31	6.4	profile	profile	profile	13.1	0.2	3.3	<0.06	<0.01			
7/14/2017	VHB/DK/Keene	Woodward Deep Spot	8	11.9					0.898	0.21	0.06	0.15	75		profile	profile	profile				0.08	0.072			
7/14/2017	VHB/DK/Keene	W-3	0	2.9										5.8	8.2	13.3	0.0137		0.2	2.8			5.2	866	12
7/14/2017	VHB/DK/Keene	W-5	0	10.1										6.4	9.1	14.3	0.0317		1.6	3.8			52.9	1733	165
7/14/2017	VHB/DK/Keene	W-6	0	18.7										5.6	6.8	15.4	0.0318		0.4	9.3			55.6	>2420	1099
7/14/2017	VHB/DK/Keene	RB-1	0	6										6.2					0.2	4.1			6.3	579	15
7/14/2017	VHB/DK/Keene	RB-2	0	7.2										6.2	9.7	16.1	0.0187		0.2	4.9			22.8	286	27
7/14/2017	VHB/DK/Keene	B-1	0	4.1										5.5	8.9	14.7	0.0271		0.1	3.7			4.1	457	10
7/14/2017	VHB/DK/Keene	B-3	0	6.2										4.7	9.3	13.8	0.0195		0.1	8.1			7.5	326	9
9/21/2017	VHB/DK/Keene	Babbidge Deep Spot	0												profile	profile	profile						3	197	<1
9/21/2017	VHB/DK/Keene	Babbidge Deep Spot	core (0-3)	4.8	1.2	3.6	5.3			0.22	0.05	0.17		6.9	profile	profile	profile		0.4	3.6	0.25	0.022			
9/21/2017	VHB/DK/Keene	Babbidge Deep Spot	5	8.3											profile	profile	profile								
9/21/2017	VHB/DK/Keene	Woodward Deep Spot	0												profile	profile	profile							272	2
9/21/2017	VHB/DK/Keene	Woodward Deep Spot	core (0-6)	5.5	<1.0	2.1	5.6			0.16	<0.05	0.14		6.9	profile	profile	profile		0.4	4.4	0.06	0.018			
9/21/2017	VHB/DK/Keene	Woodward Deep Spot	8	7.3											profile	profile	profile								
9/21/2017	VHB/DK/Keene	W-3	0	4.3										3.4?	6	15.5	0.0191		0	2.8			3.1	308	16
9/21/2017	VHB/DK/Keene	W-5	0	5.5										6.9	8.5	16	0.0462		1.4	2.7			151.5	1203	291
9/21/2017	VHB/DK/Keene	W-6	0	35.2										6.9	5.8	16.7	0.0196		1.4	8.2			14.6	>2420	49
9/21/2017	VHB/DK/Keene	RB-1	0	5.2										6.4					0.1	3.0			<1	649	12
9/21/2017	VHB/DK/Keene	RB-2	0	8.0										6.8	8.3	18.3	0.0229		0.3	3.3			16	1046	11
9/21/2017	VHB/DK/Keene	B-1	0	5.2										5.8	7.1	16.4	0.0305		0	2.4			3	687	7
9/21/2017	VHB/DK/Keene	B-3	0	13.4										5.7	9	14.8	0.0206		0.1	5.0			<1	579	1

[1]Where vaues were below detection limit, a value of 0.5(detection limit) was used for calculations

[2]Maximum Contamination Level (MCL) is based on NH Env-Wq 1700.

Figure E-1. Dissolved oxygen and temperature profile for Woodward Reservoir, 4/27/17.

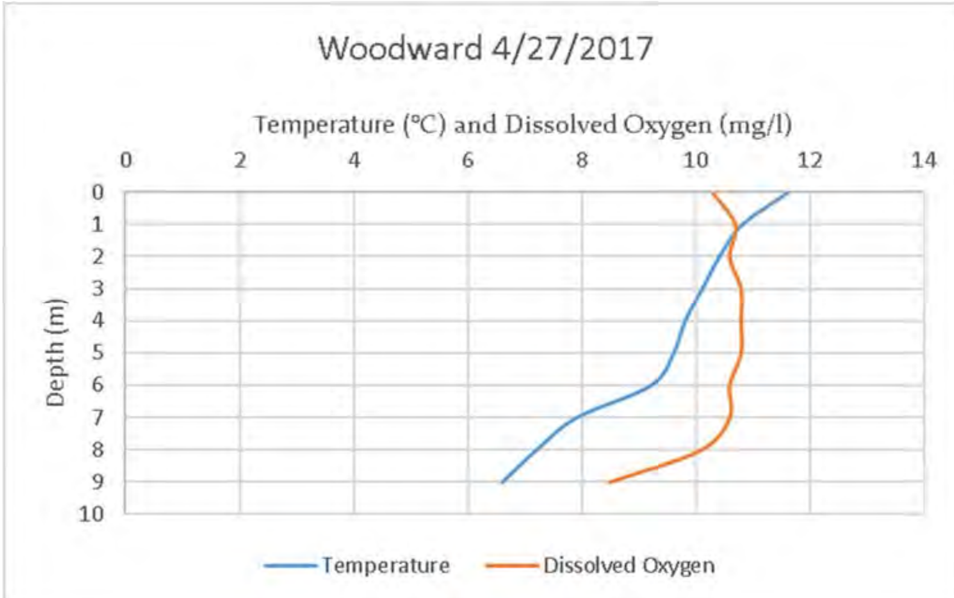


Figure E-2. Dissolved oxygen and temperature profile for Babbidge Reservoir, 4/27/17.

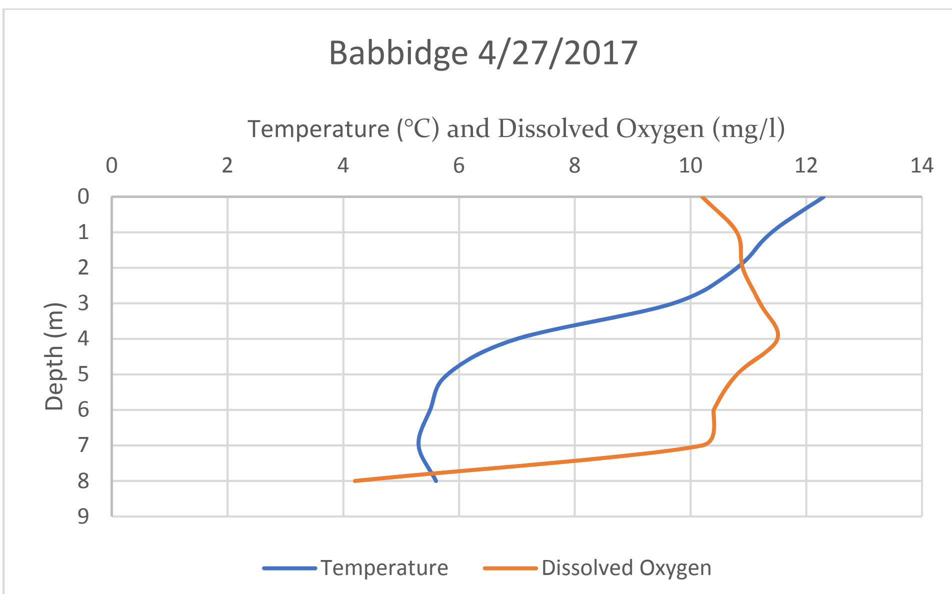


Figure E-3. Dissolved oxygen and temperature profile for Woodward Reservoir, 7/14/17.

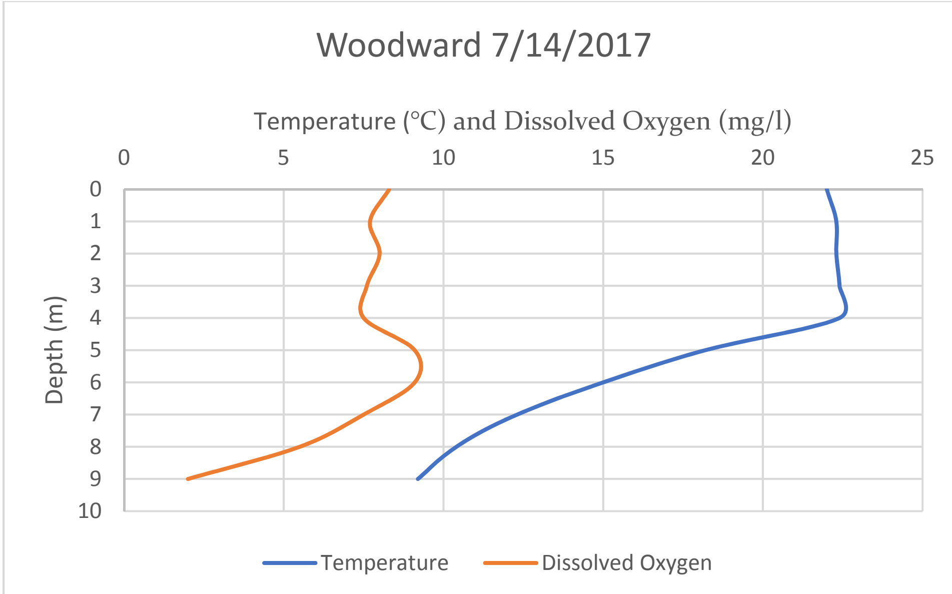


Figure E-4. Dissolved oxygen and temperature profile for Babbidge Reservoir, 7/14/17.

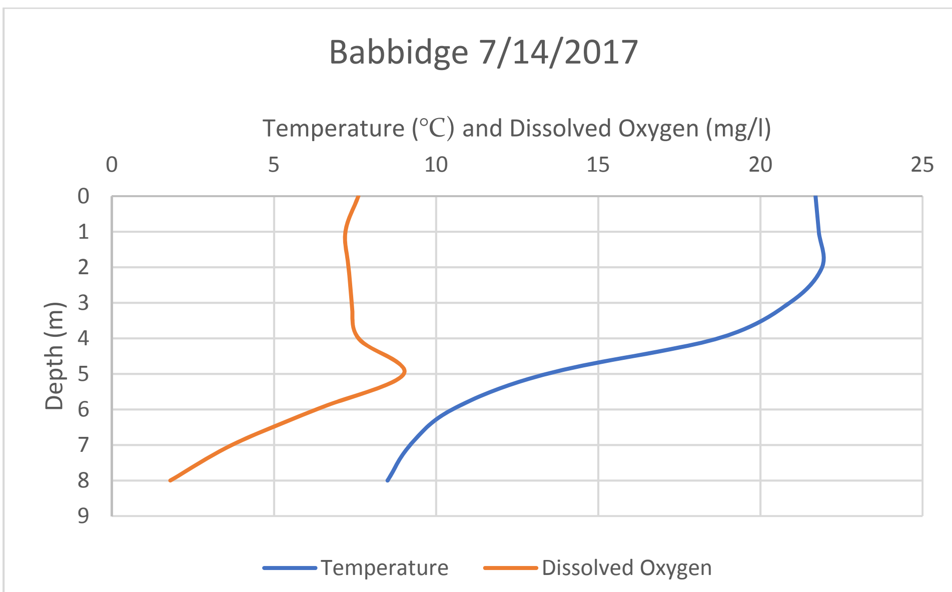


Figure E-5. Dissolved oxygen and temperature profile for Woodward Reservoir, 9/21/17.

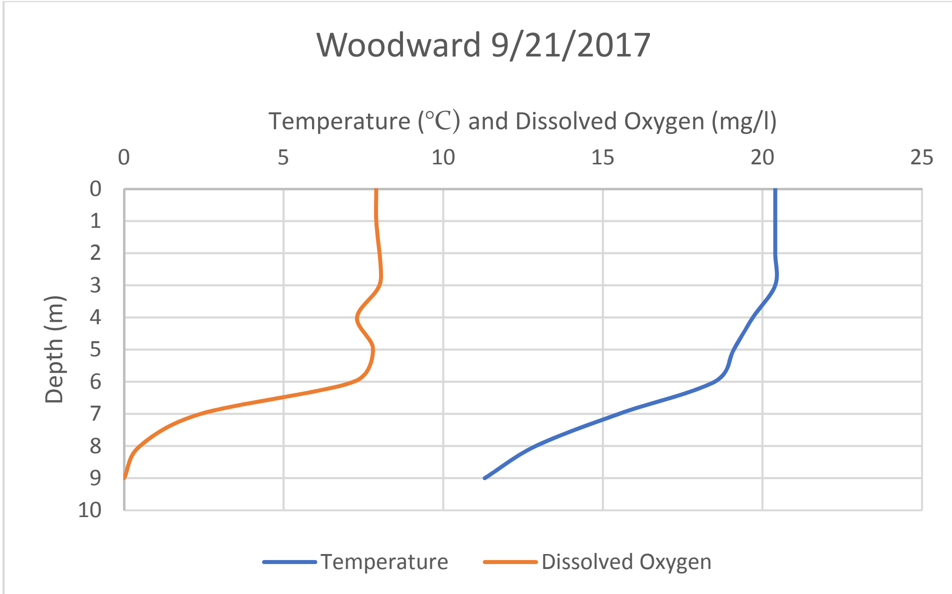
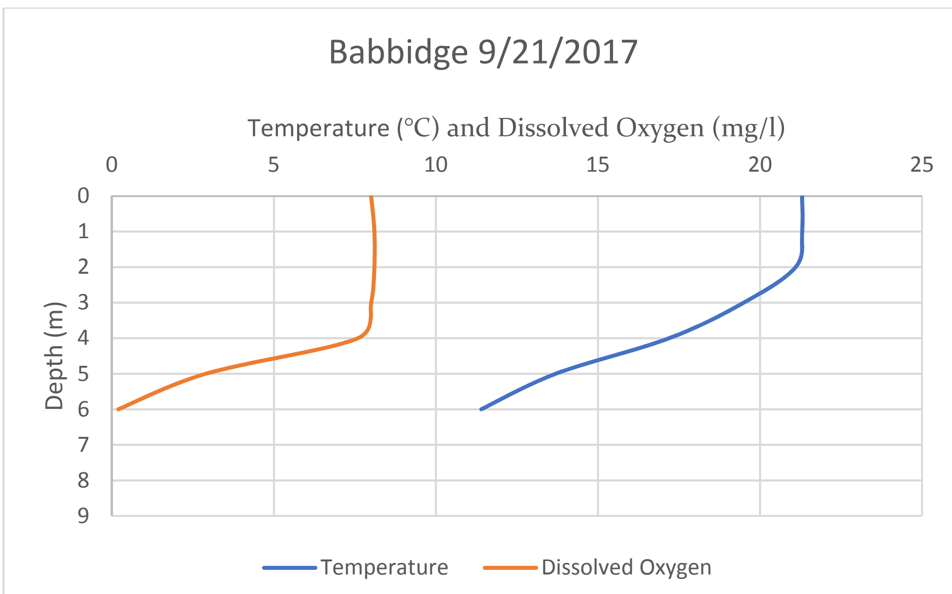


Figure E-6. Dissolved oxygen and temperature profile for Babbidge Reservoir, 9/27/17.



Appendix F

Water Quality Future Monitoring Plan

Roaring Brook Water Quality Future Monitoring Plan for:

The Roaring Brook Watershed Plan

City of Keene, New Hampshire

December 2018

Prepared by:

DK Water Resource Consulting LLC
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Contents

Background

The City of Keene has a very strong interest in maintaining high quality water in its surface water supply. Current and potential future water quality threats linked to both human activities (development, roads, timber harvesting) and natural processes and episodic events (i.e. intense storms, increased runoff and natural lake aging processes) can be evaluated using data collected through this monitoring plan.

Occasional episodic disturbances or even prolonged incremental changes in water quality can ultimately affect water treatment effectiveness and the production of disinfection byproducts. Preserving excellent water quality through appropriate watershed protection measures is not only fiscally prudent by avoiding costly treatment upgrades but also enables the City to consistently provide safe and aesthetically pleasing water to its customers.

Recent research suggests that future climate could increase future nutrient runoff and associated algal growth which will be reflected in higher TOC concentrations. More frequent, intense storms resulting in increased runoff and streambank erosion, increased soil temperatures, shorter frozen ground periods as well as major changes in the forest stand due to climate change, wind, ice storms, disease or insect infestations also have the potential to increase the delivery of nutrients to the reservoirs from the watershed. Higher water temperatures, longer growing seasons and seasonally lower flushing rates due to prolonged droughts also have the potential to increase the magnitude and duration of elevated algal growth in the reservoirs. In addition to issues related to increased TOC and the potential formation of disinfection byproducts, nutrient enrichment can also increase the risk for cyanobacteria (blue-green algae) blooms. Many cyanobacteria species produce toxins which can be problematic in drinking water. A comprehensive monitoring program allows detection of trends in parameters of concern before concentrations reach critical levels. This gives the water utility time to either adapt treatment processes and/or increase levels of watershed protection to keep finished water quality high.

Historic raw water data collected by Keene shows occasionally elevated total organic carbon (TOC) and turbidity. These parameters can interfere with the disinfection process and can lead to additional releases of disinfection byproducts (DBP's). These are likely related to storm events and associated runoff. Coliform bacteria are occasionally detected in Roaring Brook and several other small tributaries. These bacteria are likely from wildlife sources.

Few data currently exist to describe the nutrient concentrations or cyanobacteria in the Roaring Brook watershed beyond those data collected as a part of this watershed planning effort. Because the watershed is largely undeveloped, and the reservoirs are relatively nutrient poor, concern has been low for many years. However, recent study throughout the northeast U.S. has documented the presence of cyanobacteria in many lakes and reservoirs including low nutrient systems (Cottingham et al 2015) like the Roaring Brook reservoirs. These findings coupled with advances in methodologies to detect and identify cyanobacteria has led to a recommendation of more intensive monitoring in the Roaring Brook reservoirs and watershed as a part of Keene's source monitoring program.

Introduction

Collection of high-quality watershed and reservoir water quality monitoring data in conjunction with a program such as this serves several purposes. First, collection of water quality data allows tabulation of accurate loading estimates from the watershed and accurate modeling of reservoir concentrations. Second, collection of data allows identification of and ranking of sources to characterize loading and to inform the selection of appropriate structural and non-structural best management practices (BMPs) to address identified problems. Third, source water quality data are critical to optimal operation of the water treatment plant by providing advance notice of potential treatment challenges. Finally, a water quality monitoring program allows evaluation of effectiveness of existing and future treatment measures. This allows the water utility to adaptively manage the watershed and treatment process.

It is assumed that routine monitoring will be conducted by city employees. Water quality sampling is proposed for specific locations in the Woodward and Babbidge reservoirs and watersheds. Monitoring will be conducted in accordance with the University of New Hampshire Lakes Lay Monitoring Program protocols (UNH 2016), the Cyanobacteria Monitoring Collaborative QAPP (USEPA 2017), NHDES guidance for cyanobacteria monitoring in public water supplies (NHDES 2017) and the Roaring Brook Cyanobacteria Monitoring SSPP (DKWRC 2018). In-situ monitoring will be conducted, and samples collected will be analyzed for a variety of water quality parameters as discussed below. Because many of the parameters of concern are related to nutrient enrichment, an increased focus will be placed on parameters related to algal growth (nutrients) in addition to the traditional parameters used to evaluate treatment of the finished water.

a. Monitoring Design

In-reservoir monitoring will occur in the deep spot of each reservoir as soon as practicable after ice-out and twice monthly from mid-May through mid-October. After mid-October, monitoring should continue monthly until the reservoirs freeze. It is estimated that this will result in 15 reservoir monitoring events over the course of a typical year. These data can be used to assess the variability of water quality in Woodward and Babbidge Reservoirs and detect seasonal changes. Locations are described in Table 1 and depicted in Figures 1 and 2. A schedule is presented in Table 2.

Tributary monitoring will be conducted three times each year. Monitoring will target three (3) separate runoff events roughly coinciding with spring, summer and fall depending on precipitation patterns. Since flow in many of the small tributaries is primarily storm related, monitoring will occur as soon as practicable after a rainfall of at least 0.25 inches or a period of snowmelt. One event will occur in spring prior to leaf-out. The second event will occur in the mid-summer and the third event will occur in the mid-fall. Sample analyses will be performed by City of Keene or the UNH LLMP lab in Durham. This monitoring is expected to be shore based with grab sample collection. Locations are described in Table 1 and depicted in Figures 1 and 2. A schedule is presented in Table 2. Consistently high readings of one or more parameter may trigger additional investigation upstream in the tributary to identify the source of the high readings.

The monitoring consists of runoff monitoring at seven (7) tributary locations (Figure 1) and one (1) in-reservoir monitoring station in each reservoir. Each tributary monitoring event will include a duplicate sample collected at a randomly chosen location. Every other reservoir sampling event will include the collection of a duplicate sample at a randomly selected station/depth.

Table 1. Baseline Monitoring Location Descriptions

Monitoring ID #	GPS Coordinates (latitude – longitude)	Location Description
W-3	42.963165 -72.177719	Northwest tributary to Woodward Reservoir
W-5	42.963852 -72.171224	Northeast tributary to Woodward Reservoir
W-6	42.961387 -72.170307	East Tributary to Woodward Reservoir
Woodward Reservoir	42.9962011 -72.174689	Deep Spot
RB-1	42.944127 -72.200866	Roaring Brook at North Hill Road
RB-2	42.935013 -72.213558	Roaring Brook at Babbidge Reservoir
B-1	42.935898 -72.217711	Northwest tributary to Babbidge Reservoir
B-3	42.932874 -72.213315	East tributary to Babbidge Reservoir
Babbidge Reservoir	42.934297 -72.218125	Deep Spot
Babbidge and Woodward	various	BloomWatch twice-weekly monitoring

Figure 1. Babbidge Reservoir Sampling Locations

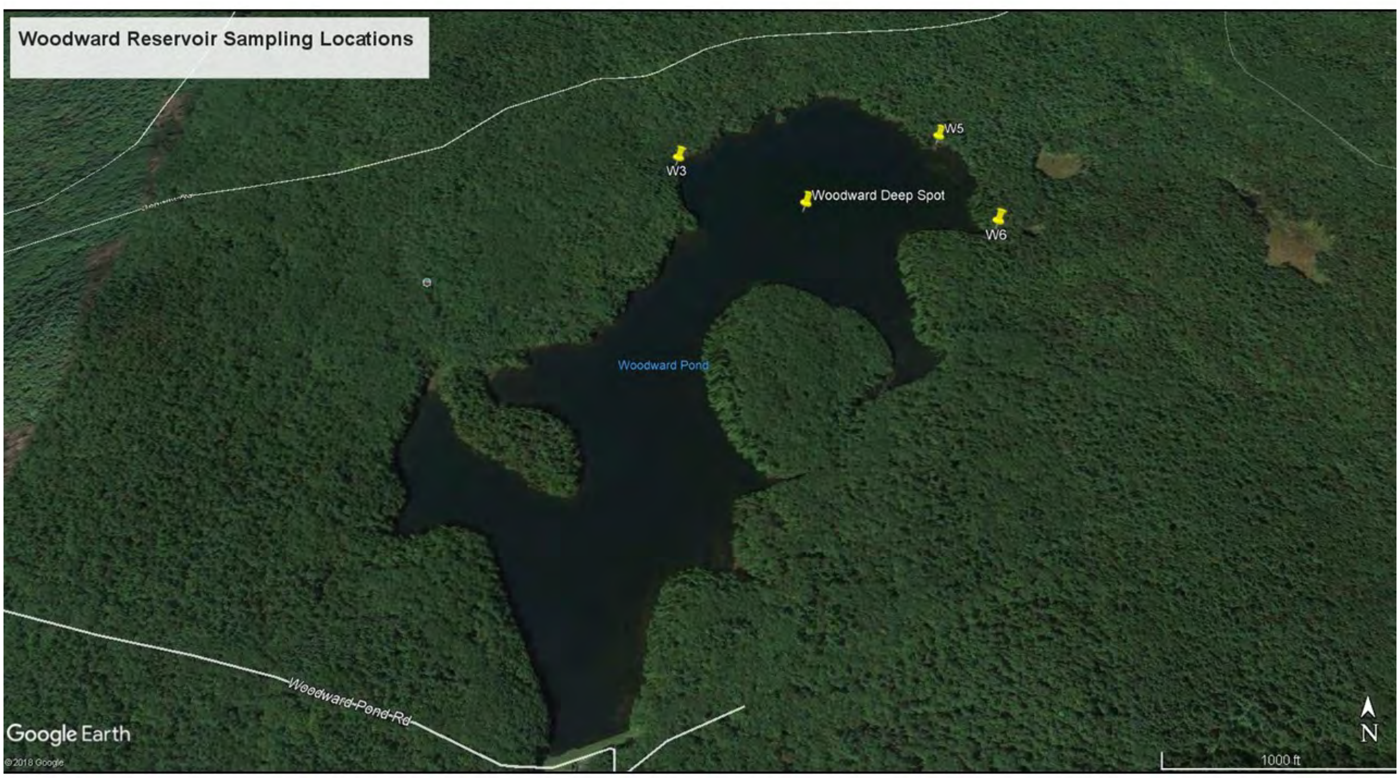

Figure 2. Woodward Reservoir Sampling Locations

Table 2. Baseline Monitoring Schedule

Target Period	Frequency	Target Conditions	Location
Ice-free season	Twice weekly	BloomWatch-all conditions	Reservoirs
Within 2 weeks of ice out	Once/yr	Spring turnover-well mixed	Reservoir stations
Spring	Once/yr	Pre leaf-out spring runoff	Tributary stations
May through mid-October	Twice Monthly	Growing season	Reservoir Stations
Summer	Once/yr	Summer rain event	Tributary Stations
Late fall	Once/month	Fully mixed pre-winter	Reservoir Stations
Late summer/early fall	Once/yr	Fall runoff event	Tributary Stations

b. Baseline Monitoring

Nine (9) sites have been identified as permanent monitoring stations. These stations, shown in Figure 1 were monitored as a part of the baseline monitoring program conducted for the watershed plan in 2016 and 2017. These include 7 stream locations and two reservoir locations. Monitoring parameters are described in Table 3. Samples for laboratory analysis will be collected in accordance with the latest UNH LLMP QAPP protocols (UNH 2016) and the Cyanobacteria Monitoring Collaborative QAPP (USEPA 2017) which are summarized below. Parameters to be analyzed in tributary water samples are presented in Table 3. Monitoring protocols can be found in the latest UNH LLMP QAPP (UNH 2016).

Reservoir monitoring will occur throughout the open water season and may coincide with the tributary events if conditions allow. BloomWatch monitoring will occur twice weekly throughout the ice-free season. A full suite of monitoring parameters and samples will be collected as soon as practicable after ice-out, twice monthly from May through mid-October and monthly from mid-October until ice-in. When the reservoir is stratified (defined as a temperature difference of >4 °C between surface and bottom), both an epilimnetic core and a deep sample will be collected from each reservoir. Samples for laboratory analysis will be collected in accordance with the latest UNH LLMP QAPP protocols (UNH 2016) which are summarized below.

Cyanobacteria related parameters are to be included as part of the monitoring program. Protocols should follow those listed in the Quality Assurance Program Plan (QAPP) for the Cyanobacteria Monitoring Collaborative Program (USEPA 2017) (Appendix F-1). Specifically, protocols for the BloomWatch (Tier 1) will be followed twice a week while CyanoScope (Tier 2) and CyanoMonitoring (Tier 3) will be followed at reservoir stations twice monthly from June through September and once per month in May and October or if raw water results or BloomWatch observations suggest a bloom is in progress.

Table 3: List of Parameters for the Roaring Brook Watershed Monitoring Program with laboratory responsibility.

Laboratory Parameter	Field Parameter
Reservoir Stations	
UNH Laboratory	
Chlorophyll a (chlor a) (epilimnetic core only)	Temperature (T) (profile)
Dissolved color	Dissolved Oxygen (DO) (profile)
Total phosphorus as P (TP)	pH (from epilimnetic core)
Soluble reactive phosphorus as P (SRP)	Secchi transparency
TN/TP ratio (calculated)	Specific Conductance (profile)
Nitrite plus nitrate as N (NO2 + NO3)	Turbidity (from epilimnetic core)
Organic nitrogen (ON calculated)	BloomWatch observations
Total nitrogen as N (TN calculated)	Phycocyanin (0-3 m core)
City of Keene Laboratory	
Iron	
Manganese	
Ammonia as N	
Total Kjehldahl Nitrogen (TKN)	
Total organic carbon as C (TOC)	
Total coliform (surface layer only)	
Fecal coliform (surface layer only)	
Escherichia coli (E. coli) (surface layer only)	
CyanoScope (epilimnetic net tow)	
CyanoScope (cyanobacteria cell numbers 0-3m core)	
CyanoMonitoring (contingency-cyanobacteria toxins)	
Tributary Stations	
UNH Laboratory	Temperature (T)
Total phosphorus as P (TP)	Dissolved Oxygen (DO)
City of Keene Laboratory	pH
Total organic carbon as C (TOC)	Specific Conductance
Total coliform	Turbidity
Fecal coliform	
Escherichia coli	

c. Contingency Monitoring

At times, unanticipated conditions in the Roaring Brook watershed will trigger additional monitoring effort. In nearly all instances, the additional monitoring will result in an increase in frequency of monitoring effort until the underlying conditions return to baseline levels. Some of the more likely scenarios are detailed in Table 4 below with suggested responses.

Table 4. Contingency Monitoring Triggers and Actions

	Trigger	Response
1.	BloomWatch Observations suggest a bloom is in progress.	Collect samples for CyanoScope analysis at the site of the bloom and determine if Cyanobacteria are causing the bloom.
2.	CyanoScope analysis indicates the presence of a toxin forming species of cyanobacteria.	Complete BloomWatch observations daily until the bloom dissipates. Conduct cyano-monitoring toxicity testing on core sample from the reservoir.
3.	Presence of cyanotoxins confirmed	Continue monitoring for cyanotoxins twice weekly until concentrations decline.
4.	Tributary samples are consistently elevated with respect to one or more parameters.	Investigate upstream for sources. Consider collecting samples at the next upstream stream junction to determine which branch is the cause of the elevated concentration
5.	Cyanobacteria bloom is confirmed in Woodward Reservoir	Collect CyanoScope and CyanoMonitoring samples in Woodward, at RB2 and at Babbidge Deep Spot.

d. Future Monitoring Recommendations

Monitoring of the Roaring Brook watershed should be continued for the foreseeable future however, the intensity of the monitoring effort is dependent on the findings. The minimal plan, consistent with other water utilities with surface water supplies should include a combination of parameters designed to assist with treatability of the raw water and parameters to measure trophic state or the relative fertility of the reservoirs. Increases in the concentrations of parameters related to trophic state may lead to more serious long-term ramifications for the water supply including increases or changes in treatment, the presence of harmful algal blooms (cyanobacteria), depression of oxygen at depth in the reservoirs and a more favorable environment for invasive aquatic species, particularly plants.

In addition to routine monitoring, consideration should be given to installing staff gages in the major tributary streams and establishing stage discharge curves for these gages. This will allow flow to be estimated during future monitoring events.

e. Monitoring Protocol

This project Standard Operating Procedure (SOP) defines the procedures for the collection of water samples from a shore-based station and an in-lake station. The collection of water samples is limited to the parameters described in Table 3.

1.0 Health and Safety Considerations

Daily safety briefs are to be conducted at the start of each monitoring event before any work commences. These daily briefs are to be facilitated by the monitoring coordinator or his/her designee to discuss the day's events and any potential health risk areas covering every aspect of the work to be completed. Weather conditions are often part of these discussions. Everyone on the field team has the authority to stop work if an unsafe condition is perceived and not resume work until the conditions are fully remedied.

2.0 Equipment and Materials

The equipment list in Table 5 contains materials which may be needed in carrying out the procedures contained in this monitoring plan. Not all equipment listed below may be necessary for a specific activity. Additional equipment may be required, pending field conditions.

Table 5. Monitoring Equipment List

Water sample containers.
Sample Bottle Labels
Sample collection forms (Appendix F-1)
Field logbook (optional)
Dipper with long handle
Chain of Custody forms (Appendix F-2)
YSI multiparameter water quality meter (or equivalent) equipped with Dissolved Oxygen, Temperature and Specific Conductance sensors.
Field Turbidity meter
Secchi Disk and line
Turbidity meter
pH meter
Phycocyanin/chlor *a* fluorometer
Integrated tube sampler (for epilimnion)
Alpha Bottle (or equivalent)
Boat and boat related safety equipment
Anchor and line
Depth sounder (optional)
CyanoScope 3m integrated tube sampler
Plankton Net
Squeeze bottle for rinsing plankton net.
250 ml plastic beaker for in-situ field readings

3.0 Sample Collection Procedures

Sample collection information will be recorded at the time of collection using either standardized forms, a field logbook, or a combination. This information will include, but not be limited to, the station ID, time and date of sample collection, the sampler's name, and any pertinent observations on weather, rainfall, presence of wildlife or waterfowl and other circumstances potentially relevant to water quality. A sample data sheet is provided in Appendix F-1.

Sample bottles are labeled in the field with waterbody name/town, sample location, sample date, sample time, and the collector's initials. Monitoring procedures will follow the University of New Hampshire Lakes Lay Monitoring Program protocols (UNH 2016) and the Cyanobacteria Monitoring Collaborative protocols (USEPA 2017). Those protocols are summarized below but the original reference should be consulted for detailed field procedures.

BloomWatch observations will be made twice weekly throughout the open water season. Observations at each reservoir should be made along the downwind shore of each reservoir.

In-lake monitoring will consist of field measurements of Secchi depth transparency and pH as well as performing temperature/dissolved oxygen/specific conductance profiles at 1-meter intervals (starting at the surface) at the deep spot locations in each reservoir. Water quality samples will be collected at these two deep stations. If the temperature profile indicates that the reservoir is stratified (greater than 4 °C difference between surface and bottom temperatures), samples will be drawn by a core of the epilimnion (thermocline defined as a greater than 1°C drop in temperature for a 1-meter change in depth). Sampling steps for reservoir monitoring are summarized in Table 6.

If collecting samples from an open tributary channel: 1) Direct fill bottles at the station or use a dipper to collect sample from the main portion of the flow. Rinse dipper three times with sample water at the point of collection then collect sample. Take care not to disturb sediments in the channel upstream of the sample collection location. Pre-labeled sample bottles should be filled directly from the dipper. 2) Samples should be stored on ice in the dark. Sampling steps for tributary monitoring are summarized in Table 7.

Table 6. Reservoir station sampling instructions.

Step	Action
1. Arrive at station	Use GPS to locate in-lake station
2. Record station depth	Use fathometer to record depth
3. Anchor	Lower anchor carefully to bottom. Release a minimum of rope to equal 1.5 times the water depth
4. Site conditions	Record site conditions including wind, cloud cover, time and field crew participants
5. Transparency	Determine Secchi transparency
6. Complete profile	Use YSI to complete the water quality profile starting at the surface and then at 1m intervals for dissolved oxygen, temperature and specific conductance.
7. Collect bacteriological parameters from surface	Fill bottles from reservoir surface
8. Determine epilimnetic depth	Using profile data, determine epilimnetic depth
9. Collect integrated samples	0-3 meters for CyanoScope and CyanoMonitoring, epilimnetic depth for others. Fill 1-liter Amber plastic bottle, mix and then fill all sample bottles from the 1-liter bottle. Refill the 1-liter bottle with full cores as needed to retrieve sufficient volume. Fill 1-liter bottle after all bottles have been filled and place in cooler (to be filtered for chlorophyll a and color).
10. Phycocyanin/chlor a	Use aliquot of 0-3 meter core for phycocyanin and chlorophyll a measurement
11. Turbidity and pH	Measure turbidity and pH from epilimnetic core sample (1-liter bottle)
12. Collect net sample 0-3 meters for phytoplankton ID	Lower net to 3 meters and retrieve slowly through the water column. Rinse plankton to bottom of net using squeeze bottle.
13. Collect hypolimnetic sample	Collect sample using Alpha bottle 1.5 meters from the bottom. Fill all appropriate bottles from Alpha bottle.
14. Check all bottles and	Check that all collections have been made

field book	
15. Lift anchor	Move to next site.

Table 7. Tributary station sampling instructions.

Step	Action
1. Arrive at station	Use GPS to locate tributary station
2. Site conditions	Record site conditions including wind, cloud cover, time and field crew participants
3. Complete field measurements	Use YSI to complete the water quality measurements for dissolved oxygen, temperature and specific conductance.
4. Turbidity and pH	Measure turbidity and pH from surface grab.
5. Collect bacteriological and water quality parameters from surface	Fill bottles from tributary surface
6. Check all bottles and field book	Check that all collections have been made

All samples should be placed on ice in the dark and delivered to the laboratory in Keene, NH within 6 hours of sample collection to meet the holding time for pathogens. Samples to be analyzed by UNH or NHDES should be preserved and delivered to the lab within the prescribed holding time. Samples should be accompanied with standard Chain of Custody forms (Appendix F-2).

5.0 Estimated Cost of Program

It is estimated that the proposed baseline monitoring program will cost the City of Keene $21,886 per year with an initial capital outlay of $12,300 for equipment in the first year. This budget does not include cost associated with the ongoing operations of the laboratory in Keene. There are also no costs included for contingency monitoring. A detailed cost estimate is provided in Appendix F-3.

References:

Cottingham, K. L., H. A. Ewing, M. L. Greer, C. C. Carey, and K. C. Weathers. 2015. Cyanobacteria as biological drivers of lake nitrogen and phosphorus cycling. Ecosphere 6(1):1. http://dx.doi.org/10.1890/ES14-00174.1

DKWRC. 2018. Roaring Brook Cyanobacteria Monitoring SSPP. Prepared for the City of Keene Public Works Department.

NHDES. 2017. CyanoHAB Response Protocol for Public Water Supplies. April 18, 2017.

United States Environmental Protection Agency. 2017. Quality Assurance Program Plan (QAPP) for the Cyanobacteria Monitoring Collaborative Program. Office of Measurement and Evaluation, North Chelmsford, Ma.

University of New Hampshire. 2016. Quality Assurance Project Plan for Water Quality Monitoring and Lake Surveys. New Hampshire Center for Freshwater Biology and Lakes Lay Monitoring Program.

Appendix F-1

Field Sheet

Roaring Brook Field Monitoring Form Note: Form adapted from NHDES VLAP form

Lake Name: ______________________ Town: ______________________

Field Monitors: ______________________ Date Sampled: ______________________

______________________ Time Sampled: ______________________

______________________ Bottom Depth at deep spot: ______m

WEATHER CONDITIONS *(Circle one for each):*

Cloud Cover	Air Temperature	Wind Conditions	Water Surface	Lake Level
Clear	<40° cold	Calm	Calm	High
Hazy	41°-60° cool	Breezy	Ripples	Normal
Partly cloudy	61°-80° warm	Strong	Small waves	Low
Overcast	>80° hot	Gusty	Moderate waves	
			White Caps	

PRECIPITATION CONDITIONS *(Check off all that apply):*

Rain while sampling:____ Rain previous 24 hrs:____ Rain previous 48 hrs:____ Rain previous 72 hrs:____

Indicate how much rain:______________ OR No rain for past ______ days

TRIBUTARY SAMPLES COLLECTED *One large white and one small brown (contains acid) at each station.* ***Optional:*** *one small white (E. coli). List the station name, stream flow and conditions at time of sampling. Check off appropriate column for samples collected.*

Station Name	Stream Flow Conditions and Observations (Dry, Stagnant, Low, Moderate, High)	Large White Bottle (total suspended solids)	Sm. Brown Bottle (phosphorus)	Sm. White Bottle (*E. coli*)

NEW SAMPLING LOCATION:

Did you sample at a new location this sampling event? (Circle one) **YES** **NO**

If "Yes", provide a map with station location and complete a station identification form for each new sampling station and submit with samples.

Contact the VLAP Coordinator for a station identification form or print out a form from the DES website at: http://des.nh.gov/organization/divisions/water/wmb/sampling.htm

If you do not have a station identification form, provide the following information:

Station Name:______________________________________

Type of Station *(specify in-lake (near shore), tributary)*: ______________________

Station Location: *(Please provide one of the following):*

1. **Latitude/Longitude Coordinates:** GPS coordinates: __________°N Lat __________°W Long

   Specify make and model of GPS: ______________________

2. **Include a map indicating the approximate location of station and station name.**

FIELD OBSERVATIONS *(Please note any watershed observations, areas of erosion and sedimentation, recent storms/droughts, algal blooms, suspicious looking plants, wildlife observed, sampling problems, equipment problems, and areas of concern):*

Appendix F-2

Chain of Custody Form

CHAIN OF CUSTODY RECORD

STANDARD

Page __1__ Of __1__

CLIENT NAME:	PROJECT:	ANALYSES REQUESTED	SPECIAL HANDLING
ADDRESS:	PHONE:		☐ Same Day Rush 150%
	FAX:		☐ 24 Hour Rush 100%
	EMAIL:		☐ 48-72 Hour Rush 75%
PROJECT MANAGER	SAMPLER		☐ 4 - 5 Day Rush 30%
			☐ Rush Extractions 50%
			☐ 10 - 15 Business Days
			☐ QA/QC Data Package
			Charges will apply for weekends/holidays
			Method of Shipment

ID# (For lab Use Only)	DATE SAMPLED	TIME SAMPLED	SMPL TYPE	SAMPLE IDENTIFICATION/SITE LOCATION	# OF CONT.											COMMENTS

RELINQUISHED BY	DATE / TIME	RECEIVED BY	SAMPLE CONDITION:		SAMPLE TYPE CODE:
					AQ=Aqueous
			Actual Temperature:		NA= Non Aqueous
					SL = Sludge
RELINQUISHED BY	DATE / TIME	RECEIVED BY	Received On Ice	Y / N	DW = Drinking Water
			Preserved	Y / N	WW = Waste Water
			Evidence Seals Present	Y / N	RW = Rain Water
			Container Attacked	Y / N	GW = Ground Water
RELINQUISHED BY	DATE / TIME	RECEIVED BY	Preserved at Lab	Y / N	SO = Soil
					SD = Sediment
					OL = Oil
					OT = Other Matrix

SPECIAL REQUIREMENTS / BILLING INFORMATION

COC version 042707

Appendix F-3

Monitoring Program Cost Estimate

Cost Estimate for Roaring Brook Watershed Monitoring

Summary

	Number of events	Labor Costs/event	Non-Labor costs/event	Cost per year
Task 1 Reservoir Routine Water Quality Sampling (per event)	15	$ 820.00	$ 138.00	$ 14,370.00
Task 2 Tributary Routine Water Quality Sampling (per event)	3	$ 500.00	$ 192.00	$ 2,076.00
Task 3 : Bloomwatch (per day- 2 reservoirs)	68	$ 80.00		$ 5,440.00
Task 4 : Capital Expenses (first year only)	1	$ -	$ 12,300.00	$ 12,300.00
		First year total		$ 34,186.00
		Subsequent Year total		$ 21,886.00

Detail

Task 1 Reservoir Routine Water Quality Sampling (per event)

Per Event: Mobilize, travel to site, collect, filter, preserve and deliver samples to lab.

Labor	Hours	Rate		Costs	
Field Tech	5	$ 40.00		$ 200.00	
Scientist	6	$ 50.00		$ 300.00	(includes mobilization)
Technician (Cyanoscope)	4	$ 40.00		$ 160.00	
Technician (CyanoMonitoring)	4	$ 40.00		$ 160.00	
	19		Labor subtotal	$ 820.00	

Non Labor Expenses	Units*	Unit Cost	Costs	Laboratory
Analytic Laboratory (UNH)				
Total Phosphorus (TP)	4.5	12 /analysis	$ 54.00	UNH LLMP
Chlorophyll *a*	2.5	12 /analysis	$ 30.00	UNH LLMP
Dissolved Color	2.5	0 /analysis	$ -	UNH LLMP
Soluble Reactive Phosphorus as P	4.5	12 /analysis	$ 54.00	UNH LLMP
Total Organic Carbon (TOC)	2.5	0 /analysis	$ -	assumed completed by city
Nitrate + nitrite (NO2 + NO3)	2.5	0 /analysis	$ -	assumed completed by city
Ammonia as N	2.5	0 /analysis	$ -	assumed completed by city
Total Kjehldahl Nitrogen	2.5	0 /analysis	$ -	assumed completed by city
Iron	4.5	0 /analysis	$ -	assumed completed by city
Manganese	4.5	0 /analysis	$ -	assumed completed by city
Total coliform	2.5	0 /analysis	$ -	assumed completed by city
Fecal coliform	2.5	0 /analysis	$ -	assumed completed by city
Escerichia coli (E. coli)	2.5	0 /analysis	$ -	assumed completed by city
Cyanobacteria toxins	2.5	0 /analysis	$ -	assumed completed by city
boat rental	0	50 /day	$ -	
mileage (per round trip)	0	0.55 /mile	$ -	
Meters (specific conductance,temperature, oxygen, pH, turbidity)	0		$ -	
		Non labor subtotal	$ 138.00	
		Total Cost Per Event	**$ 958.00**	

*Partial units are to account for duplicate sample to be collected during every other reservoir sampling event

Field Assumptions - Resevoirs

1) Laboratory samples will be analyzed under standard turnaround of 3 weeks. Fast turnaround, if required, may result in a surcharge.
2) Any changes in the specified program may result in a change in associated costs.
3) Estimate assumes that City has watercraft and appropriate safety gear to collect samples on reservoirs.
4) Assumed that Phosphorus, Soluble Reactive Phosphrus, Iron and Manganese will be collected from epilimnetic core and deep discrete sample on each sampling date.
5) QA samples should be collected at a rate on one duplicate per 2 routine reservoir sampling events. This sample will be at one randomly selected reservoir and one depth.

Task 2 Tributary Routine Water Quality Sampling (per event)

Per Event: Mobilize, travel to site, collect, filter, preserve and deliver samples to lab.

Labor	Hours	Rate		Costs	
Field Tech	5	$ 40.00		$ 200.00	
Scientist	6	$ 50.00		$ 300.00	(includes mobilization)
	11		Labor subtotal	$ 500.00	

Non Labor Expenses	Units*	Unit Cost	Costs	Laboratory
Analytic Laboratory (UNH)				
Total Phosphorus (TP)	8	12 /analysis	$ 96.00	UNH LLMP
Chlorophyll *a*	0	12 /analysis	$ -	UNH LLMP
Dissolved Color	0	0 /analysis	$ -	UNH LLMP
Soluble Reactive Phosphorus as P	8	12 /analysis	$ 96.00	UNH LLMP
Total Organic Carbon (TOC)	0	0 /analysis	$ -	assumed completed by city
Nitrate + nitrite (NO2 + NO3)	0	0 /analysis	$ -	assumed completed by city
Ammonia as N	0	0 /analysis	$ -	assumed completed by city
Total Kjehldahl Nitrogen	0	0 /analysis	$ -	assumed completed by city
Iron	0	0 /analysis	$ -	assumed completed by city
Manganese	0	0 /analysis	$ -	assumed completed by city
Total coliform	8	0 /analysis	$ -	assumed completed by city
Fecal coliform	8	0 /analysis	$ -	assumed completed by city
Escerichia coli (E. coli)	8	0 /analysis	$ -	assumed completed by city
Cyanobacteria toxins	0	0 /analysis	$ -	assumed completed by city
boat rental	0	50 /day	$ -	
mileage (per round trip)	0	0.55 /mile	$ -	
Meters (specific conductance,temperature, oxygen, pH, turbidity)	0		$ -	
		Non labor subtotal	$ 192.00	
		Total Cost Per Event	**$ 692.00**	

*One duplicate sample per sampling event will be collected for QA purposes.

Field Assumptions-tributaries

1) Lack of flow in the stream due to drought or freezing may cause a break in the sampling schedule until conditions allow sampling.
2) Samples will be collected in the main flow (thalweg) of the stream, in stream instrument readings will be collected at the same location.
3) Laboratory samples will be analyzed under standard turnaround of 3 weeks. Fast turnaround, if required, may result in a surcharge.
4) Any changes in the specified program may result in a change in associated costs.
5) QA samples should be collected at a rate on one duplicate per tributary sampling event. This sample will be at one randomly selected tributary.

Task 3 : Bloomwatch (per day- 2 reservoirs)

Labor

	Hours	Rate	Costs	
Lab Tech	2	$ 40.00	$ 80.00	assumed completed by city
		subtotal	$ 80.00	

Task 4 : Capital Expenses (first year only)

Non- Labor

	Quantity	Cost	Costs
Jon Boat, Electric motor and safety equipment	1	$ 2,500.00	$ 2,500.00
Water Quality Meter (oxygen, temperature specific conductance, 30 meter cable)	1	$ 2,200.00	$ 2,200.00
Secchi Disk and line	1	$ 50.00	$ 50.00
Field turbidity meter	1	$ 1,000.00	$ 1,000.00
Field pH meter	1	$ 200.00	$ 200.00
Alpha Sampling Bottle (horizontal) with messenger and line	1	$ 250.00	$ 250.00
Cyanoscope sampling kit and microscope	1	$ 900.00	$ 900.00
Integrated tube sampler	1	$ 200.00	$ 200.00
Hand held depth sounder	1	$ 100.00	$ 100.00
Phycocyanin/chlor a 2 channel fluorometer	1	$ 1,700.00	$ 1,700.00
Elisa Test kit(s) for cyanotoxins (Microcystins, anatoxin a, BMAA, cylindrospermopsin, anabaenopeptin)	5	$ 600.00	$ 3,000.00
Miscellaneous sampling supplies	1	$ 200.00	$ 200.00
		subtotal	$ 12,300.00

Appendix G

NEWWA Recreation Policy

NEW ENGLAND WATER WORKS ASSOCIATION, INC.
WATER RESOURCES COMMITTEE

FINAL REVISED POLICY

DECEMBER 20, 2006

RESOLUTION & POLICY CONCERNING RECREATIONAL USE OF PUBLIC WATER SUPPLIES

It is a fundamental principle of water supply development and protection that water should be obtained from the highest quality source feasible, and every effort should be made to prevent contaminants from entering the source. When faced with efforts by recreational users or others to increase recreational access to water supply reservoirs and/or surrounding land, utilities should oppose such efforts on the basis of increased risk and communicate those risks accordingly.

Maximizing drinking water quality to protect public health is of the highest priority to public water suppliers. Public water suppliers recognize that multiple barrier protection of drinking water supplies and their watersheds is essential in order to meet these goals.

WHEREAS:

In New England, many public water supply reservoirs were created and developed primarily as sources of drinking water that now serve approximately 80% of the region's population, while other surface water sources accommodate recreational uses that predated their use as water supply sources.

Body-contact recreation introduces disease-causing organisms into water bodies, and many other forms of water-dependent recreation are known to introduce contaminants into source waters as well.

As the science of pathogen detection improves, new waterborne diseases associated with drinking water continue to emerge.

Most surface water treatment facilities are designed to greatly reduce, but not completely eliminate, the activity of known pathogenic organisms present in the source water.

NOW, THEREFORE, BE IT RESOLVED:

That New England Water Works Association recognizes society's wish to accommodate legally existing recreational uses on or adjacent to water supply sources, despite the risk to the quality of the water supply and to public health.

That the New England Water Works Association (NEWWA) opposes legislation or any administrative action that would permit or require the opening of domestic water supply reservoirs and adjacent lands to increased recreational use, and

That the official policy of the NEWWA with respect to recreational usage of water supply reservoirs, including reservoirs that provide storage of water at various points in the watershed, and adjacent lands is as follows:

> POLICY – Recreational use of or upon any natural lake, artificial reservoir or impoundment used as a source of water supply as well as the supporting land-based infrastructure necessary to support recreational activities, increases the potential for microbial, physical, and chemical contaminants in the drinking water produced from these source waters. Body-contact recreation (e.g., swimming, bathing, water skiing, wind surfing, and use of personal watercraft) should not be allowed on water bodies used as sources of public water supply. Where it is allowed to occur, it should be separated from the water intake by the greatest distance possible, and it should not be expanded or increased.
>
> Non-body-contact water-based recreation, particularly the use of two-stroke carbureted gasoline engines that discharge exhaust into the water and the use of petroleum-powered vehicles and tools on the ice, should be discouraged. Where it is allowed to occur, it should be separated from the water intake by the greatest distance possible, and it should not be expanded or increased.
>
> Recreation on land adjacent to the water supply source and its tributaries should be restricted to prevent the disturbance of soil and vegetation, the depositing of waste or other contaminants, and the channelization of overland flow; and to maintain the ability of the buffer to trap nutrients, sediment, and other pollutants and to infiltrate runoff. The suggested minimum distance based on maintaining the functions of an undisturbed buffer is several hundred feet. This may vary based on the topography and site-specific features of the surrounding area and the intensity of the recreational use.

IN ADDITION, IT IS RECOMMENDED that water suppliers develop watershed protection plans and policies, and that all proposals to allow recreation activities, or the expansion or increase of existing recreation activities, on a water supply reservoir or within the watershed and other contributing sources to a water supply reservoir should be reviewed for consistency with said plans and policies. This will insure that such proposed activities do not conflict with measures required to protect source water quality.

A proponent of recreational use near or on a public water supply must be required to provide technical evidence supporting the claim that such activity will not adversely affect the water quality, or the public health of the water consumer served by said water supply. When a proposal for recreational use is inconsistent with this policy it should be opposed by the water supplier.

Where recreational or other non-water supply uses of a drinking water source are permitted, the public health risks of this practice should be communicated to the recreational users, drinking water consumers and public decision makers. Efforts should be made to unify all three of these factions in protection, enforcement and outreach activities designed to minimize the risk of contamination and degradation of water quality.

The water utility and its ratepayers should not be forced to bear the burden of financing recreational use. Consequently, any cost for water quality monitoring, evaluations and mitigation programs should be borne by those proposing or benefiting from the recreational activity, not by the water utility or its customers.

Adopted by vote of the Executive Board: December 20, 2006 www.vhb.com