Photo courtesy of Patrick Smith

Roseland Lake Management Plan

Woodstock, Connecticut

Eastern Connecticut Conservation District 3/14/18 Grant # 13-01e, Task 1j

Funded in part by the Connecticut Department of Energy & Environmental Protection through a United States Environmental Protection Agency Clean Water Act Section 319 Nonpoint Source Grant and the Town of Putnam Water Pollution Control Agency.

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Executive Summary

Roseland Lake is a natural lake located in Woodstock, Connecticut. Roseland Lake does not meet Connecticut Water Quality Standards due to nutrient enrichment, eutrophication and biological indicators. Algae blooms are common. The potential for cyanobacteria blooms are of particular concern because two miles downstream of Roseland Lake water is withdrawn for use as a public drinking water supply.

The Eastern Connecticut Conservation District (ECCD), supported by its project partners, collected water quality and other data to determine where the nutrients supporting the Roseland Lake algae blooms are originating. The purpose of this research was to determine whether the main source of nutrients are from the upper watershed or in-lake sources, or both. The over-arching goal of the Roseland Lake Management Plan is to address the nutrient enrichment of the lake and to eliminate potentially harmful algae blooms and to restore surface water conditions in compliance with Connecticut Water Quality Standards.

Background

Water quality data from Roseland Lake dates back to the 1930s. The data suggests an acceleration of nutrient enrichment in the lake due to diversified human activity in the watershed. In 2009, ECCD prepared a Muddy Brook and Little River Water Quality Improvement Plan that included a recommendation to study where the nutrients impacting water quality in Roseland Lake were originating.

Muddy Brook and Mill Brook are the main tributaries to the lake. Little River begins at the lake outlet of Roseland Lake. The United States Geological Survey (USGS) conducted a study in the watershed from 1981-1983 documenting the nutrient and sediment concentrations in Muddy Brook, Mill Brook and Little River. Of particular note was the presence of high concentrations of sediments entering into Roseland Lake from Muddy Brook.

In 2015 – 2016, ECCD collected and analyzed water samples from Muddy Brook, Mill Brook and Little River, using the same locations as those used by USGS for its study. Additional sampling sites were selected at upstream locations in Muddy Brook and Mill Brook, and select tributaries to those streams were also sampled. The purpose of the assessment was to determine if nutrient and sediment runoff increased, decreased or was the same as the found in the USGS study, and to track down specific regions of the watershed where future watershed improvements would be most needed and most effective to restore water quality conditions. Roseland Lake was also monitored as part of this study.

Funding for this project was provided in part by CT DEEP through the US EPA Clean Water Act § 319 nonpoint source pollution grant program. Additional funding for this project was provided by the Town of Putnam Water Pollution Control Authority. Water testing fees were waived by the CT Department of Public Health Drinking Water Division for samples analyzed at the Dr. Katherine A. Kelley State Public Health Laboratory (DPH lab) in Rocky Hill. CT DEEP provided water quality data, Quality Assurance Protocol Plan review, modeling guidance and technical grant management assistance. Volunteers involved with The Last Green Valley Water Quality Monitoring Program assisted with water sample

collection and data management. Dr. Mauri Pelto of Nichols College installed river stage rulers and determined flow curves. Staff from the Windham County office of the USDA Natural Resources Conservation Service provided guidance on agriculture best management practices. CME Associates and Dr. Richard Canavan were hired as project consultants.

Process

Water quality data was collected from Roseland Lake ten times between May 2015 and July 2016. Each sampling event took place over the deep part of the lake and included a depth profile of temperature, dissolved oxygen, pH, conductivity and turbidity, as well as a secchi disk reading. After determining the depth to the thermocline, a discrete depth sampler was used to collect water samples from the thermocline and the bottom of the lake. A grab water sample was also obtained at 0.5 meters. Water samples were analyzed for Alkalinity, Total Phosphorous, ortho-Phosphorus, Total Nitrogen, NO_X, Nitrite nitrogen (NO_2-N), and Ammonia-N. Nitrate nitrogen (NO_3-N), Organic nitrogen and Total Kjeldahl nitrogen (TKN) values were determined by calculation by the lab. Surface samples were also analyzed for Chlorophyll a concentrations. Wet chemistry analysis was performed at the University of Connecticut Center for Environmental Science and Engineering (UCONN CESE) laboratory in Storrs, CT. Depth profiles and secchi disk readings were also conducted at the northern and southern ends of the lake. In June, July, August and September 2015, a grab sample from the surface was collected and brought to Northeast Laboratory in Berlin, CT for algae identification and enumeration.

Stream water samples were also collected and analyzed. A total of fifteen sampling sites were selected. The same Muddy Brook, Mill Brook and Little River sites surveyed by USGS in the 1980s were included. Twelve other monitoring sites were selected to bracket water quality changes within the upper watershed. The samples from the sites closest to Roseland Lake were analyzed at the UCONN CESE lab, where lower detection limits were available for certain parameters. Peckham Brook samples were also analyzed at the UCONN CESE lab after the first sample set indicated high nutrients. Samples were analyzed for Total Phosphorus (TP), ortho-Phosphorus (ortho-P), Total Nitrogen (TN), NO_X, Nitrite nitrogen (NO2-N), Ammonia-N and Total Suspected Solids (TSS). Nitrate nitrogen (NO3-N), organic nitrogen (Org-N) and Total Kjeldahl nitrogen (TKN) values were determined by calculation.

Samples from the upper watershed were analyzed at the CT DPH lab. Stream samples were analyzed for Total phosphorus, ortho-Phosphorus, NO_3-N, NO_2-N, TKN, and NH_3-N and TSS. Org-N, NO_X and Total Nitrogen were determined by calculation. The calculated TN values captured by the samples analyzed at the CT DPH laboratory were likely under-reported because the higher detection limit for certain nitrogen compounds caused values to be reported as non-detectable.

Stream sampling was structured to collect a pre-storm water sample while setting up a passive stormwater sampler at each location. Passive stormwater samplers were used to collect the first flush of stormwater off the land as the stream water level rose above the top of the sampler. A post-storm water sample was collected when the passive stormwater water samples were retrieved from the field. A multi-parameter probe was used to determine the water temperature, dissolved oxygen, pH, conductivity and turbidity in-situ at each sampling location before and after each storm event.

River stage rulers were installed and calibrated at select monitoring locations. Water pressure loggers were installed at the Muddy Brook #1, Mill Brook #1, Peckham Brook and Little River monitoring stations to capture changes in stream depth at hourly intervals.

Sediment samples were also collected from the bottom of Roseland Lake in the area beneath the summer anoxic zone. The summer anoxic zone was determined by the depth profile data obtained from the lake. The sediment samples were analyzed at Northeast Laboratory in Berlin, CT for Iron Bound Phosphorus, Loosely Sorbed Phosphorus, percent moisture and Total Phosphorus. Four sampling locations within the summer anoxic zone were selected randomly and the sediment samples were analyzed for their phosphorus make up.

Table 1: Stream sampling locations

Stream Name	Site number	Latitude	Longitude	Location of site upstream (US) or downstream (DS)
Mill Brook #1	Mill-01	41.939982	-71.957134	US Stone Bridge Road
Little River	LR-01	41.943235	-71.950128	US Stone Bridge Road
unnamed brook by baseball field	un-01	41.946759	-71.957662	DS Roseland Park Road
unnamed brook by golf course	un-02	41.953104	-71.958082	DS Roseland Park Road
Muddy Brook #1	MB-01	41.966200	-71.963645	US Roseland Park Road
North Running Brook	NRB-01	41.965876	-71.963948	US Muddy Brook Confluence
Muddy Brook #2	MB-02	41.966326	-71.963788	US North Running Brook
Peckham Brook	PB-01	41.974912	-71.964912	US Dugg Hill Road
May Brook	May-01	41.983886	-71.970218	US Woodstock Road
Muddy Brook #4	MB-04	41.983519	-71.98025	DS Woodstock Road
Gravelly Brook	GB-01	41.981385	-71.984580	US Cady Lane
English Neighborhood Brook	ENB-01	41.990895	-71.997685	US Route 169
Muddy Brook #5	MB-05	41.996299	-71.990017	US Route 197
Taylor Brook	TB-01	41.950344	-72.004466	US Pulpit Rock Road
Mill Brook #2	Mill-02	41.938115	-71.990322	DS New Sweden Road

Findings and Conclusions

Roseland Lake continues to experience hypereutrophic conditions periodically during the summer months. Conditions that favor cyanobacteria over other forms of true algae exist during those periods. Based on a comparison of data collected by ECCD in 2015-16 to samples collected by the United States Geological Survey in 1981-83, nutrients from upland sources have declined but continue to be substantial after storm events. Using morphometric and land use models to predict phosphorus annual loads to Roseland Lake, Dr. Richard Canavan calculated an approximate load of 2948 pounds of Total Phosphorus per year flowing into Roseland Lake. Mathematical modeling estimated the internal recycling load of phosphorus from in-lake legacy deposits as 300-600 lbs P/yr, about 10-16% of the annual load. However, since the release of these legacy deposits are limited to the summer growing season, they account for 21-55% of the load during summer and fall when anoxia in the bottom of the lake is most likely to occur.

In order to reduce nutrients that will lead to the eliminate HABs in Roseland Lake, a combination of watershed and in-lake practices will have to be implemented, evaluated and modified as necessary over time. Through watershed nutrient monitoring, local watersheds contributing the highest nutrient concentrations to the lake were determined. Those local watersheds should be targeted for implementing nutrient reduction strategies. In-lake monitoring, including lake sediment sampling and analysis, demonstrated that nutrients stored in the sediments beneath the lake are released in the hypolimnion during summer anoxic conditions and become available to cyanobacteria. Cyanobacteria can alter their buoyancy, allowing them to descend through the water column to the hypolimnion, to access this nutrient source during periods of high algae productivity. The data also demonstrates a loss in NO_3-N at the lake surface. Unlike other types of algae, cyanobacteria are capable of using atmospheric nitrogen when dissolved forms are limited. Several types of cyanobacteria produce toxins, a major concern since the public water supply water treatment facility downstream does not have the ability to filter out cyanotoxins.

Recommendations for Further Actions

The Roseland Lake Management Plan includes actions items and a 5 year implementation schedule. The action items are divided into two sections, including practical and effective action items for nonpoint source pollution controls and in-lake techniques to manage eutrophication and aquatic algae. Nonpoint source controls are ongoing, but should continue and be expanded, especially in targeted locations. Options and strategies to manage accelerated eutrophication and cyanobacteria blooms in the lake need to be reviewed. Algaecide treatments utilized in the past to control cyanobacteria blooms will not be permitted going forward to due potential impacts to a non-target species of fresh water snail listed as a Special Concern species in the Connecticut Natural Diversity Data Base. Using data collected as research in preparing this plan, a Certified Lake Manager is needed to provide the guidance for practical and effective in-lake management strategies for nutrient management within Roseland Lake.

Refer to the 2018 Roseland Lake Management Plan for a complete outline of the recommendations. http://www.ConserveCT.org/Eastern

Table 2: List of Recommended Team Members with Suggested Responsibilities

Team Members	Responsibilities
Putnam WPCA	Work with a Certified Lake Manager to select in-lake management strategies to eliminate cyanobacteria blooms in Roseland Lake. Support efforts of other agencies or organizations working to reduce pollution sources impacting Roseland Lake. Initiate or support cyanobacteria bacteria monitoring. Utilize tools in the Roseland Lake Management Plan in future lake stewardship initiatives. Continue watershed inspections. Participate in the Roseland Lake/Little River Collaborative
Putnam Mayor/Board of Selectmen	Adopt Roseland Lake Management Plan and work with other town entities to implement the recommendations in the plan Work with the Town of Woodstock (others) to develop a Transfer of Development Rights program for preserving critical watershed land.
Putnam Town Administrator	Facilitate the formation of and participate in a Roseland Lake/Little River Healthy Watershed Collaborative
Putnam Board of Finance	Include watershed management funding in future funding cycles

Woodstock Board of Selectmen	Adopt Roseland Lake Management Plan and work with other town entities to implement the recommendations in the plan. Work with the Towns of Putnam to develop a Transfer of Development Rights program for preserving critical watershed land.
Woodstock Highway Department	Evaluate stormwater system and develop a plan to reduce impacts to Roseland Lake. Participate in the Roseland Lake/Little River Collaborative
Woodstock Board of Finance	Include watershed management funding, including open space funding, in future funding cycles.
Woodstock Planning and Zoning Commission	Review local regulations for compliance with PHC Section 19-13-B32-b Sanitation of Watersheds regulations.
Woodstock Town Planner	Incorporate relevant components of the Roseland Lake Management Plan into the Woodstock Plan of Conservation and Development. Participate in the Roseland Lake/Little River Collaborative
Woodstock Conservation Commission	Continue education and outreach effort on watershed protection issues. Participate in the Roseland Lake/Little River Collaborative
Woodstock Agricultural Commission	Promote agricultural best management practices and funding resources available to implement them. Participate in the Roseland Lake/Little River Collaborative
The Last Green Valley	Support for volunteer water quality monitoring; Promote easements for forest land owners; Promote Healthy Soil Initiative. Participate in the Roseland Lake/Little River Collaborative
Roseland Park Management	Intercept runoff from the park to reduce NPS. Participate in the Roseland Lake/Little River Collaborative
Eastern Connecticut Conservation District	Continue to seek grant funding to continue NPS reduction in the Roseland Lake Watershed. Participate in the Roseland Lake/Little River Collaborative
CT DEEP	National Pollution Detection and Elimination (NPDES) permitting for algaecide use, 319 and other grant administration; Lake management and water quality resource and support, technical programming support - water monitoring, TMDL, stormwater management, natural resources and open space acquisition and management; Participate in the Roseland Lake/Little River Collaborative
CT DPH	Continue to be an information resource on harmful algae blooms for water utilities Promote PHC Section 19-13-B32-b The Sanitation of Watersheds regulations in the towns with public drinking water watersheds. Participate in the Roseland Lake/Little River Collaborative

Northeast District Department of Health	Promote septic system maintenance Track down illicit discharges Participate in the Roseland Lake/Little River Collaborative
US EPA	Funding support for Non-point source pollution abatement projects
USDA NRCS	Funding support for agricultural producers Participate in the Roseland Lake/Little River Collaborative
Woodstock Open Space Land Acquisition and Farmland Preservation Committee	Cooperator on open space planning. Participate in the Roseland Lake/Little River Collaborative
Wyndham Land Trust	Cooperator on open space planning Participate in the Roseland Lake/Little River Collaborative
The New Roxbury Land Trust	Cooperator on open space planning Participate in the Roseland Lake/Little River Collaborative

Special Acknowledgements

The Eastern Connecticut Conservation Districts wishes to acknowledge the in-kind assistance received to help make this project possible.

Patrick Smith and his Portland Pudgy, (AKA the SS Intimate) possibly the smallest research vessel around.

Devon Avery, ECCD Summer Intern

The Last Green Valley Water Quality Monitoring Program Volunteers
Michelle Weiss, Kevin Johns, Lisanne Tholl, Daniel Zecco, Kevin Kelly

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Douglas Cutler, Putnam Town Manager, and Norman Rogers, Watershed Inspector for the Putnam Water Pollution Control Authority

Patrick Bernardo, Suez Water Quality and Solutions

Dr. Mauri Pelto, Professor, Nichols College, Dudley, MA

The Town of Woodstock Conservation Commission

Dr. Ken Wagner, Water Resource Manager, Water Resource Services

Jean Cass Muddy Brook Stream Gage Reader

Dr. Richard Canavan (project consultant)

Connecticut Audubon Society Center at Pomfret (office space)

Eric Thomas, Charles Lee, Christopher Bellucci, Margaret Thomas, CT DEEP

CME Engineering Associates, Inc.

Solitude Lake Management

Thames River Basin Partnership

Rick Harless, Roseland Park Manager and the Roseland Park Board of Trustees

Dr. Peter Siver, Connecticut College

John Mullaney, Hydrologist, USGS

ECCD staff that contributed to this project include Jean Pillo (project lead), Dan Mullins, Judy Rondeau, Matt Snurkowski, Kate Johnson, Michael Soares and Maura Robie

Glossary of Terms

Term	Definition
Aerobic composting	principle at work in aboveground composting environments that provide air circulation
Algastatic	inhibits the growth of algae
Alkalinity	the quantitative capacity of an aqueous solution to neutralize an acid
Alluvium	a deposit of clay, silt, sand, and gravel left by flowing streams in a river valley
Ammonia nitrogen	(NH_3-N) a form of plant nutrient that can be used by plants or oxidized by bacteria into nitrate nitrogen
Anaerobic digestion	a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen.
Anoxia	an absence of oxygen
Anoxic water	water with dissolved oxygen concentration of less than 0.5 mg/l
Anthropogenic inputs	the direct or indirect results of human activities
Aquatic macrophytes	aquatic plants large enough to be seen without magnification
Base flow	The portion of stream flow that is not runoff and results from seepage of water from the ground into a channel
Benthic	ecological region associated with the bottom of a body of water
Best management practices	a practice that is determined to be an effective and practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources
Biomanipulation	the deliberate manipulation of an ecosystem, especially by adding or removing species
Biomass	the amount of living matter in a given habitat, expressed either as the weight of organisms per unit area or as the volume of organisms per unit volume of habitat
Bioswale	a landscape element designed to remove silt and pollution out of surface runoff water, consisting of a swaled drainage course with sloped sides filled with vegetation, compost or riprap
CAFO	concentrated animal feeding operation, as defined by the United States Department of Agriculture (USDA) is an animal feeding operation (AFO)that has over 1000 "animal units" confined for over 45 days a year.
Chlorophyll a	Chlorophyll a is a specific form of chlorophyll used in oxygenic photosynthesis

Comprehensive Nutrient Management Plan	a conservation plan for an animal feeding operation
Conductivity	a measure of water's capability to pass electrical flow; it is related to the concentration of ions in the water
Constructed wetland	a treatment system that uses natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality
Cyanobacteria	a phylum of bacteria that obtain their energy through photosynthesis (formerly known as blue green algae)
Cyanotoxins	toxins produced by cyanobacteria
Dissolved oxygen	microscopic bubbles of gaseous oxygen that are mixed in water and available to aquatic organisms for respiration
Diurnal vertical phytoplankton migration	a pattern of movement in which phytoplankton remain beneath the photic zone during the day, moving toward the surface after dusk and returning to the depths before dawn
Epilimnion	the upper layer of water in a stratified lake
Eutrophic	descripion of a lake the water is highly enriched with plant nutrients and with high biological productivity characterized by occasional blooms of algae or extensive areas of dense macrophyte beds
Eutrophication	the natural aging process in which a lake transitions to a shallow pond to a wetland and eventually to dry land
Farmland soils of statewide importance	Category of soils that are nearly prime farmland and that economically produce high yields of crops when treated and managed according to acceptable farming methods.
"First Flush" Stormwater	Initial surface runoff after a rain event
Gastropods	mollusks of the class Gastropoda, as snails, whelks, and slugs, having a single shell, often coiled, reduced, or undeveloped, and moving by means of a wide muscular foot
Geometric mean	special type of average where numbers are multiplied together and then take a square root (for two numbers), cube root (for three numbers) etc.
Glyphosate	a synthetic herbicide that is particularly effective against perennial weeds
Healthy soil practices	practices that support the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans
Hydraulic residence time	a measure of the average length of time that water remains in a lake or pond
Hydroponically	the process of growing plants in sand, gravel, or liquid without soil

Hypereutrophic	description of a lake that is extremely rich in nutrients and minerals
Hypolimnion	the lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant
Impervious cover	any surface in the landscape that cannot effectively absorb or infiltrate rainfall, such as driveways, roads, parking lots, rooftops, and sidewalks
Intermittent stream	streams which normally cease flowing for weeks or months each year
Internal loading of phosphorus	phosphorus released from stored accumulations in the bottom of a lake in an anoxic environment
Kjeldahl nitrogen	(TKN) total concentration of organic nitrogen and ammonia
Iron bound phosphorus	(Fe-P) an inorganic molecule containing iron and phosphorus
Legacy phosphorus	phosphorus that has accumulated in soil over time
Limnologist	a scientist who studies the physics, chemistry, geology, and biology of lakes and other inland waters
Littoral zone	The littoral zone is the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants to grow
Loosely sorbed phosphorus	(Org-P)Phosphorus bound with organic molecules
Lysing	the disintegration of a cell by rupture of the cell wall or membrane
Macropores	Cavities that are larger than 75 µm. Functionally, soil pores of this size host preferential soil solution flow and rapid transport of solutes and colloids
Median value	The median is the middle point of a number set, in which half the numbers are above the median and half are below.
Mesotrophic	description of a lake that has a moderate amount of dissolved nutrients
Metalimnion	The layer of water in a stratified lake which lies beneath the epilimnion and above the hypolimnion, in which the temperature decreases rapidly with depth.
Mollusk	any invertebrate of the phylum Mollusca, typically having a calcareous shell of one, two, or more pieces that wholly or partly enclose the soft, unsegmented body
Morphometric	mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms
MS4	acronym for municipal separate storm sewer system
Natural succession	the process of change in the species structure of an ecological community over time

Nitrate nitrogen	(NO_3-N) an inorganic form of nitrogen readily used as a plant nutrient
Nitrite nitrogen	(NO_2-N) an inorganic form of nitrogen in the nitrogen cycle
No-till farming	a way of growing crops or pasture from year to year without disturbing the soil
Oligotrophic	description of a lake that is relatively low in plant nutrients and containing abundant oxygen in the deeper parts
Organic molecules	molecules that contain carbon, oxygen and hydrogen. May be combined with other types of atoms.
Organic nitrogen	(Org-N) nitrogen associated with organic compounds
Ortho phosphorous	(ortho-P) soluble reactive phosphorus and is the form directly taken up by plant cells
Passive stormwater sampler	samplers that rely on the physical flow of stormwater to obtain a sample
pH	a measure of the acidity or alkalinity of a solution
Photosynthesis	the process by which green plants use sunlight to synthesize foods from carbon dioxide and water
Phytoplankton	plankton consisting of microscopic plants
PPM	Parts per million which is equivalent to 1 mg/l or 1000 µg/l
Prime farmland soils	Soils that have the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oil seed crops
Rain garden	a planted depression that allows rainwater runoff from impervious urban areas, like roofs, driveways, walkways, parking lots, and compacted lawn areas, the opportunity to infiltrate and be filtered of non-point source pollution
Secchi disk	an opaque disk, typically white and black, used to gauge the transparency of water by measuring the depth (Secchi depth) at which the disk ceases to be visible from the surface
Subaqueous soil	soils formed in sediment found in shallow, permanently flooded environments or soils in any areas permanently covered by water too deep for the growth of rooted plants
Suspended solids	small solid particles which remain in suspension in water
Thermal resistance to mixing	a measure of the amount of energy that is needed for water from two different temperatures layers to mix together
Thermocline	where the water temperature changes rapidly and can act as a barrier to mixing the layers above and below this zone

Tile drain system	a network of below-ground pipes installed below the surface of agricultural fields, that allow subsurface water to move out from between soil particles and into the tile line
Total Nitrogen	the sum of total Kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite and nitrite-nitrogen.
Total Phosphorous	ithe sum of all phosphorus compounds that occur in various forms
Total suspended solids	(TSS) the dry-weight of particles trapped by a filter; it is a water quality parameter used assess water quality; includes both sediments and organic material
Tributary	a river or stream flowing into a larger river or lake
Trophic state	the total weight of biomass in a given water body at the time of measurement
Turbidity	Turbidity is the measure of relative clarity of a liquid; material that causes water to be turbid include clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, plankton and other microscopic organism
Wet weather sampling	Water sampling after a rainfall event greater than 0.1”
Woodchip bioreactor	subsurface trenches filled with a carbon source, mainly wood chips, through which water is allowed to flow just before leaving the drain to enter a surface water body; the carbon source in the trench serves as a substrate for bacteria that break down the nitrate through denitrification or other biochemical processes
Zooplankton	plankton consisting of small animals and the immature stages of larger animals

Commonly used acronyms

ALUS **Aquatic Life Use Support**

BMP **Best Management Practices**

CAES **CT Agricultural Experiment Station**

CAFO **Confined Animal Feeding Operation**

CESE **Center for Environmental Science and Engineering**

CGS **CT General Statutes**

CLEAR **Center for Landuse Education and Research**

CTA **Conservation Technical Assistance**

ECCD **Eastern CT Conservation District**

EPA **Environmental Protection Agency**

DEEP **Department of Energy and Environmental Protection**

DEP **Department of Environmental Protection**

DPH **Department of Public Health**

EQIP **Environmental Quality Incentives Program**

HAB **Harmful Algae Blooms**

MOA **Memorandum of Agreement**

MS4 **Municipally Separate Storm Sewer System**

NDDB **Natural Diversity Data Base**

NDDH **Northeast District Department of Health**

NOAA **National Oceanic and Atmospheric Administration**

NRCS **Natural Resources Conservation Service**

NTU **Nephelometric Turbidity Unit**

NWQI **National Water Quality Initiative**

PATH **Path to Reduce Pathogens in Agricultural Runoff**

TLGV **The Last Green valley**

TN **Total Nitrogen**

TP **Total Phosphorous**

TSS **Total Suspended Solids**

USGS **United States Geological Survey**

USDA – ARS **United States Department of Agriculture - Agricultural Research Service**

USDA-NRCS **United States Department of Agriculture - Natural Resources Conservation Service**

US EPA **United States Environmental Protection Agency**

UCONN **University of Connecticut**

WI DNR **Wisconsin Department of Natural Resources**

WPCA **Water Pollution Control Authority**

SECTION 1: INTRODUCTION: ABOUT THIS PLAN

The *Roseland Lake Management Plan* is a guide to assist water quality managers, as well as land-use decision-makers and landowners upstream of and around the lake, to understand complex water quality processes that contribute to the water quality of the lake and implementation actions needed to improve, evaluate and protect the water quality in Roseland Lake.

Roseland Lake is located in Woodstock, CT. Responsible lake management is critically important because Roseland Lake is a key component of the Town of Putnam public drinking water supply. Nutrient contributions to the lake and nutrient cycling within the lake influence water quality both in the lake and at a downstream surface intake to a public water supply drinking water filtration plant. Roseland Lake experiences seasonal algae blooms. A major concern is avoidance of conditions that could support a cyanobacteria bloom. Certain cyanobacteria in high concentrations may produce toxins that are detrimental to human health. Serious health concerns from exposure to cyanobacteria toxins include gastro-intestinal distress, skin rashes and liver and kidney damage. The direct consumption of unfiltered impacted water can be lethal to dogs and cattle. All algae blooms increase the cost of water treatment at the water treatment plant and can alter the ecology within the lake. Additionally, even treated water can retain a bad taste or odor from the algae. At present time, the water filtration plant does not have the capacity to remove algal toxins from the water.

The *Roseland Lake Management Plan* is the product of a collaborative effort from multiple state, federal and non-profit agencies, educational institutions and municipal partners and volunteers. The study to determine the nutrient sources in Roseland Lake was recommended in the *2009 Muddy Brook and Little River Water Quality Improvement Plan* (Eastern Connecticut Conservation District).

SECTION 2: BACKGROUND INFORMATION

The Origin and Nature of Roseland Lake

Roseland Lake has been known by many other names including Great Pond by the first settlers, Woodstock Lake or Pond and Senexet Pond (Wakely). Roseland Lake is a natural lake; there are no dams or other flow control structures impounding water in the lake or restricting flow into the lake from upstream tributary sources.

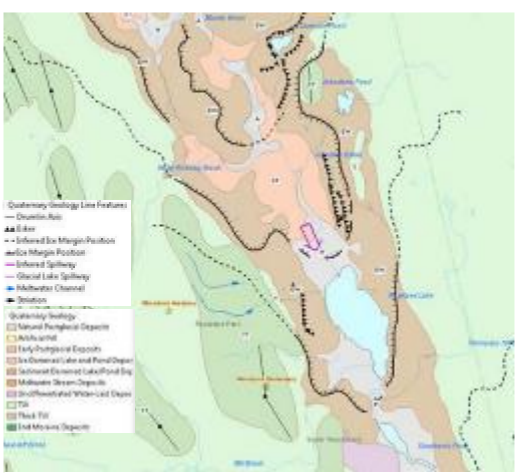

Figure 1: Roseland Lake, Woodstock, CT is located in within the East Woodstock Stratified Drift Deposits.

At the end of the most recent ice age, approximately 12,000 years ago, the East Woodstock Glacial Deposits were laid down in what is now known as the Little River valley in Woodstock. As the glacier retreated generally northward, different ice margins formed and held back meltwater. When a breach would form through an ice margin, the spillway would concentrate water with great force through the valley below. Immediately below the spillway, a scour pool would develop. Roseland Lake was created as the result of a breach in an ice margin during the melting of the glacier (Thomas).

Key Features of the Roseland Lake Watershed

Roseland Lake is located within the Little River watershed, a sub-regional watershed of the Quinebaug River, and part of the greater Thames River regional watershed, which discharges to Long Island Sound.

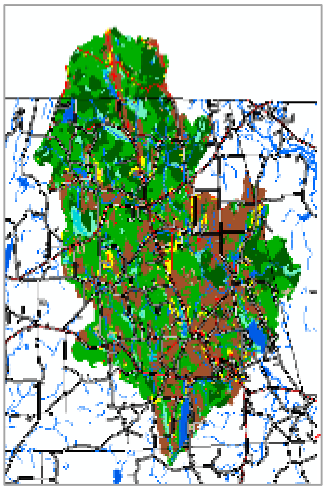

Figure 2: Roseland Lake watershed land cover based on CLEAR 2010 Land use data.

The watershed upstream of Roseland Lake is 30.38 square miles. The majority of the contributing watershed upstream of the lake is located in Woodstock, CT, but also extends into Thompson and Pomfret, CT and Southbridge, MA.

The watershed of Roseland Lake is rural and the predominant land cover is forest or forested wetlands (61.7%). The second highest land cover by percentage is land in agricultural use[1] (23.0%). Total developed land[2] represents 11.8% (CLEAR).

The land currently and historically in use for agriculture is scattered throughout the watershed but primarily clustered in the lower valley closer to the lake. Dairy farming is the presently the dominant type of farming in the watershed. The number of active dairy farms has declined over the past decades, but herd sizes at some of the remaining farms have significantly increased. Other agribusinesses in the watershed include orchards, vegetable production, plant nurseries, beef farms, and equestrian facilities.

Zoning in Woodstock is rural residential, with special permits required for other than residential uses. The effective zoning lot size is 2.5 acres, with an open space subdivision concept required unless waived by special permit. The Zoning Regulations have a maximum for impervious surfaces (hard surfaces that prohibit the infiltration of rainwater) for multi-family residential uses of 30% and 50% for non-residential uses. There is no maximum impervious surface requirement for single family residences[3].

The watershed portion in Thompson, CT is zoned R-80 Residential and Agricultural. The minimum lot size in this zone is 80,000 square feet with the maximum building cover of the lot not to exceed 20%. The watershed in Thompson is located on the west-facing slope of the Bull Hill ridgeline.

The watershed portion in Pomfret, CT is zoned as rural residential, with special permits required for other than residential uses. The minimum lot size is 2 acres with maximum impervious cover not to exceed 35%. Pomfret zoning regulations have minimum land requirements for grazing horses.

The watershed portion in Southbridge, MA is zoned as a single family resident district. The minimum lot size is 30,000 square feet with a maximum building coverage of the lot not to exceed 20%.

Uses of Roseland Lake

A primary human use of the water discharging from Roseland Lake is as a major source of drinking water for the Town of Putnam. The Town of Putnam operates a water treatment plant in Woodstock, withdrawing water from a bypass of Little River. Several homes in southeastern Woodstock also are

[1] Land in agricultural use includes agricultural fields and other grasses.
[2] Developed land includes impervious cover and turf grass.
[3] 1/9/18 email communication with Delia Fey, Woodstock Town Planner.

connected to this water supply. The intake for the Town of Putnam water treatment plant is located approximately two river miles downstream of Roseland Lake.

Figure 3: Fishing pier at Roseland Park. Photo by ECCD.

In addition to providing drinking water to Putnam, Roseland Lake has historically been used for swimming, boating, fishing, ice fishing and ice skating. Pomfret School formerly used the lake for crew racing. With the sport of kayaking on the rise, an increasing number of people use the lake for passive recreation.

Roseland Lake supports a diverse biological community of organisms, including warm water fish species which are a popular target of fishermen. Bald eagles and other fish-eating bird species are frequent visitors to the lake. The CT DEEP determined the lake does meet the requirements for aquatic life use support in the 2016 Integrated Water Quality Assessment Report.

Roseland Park is a 161-acre park located on the western shore of Roseland Lake. Formerly, a portion of the land where the park is now located was a forested wetland floodplain. These wetlands once extended from the barn located on the property to the southern end of the park. In order to expand the park and accommodate larger crowds for Fourth of July picnics hosted by the park's benefactor, Henry Bowen, the wetlands were filled with 90,000 wagon loads of sand and gravel in the late 1880s. A mile-long retaining wall along the park's shoreline was constructed at that time (Wakely). The park currently has an unimproved boat launch for small powerboats and provides public access to the lake for passive recreation such as fishing and canoeing/kayaking. Once a popular spot for swimming, swimming is currently prohibited in Roseland Lake due to changes in the State of Connecticut public health code regulations decades ago which prohibit swimming within two river miles from a public drinking water supply surface intake (*CGS 25-43 Bathing In and Pollution of Reservoirs*). Roseland Park currently attracts 60,000 visitors per year to their lakeside park, with peak visits from mid-April – October. The park is a popular venue for weddings, drawing up to 3000 people on Saturdays for weddings and other events.

Existing Water Quality Regulations

The State of Connecticut established a long-range plan for the management of the water resources of the State (*CGS Section 22a-352*). Because Roseland Lake is located upstream of a public drinking water supply intake, the water quality goal for Roseland Lake is Class AA. Designated uses for Class AA water in Connecticut include existing or proposed drinking water supply, fish and wildlife habitat, recreational use (may be restricted), and agricultural and industrial supply.

By state statute, discharges from municipal wastewater or industrial wastewater pipes into a Class AA watershed are prohibited. Legal discharges into a Class AA water in Connecticut include discharges from public or private drinking water treatment systems, dredging and dewatering, emergency and clean water discharges.

The *Regulations of Connecticut State Agencies Sec. 19-13-B32 Sanitation of Watersheds* applies to land and watercourses that are tributary to a public drinking water supply, including both surface and ground water sources. Within the provisions of these regulations is a restriction on the location of structures where animal manure accumulates. The regulations specify that such structures not be located within 50 feet of a tributary stream or 100 feet of the high water mark of a reservoir, unless provisions are made for preventing manure or other polluting material from flowing or being washed into such waters. Any on-site sewage disposal system, cesspool or privy should also be set back 50 feet from a stream or 100 feet of the high-water mark of a reservoir. Storm drain outlets should discharge at least 100 feet from a stream unless it is impractical to do so. The full text of *Section 19-13-B32 Sanitation of Watersheds* can be found in Appendix A.

On-site waste water disposal systems in Massachusetts are regulated by local health departments under the *CMR 15.00 Title 5* regulations. Table 3 outlines the required separating distances from wetlands and water courses.

Table 2: Separating distances for onsite waste water disposal components under MA Title 5 Regulations

Water resource type	**Septic tank separating distance**	**Leach field separating distance**
Wetlands	100 feet	100 feet
Surface water	25 feet	50 feet
Tributary upstream of a surface water drinking water supply	200 feet	200 feet

Based on *Connecticut General Statutes (CGS), Sections 22a-424, Concentrated animal feeding operations Regulations 40 CFR 412.4(c)(5)*, the USDA Natural Resources Conservation Service (NRCS) has developed guidance recommendations when working with clients to develop Comprehensive Nutrient Management Plans (Purcell).

Table 3: Manure Application Setbacks for Surface Water

Application Criteria	Setback (feet)
Manure applied downslope of surface water	35
Manure applied upslope of surface water with permanent, vegetated setback ≥ 35 feet	35
Manure applied up-slope of surface water with not permanent or insufficient vegetated setback	100

Water Quality Status in Roseland Lake

Roseland Lake was assessed in 2016 by the CT Department of Energy and Environmental Protection (DEEP[4]) in its Integrated Water Quality Assessment Report to Congress as impaired for recreational contact due to nutrient/eutrophication and biological indicators. DEEP defines eutrophic as "water

[4] On July 1, 2011, the CT Department of Environmental Protection (DEP) was restructured into the Department of Energy and Environmental Protection (DEEP). The acronym used to describe the agency will reflect its name at the time of publication of any document referred to in this report.

highly enriched with plant nutrients and with high biological productivity characterized by occasional blooms of algae or extensive areas of dense macrophyte beds." The lake has been assessed as impaired in every Connecticut Water Quality Assessment Report to Congress since the inception of the report in 1992.

Based on an analysis by CT DEP scientists in 1978, the water quality in Roseland Lake was predicted to be eutrophic due to the ratio of the relatively large watershed upstream of the lake to the lake surface area. This would be the expected condition of the lake even if the watershed was undisturbed (CT DEP). In a February 16, 2018 phone interview, Charles Lee, a Senior Environmental Analyst at CT DEEP, reviewed this statement and reported that the lake to watershed ratio would predict naturally hypereutrophic conditions.

ECCD compiled historic Roseland Lake data collected from 1937 – 2012 from numerous sources as part the research to develop the Roseland Lake Management Plan (refer to Table 4). The Total Nitrogen, Total Phosphorus, Chlorophyll A concentration values and Secchi disk depth were compared to the *Parameters and Defining Ranges for Trophic State of Lakes in Connecticut* as presented in the Connecticut Water Quality Standards (refer to Table 5). The data suggests the lake trophic status has transitioned from mesotrophic to borderline highly eutrophic since the late 1930s.

Table 4: Compilation of Historic Roseland Lake Water Quality Data

Date	**Total N (ppm)**	**Total P (ppm)**	**Chlorophyll a (ppm)**	**Secchi depth (m)**	**Trophic State based on Parameters and Defining Ranges for Trophic State of Lakes in Connecticut in Table 5**
Summer 37-39 average	--	13	4.8	2.5	Mesotrophic
June 1971	2280	240	--	--	Highly Eutrophic
August 1971	960	400			Eutrophic/ Highly Eutrophic
October 1973	900	24	--	--	Mesotrophic/ Eutrophic
May 1974	950	30	--	2.0	Mesotrophic/ Eutrophic
July 1974	1220	47	31	2.5	Parameters Ranged from Mesotrophic to Highly Eutrophic
August 1974	650	29	9.9	3.0	Mesotrophic/ Eutrophic
August 1977	640	7	--	2.25	Parameters ranged from Oligotrophic to Eutrophic
June 1992	--	120	37.5	--	Highly Eutrophic
June 1993	--	71	100.8	0.6	Highly Eutrophic
July 2007	820	44	26.24	1.05	Eutrophic
June 2012	--	82.1	--	--	Highly Eutrophic

Table 5: Connecticut Water Quality Standards Lake Trophic Categories

Parameters and Defining Ranges for Trophic State of Lakes in Connecticut (CT DEEP)		
Trophic State Based on Water Column Data	**Parameter**	**Defining Range**
Oligotrophic	Total Phosphorus	0-10 µg/L spring/summer
	Total Nitrogen	0-200 µg/L spring/summer
	Chlorophyll a	0-2 µg/L mid-summer
	Secchi Disk Transparency	6+ M mid-summer

Mesotrophic	Total Phosphorus	10 - 30 µg/L spring/summer
	Total Nitrogen	200 – 600 µg/L spring/summer
	Chlorophyll a	2 - 15 µg/L mid-summer
	Secchi Disk Transparency	2 – 6 M mid-summer
Eutrophic	Total Phosphorus	30 - 50 µg/L spring/summer
	Total Nitrogen	600 - 1000 µg/L spring/summer
	Chlorophyll a	15 - 30 µg/L mid-summer
	Secchi Disk Transparency	1 – 2 M mid-summer
Highly Eutrophic	Total Phosphorus	50+ µg/L spring/summer
	Total Nitrogen	1000+ µg/L spring/summer
	Chlorophyll a	30+ µg/L mid-summer
	Secchi Disk Transparency	0 – 1 M mid-summer

(a) The ranges of Total Phosphorus, Total Nitrogen, Chlorophyll-a, and Secchi Disk Transparency appearing in the table in this section titled "Parameters and Defining Ranges for Trophic State of Lakes in Connecticut" shall be assessed collectively to determine the trophic state of a lake. In addition to water column data, the trophic state of a lake shall be determined by the percentage of the surface area covered by macrophytes in accordance with subsection (b) of this section. For the purpose of determining consistency with the Connecticut Water Quality Standards, the natural trophic state of a lake shall be compared with the current trophic state to determine if the trophic state of the lake has been altered due to excessive anthropogenic inputs. Lakes in advanced trophic states which exceed their natural trophic state due to anthropogenic sources shall be considered to be inconsistent with the Connecticut Water Quality Standards.

(b) Aquatic Macrophytes

(1) Macrophytes are aquatic plants large enough to be seen without magnification. Macrophyte distribution and abundance data shall be reviewed in conjunction with the water column data to determine the trophic states of lakes and ponds.

(2) If macrophyte growth is very extensive (75 - 100% of water body area) and dense, the trophic state of a lake or pond shall be considered "highly eutrophic" regardless of the water column data.

(3) If macrophyte growth is extensive (30 - 75% of water body area) and dense, the trophic state shall be considered "mesotrophic" when the water column indication is oligotrophic, and the trophic state shall be considered "eutrophic" when the water column indication is mesotrophic or eutrophic.

SECTION 3: ECCD ROSELAND LAKE NUTRIENT SOURCE STUDY

In order to evaluate the current water quality conditions in Roseland Lake, its tributaries and outlet stream, ECCD developed a monitoring plan to evaluate both in-lake water quality and water quality in the streams flowing into and out of the lake. Lake monitoring began in May 2015 and concluded in July 2016, omitting November 2015 – March 2016 due to cold water/ice conditions, and was conducted monthly. Lake water samples were analyzed for total nitrogen, organic nitrogen, ammonia nitrogen, nitrite nitrogen and NO_X, total phosphorus, ortho-phosphorus, alkalinity and Chlorophyll a. Nitrate nitrogen was determined by calculation. Surface samples were also analyzed for Chlorophyll a. A multi-parameter probe was used to develop a depth profile of the water column. Temperature, dissolved oxygen, pH, conductivity and turbidity measurements were collected. A Secchi disk depth reading was also collected. Surface, mid-depth and bottom water samples were collected and analyzed at the University of Connecticut Center or Environmental Science and Engineering (CESE) lab in Storrs, CT for nutrient content. Lake surface water was also collected and analyzed at Northeast Laboratories in Berlin, CT for algae identification and counts from June to September of 2015. Sediments from the bottom of the lake were collected and evaluated for phosphorus content at Northeast Laboratories.

The tributary sampling plan was designed to evaluate and compare stream base flow nutrient loads during dry weather (no precipitation causing runoff for at least 48 hours prior to sampling), and stream nutrient loads under wet weather conditions after a rain event measuring > 0.1 inch of precipitation. The tributary monitoring plan included sampling the tributary streams upstream of Roseland Lake, and Little River at the outlet of Roseland Lake, prior to, during and immediately after a rain event. The goal was to collect three sets of pre-, during and post-storm samples, or a total of nine samples at each location. Passive stormwater samplers were set up to capture the "first flush" of stormwater (the portion of stormwater most likely to contain the highest levels of pollutants).

The following factors were used to determine selection of rainfall events for monitoring:

1. Adequate notification (and accuracy of the weather forecast) was required to allow for scheduling a team to collect pre-storm samples and set up passive stormwater collectors before the storm event.
2. Sampling activity needed to be scheduled around the operating hours of the DPH lab in order to deliver and analyze samples within the maximum sample hold time as required by the Quality Assurance Protocol Plan. This limited the sample drop off to Monday – Thursday.

Water samples collected from the lake inlet streams (Muddy Brook and Mill Brook), and at the lake outlet (Little River) were analyzed for total nitrogen, organic nitrogen, ammonia nitrogen, nitrite nitrogen (NO_2) and NO_X, total phosphorus, ortho-phosphorus and total suspended solids at the CESE lab. Nitrate nitrogen was determined by calculation by subtracting the NO_2 value from the NO_X value. Duplicate samples from the inlet and outlet sites, and twelve additional upstream sites, were analyzed for Kjeldahl nitrogen, ammonia nitrogen, nitrate and nitrite nitrogen, total phosphorus, ortho-phosphorus and total suspended solids at the Department of Public Health Chemistry lab in Rocky Hill, CT. Total nitrogen was determined by calculation by adding the Kjeldahl nitrogen to the NO_X. A multi-parameter sampler was used to collect stream temperature, dissolved oxygen, pH, conductivity and turbidity data when the nutrient samples were collected. The outcomes of this study will be presented in individual sections throughout this report.

It was the intent, as part of this study, to measure stream flow into and out of Roseland Lake in order to directly calculate nutrient loading. However, there was below-average rainfall during the summer and fall of 2015, leading to several months of moderate drought (United States Geological Survey). Due to lack of streamflow as a result of the drought, equipment failures and the presence of temporary unpermitted dams (either of human, animal or natural origin) downstream of key monitoring stations, attempts to directly measure flow into and out of Roseland Lake during the 2015-16 monitoring season were unsuccessful.

Roseland Lake Monitoring Results

The results of water quality monitoring in Roseland Lake are presented in Table 6. Water quality data, collected during the growing seasons of 2015 and 2016, indicates the lake trophic level varied from mesotrophic/eutrophic to eutrophic/highly eutrophic when compared to the Parameters and Defining Ranges for Trophic State of Lakes in Connecticut.

Table 6: Roseland Lake Monitoring Results 2015-16

Date	Total N (ppm)	Total P (ppm)	Chlorophyll a (ppm)	Secchi Depth (m)	Trophic State
May 22, 2015	705	38	15	1.38	Eutrophic
June 22, 2015	857	55	16.5	1.37	Eutrophic/Highly Eutrophic
July 15, 2015	580	34	13	1.2	Mesotrophic/ Eutrophic
August 13, 2015	623	30	16.3	1.37	Eutrophic
September 16, 2015	571	44	21.3	1.4	Mesotrophic/ Eutrophic
October 13, 2015	821	40	9.4	2.6	Mesotrophic/ Eutrophic
April 13, 2016	676	24	4.8	2.03	Mesotrophic/ Eutrophic
May 17, 2016	757	33	12.2	1.7	Mesotrophic/ Eutrophic
June 16, 2016	759	45	13.5	1.94	Eutrophic
July 21, 2016	869	63	44.8	1.11	Eutrophic/ Highly Eutrophic

In 2013, the *Connecticut Water Quality Standards for Lake Trophic Categories* were updated. The following statement was added: “For the purpose of determining consistency with the Connecticut Water Quality Standards, the natural trophic state of a lake shall be compared with the current trophic state to determine if the trophic state of the lake has been altered due to excessive anthropogenic inputs. Lakes in advanced trophic states which exceed their natural trophic state due to anthropogenic sources shall be considered to be inconsistent with the Connecticut Water Quality Standards.” As previously stated, the natural trophic state for Roseland Lake, based solely on the area of the watershed in comparison with the surface area of the lake, was predicted to be eutrophic. The data obtained by ECCD on June 22, 2015 determined the lake to be in the highly eutrophic range based on Total Phosphorus levels, and on July 21, 2016 was highly eutrophic based on Total Phosphorus and Chlorophyll a levels. These values demonstrate that Roseland Lake is periodically categorized as highly eutrophic based on certain water quality parameters and is not meeting its designated water quality goal.

Water Quality of Roseland Lake Tributaries

The main tributary to Roseland Lake is Muddy Brook. This 9.2 mile brook begins at the outlet of Muddy Pond drains into Roseland Lake at the northern end of the lake. Muddy Brook does not meet Connecticut water quality standards for recreational contact due to concentrations of fecal bacteria *Escherichia coli (E. coli*) above the State water quality limit for a non-bathing area, which is 576 colony forming units (cfu)/100 ml, and/or a geometric mean of the samples set of ≤126 cfu/ 100 ml. The recreational impairment status of Muddy Brook extends from Roseland Lake up to the English Neighborhood Brook confluence with Muddy Brook. This determination was based on multiple years of sampling collected at a monitoring location upstream of Roseland Park Road.

The Muddy Brook watershed extends into Massachusetts and drains through the East Woodstock agricultural valley. Tributaries to Muddy Brook include North Running Brook, Peckham Brook, Gravelly Brook, May Brook and English Neighborhood Brook, which were also evaluated during the study. Peckham Brook is also classified by CT DEEP as not meeting water quality standards for recreation due to unacceptable levels of fecal bacteria. North Running Brook had previously been listed as not supporting aquatic life, but after the completion of a remediation project on a local farm, the source of the impairment was corrected. North Running Brook is now listed as fully supporting aquatic life. More information on the North Running Brook success story can be found at https://www.epa.gov/sites/production/files/2015-10/documents/ct_running.pdf. There are no documented water quality issues in English Neighborhood Brook, Gravelly Brook or May Brook. Several smaller tributaries to Muddy Brook were not evaluated as part of this project.

The second largest tributary draining into Roseland Lake is Mill Brook. The 4.4 mile long Mill Brook flows into Roseland Lake along the southwestern shoreline, relatively close to the Little River outlet. Tributaries to Mill Brook include Taylor Brook, Mascraft Brook and the outlet stream from Quassett Pond. There are no documented water quality issues in Mill Brook or its tributaries.

Other Tributaries

Two unnamed intermittent streams drain into Roseland Lake on its western side. In order of the sampling route used by ECCD during the 2015/16 study of Roseland Lake, the first unnamed stream (UN-01) drains from a portion of Woodstock Hill, including the Woodstock Academy Bentley Fields Sports Complex, Woodstock Town Hall and Woodstock Elementary School. The stream drains toward Roseland Lake south of the Roseland Park Little League Fields, then through a forested wetland floodplain on the western side of Roseland Lake. For the purposes of this project, this stream does not have a defined watershed. Instead, it is included in the drainage area for the shoreline of Roseland Lake, which also includes land along the eastern shoreline of the lake. The second unnamed intermittent stream that flows into Roseland Lake along the western shore was designated UN-02 in the ECCD Roseland Lake study. This seasonal stream also originates on Woodstock Hill and flows to the lake via a channel through the Woodstock Golf Course. The “golf course” brook does have a defined watershed. In 2012, ECCD partnered with the golf course to install a 15’-wide vegetated buffer along a section of the stream channel to reduce potentially nutrient-laden surface runoff to the stream. Figure 4 shows a map of the Roseland Lake local watersheds. Monitoring locations are identified on the map.

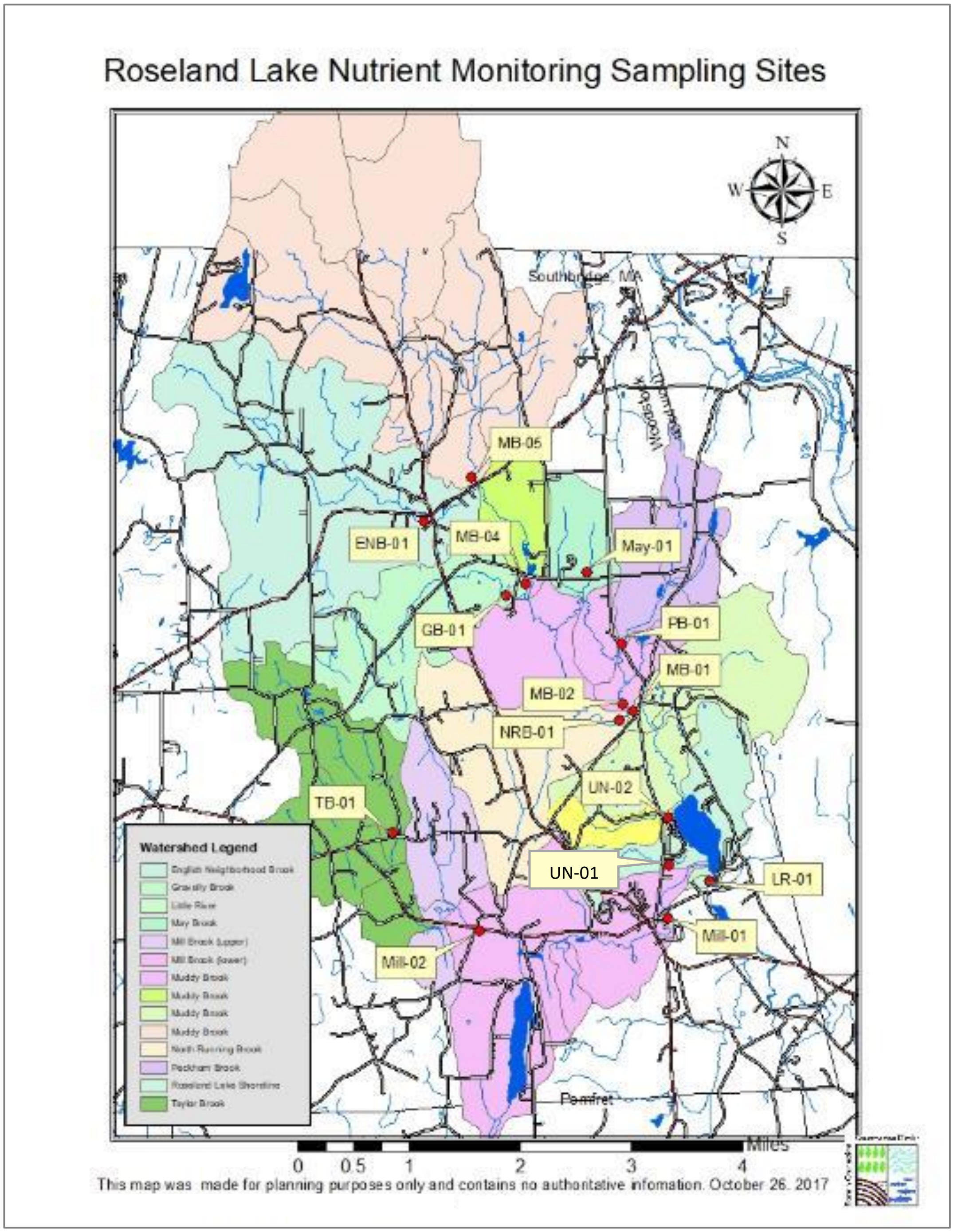

Figure 4: Roseland Lake Nutrient Monitoring Sampling Sites

Interpreting Water Quality Data

The *Connecticut Water Quality Standards* (CT WQS), last updated in 2013, contain very clear defining ranges for nutrients, Chlorophyll a and Secchi depth for determining the trophic status of a lake (refer to Table 2) and for fecal bacteria *Escherichia coli* (*E. coli)*. However, Connecticut has not yet determined specific values or limits for many common water quality parameters in streams, including nutrients. For

Class AA streams, there are few exact numeric limits by which to evaluate water quality data. The CT WQS provide the following water quality guidelines for Class AA streams:

Dissolved oxygen: Not to be less than 5 mg/l at any time.

Suspended and settleable solids: None in concentrations or combinations which would impair designated uses; none aesthetically objectionable; none which would significantly alter the physical or chemical composition of the bottom; none which would adversely impact aquatic organisms living in or on the bottom substrate.

Turbidity: Shall not exceed 5 NTU over ambient levels and none exceeding levels necessary to protect and maintain all designated uses. All reasonable controls or Best Management Practices are to be used to control turbidity.

pH: As naturally occurs.

Nutrients: The loading of nutrients, principally phosphorus and nitrogen, to any surface water body shall not exceed that which supports maintenance or attainment of designated uses.

The State of Connecticut is evaluating different means to assess the impact of Total Phosphorus. In a paper published in the journal Ecological Indicators, Nathan Smucker of the US EPA, along with several other contributing authors, conducted a field study to determine the impacts of Total Phosphorus on in-stream algal biomass, specifically diatoms. The goal of the study was to characterize the ecological responses of diatoms to Total Phosphorus concentration. Streams were sampled in conditions representing base flow conditions (Smucker).

Table 7: TP concentration impact on stream diatom community

TP range	Diatom diversity impacts	Stream impact
< 20 µg/l	Highest quality streams and restoration targets	Not impacted
20 - 40 µg/l	Sensitive taxa steeply decline, tolerant taxa increases, community structure changes	
40 – 65 µg/l	Community level change points begin to occur, sensitive diatoms greatly reduced	
65 – 82 µg/l	Sensitive diatoms lost; tolerant diatoms steeply increase to their maxima	
> 82 µg/l	Saturated threshold; sustained altered community	Severely impacted

Additional guidance on evaluating stream water quality parameter limits was obtained from a series of fact sheets created for Connecticut municipalities, including Woodstock, by CT DEEP for the Municipal Separate Storm Sewer System (MS4) program. According to MS4 guidelines, a follow-up investigation is required if Total Nitrogen in a stormwater sample exceeds 2.5 mg/l or Total Phosphorus exceeds 0.3 mg/l, or if in-stream monitoring detects an increase in turbidity of 5 NTU over ambient levels.

US EPA Quality Criteria for Water

In 1986, the US Environmental Protection Agency (EPA) developed *Quality Criteria for Water*. This document is often referred to as the "*Gold Book*". As stated in the *Gold Book,* "These criteria are not rules and they do not have regulatory impact. Rather, these criteria present scientific data and guidance of the environmental effects of pollutants which can be useful to derive regulatory requirements based on considerations of water quality impacts." Recommendations from the Gold Book document regarding total phosphorous are presented in Table 7.

Table 8: EPA 1986 Water Quality Criteria Total Phosphorus Recommendations (EPA)

Guidance		
Parameter	**Acceptable Range**	**Rationale for Metric**
Total Phosphorus	< 0.050 mg/L	entering lakes of reservoirs
Total Phosphorus	< 0.100 mg/L	in streams or other flowing waters not discharging directly to lakes or impoundments

Other Water Quality References

Warren Kimball of MA Department of Environmental Protection (now retired) developed a method to compare water quality data within specific EPA ecoregions. His SMART Program Water Quality Screening Charts offer a means to compare water quality data within EPA Ecoregion XIV, of which Woodstock is a part. This water quality criteria reference resulted from many years of bi-monthly water quality sampling in Massachusetts. The project included reference stations in the French and Quinebaug watersheds. Little River (Woodstock/Putnam) is located within the Quinebaug watershed. While the charts do not provide statutory water quality standards, they do offer a means to compare and evaluate the water quality data collected for this project against water quality criteria for similar streams in this region. Please refer to the SMART Monitoring Program Water Quality Screening Chart in Appendix B for more information.

Stream Water Quality Monitoring Sites

In order to evaluate nutrient levels in Roseland Lake, water quality data was collected at Muddy Brook and Mill Brook, the two primary tributaries to Roseland Lake. To evaluate the concentration and chemical composition of nutrients leaving the lake, Little River at the lake outlet was also monitored. Nutrient inputs, outputs and in-lake nutrient levels were evaluated to determine whether Roseland Lake nutrients were derived from the contributing watershed (external), from in-lake sources (internal), or whether nutrient levels in the lake varied from external to internal sources seasonally as a result of in-lake nutrient cycling and biological activity. The stream sampling sites are described in Table 8 below.

Table 9: Stream sampling locations

Stream Name	Site number	Latitude	Longitude	Location upstream (US) or downstream(DS) to landmark
Mill Brook #1	Mill-01	41.939982	-71.957134	US Stone Bridge Road
Little River	LR-01	41.943235	-71.950128	US Stone Bridge Road
unnamed brook by baseball field	un-01	41.946759	-71.957662	DS Roseland Park Road
unnamed brook by golf course	un-02	41.953104	-71.958082	DS Roseland Park Road
Muddy Brook #1	MB-01	41.966200	-71.963645	US Roseland Park Road
North Running Brook	NRB-01	41.965876	-71.963948	US Muddy Brook Confluence

Muddy Brook #2	MB-02	41.966326	-71.963788	US North Running Brook
Peckham Brook	PB-01	41.974912	-71.964912	US Dugg Hill Road
May Brook	May-01	41.983886	-71.970218	US Woodstock Road
Muddy Brook #4	MB-04	41.983519	-71.98025	DS Woodstock Road
Gravelly Brook	GB-01	41.981385	-71.984580	US Cady Lane
English Neighborhood Brook	ENB-01	41.990895	-71.997685	US Route 169
Muddy Brook #5	MB-05	41.996299	-71.990017	US Route 197
Taylor Brook	TB-01	41.950344	-72.004466	US Pulpit Rock Road
Mill Brook #2	Mill-02	41.938115	-71.990322	DS New Sweden Road

Muddy Brook

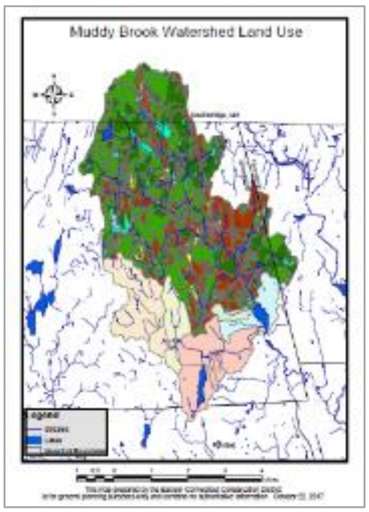

Figure 5: Muddy Brook Watershed

The Muddy Brook watershed is the largest land area draining to Roseland Lake. Four sampling sites were selected along Muddy Brook to bracket other tributaries flowing into it. The sampling locations were selected for accessibility, sample route convenience and to approximate the sampling locations used during a 1980 Muddy Brook water quality reconnaissance survey conducted by the United States Geological Survey (USGS). One USGS sampling site was omitted because ECCD was denied access by the property owner.

MB-01 was the sampling site closest to Roseland Lake. This location is downstream of the North Running Brook confluence. For reference purposes, water samples from the site were analyzed at both the CESE lab and the DPH lab. The samples for the remaining Muddy Brook sampling locations were analyzed at the DPH lab. The minimum detection limits for certain nutrient parameters were higher at the DPH lab than at the CESE lab, meaning that for many of the upstream monitoring locations, some of the nitrogen series results were below the minimum detection limits, and the calculated total nitrogen values were likely under-represented the true total nitrogen value, especially in the streams with less impacted water quality. In samples for which the nitrogen series results exceeded the minimum detection limit, confidence in those results is higher. This was also true for ortho-phosphorus concentrations. Total phosphorus was measured directly and confidence in the results is high. The total suspended solids (TSS) values, with a minimum detection limit of 4 mg/l at the DPH lab, provided valuable data as the higher values increase cause for concern.

Mill Brook

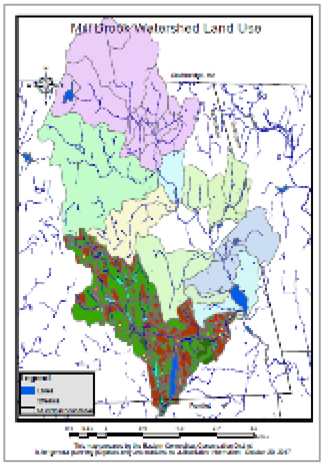

Figure 6: Mill Brook Watershed

The second major tributary flowing into Roseland Lake is Mill Brook. Tributaries to Mill Brook include Taylor Brook, Mascraft Brook and the outlet stream from Quasset Lake.

Mill Brook was sampled in two locations. The site closest to Roseland Lake (Mill-01) was upstream of Stonebridge Road behind the South Woodstock Baptist Church. This site was utilized in 1981-83 by the USGS and results reported in the 1991 Kulp study. The bottom substrate at this location was bedrock, and for an undetermined period of time during the summer of 2015, there was no flow going through the stream channel due to drought conditions.

A second monitoring site in Mill Brook (Mill-02) was located upstream of the Quasset Lake outlet stream. A monitoring site was also established in Taylor Brook (TB-01).

Little River

Little River begins at the outlet of Roseland Lake. Water samples from Little River were collected upstream of Stonebridge Road at the Putnam Fish and Game Club boat launch (LR-01). Thompson Hill Brook drains into Little River above the monitoring station but was not monitored as part of this project but is mentioned for its potential to dilute nutrient concentrations in Little River at the monitoring site.

Stream Monitoring Results

A composite of the monitoring data from the tributary sampling and indications for unmonitored upland nutrient sources from land runoff is presented in Figure 7. The numbers in the chart represent the average for all the samples at each location. The nutrient data is located in Appendix D.

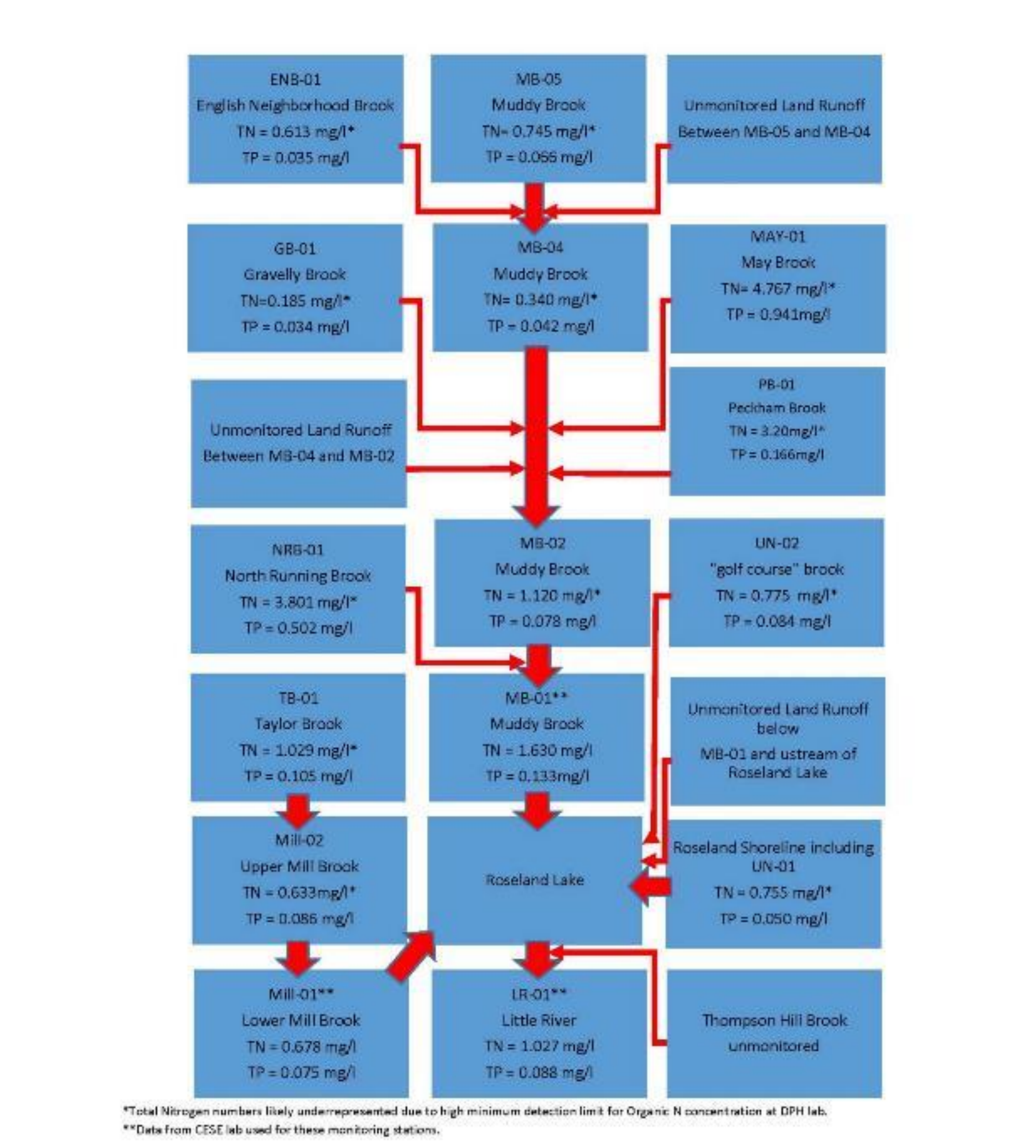

Figure 7: Roseland Lake Nutrient Flow Schematic

Roseland Lake Watershed Prioritization for Restoration Work

Several methods of evaluation were conducted to determine if any of the local watersheds upstream of Roseland Lake should be prioritized for non-point source nutrient reduction activities. These methods included: 1) comparing water quality data averages collected by ECCD in 2015/2016 to various established guidelines, 2) using land cover data and established runoff coefficients associated with various land use types to estimate the annual phosphorus yield in pounds per acre per year, without considering the water quality data, 3) estimating nutrient loads based on the average stream nutrient measurements (total nitrogen [TN] & total phosphorus [TP] in mg/l) collected in 2015-2016 by ECCD and employing a runoff coefficient developed by ECCD using USGS flow data from three gaged stations in the Muddy Brook watershed to estimate what portion of precipitation runs off in non-gaged and 4) comparing the base flow total phosphorus values to the Smucker stream diatom impact scale.

Method 1: Comparing 2015/2016 data to non-regulatory water quality guidelines

Water quality data collected in the tributaries upstream of Roseland Lake was compared to guidelines from multiple sources. These criteria are not rules and they do not have regulatory impact, but were used as a means to assign importance to areas of the watershed where more focused implementation efforts may be needed.

The emphasis of this effort was to focus on total phosphorus concentrations. Due to many nitrogen parameters testing below detection limits, the total nitrogen values from the CT Department of Public Health lab were scored only for streams in which nitrogen values were high enough to surpass the confidence limits.

The four guidelines that were used for reference include the 1986 US Environmental Protection Agency (EPA) Quality Criteria for Water (Gold Book), the MA DEP SMART Program Water Quality Screening Charts (Smart Charts), phosphorus concentration metrics outlined in Using algal metrics and biomass to evaluate multiple ways of defining concentration-based nutrient criteria in streams and their ecological relevance by Nathan Smucker et al, and proposed thresholds for stormwater monitoring under the CT MS4 General Permit. For the Gold Book and MS4 permit guidelines, each stream was assigned a pass or fail score. For the Smucker guidelines, average base flow Total Phosphorus values for each stream were compared to the impact scale outlined in the paper introduction and rated on a scale from 1 (high quality) to 5 (substantially altered). If the total phosphorus value was on the cusp of two categories, it was scored for both categories. For the Smart Charts, nutrient averages were compared to the value ranges in streams in EPA Region XIV and ranked as excellent, good, fair or poor. Parameters that received a score of Fail or Poor, or rated poor in the Smart Chart ratings, or scored a 3 or more in the Smucker guidelines were highlighted in red text. Additional comments were also noted. To review the tributary monitoring sites, please refer to figure 4 on page 19.

Table 10 Stream Sample Results Compared to Water Quality Guidance Documentation

Stream name	Site location	Gold Book TP < 50 µg/l lake inlet	Gold Book TP < 100 µg/l Other streams	Smart Charts	Smucker et al values	MS-4 TP < 300 µg/l	MS-4 TN < 2500 µg/l	Comments CESE = UCONN Center for Environmental Science and Engineering laboratory DPH = CT Department of Public Health laboratory
Muddy Brook #1	Upstream of Roseland Park Road/Roseland Lake	Fail	Fail	TP poor TN poor	0.021 mg/l 2	Pass	Pass	CESE data
Mill Brook #1	Upstream of Stone Bridge Road/Roseland Lake	Fail	Pass	TP fair/poor TN good	0.032 mg/l 2	Pass	Pass	CESE data; no flow late summer 2015
North Running Brook	Upstream of Muddy Brook	--	Fail	TP poor TN poor	0.057 mg/l 3	Fail	Fail	DPH data; intermittent flow at the sampling station; highest nutrient concentrations in the brook correlates with nearby construction activity
Muddy Brook #2	Upstream of North Running Brook confluence	--	Pass	TP poor TN --	0.021 mg/l 2	Pass	Pass	DPH data; downstream of small dam; upstream of North Running Brook
Peckham Brook	Upstream of Dugg Hill Road	--	Fail	TP poor TN poor	0.017 mg/l 1	Pass	Fail	CESE data; high background levels of NO_3-N in dry weather samples
May Brook	Upstream of Woodstock Road	--	Fail	TP poor TN poor	0.048 mg/l 3	Fail	Fail	DPH data; high background levels of NO_3-N in dry weather samples
Muddy Brook #4	Downstream of Woodstock Road	--	Pass	TP fair TN --	0.029 mg/l 2	Pass	pass	DPH data
Gravelly Brook	Upstream of Cady Lane	--	Pass	TP –good TN --	0.009 mg/l 1	Pass	pass	DPH data; intermittent flow at the sampling station
English Neighborhood Brook	Upstream of Route 169	--	Pass	TP good TN --	0.021 mg/l 2	Pass	Pass	DPH data; possible illicit discharge upstream
Muddy Brook #5	Upstream of Route 197	--	Pass	TP fair TN --	0.040 mg/l 2/3	Pass	Pass	DPH data; downstream beaver activity influenced flow
Taylor Brook	Upstream of Pulpit Rock Road	--	Fail	TP poor TN fair/poor	0.086 mg/l 5	Pass	Pass	DPH data, 9/2015 data may have been impacted by illegal dumping
Mill Brook #2	Downstream of New Sweden Road	--	Pass	TP poor TN --	0.065 mg/l 4/5	Pass	Pass	DPH data, 9/2015 data may have been impacted by Taylor Brook illegal dumping
Unnamed stream #1	Downstream of Roseland Park Road near baseball field	--	Pass	TP good/fair TN --	0.013 mg/l 1	Pass	Pass	DPH data; intermittent flow
Unnamed stream #2	Downstream of Roseland Park Road near golf course	--	Pass	TP fail TN --	0.013 mg/l 1	Pass	pass	DPH data; intermittent flow

Method 2 – Using land cover data and established runoff coefficients

The UCONN Center for Land-use Education and Research (CLEAR) collected data using remote sensing technology to detect land cover types and translated the information to a map data set. The most current data set was developed based on 2010 data.

The CT DEP, using land cover data combined with water quality data, developed coefficients to estimate the amount of nutrients in runoff for different land covers. The following chart lists the nutrient amounts per area of each land cover.

Table 11 DEP land use coefficients for total phosphorus

Land Use	Phosphorus lbs/ac/day	Phosphorus mg/m^2/yr
Agriculture	$4.33*10^{-4}$	17.7
Forest	$1.04*10^{-4}$	4.3
Urban (developed land)	$1.98*10^{-3}$	80.8

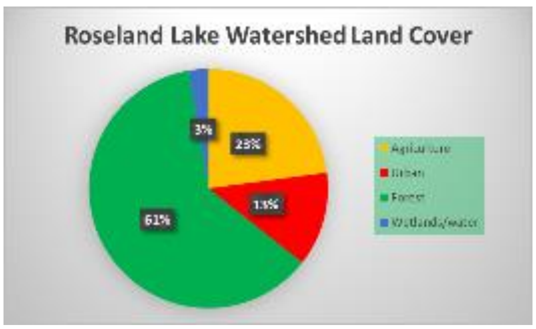

Figure 8: Land cover % upstream of Roseland Lake

Figure 8 represents the land cover percentages for agriculture (agricultural fields and other grasses), forested land (coniferous forest, deciduous forest and wetland forest) and urban (developed land, turf and grass, and barren land) which make up 97% of the land cover upstream of Roseland Lake. ECCD divided up the Roseland Lake watershed into local watersheds representing the land upstream of each sampling location used in its 2015/16 water quality study. Using geographic information system technology, each local watershed was broken down into three general land cover types: forest, agriculture and urbanized developed land. By multiplying the area of each type of land cover by the corresponding coefficient for that land cover type, the amount of total phosphorus potentially draining off the land and into the streams was calculated. The following figure demonstrates the total potential load by land type in each watershed.

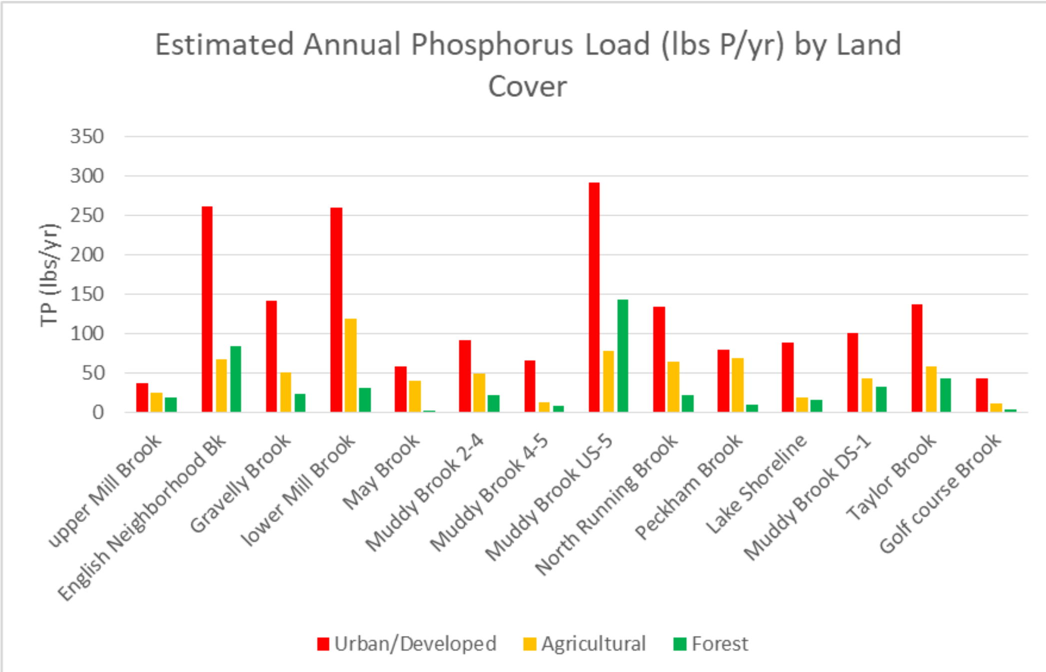

Figure 9: Potential phosphorus load by land cover type per watershed area

The sum of the total phosphorus load from each local watershed was determined and then divided by the total area of each local watershed. The results are displayed in Figure 9.

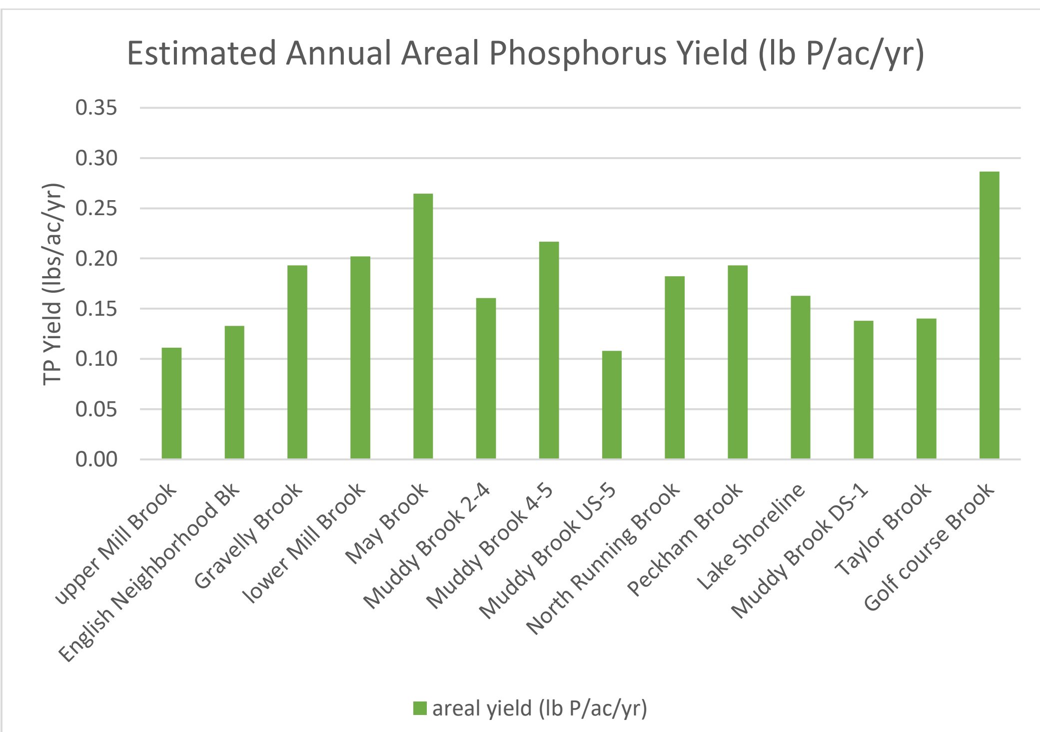

Figure 10: Sum of potential TP load by sub-watershed area

Table 12: Estimated phosphorus export based on land cover

	Estimated Annual Phosphorus Load (lbs. P/yr.)				Estimated Annual Areal Phosphorus Yield (lbs. P/acre/yr.)		
Sub-watershed	**Urban/Developed**	**Agricultural**	**Forest**	**Total**	**ws area (ac)**	**areal yield (lb. P/ac/yr.)**	**ave TP (mg/l)**
upper Mill Brook	37.1	24.35	19	80	720	0.11	0.086
English Neighborhood Brook	261	66.4	84.4	412	3100	0.13	0.035
Gravelly Brook	141.7	50.32	22.4	214	1108	0.19	0.034
lower Mill Brook	260.2	118.86	30.6	410	2028	0.20	0.075
May Brook	58.7	40.02	1.6	100	378	0.26	0.941
Muddy Brook 2-4	91.5	49.34	21.2	162	1009	0.16	0.078
Muddy Brook 4-5	66	13.03	8.6	88	406	0.22	0.042
Muddy Brook US-5	292.4	77.61	142.5	513	4751	0.11	0.066
North Running Brook	133.4	64.26	22.1	220	1207	0.18	0.502
Peckham Brook	79.9	68.61	10.1	159	823	0.19	0.166
Lake Shoreline	88	18.18	15.1	121	743	0.16	0.050
Muddy Brook DS-1	100.5	43.03	32.1	176	1275	0.14	0.133
Taylor Brook	137	58.09	42.6	238	1696	0.14	0.105
Golf course Brook	43.2	11.07	2.6	57	199	0.29	0.084
Total	1790.6	703.17	454.9	2950	19443	-	-

Using this analysis, the unnamed brook by the Roseland golf course and May Brook have the highest potential per acre of land to contribute a large load of phosphorous to Roseland Lake. However, this analysis was not ranked by watershed size, and the golf course brook and May Brook watershed areas are significantly smaller in size than the watershed area upstream of the Muddy Brook sampling station #5, and therefore is likely-delivering less of an annual phosphorus load to Roseland Lake

Method 3 – Nutrient load estimates influenced by average flow data

In the third analysis, historical flow data was used to estimate the volume of water leaving each watershed. Nutrient loads were based on the average stream nutrient measurements (TN & TP mg/l) collected in 2015-2016 by ECCD. Runoff (in/yr) was used as a surrogate for flow (cfs) for ungaged streams. USGS StreamStats, an internet map-based user interface that is used to delineate drainage areas for user-selected sites on streams, were used to calculate local watershed area (sq mi) and annual precipitation (in). A runoff coefficient was developed using USGS flow data from three gaged stations in the Muddy Brook watershed to determine what portion of precipitation runs off. The results of these calculations are found in Table 4 Roseland Lake Local Watershed Nutrient Loads (lb. /yr.) and Yields (lb. /ac/yr.). The load from each watershed was expressed as pounds per year (lb. /yr.) and the yield was calculated by the number of pounds per acre per year (lb. /ac/yr.). Watersheds designated "all" include the contributing local watersheds upstream of a sampling station. Watersheds designated "isolated" are calculated by subtracting contributing local watersheds from the subject sub-watershed. Unidentified watershed conditions may influence these calculated results and render them unreliable.

Table 12

WS Groups	Local Watershed	WS Area (ac)	TP load (lbs/yr)	TN load (lbs/yr)	TP Yield (lb/ac/yr)	TN Yield (lb/ac/yr)
Roseland Lake Local Watershed Nutrient Loads (lb/yr) and Yields (lb/ac/yr)						
MB-04 WS	Muddy Brook-04 - all	8,256	1,776.96	14,384.93	0.22	1.74
	Muddy Brook-05	4,781	1,616.98	18,252.23	0.34	3.82
	English Neighborhood Brook	2,810	548.28	9,602.66	0.20	3.42
	Muddy Brook-04 - isolated	*666*	*(388.29)*	*(13,469.96)*	-	-
MB-02 WS	Muddy Brook-02 - all	11,520	4,608.74	66,176.75	0.40	5.74
	Muddy Brook-04 - all	8,256	1,776.96	14,384.93	0.22	1.74
	Peckham Brook	819	696.88	13,433.81	**0.85**	**16.40**
	May Brook	179	940.19	4,762.88	**5.25**	**26.58**
	Gravelly Brook	1,075	203.82	1,109.04	0.19	1.03
	Muddy Brook-02 - isolated	*1,190*	*990.89*	*32,486.09*	*0.83*	***27.29***
MB-01 WS	Muddy Brook-01 - all	12,736	8,644.34	105,941.88	0.68	8.32
	Muddy Brook-02 - all	11,520	4,608.74	66,176.75	0.40	5.74
	North Running Brook	1,203	3,095.29	23,436.61	**2.57**	**19.48**
	Muddy Brook-01 - isolated	*13*	*940.31*	*16,328.52*	*73.46*	*1,275.67*
Mill-02 WS	Upper Mill Brook - all	2,624	1,258.02	9,259.59	0.48	3.53
	Taylor Brook	781	459.79	4,505.93	0.59	5.77
	Upper Mill Brook - isolated	*1,843*	*798.23*	*4,753.65*	*0.43*	*2.58*
Mill-01 WS	lower Mill Brook - all	4,307	1,802.13	16,291.30	0.42	3.78
	upper Mill Brook - all	2,624	1,258.02	9,259.59	0.48	3.53
	lower Mill Brook - isolated	*1,683*	*544.12*	*7,031.71*	*0.32*	*4.18*
Direct Discharge WS	"Golf Course" brook (UN-02)	186	78.93	728.20	0.43	3.92
	Unnamed brook 01	166	42.13	636.10	0.25	3.82

In the first example in Table 12, Muddy Brook #4 sampling station includes all the land upstream of the monitoring station, plus watershed drainage that is directed to Muddy Brook above the sampling location. This includes the area of land upstream of the Muddy Brook #5 sampling station and the entire English Neighborhood Brook watershed. When the local watershed below the English Neighborhood Brook confluence was isolated from the upland drainage, it indicates less of a pollutant load in Muddy Brook at that sampling location. This may be due to a combination of a beaver dam plus a large marsh complex below the Muddy Brook #5 sampling station that each may allow for phosphorus rich sediment from Muddy Brook to settle out of suspension.

When the land area downstream of the North Running Brook confluence with Muddy Brook and upstream of the Muddy Brook #1 sampling station was isolated, the 13-acre Muddy Brook/North Running Brook confluence watershed appears to contribute an excessive nutrient load, much higher than would be predicted using land use runoff models. While it is highly improbable that the numbers are correct, there are local areas of concern in the watershed that are worthy of further investigation.

- This small watershed area includes hobby farms but it was not directly investigated how or where the drainage from these hobby farms enters Muddy Brook.
- There are historic homes in the watershed. There are no data available to ECCD on the age or maintenance records for the septic systems associated with those historic homes. The Northeast District Department of Health (NDDH) conducted a soil test on one of the properties prior to its sale in 2016 which indicated there was no septic system failure on that property[5].
- Data collected in 2017 on the downstream side of Roseland Park Road as part of a bacteria source trackdown project headed by the University of Connecticut indicates *E. coli* bacteria levels in Muddy Brook exceed the state maximums for recreational contact.

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[5] Email communication with M. Marcoux, NDDH, Woodstock Town Sanitarian

  - Further analysis of those samples at a specialty lab in Florida isolated biomarkers from ruminants, specifically cows.
  - Human biomarkers were tested for and not found in the sample from Muddy Brook.
  - The sample was not tested for horse, waterfowl or chicken biomarkers.
- North Running Brook did not consistently flow during the 2015/16 ECCD study of the watershed. Contributions to Muddy Brook from North Running Brook may be underestimated based on sampling conducted in 2015/16.

The highest yield local watershed results for total phosphorus and total nitrogen loads are highlighted in bold red text in Table 12.

Based on flow weighted analysis, the local watersheds with the highest potential nutrient contributions per acre in the Muddy Brook watershed were May Brook, North Running Brook and Peckham Brook. The local watershed with the highest potential nutrient contributions per acre in the Mill Brook watershed was Taylor Brook.

Table 13 Roseland Lake top results for flow weighted TP and TN yields

Watershed name	Total Phosphorus yield	Total Nitrogen yield
May Brook	5.25 lb/ac/yr	26.58 lb/ac/yr
North Running Brook	2.57 lb/ac/yr	19.48 lb/ac/yr
Peckham Brook	0.85 lb/ac/yr	16.4 lb/ac/yr
Taylor Brook	0.59 lb/ac/yr	5.77 lb/ac/yr

In one of the four May Brook sample sets, the concentration of Total Suspended Solids from the first flush stormwater sample collected on October 29, 2015 was 1590 mg/l. This is notably higher than any other sample collected at that location or any other sampling station. There was a visible sediment layer greater than 1 inch deep on the bottom of the sample container. The corresponding nutrient loads from the first flush stormwater sample were also higher than other samples collected after any rain event at that sample location, although there was no notable reason to explain this. The total phosphorus concentration in the post rain event grab sample collected later that afternoon, although lower than the first flush stormwater sample, was still high when compared to other samples collected at that location. If the first flush sample was to be excluded as an outlier, the TP and TN values from the remaining samples were still higher than obtained from most other watersheds. Possible causes are agricultural activity and stormwater runoff from Woodstock Road.

The highest values for TN and TP concentrations obtained from North Running Brook in September 2015 may have been influenced by upstream construction activity, although the TSS value was within the normal range for that sample location.

The isolated Muddy Brook #2 watershed had the highest TN yield at 32.78 lb/ac/yr. This sampling site is downstream of the May Brook and Peckham Brook confluences and Muddy Brook was likely impacted by receiving flow from those watersheds. However, the local Muddy Brook #2 watershed is nearly 30% agricultural land and its runoff was also likely contributing to the nutrient load documented at the Muddy Brook #2 monitoring location.

Further review of the isolated Muddy Brook #1 watershed is warranted for both agricultural and residential land uses.

Taylor Brook upstream of Pulpit Rock Road exhibited the highest annual yield per area load for both total nitrogen and total phosphorus in the Mill Brook watershed. The September 2015 samples were possibly impacted by illicit dumping of filleted fish carcasses into the brook upstream of the sampling site. Further review of this watershed is warranted for both agricultural and residential land uses.

Mill Brook #2 is downstream of Taylor Brook. Although there were elevated nutrient concentrations in water samples collected in September 2015, they were lower than the upstream Taylor Brook monitoring site and likely diluted by flow from Mascraft Brook. Mill Brook #1 had no flow at the September 2015 pre-storm sample date. The September 2015 post-storm sample demonstrated lower nutrient concentrations than Mill Brook #2, indicating potential dilution of nutrient concentrations in the stream from the outflow of Quasset Lake and other runoff.

Method 4

In a paper published by Nathan Smucker et al. in the March 2013 edition of Ecological Indicators, a method to determine stream water quality based on total phosphorus concentration was discussed. Eighty-seven stream sites distributed throughout Connecticut were sampled by CT DEEP for benthic algae (diatoms) and water chemistry under dry weather conditions (samples were collected at least 48 – 72 hours after a runoff producing event) in July to September 2002–2004. A comparison of TP values to nutrient sensitive diatom communities were used as a means to measure water quality in a stream. Their results suggest a means to indicate which TP management practices and decisions at the watershed scale will likely be important for improving degraded streams and/or conserving high quality streams (Smucker).

ECCD compared the average TP values collected at base flow/dry weather conditions for each stream monitoring location upstream of Roseland Lake to the range of values in the Smucker et al. scale outlined in Table 7 on page 30. The streams were assigned an impact value of 1 – 5 to correspond with the values in Table 7. Streams in which the TP values at base flow were <0.020 mg/l were scored a 1 and the focus of upstream management should be on anti-degradation. Streams in which the TP values at base flow were >0.086 mg/l were scored a 5 and the focus for watershed management should be on restoration. Intermediate scores of 2, 3 and 4 demonstrate a need for some level of watershed restoration. Outcomes of this data review are included in Table 10 as Smucker et al values.

Watershed priority conclusions

Based on actual field water sampling results, potential yield per acre evaluation and flow weighted data analysis of field sampling results, **the recommended highest priority watersheds for nutrient reduction** upstream of Roseland Lake are May Brook, North Running Brook, Peckham Brook and Muddy Brook beginning downstream of Woodstock Road. May Brook and North Running Brook watersheds each are contributing higher TP and TN loads to Muddy Brook after storm events. May Brook, Peckham Brook and North Running Brook each have high baseload concentrations of TN. The TN baseflow concentrations in these streams, if found in an urban stormwater sample, would require further investigation. It is reasonable to suggest further investigation of the sources of TN in these streams is necessary.

There were no in-field water sampling results for the Muddy Brook watershed below the Muddy Brook #1 sampling location. Because this segment of the brook flows directly into Roseland Lake, runoff from the area has limited potential to be mitigated by natural environmental factors, and therefore has been ranked a **medium priority**.

At the Muddy Brook #1 site, when compared to the Smucker et al TP ranges, the average base flow concentrations of TP based on 4 samples was 0.021 mg/l. Two samples were above 0.020 and two were below 0.020 mg/l, which is the cutoff for non-impacted streams. This TP concentration at base flow would support mesotrophic conditions in the epilimnion in Roseland Lake. Stormwater runoff increases the TP load in Muddy Brook.

The “golf course” brook watershed was included as a **medium priority** based on the percent developed and agricultural land in the watershed, as well as its direct drainage into Roseland Lake with limited potential to be mitigated by natural environmental factors.

In the Mill Brook watershed, Taylor Brook upstream of Pulpit Rock Road exhibited higher nutrient concentrations in water samples and ranked fourth highest in potential yield per acre of all sampling locations upstream of Roseland Lake. The average phosphorus concentration in the Mill Brook #1 water samples exceeded the recommended concentration for lake tributaries when compared to the EPA Gold Book recommendations and this may have in part originated in Taylor Brook. Taylor Brook was ranked a **medium priority** based on the phosphorus load it carries into Mill Brook.

Mill Brook #1 base flow TP values were higher than Muddy Brook based on three dry weather samples. The average TP value of 0.032 mg/l indicates concentrations that would begin to impact sensitive diatom taxa in streams. This concentration of TP at base flow conditions also supports eutrophic conditions in the epilimnion of Roseland Lake.

Figure 12 is a map highlighting the Roseland Lake watershed prioritization for restoration work based on the outcomes of the ECCD Roseland Lake watershed investigation in 2015-16.

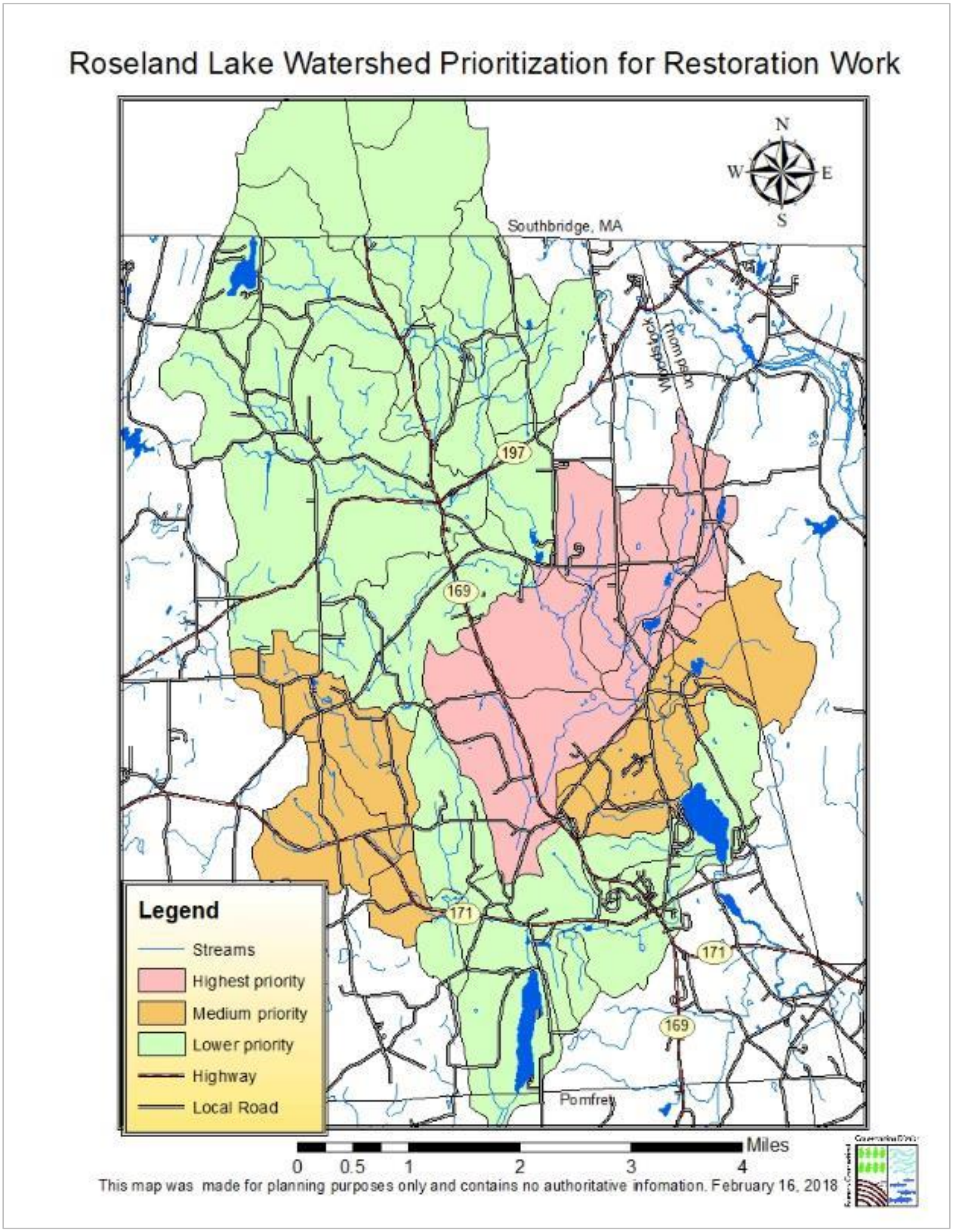


Figure 11: Roseland Lake watershed prioritization for restoration work

SECTION 4: ROSELAND LAKE CHARACTERISTICS

The surface area of Roseland Lake is approximately 96 acres. The maximum depth of the lake is approximately 20 feet. The average depth of the lake is 10 feet (DEP). Lake depth can vary depending on rainfall and season of the year.

Figure 12: Roseland Lake Bathymetry

Hydraulic Residence

A CT DEP study of Roseland Lake estimated the hydraulic residence time (the time it takes one drop of water to travel through the lake) of Roseland Lake to be 8 days during periods of high flow and up to 25 days during the summer months (CT DEP).

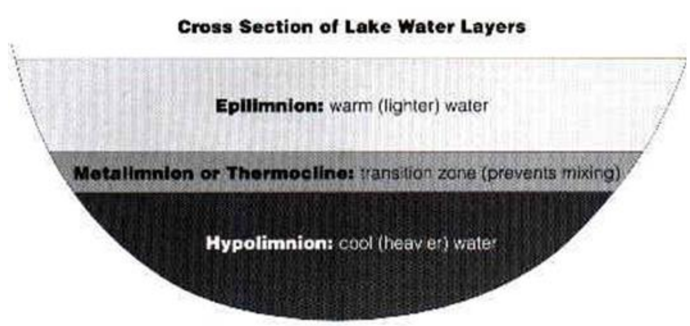
There was below average rainfall during the summer and fall of 2015, leading to several months of moderate drought conditions (United States Geological Survey). It is reasonable to expect that the lack of rain during that time period likely increased the hydraulic residence time to the upper limit.

Thermal Stratification

Pure water is most dense at 4 °C. As the temperature of water increases above 4 °C, it becomes less dense. As solar radiation intensifies and the air temperatures increase during the summer season, water near the surface of the lake becomes warmer and less dense. Water in the deeper parts of a lake that is not directly exposed to solar radiation does not warm up as quickly, and the water in the deepest regions of a lake stays significantly cooler and remains denser. These temperature variations lead to density/temperature zones within a lake: the epilimnion at the top and the hypolimnion at the bottom. Between those two zones is a transitional layer known as the metalimnion, or the thermocline. The thermocline is where the water temperature changes rapidly and can act as a barrier to mixing the layers above and below this zone. Due to this phenomenon, in temperature-stratified lakes, it is possible to deplete the supply of dissolved oxygen below the thermocline when organisms requiring oxygen use up the oxygen faster than it is being replenished.

The warmer nutrient-rich water at the surface supports algae blooms. When those algae die, they lose their buoyancy and sink to the bottom. Oxygen-dependent bacteria and other organisms on the bottom of the lake utilize the algae and other dead organic matter as a food resource as long as there is oxygen present to support them. This process of decay depletes the oxygen supply below the thermocline.

The thermocline acts as a density barrier that prevents atmospheric oxygen available in the epilimnion from mixing with the colder/denser water in the hypolimnion. The lack of oxygen (anoxia) creates conditions in the hypolimnion that influence how nutrients cycle in the lake, which will be discussed in more detail later in this report.



Graphic Courtesy of State of Washington Department of Ecology (Washington DOE)

Figure 13: Cross Section of Lake Water Layers

Using a temperature sonde, a thermal profile of Roseland Lake was developed at its deepest location. Temperature measurements were made at monthly intervals from May to October 2015 and again from April to July, and October 2016. The 2015 spring season included above-average temperatures during the month of March, followed by cooler weather in April. The lake began to stratify by May 2015 and became more strongly stratified through September. By October 2015, the lake began to de-stratify (mix), with more consistent water temperatures from top to bottom.

Monitoring resumed in April 2016 and continued on a monthly basis through July. End-of-the-season thermal profiling in late October indicated that the lake was fully mixed. Using data collected in Roseland Lake during 2015 and 2016, Figures 9 and 10 illustrate the relationship between temperature and dissolved oxygen concentration.

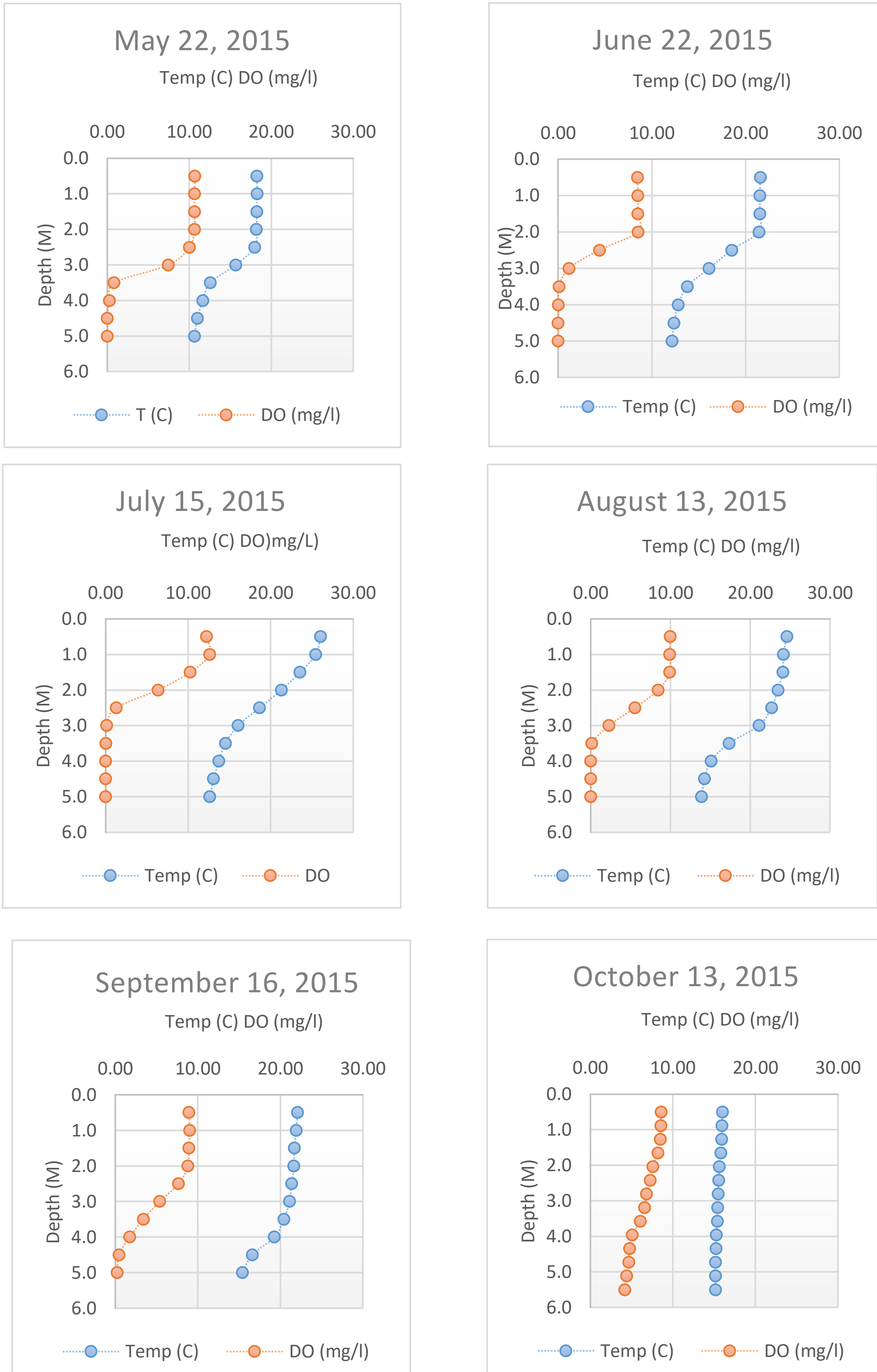


Figure 14: Water Temperature/Dissolved Oxygen Curves in Roseland Lake 2015

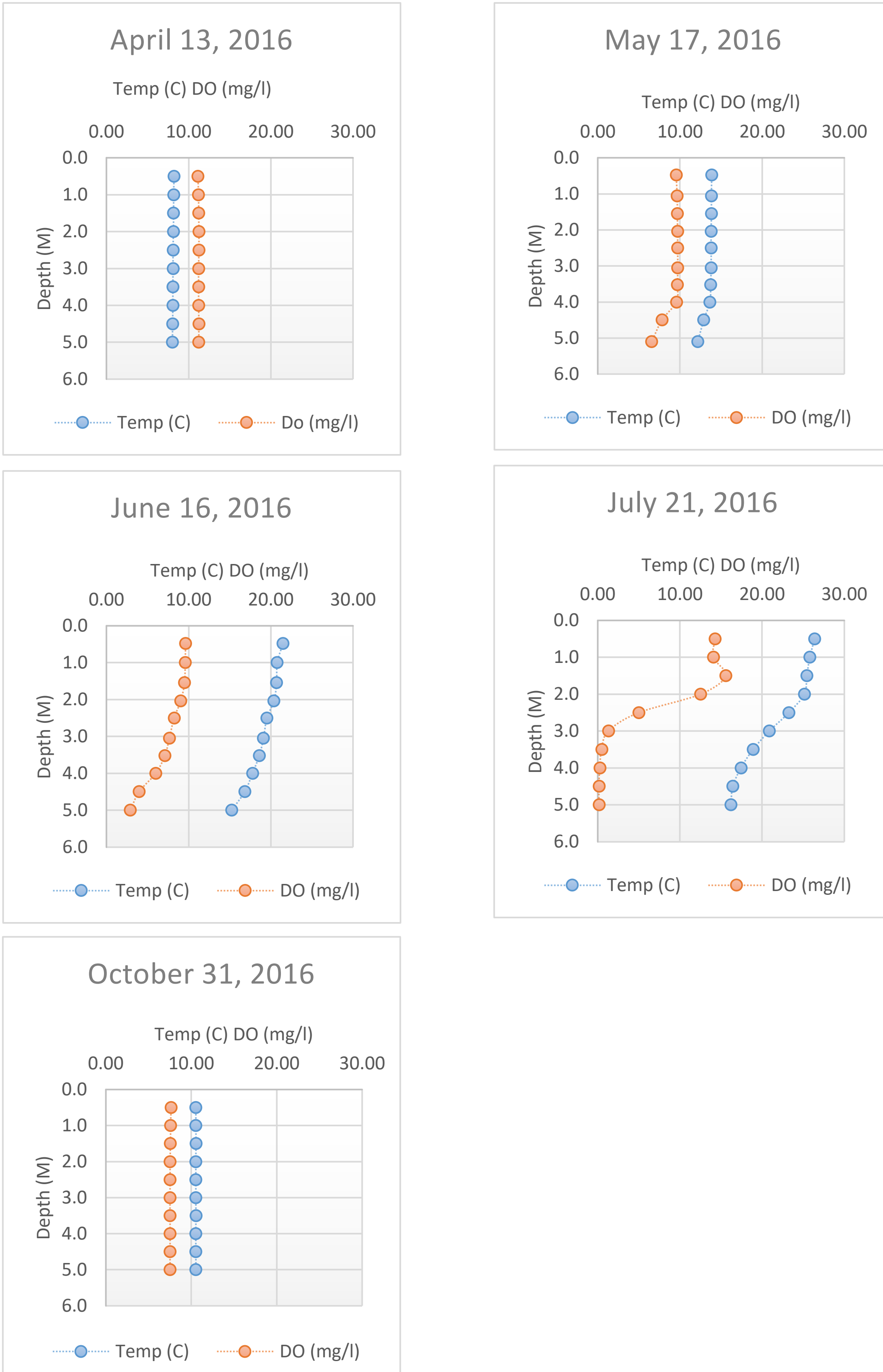
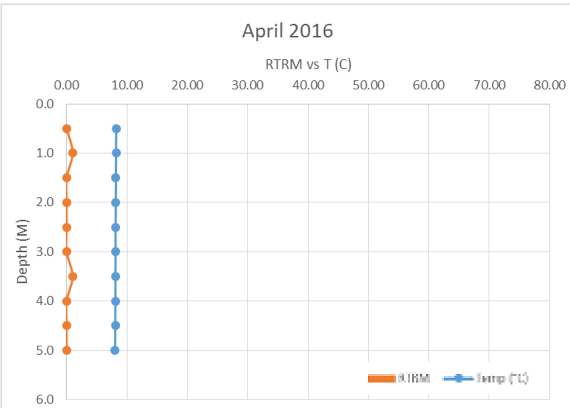


Figure 15: Water Temperature/Dissolved Oxygen Curves in Roseland Lake 2016

Thermal resistance to mixing

The thermal resistance to mixing is a measure of the amount of energy that is needed for water from two different temperatures layers to mix. The greater the value, the greater the energy required to mix the two layers. In the spring and fall, when there is little difference between the top and the bottom temperatures in the lake, wind can provide enough energy to circulate the water. During summer temperature stratification, greater amounts of energy are required to get the same result. This concept will play an important role when selecting effective lake management tools.



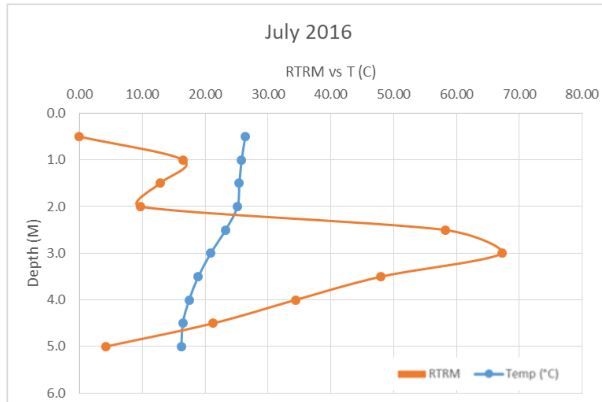


Figure 16: Thermal resistance to mixing April 2016 vs July 2015

Lake Nutrients

Dissolved nutrients, along with sunlight and warm temperatures, are the driving factors that support the growth of plants and algae. While there are many micronutrients contributing to plant and algae growth in an aquatic environment, the major nutrients studied during this project were nitrogen and phosphorus. Total nitrogen (TN) consists of a composite of different nitrogen-containing molecules, including ammonia nitrogen, nitrate and nitrite nitrogen, and organic nitrogen. Ortho-phosphate is a subset of Total phosphorus (TP). All were determined as part of the lake monitoring protocol.

Table 6. Roseland Lake Epilimnetic Parameters 2015 and 2016

Date	Water Temp (0.5 M)	Surface TN (mg/l)	Surface TP (mg/l)	TN:TP	Chlorophyll a (mg/l)	Secchi Depth (M)
5/22/15	18.26	0.705	0.038	18.55	10.8	1.38
6/22/2015	21.57	0.857	0.055	15.58	16.5	1.37
7/15/2015	26.05	0.580	0.034	17.06	13.0	1.25
8/13/2015	24.60	0.623	0.030	20.77	16.3	1.37
9/16/2015	22.09	0.571	0.044	12.98	21.3	1.40
10/13/2015	15.99	0.821	0.040	20.53	9.4	2.60
4/13/2016	8.22	0.667	0.023	29.00	6.7	2.03
5/17/2016	13.89	0.759	0.033	23.00	12.2	1.66
6/16/2016	21.46	0.727	0.045	16.16	13.5	1.99
7/21/2016	26.38	0.889	0.066	13.47	41.8	1.11

Most commonly in freshwater ecosystems, phosphorus has been determined to be the limiting nutrient controlling algae and plant growth and influencing the trophic status of a lake. The ratio of total nitrogen to total phosphorus (N:P ratio), along with other factors, influences the type of algae that is dominant in a lake. In general, the growth of cyanobacteria is favored when warmer lake temperatures (>25°C, or 77°F) combine with a high phosphorus-to-nitrogen ratio (EPA). Many types of cyanobacteria can “fix” atmospheric nitrogen gas at the water/surface interface and transform it into a usable form. This is not true for true algae. Climate change is expected to increase summer temperatures and the number of days when the temperature exceeds 32.2°C (90°F), cause earlier winter breakup of ice on lakes and rivers and extend the growing season (ASGSCCC). This may increase the surface temperature of Roseland Lake, favoring the growth of cyanobacteria over other types of algae.

Eutrophication

Eutrophication is the natural aging process of a lake. Anthropogenic (human-influenced) sources of nutrients can drastically accelerate the transition of a lake into a shallow pond, a wetland, and eventually to dry land. This is known as cultural eutrophication. There are multiple anthropogenic influences in the Roseland Lake watershed that affect the rate of the eutrophication of Roseland Lake. These include land clearing and development, hydromodification, stormwater runoff, agriculture, removal of streamside vegetation, over-fertilization of lawns, inadequately designed or improperly managed septic systems, and pet waste. Analysis of the water quality data collected by ECCD, as discussed in other sections of this document, indicates that Roseland Lake fluctuates from mesotrophic/eutrophic to highly eutrophic.

SECTION 5: NUTRIENT POLLUTION AND OTHER WATER QUALITY ISSUES

Residential Development Sources

With 61.8 square miles of land, Woodstock is the second largest municipality in Connecticut. According to the 2010 US Census, the population of Woodstock was 7,964 or 129 people per square mile. A total of 2.4, square miles or 8.9% of the Roseland Lake watershed has impervious cover. Impervious cover (IC) is any surface in the landscape that cannot absorb or infiltrate rainfall. Impervious surfaces include rooftops and paved areas like roads, sidewalks, driveways and parking lots. Because IC prevents rainwater from soaking into the ground, it contributes to the volume of stormwater runoff that is shed from developed areas into nearby waterbodies and can be a significant vector for the conveyance of pollutants such as nutrients and sediment. A recognized threat to clean water this watershed is the potential for additional residential and related land use growth to increase impervious cover.

The amount of impervious cover in a watershed has been directly linked to impacts to stream quality and stream biodiversity. Numerous studies, including those conducted by Schueler, have demonstrated that the amount of impervious cover in a watershed directly impacts stream quality (Schueler). A 2008 study conducted by CT DEEP indicated that water quality declined when impervious cover in a watershed exceeded 6% (Bellucci). The *Connecticut Watershed Response Plan for Impervious Cover*, which was developed to provide guidance for “managing stormwater and impervious cover to support water quality improvements,” suggests a target impervious cover limit of 12%. Twelve percent impervious cover represents “the level of impervious cover in the contributing watershed, below which a stream is likely to support a macroinvertebrate community that meets aquatic life use goals in Connecticut Water Quality Standards” (CT DEEP).

Figure 17: Schueler Impervious Cover Model

If the impervious cover model developed by Schueler in 1994 was solely used to predict water quality in the Roseland Lake watershed, no stream water quality impacts to aquatic life would be anticipated. However, by adding the combined turf area (1.23 square miles) to the equation, the developed land upstream of Roseland Lake increases to 11.9%, approximately the threshold recommended by DEEP. At this level, water quality impacts to both tributary streams and Roseland Lake from pollutants contained in stormwater runoff could be anticipated.

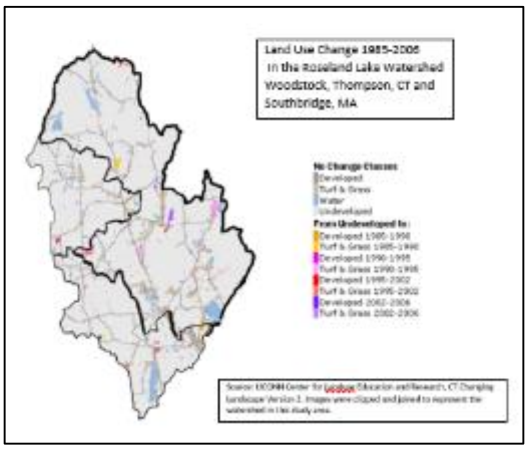


Figure 18: Land Use Change 1985 - 2006

As part of its statewide initiative, Connecticut's Changing Landscape, the UCONN Center for Land Use Education and Research (CLEAR) estimated residential development in the Roseland Lake watershed between 1985 and 2006. Using remote sensing technology which differentiates the way light reflects off different surfaces, CLEAR was able to approximate the amount of land area in different land covers. These estimates were developed in 1985, 1990, 1995, 2002 and 2006. The image on the left represents where land changed to either impervious cover (rooftops, driveways and roadways) or turf and grass. The Roseland Lake watershed has experienced an increase in suburbanization.

Many regulatory and voluntary actions that have been implemented to reduce water quality impacts originating from developed land. These regulations and actions influenced phosphorus reduction from developed land:

1972 – The US Congress passes the Clean Water Act

1972 - Connecticut Legislature enacted the Inland Wetlands and Watercourses Act and in 1987, the Connecticut Legislature amended the Act and provided language to delegate responsibility to each community to administer the law

1974 – Ban on Phosphates in laundry detergent P.A. 73-192 revised in CT Gen Stat § 22a-462 (2012) (The original switch from soap to phosphate-laced detergents took place after WWII)

1982- Technical Standards for Subsurface Sewage Disposal Systems were initiated

1985 – Connecticut adopted Sediment and Erosion Control Regulations, which were updated in 2002

2002 – Connecticut implemented the General Stormwater Permit, which was updated in 2013 to encourage low-impact development

2010 – Industry began to institute a voluntary removal of Phosphates from dishwashing detergents

2012 – PA 12-155 regulates phosphorus in lawn fertilizer in addition to other phosphorus reduction strategies.

2017 – CT DEEP updated the Municipal Separate Storm Sewer System (MS4) permit and expanded the number of population centers included under the permit, though Woodstock was exempted. Southbridge, MA and Thompson, CT were previously included as MS4 population centers and continue be included under the current regulations.

Agricultural Sources

Prior to European colonization of the region, the area was used for agriculture by indigenous people (Wakely). Settlers of European descent began to colonize the region in the late 17th century, and for good reason. The Muddy Brook valley has a high amount of acreage of land with fertile agricultural soils. The State of Connecticut has classified certain soil types as Prime Farmland and Farmland Soils of Statewide Importance. The Town of Woodstock has also adopted the category of Locally Important Farm Soils as determined by the USDA Natural Resources Conservation Service.

Historically, a much higher percentage of the Roseland Lake watershed was used for agriculture than today. Sheep farming was once important in the region. It is likely not a coincidence that the current active farms are located on the best available agricultural soils. Marginal farmland previously used for agriculture was abandoned as migration to the mid-western United States began after the Civil War. Once abandoned, marginal farmlands reverted back to forest through natural succession.

Many types of water quality impacts are associated with runoff from agricultural operations, such as sedimentation from soil erosion from tilled fields, overgrazing and nutrient loading from the over-application of soluble nutrients and manure. Over time, changes in agricultural practices to improve productivity have influenced water quality to varying positive and negative degrees. The following examples illustrate changes to crop field management practices and their impacts on water quality.

Table 7: Changes in Agriculture Practices and Their Impact on Water Quality

Farm practice	Positive Impacts	Negative Impacts
Use of “green manure” (cover crops such as rye grass) (Pre-WWII era)	Reduce erosion, improve soil health	Attract migratory Canada geese
Introduction of chemical fertilizer (mid-1940s)	Increase crop yields, increase herd size in concentrated areas	Over application of soluble forms may increase nutrient concentrations in streams
Change from grass-fed cows to feeding in confined areas	Less labor intensive to bring in herds for milking	Manure and nutrient contaminated runoff from concentrated feeding areas
Improved farm machinery	Less labor to till and plant crops	More soil exposed to the forces of wind and rain resulting in increased erosion
Herbicides introduced (mid-1940s)	Crops have less competition with weeds	More soil exposed to the forces of wind and rain resulting in increased erosion

Abandonment of Cover Crop usage (post-WWII)	Save money on seed	More soil exposed to the forces of wind and rain resulting in increased erosion
Installation of Tile drainage systems	Extend growing season on wetter agricultural soils	Creates conveyance system for water soluble nutrients to be exported from the fields
Improved manure storage	Reduce the need for daily spread on frozen ground	Cost of installation and purchase of new equipment for manure management can be unaffordable by smaller dairy operations.
Healthy Soil Initiative, Diverse Cover Crops (2010 – present)	Improve soil health, reduce chemical fertilizers	Decrease erosion, decrease nutrients in overland runoff

The USDA Natural Conservation Service, CT DEEP, UCONN Cooperative Extension Service and ECCD have been actively involved with the agribusinesses in the Roseland Lake watershed encouraging conservation practices to reduce non-point source pollution.

Waterfowl

Migratory Canada geese inhabit Roseland Lake during the spring and fall migration seasons. The geese forage on farmland and at golf courses during the day and roost on the lake at night. The flock size roosting on Roseland Lake at night during the spring and fall and under no-ice winter conditions can be in the multiple thousands of birds.

Migratory geese are attracted to the Woodstock area due to available food resources, especially chopped corn residue and tender rye grass shoots planted as a winter cover crop on cropland in the Roseland Lake and nearby watersheds. In an email interview, Min Huang, the CT DEEP Migratory Bird Program Leader, noted there is one cover crop that he has more recently noticed planted in fields that the birds will avoid. While he could not positively identify the plant and was not sure exactly what it was, he described it as being wide-leafed and looking like a radish (Huang). ECCD was unable to find any studies on whether diverse cover crop plantings that include radishes deter migratory Canada Geese from foraging on crop fields.

A well-fed Canada goose can produce up to 1.5 pounds of feces every day. “Canada geese feces contain 14 mg of phosphorus and 5.7 mg of nitrogen using dry weight with 80% moisture content” (Pettigrew). Geese may or may not defecate while roosting on water, but they do leave fecal matter on the shoreline and on the edge of ice openings in winter, and they tend to defecate upon take-off.

No attempt was made to quantify impacts of migratory Canada geese on water quality in Roseland Lake during this study. A previous study conducted in 2009 by ECCD documented that resident Canada geese were not an issue in the watershed at that time.

Atmospheric Deposition Sources

Numerous studies have demonstrated that air currents can carry nutrient-laden aerosols and particles long distances in enough volume to impact water quality. In 2000, the USGS released a Water Resource Investigation Report, *Nutrients Sources and Loads in the Housatonic, Connecticut and Thames River*

Basins. Based on data collected from 1991-93 by scientists from the University of Connecticut, the USGS report included a summary of the UCONN research that estimated nutrient loads from atmospheric sources. Those sources may include aerosolized ocean water, near and distant agricultural activity, gravel mining, burning of biomass and coal, and internal combustion engines. Estimated deposition of total nitrogen ranged from 4,600 to 4,900 lb/mi^2, including both wet and dry deposition, and annual deposition of total phosphorus ranged from 22 to 27 lb/mi^2 (Trench). The impact of atmospheric deposition on water quality varies by land cover. A forested landscape is likely to absorb some of the nutrients delivered by atmospheric deposition. A paved urban landscape is more likely to shed these nutrients into surface water when it is carried in stormwater runoff.

Sources from Roseland Lake Legacy Nutrients in Sediment Deposits

Nutrients (particularly phosphorus) stored in lake sediments can be a significant source of in-lake nutrient loading. Nitrogen dissolves easily in water, but phosphorus does not. Instead, it binds with sediment. Phosphorus-rich sediment is carried to the lake by tributary streams. As it settles to the bottom of the lake it accumulates, creating a "legacy" phosphorus load stored in the sediments. When plants and animals within the lake die and settle as organic matter on the bottom of a lake, nutrients, including phosphorus, contained within the dead organisms add to the nutrient load in the sediments. Phosphorus combines with components of the subaqueous soil, especially iron. Under anoxic (no oxygen) conditions, legacy phosphorus associated with normally insoluble Ferric iron (Fe^{+++}) is released into the water, as the iron is reduced to soluble Ferrous ion (Fe^{++}). Because Roseland Lake is relatively shallow, this phosphorus becomes available to support algal growth at the surface, either through lake mixing or through daily vertical migration of cyanobacteria in the water column. The evaluation of the in-lake nutrient source was a critical component for developing this lake management plan.

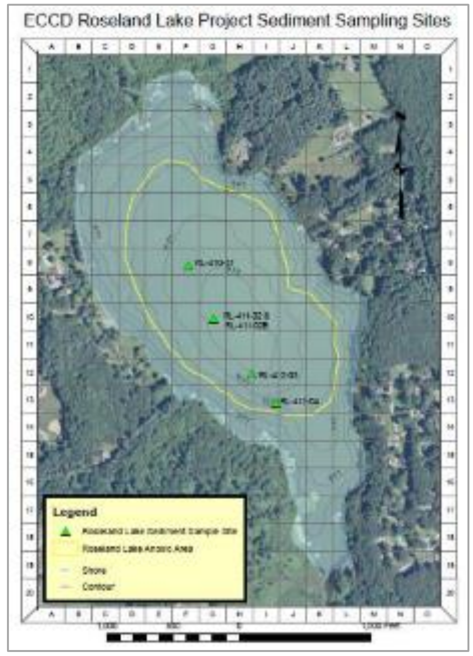


Figure 19: Estimated summer anoxic zone in Roseland Lake

Using data collected by ECCD in 2015 and 2016 and a bathymetric map of Roseland Lake, the area of the lake that experienced seasonal anoxic conditions was estimated by using the measured depth to the anoxic layer and delineating, on the bathymetric map, water deeper than that depth. ECCD contracted with Solitude Lake Management to collect sediment samples at randomly selected locations from the top layer of bottom sediment within the anoxic zone. Those samples were analyzed at Northeast Laboratories in Berlin, CT for iron-bound phosphorus, loosely-sorbed phosphorus, percent moisture and total phosphorus. The results of those samples are presented in Table 9 below.

Table 8: Sediment Phosphorus Concentrations in the anoxic hypolimnion region of Roseland Lake, Woodstock CT October 31, 2016

Sample Description	Iron Bound Phosphorus (mg/kg dry weight)	Loosely Sorbed Phosphorus (mg/kg dry weight)	% Moisture	Total Phosphorus (mg/kg dry weight

RL-410-01	949	55.0	87.3	3020
RL-411-02	985	51.1	86.4	2750
RL-411-02B	840	40.8	86.5	2680
RL-412-03	812	39.4	86.6	1930
RL-413-04	570	43.7	86.6	2020

The analysis and report produced by Solitude Lake Management on the sediment phosphorus results stated that internal loading in Roseland Lake provides a significant source of phosphorus, especially in the summer months when the lake is stratified and water retention time is at its highest. From the report, "In general, addressing the internal loading will provide substantial benefit when it comprises >25% of the annual phosphorus load and will be required [when] internal loading is >50% of the annual loading".

From the report provided by Solitude Lake Management, "All five samples were similar in terms of % solids, % moisture and % Ash (organic content) indicating physical consistency across the sampling stations. The total phosphorus content varies but all are significantly elevated and at or above what is considered moderate levels of phosphorus (300-800 mg/kg). Values over 1,000 mg/kg are considered high. Loosely sorbed phosphorus is low as compared to the total phosphorus content, but is elevated compared with results seen at other lakes in the region. Typically, loosely sorbed phosphorus is a negligible (< 10 mg/kg) portion of the sediment phosphorus in most lakes so the presence of elevated levels at Roseland Lake is indicative of substantial available phosphorus reserves. Iron-bound phosphorus, which is the form that is released under anoxic conditions is also in the high end of the typical range at 570-949 mg/kg."

Data collected by ECCD in 2015 and 2016, from within Roseland Lake and its tributaries, were analyzed by Richard Canavan, a Senior Environmental Scientist, formerly with CME Associates. Using the spring 2016 surface phosphorus concentration as the baseline to represent the phosphorus concentration in the epilimnion before lake stratification, and comparing that value to the average 2015 and 2016 summer total phosphorus concentrations, demonstrated a 42 – 52% increase of total phosphorus during the summer months, indicating an internal loading of phosphorus.

- April 2016 surface total phosphorus 23 µg/L
- May-Sept 2015 average total phosphorus 40.2 µg/L
- May-July 2016 average total phosphorus 48 µg/L

Increases in the epilimnion Total Phosphorus concentrations corresponded with anoxic conditions and elevated TP concentrations in the hypolimnion of Roseland Lake.

Using morphometric and land use models to predict phosphorus annual loads, Dr. Canavan calculated an approximate load of 2949 pounds of phosphorus per year to Roseland Lake.

Mathematical modeling completed by Dr. Canavan estimated the internal recycling load of legacy phosphorus to be 300-600 lbs. P/year, or about 10-16% of the annual load. However, since this release is limited to summer, it accounts for 21-55% of the load during the five months of summer and fall when anoxia is likely to occur. A full copy of Dr. Canavan's Roseland Lake Nutrient Modeling Summary is located in Appendix D.

Total Suspended Solids

Total Suspended Solids (TSS) are the total of organic and inorganic solids suspended in water. Suspended solids include silt and clay particles, plankton, algae, fine organic debris, and other particulate matter. Suspended solids will not pass through a 2-micron filter (EPA). TSS is an indicator of erosion. As part of the 2015-16 water quality monitoring, stream samples were analyzed for TSS.

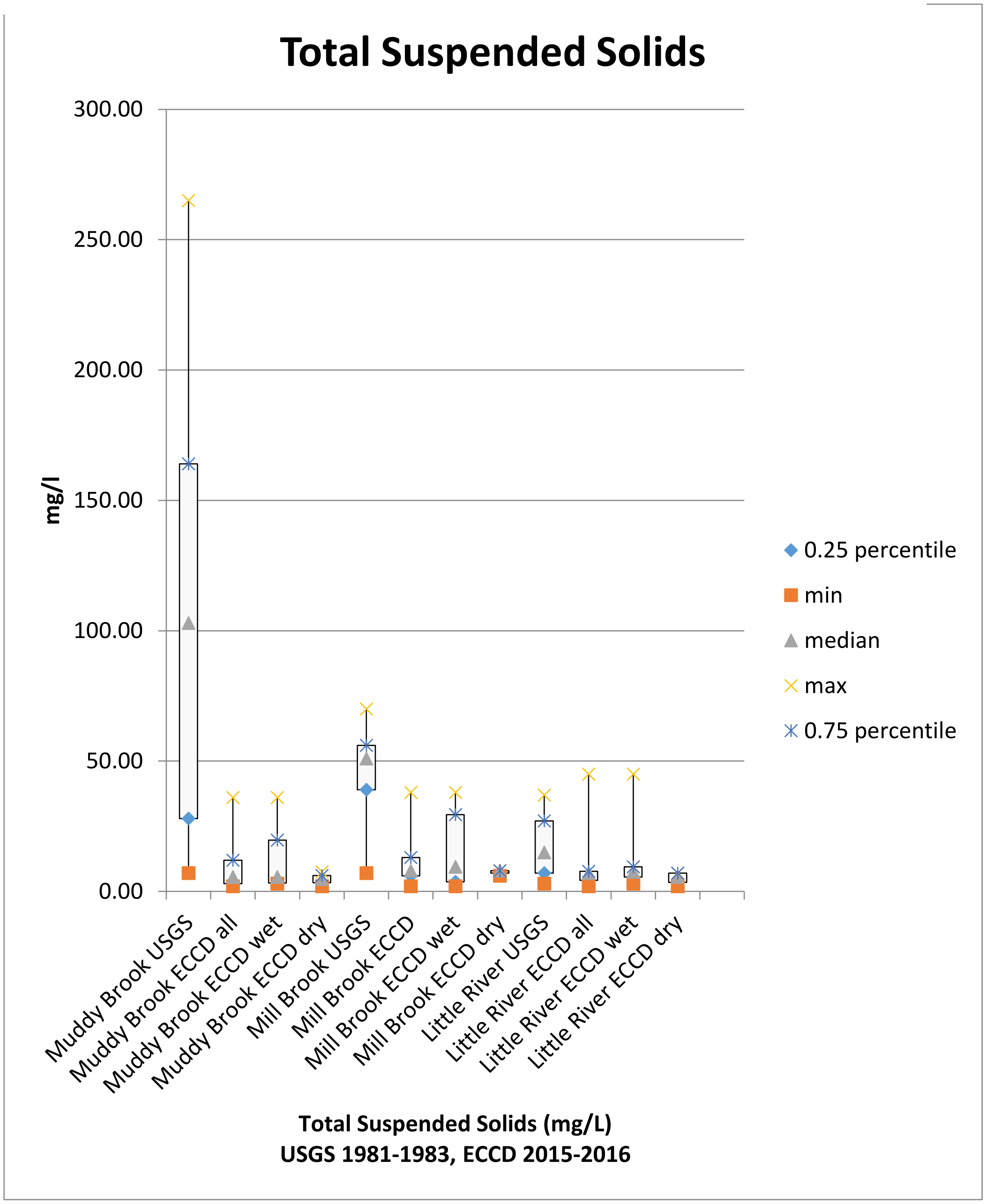
Higher concentrations of total suspended solids (TSS) in a water sample are significant because they are often the transport mechanism for phosphorus. Phosphorus binds with available iron and other ions in soil particles and is transported with eroded material via stormwater runoff containing high sediment loads.

The Roseland Lake nutrients study included an assessment of TSS in the main tributaries flowing into Roseland Lake. Samples were collected from Muddy Brook and Mill Brook, upstream of the lake. Samples were also collected from Little River at the outflow of Roseland Lake. All samples were processed at the UCONN Center for Environmental Studies and Engineering Lab in Storrs, CT.

In a report produced by the USGS in 1991, *The Suspended Sediment Characteristics of Muddy Brook, Woodstock, CT*, based on data collected in 1981 – 1983, the sediment load into Roseland Lake from Muddy Brook alone was estimated to be 427 tons annually (Kulp). The USGS samples were collected after measurable precipitation. There were nine sampling events during the study. Six of the sampling events followed rainfalls measuring 1.4 – 2.7 inches in a 24-hour period. One sampling event followed a multiday storm with a rainfall total of nearly 7 inches. Since that study was completed, multiple measures have been instituted for upstream erosion and sediment control and other means to reduce the release of phosphorus into the environment. Figure 16 demonstrations the comparison of TSS results in samples collected by the USGS in 1981-83 and ECCD in 2015 – 2016. ECCD samples were collected in both wet (following a rain fall event >0.1") and dry weather sampling. Box and whisker plots labeled ECCD all include an average including both wet and dry samples. This chart indicates a significant decline in TSS concentrations in Muddy Brook and Mill Brook between the 1981-83 sample set and the 2015-16 sample set.

A transition from deep till plowing to no-till healthy soil practices may be partially responsible for the changes represented in Figure 20.

Figure 20: A comparison of TSS concentrations in the study area under wet and dry runoff conditions



The impact of the previous sediment loading into Roseland Lake is evident from the deposition of sediment at the former swimming area at Roseland Park. Local residents shared memories of children jumping off the roof of the gazebo at the end of the pier into water that was over their heads. Local residents reported that swimming continued at the park into the early 1980s. In the summer of 2015, a Secchi disk lowered into the water from the end of the pier hit bottom before 1-meter depth.

SECTION 6: SELECT BIOTA OF ROSELAND LAKE

Algae

Figure 21: Planktonic algae blooms reduce water clarity as demonstrated by this secchi disk photo.

There are many different kinds of algae in Roseland Lake. Certain types may be more abundant in spring, while other forms become dominant during warmer weather. A major water quality concern for the lake is the potential for one type of algae, cyanobacteria, to dominate. When cyanobacteria form blooms, there is a risk they can potentially produce cyanotoxins as a by-product. This is generally referred to as a Harmful Algae Bloom (HAB).

Health concerns related to cyanotoxins include:

- Skin irritation
- Nerve damage
- Liver damage
- Lethality to dogs and cattle.

Figure 22: Windblown cyanobacteria accumulated on the eastern shoreline of Roseland Lake resembles a spill of bright green paint.

In addition to the human health concerns from exposure to cyanobacteria blooms, high concentrations of algae in water that is filtered and treated for drinking causes increased water treatment costs, clogs the filters at the water treatment plant and, even after treatment, may still retain bad tastes and odors. There are currently are no means to remove cyanotoxins at the Putnam water treatment plant.

Figure 23: Floating algal mats on Roseland Lake, July 10, 2014

Nationally, the frequency of severe blooms of cyanobacteria, formerly known as blue green algae, appears to be on the rise (EPA). Algae blooms in Roseland Lake include both planktonic forms in the water column and mat-forming algae that grows on the surface of the sediments in shallow areas along the lake shoreline, which then float to the surface when stimulated into photosynthesis by sunlight. Both types may include cyanobacteria species. The best remediation strategies for planktonic algae may not solve the issues associated with mat-forming types that inhabit shallow water.

As part of the Roseland Lake Monitoring Plan, ECCD included surface sampling for algae during the summer months of 2015. A grab sample of surface water was collected mid-lake, stored on ice and transported, on the date of collection, to Northeast Laboratory in Berlin, CT. Monitoring focused on estimating the planktonic forms collected at the lake surface. It did not include algae that may have been lower in the water column, or mat-forming algae in the littoral zone.

ECCD Algae Monitoring Results

Further review of the methods for determining algae diversity and enumeration is necessary. The surface grab sample technique used by ECCD likely do not represent the true concentration and diversity of phytoplankton in Roseland Lake. The method used by ECCD does not account for cyanobacteria that may be below the surface where it has greater access to nutrient-rich water.

Aquatic Macrophytes

A criteria for determining the trophic state of a lake includes the abundance of macrophytes. Aquatic macrophytes are plants that grow in or near water that are visible without magnification. They can be emergent, submergent or floating. Aquatic macrophytes provide important habitat for many species of organisms, but an overabundance may hinder navigation and present a danger of entanglement in swimming areas.

Several species of non-native aquatic plants have been introduced to Connecticut, some which have the ability to outcompete native plants for resources and can dominate the underwater environment. Invasive aquatic plants are included on the list of *Connecticut Invasive Plants* developed by the Connecticut Invasive Plant Working Group and are available at this website: https://cipwg.uconn.edu/invasive_plant_list.

Native Aquatic Plant Species

Macrophyte growth in Roseland Lake is not extensive (>30%) or dense, and therefore does not indicate a promotion to the next trophic state.

Figure 24: Roseland Lake aquatic plants

In 2012, an aquatic plant survey was conducted in Roseland Lake by the Connecticut Agriculture Experiment Station through their Invasive Aquatic Plant Program. At that time, twelve aquatic plant species were documented growing in the lake. The most dominant plant was a lily pad, *Nuphar variegata*. It grew in large patches in the north part of the lake and in smaller patches along the western and southern shores. A shoreline species, *Pontederia cordata,* was found growing along much of the shoreline. The majority of the lake had a narrow littoral zone before descending to deeper depths where light cannot reach and plants do not grow.

The most species-rich area was in the southern cove, which is very shallow, allowing for light to reach the bottom and enabling plants to grow. Various native plant species such as *Nuphar variegata*, *Nymphaea odorata*, *Peltandra virginica*, *Pontederia cordata*, *Potamogeton epihydrus*, *Potamogeton robbinsii*, and *Sagittaria* were identified. *Potamogeton foliosus* was found only in the northern lake near an inlet. A single *Vallisneria americana* was found along the shore.

Table 10. Aquatic Plant Species documented during the CAES 2012 survey of Roseland Lake (CAES).

Callitriche sp	*Potamogeton foliosus*
Elodea nuttallii	*Potamogeton robbinsii*
Nymphaea odorata	*Sagittaria sp.*
Peltandra virginica	*Spirodela polyrhiza*
Pontederia cordata	*Vallisneria americana*
Potamogeton epihydrus	

Non-native Aquatic Plant Species

Common Reed *(Phragmites australis)* is present in scattered areas along the lake shoreline, and intermixed with native wetland plants near the outlet of the lake into Little River. Prior to 2004, much of the lake shoreline was impacted by *Phragmites*. A multiyear herbicide/mulching treatment by the CT DEEP beginning in 2004 led to the restoration of much of the shoreline habitat, especially along the western shore, where Roseland Park has frontage along the lake. Along the Roseland Park shoreline below a rock retaining wall, an area that had been previously maintained as a sandy beach for bathers was heavily impacted by *Phragmites*. The *Phragmites* acted as a trap for nutrient-rich sediment and has decreased the depth of the lake along that shoreline. In the remaining *Phragmites* plant stubble, portions of this area have been colonized by a diversity of emergent native wetland plants.

Periodically, CT DEEP Wetland Habitat and Mosquito Management staff return to Roseland Lake to conduct spot treatment of the remaining *Phragmites* stands. The most recent treatment was conducted in October 2017.

Yellow iris (*Iris pseudacorus)* was observed by ECCD staff growing along the Roseland Lake shoreline in 2016.

There were no submerged aquatic invasive plants found during the 2012 Aquatic Plant Survey by CAES.

Aquatic Animals

Limited scientifically-collected data was available for aquatic animals. The DEEP Natural Diversity Data Base office is requiring an updated snail inventory as part of pesticide permit application review.

Fisheries Data

DEEP Inland Fisheries staff typically stock Roseland Lake with trout each year before the start of the fishing season. The lake was not stocked in 2017 due to trout shortages, but will resume in 2018.

The most recent Electrofishing Survey Results for Roseland Lake by the CT DEEP Inland Fisheries Program were obtained in 2003 and 2004 (DEEP and Center for Landuse Education and Research).

Table 9: Roseland Lake Fish Survey Results

Sample Year	2003	2004
Sample ID	161842003	161842004
American Eel	0	3
Banded Killifish	1	3
Black Crappie	2	2
Bluegill Sunfish	145	206

Brown Bullhead	0	1
Brown Trout (stocked)	1	1
Chain Pickerel	5	24
Fallfish	1	1
Golden Shiner	92	80
Largemouth Bass	35	52
Pumpkinseed	5	13
Rainbow Trout (stocked)	0	3
Redbreast Sunfish	2	0
White Catfish	0	3
White Sucker	5	16
Yellow Perch	98	133

Zooplankton Data

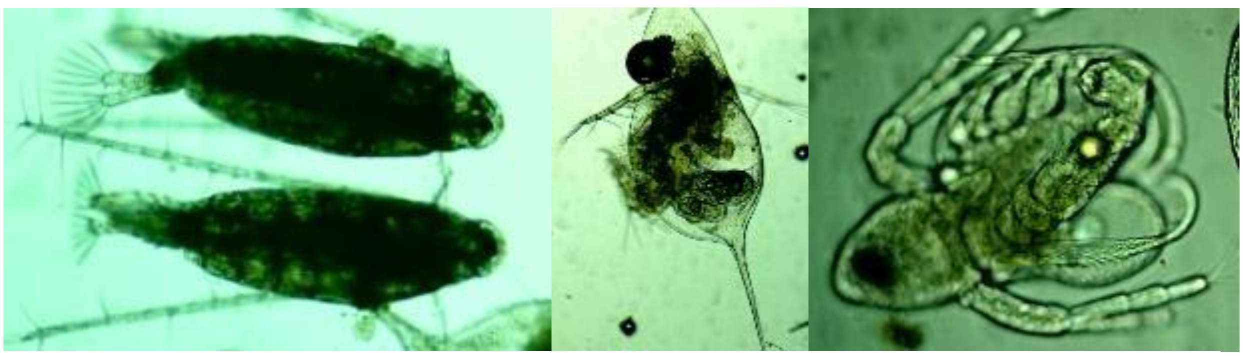


Figure 25: Assorted zooplankton netted in Roseland Lake

ECCD did not conduct a formal survey of zooplankton during its study of Roseland Lake, but a plankton net was deployed during a sampling event. Digital images of the unidentified zooplankton were used as part of an education and outreach program during the development of the Roseland Lake Management Plan.

Gastropods (Snails) Data

Gastropods are a type of mollusk. In her 1983 publication, *The Freshwater Snails of Connecticut,* Eileen Jokinen noted that Roseland Lake was surveyed between 1975 through 1979 for freshwater snails, where she documented seventeen unique species in Roseland Lake. During that sampling period, Roseland Lake hosted the richest diversity of species of freshwater snails in a fresh water lake in Connecticut. One species in her report, *Gyradualus circumstriatus*, is currently listed as a species of special concern in the Connecticut Natural Diversity Data Base, denoted with an asterisk in Table 12.

Table 10: Historic freshwater snail diversity in Roseland Lake, Woodstock, CT

Campeloma decisum	Amnicola limosa	Lyogyrus granum
Lyogyrus pupoidea	Fossaria modicella	Pseudosuccinea columella
Physella ancillaria	Gyraulus deflectus	Gyradualus circumstriatus*
Helisoma anceps	Helisoma campanulatum	Planorbula armigera
Micromenetus dilatatus	Promenetus exacuous	Laevapex fuscus
Ferrissia fragilis	Physa (new species)	

The current status of gastropods in Roseland Lake is unknown. As part of the 2012 National Lakes Assessment, which included Roseland Lake, a benthic survey documented three genera of gastropods in Roseland Lake: *Nymphophilinae, Gyraulus* and *Laevapex.* It was not a comprehensive study of the gastropod population.

SECTION 7: LAKE MANAGEMENT PLANNING

Lake Management

"A lake and/or watershed management plan is a dynamic document that identifies goals and action items for the purpose of creating, protecting and/or maintaining desired conditions in a lake and its watershed for a given period of time" (North Atlantic Lake Managment Society). Continued degradation of Roseland Lake is inevitable unless strategic steps are taken to prevent it. The measures need to include a combination of watershed as well as in-lake management strategies and a team of organizations to implement different portions of the plan.

Lake Management Goals

The goals of this plan are:

1. Identify sources of lake pollutants, including nutrients and sediment
2. Provide strategies to reduce watershed and in-lake derived nutrients
3. Provide strategies to manage algae growth, including HABs
4. Establish a coalition of partners to implement recommendations of this plan

To successfully achieve these goals, it will take a team approach. There will be no single agency or municipality responsible for completing all the actions outlined in this plan. Below is a list of recommended Roseland Lake Management Plan partners and a brief description of the role or roles they may take in this effort.

Table 11: Recommended Partners and their Roles

Team Members	Responsibilities
Putnam WPCA	Work with a Certified Lake Manager to select in-lake management strategies to eliminate cyanobacteria blooms in Roseland Lake. Support efforts of other agencies or organizations working to reduce pollution sources impacting Roseland Lake. Initiate or support cyanobacteria bacteria monitoring. Utilize tools in the Roseland Lake Management Plan in future lake stewardship initiatives. Continue watershed inspections. Participate in the Roseland Lake/Little River Collaborative
Putnam Mayor/Board of Selectmen	Adopt Roseland Lake Management Plan and work with other town entities to implement the recommendations in the plan Work with the Town of Woodstock (others) to develop a Transfer of Development Rights program for preserving critical watershed land.
Putnam Town Administrator	Facilitate the formation of and participate in a Roseland Lake/Little River Healthy Watershed Collaborative

Putnam Board of Finance	Include watershed management funding in future funding cycles
Woodstock Board of Selectmen	Adopt Roseland Lake Management Plan and work with other town entities to implement the recommendations in the plan. Work with the Towns of Putnam to develop a Transfer of Development Rights program for preserving critical watershed land.
Woodstock Highway Department	Evaluate stormwater system and develop a plan to reduce impacts to Roseland Lake. Participate in the Roseland Lake/Little River Collaborative
Woodstock Board of Finance	Include watershed management funding, including open space funding, in future funding cycles.
Woodstock Planning and Zoning Commission	Review local regulations for compliance with PHC Section 19-13-B32-b Sanitation of Watersheds regulations.
Woodstock Town Planner	Incorporate relevant components of the Roseland Lake Management Plan into the Woodstock Plan of Conservation and Development. Participate in the Roseland Lake/Little River Collaborative
Woodstock Conservation Commission	Continue education and outreach effort on watershed protection issues. Participate in the Roseland Lake/Little River Collaborative
Woodstock Agricultural Commission	Promote agricultural best management practices and funding resources available to implement them. Participate in the Roseland Lake/Little River Collaborative
The Last Green Valley	Support for volunteer water quality monitoring; Promote easements for forest land owners; Promote Healthy Soil Initiative. Participate in the Roseland Lake/Little River Collaborative
Roseland Park Management	Intercept runoff from the park to reduce NPS. Participate in the Roseland Lake/Little River Collaborative
Eastern Connecticut Conservation District	Continue to seek grant funding to continue NPS reduction in the Roseland Lake Watershed. Participate in the Roseland Lake/Little River Collaborative
CT DEEP	National Pollution Detection and Elimination (NPDES) permitting for algaecide use, 319 and other grant administration; Lake management and water quality resource and support, technical programming support - water monitoring, TMDL, stormwater management, natural resources and open space acquisition and management; Participate in the Roseland Lake/Little River Collaborative
CT DPH	Continue to be an information resource on harmful algae blooms for water utilities Promote PHC Section 19-13-B32-b The Sanitation of Watersheds regulations in the towns with public drinking water watersheds.

	Participate in the Roseland Lake/Little River Collaborative
Northeast District Department of Health	Promote septic system maintenance Track down illicit discharges Participate in the Roseland Lake/Little River Collaborative
US EPA	Funding support for Non-point source pollution abatement projects
USDA NRCS	Funding support for agricultural producers Participate in the Roseland Lake/Little River Collaborative
Woodstock Open Space Land Acquisition and Farmland Preservation Committee	Cooperator on open space planning. Participate in the Roseland Lake/Little River Collaborative
Wyndham Land Trust	Cooperator on open space planning Participate in the Roseland Lake/Little River Collaborative
The New Roxbury Land Trust	Cooperator on open space planning Participate in the Roseland Lake/Little River Collaborative

The following pages provide an overview of various land and watershed management recommendations to prevent further degradation or improve the water quality of Roseland Lake.

Section 7-1 TECHNIQUES TO MANAGE EUTROPHICATION AND AQUATIC PLANTS

Overview of Options

Left on its own, continued degradation of Roseland Lake is inevitable unless strategic steps are taken to prevent and manage it. The measures need to include a combination of watershed as well as in-lake management strategies.

Axioms for the Control of Algae in Lakes

Excess nutrients in Roseland Lake contribute to algae growth. Cyanobacteria, which can be the dominant form in late summer when the water temperature is higher, is a major concern for the quality of water in the lake and in the water leaving the lake via Little River. Little River is diverted two miles downstream into a public drinking water supply surface water intake at the Shepherds Pond Dam and is directed to the Putnam Water Treatment Plant. Without action, costs to filter the water will remain high. Residual taste and odor problems related to upstream algae blooms will continue or may worsen. Mat-forming algae that colonize the lake shallows will continue to float to the surface. Floating algal mats degrade the lake's aesthetics and increase water treatment costs. Climate change modeling indicates the lake may shift to supporting cyanobacteria more frequently, as hotter summer temperatures favor their growth over other algal forms. Certain cyanobacteria produce cyanotoxins, which are harmful to humans and other mammals when consumed or come into contact with skin. Neurotoxins associated with cyanobacteria from lake water in bloom conditions are being studied in New Hampshire as a potential factor causing Amyotrophic Lateral Sclerosis (ALS) (Caller). For many reasons, the reduction of available nutrient sources, primarily phosphorus, which support potential harmful algae blooms, is critically important from a human health perspective. The prevention of new or additional pollutant sources into Roseland Lake through thoughtful open-space planning and management is critical.

Axioms for the Control of Rooted Plants in Lakes

Excessive rooted plants are currently not an area of concern in Roseland Lake. Less than 30% of the lake surface is covered with aquatic macrophytes. There were no aquatic invasive plants found in Roseland Lake during the Aquatic Weed Survey conducted by the Connecticut Agricultural Experiment Station in 2012.

One limiting factor for rooted aquatic plants is available sunlight. Secchi depth data collected over the past decades indicates limited light available below one meter during the summer growing season. There were no rooted aquatic plants reported deeper than 1-meter in Roseland Lake during the 2012 aquatic plant survey.

Figure 26: Water lilies on Roseland Lake

On July 21, 2016, hypereutrophic conditions were documented for some parameters used to determine the trophic state of the lake. When the algae in the lake are highly productive, it causes the dissolved oxygen concentration near the surface to become supersaturated, while depleting the CO_2 in solution faster than it can be replaced through diffusion from the atmosphere. The drop in CO_2 results in a shift in the pH towards the alkaline end of the scale creating a harsh environment for aquatic plants. Water temperature is likely a factor contributing to this condition.

Table 12: Roseland Lake surface parameters on July 21, 2016

Depth m	Total Nitrogen ppb	Total Phosphorus ppb	Chlorophyll A ppb	Secchi depth M	DO mg/l	T ºC	pH	Spec Cond uS/cm	Turbidity NTUs	Lake trophic condition
0.5	869	63	44.8	1.11	14.28	26.38	9.90	180.4	11.0	Eutrophic/ Highly Eutrophic

If the in-lake treatments focus only on controlling algae growth and not on reducing nutrient sources, there is a potential for increased growth of aquatic rooted plants along the lake shoreline. Increased abundance of rooted plants in the shallow areas of the lake may decrease available sunlight at the water/ soil interface, reducing the potential for the formation of algal-mat formation in that region. As the lake is not used for swimming, this change may not be a conflict for the current uses of the lake. However, if increased amounts of decaying plants are left in the lake to decompose, legacy phosphorus deposits may increase and become available to support algae and aquatic plant growth in the future, and continue to contribute to the eutrophication of Roseland Lake.

Template for Management Technique Summaries

The following layout of lake management techniques was adapted from *The Practical Guide to Lake Management in Massachusetts*. The template was prepared by Dr. Kenneth Wagner for the Massachusetts Department of Environmental Protection and the Department of Conservation and Recreation, Executive Office of Environmental Affairs, Commonwealth of Massachusetts (Wagner). An overview of management options is provided in the following sections. Management options that are not presently relevant to Roseland Lake at this time are also discussed in the event that conditions change and future consideration is desired.

Reducing external nutrient sources

Nonpoint sources of pollution including fertilizer use, hydromodification, stormwater runoff, septic system effluent, waterfowl, agriculture runoff and rainfall can contribute nutrients to Roseland Lake. Lake management strategies, both upstream in the watershed and in-lake, need to address these nutrient sources. There are different strategies to reach the goals of this management plan to identification of the sources of lake pollutants and providing strategies to reduce watershed and in-lake derived nutrients. It may be necessary to address multiple issues to get a positive outcome. A successful lake restoration program should strive to manage both external and internal nutrient sources.

Nonpoint Source Controls: Source Management

Because Roseland Lake is upstream of a public drinking water supply surface water intake, industrial or wastewater discharge (point sources) into the lake or river upstream of the diversion to the Putnam Water Treatment Plant is not permitted as per Section 22a-417 of the Connecticut General Statutes. Therefore, all known sources of pollution are from diffuse or nonpoint sources. Development of an illicit discharge detection and elimination (IDDE) program in the watershed is recommended.

Management of multiple nonpoint sources of nutrients in the watershed are critical to meeting the goals of this management plan, which are to reduce nutrients flowing into the lake and prevent harmful algae blooms. The data collected by ECCD in 2015-16 demonstrated a significant reduction in total suspended solids (TSS) since the early 1980s when the watershed was monitored by the USGS, but there has not been a significant reduction in total nitrogen (TN) or total phosphorus (TP) in certain parts of the watershed.

Volumetrically, Muddy Brook and Mill Brook, respectively, are the first and second most significant tributaries flowing into Roseland Lake. Focusing only on phosphorus concentrations in water samples from these two tributaries, the data demonstrates there are still high levels of nutrients flowing into Roseland Lake, primarily from the Muddy Brook watershed. For example, utilizing the MS4 criteria for stormwater samples, the first flush in-stream water samples passively collected from Muddy Brook on October 29, 2015 and November 15, 2016 exceeded the 0.3 mg/l limit for TP for stormwater runoff samples, which, if the samples were collected under an MS4 permit would call for a follow-up investigation.

The EPA Gold Book-recommended acceptable range for Total Phosphorus concentrations in lake tributaries is < 0.050 mg/l, and for other streams it is less than 0.100 mg/l. These criteria may not have the same scientifically based validity of more current research[6].

Total Phosphorus concentrations in Muddy Brook and Mill Brook during dry weather (no runoff) is within the limits recommended in the EPA Gold Book. The combined wet and dry weather data average in both Muddy Brook and Mill Brook exceeds the recommended 0.050 mg/l limit for lake tributaries.

Based on the results of water quality samples collected by ECCD in 2015/16, Muddy Brook continues to transport phosphorus to Roseland Lake at high enough levels to support continued eutrophication of the lake during wet weather events. When compared to the MA DEP Smart Chart values, the average Total Phosphorus values ranked poor in Muddy Brook and at the high end of fair for Mill Brook.

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[6] Email communication with Mary Becker, CT DEEP.

Table 13: ECCD nutrient data collected from Muddy Brook upstream of Roseland Park Road

Sample Collection Date	TP All samples mg/l	Ortho P All samples mg/l	TP wet only mg/l	Ortho P wet only mg/l	TP dry only mg/l	Ortho P dry only mg/l
9/10/2015	0.023	0.011			0.023	0.011
9/11/2015	0.064	0.021	0.064	0.021		
9/11/2015	0.055	0.021	0.055	0.021		
9/30/2015	0.263	0.155	0.263	0.155		
10/27/2015	0.019	0.011			0.019	0.011
10/29/2015	0.357	0.079	0.357	0.079		
10/29/2015	0.144	0.069	0.144	0.069		
4/25/2016	0.017	0.003			0.017	0.003
4/26/2016	0.019	0.005	0.019	0.005		
4/27/2016	0.022	0.005	0.022	0.005		
11/14/2016	0.024	0.008			0.024	0.008
11/15/2016	0.606	0.327	0.606	0.327		
11/16/2016	0.049	0.025	0.049	0.025		
Average	0.128		0.175		0.021	

Table 14: ECCD nutrient data collected from Mill Brook upstream of Stonebridge Road

Sample Collection Date	TP All samples mg/l	Ortho P All samples mg/l	TP wet only mg/l	Ortho P wet only mg/l	TP dry only mg/l	Ortho P dry only mg/l
9/11/2015	0.058	0.027	0.058	0.027		
9/30/2015	0.221	0.094	0.221	0.094		
10/27/2015	0.020	0.010			0.020	0.010
10/29/2015	0.141	0.035	0.141	0.035		
10/29/2015	0.111	0.051	0.111	0.051		
4/25/2016	0.044	0.008			0.044	0.008
4/27/2016	0.027	0.005	0.027	0.005		
11/14/2016	0.031	0.005			0.031	0.005
11/15/2016	0.057	0.022	0.057	0.022		
11/16/2016	0.037	0.014	0.037	0.014		
Sample average	0.075		0.093		0.032	

Comparison of ECCD 2015/16 data to USGS 1981/83 data

Regulation changes and major investments in agricultural best management practices (BMPs) have led to improvements in water quality in the Roseland Lake/Little River watershed. There has been a decline in the number of dairy farms in the watershed and an increase in herd sizes in some of the remaining farms.

ECCD compared data collected in 2015/16 to data collected by the USGS in 1981/83 (Fig. 26). The USGS data was collected under wet weather conditions. ECCD samples included dry weather conditions, first-flush stormwater conditions and wet weather conditions after the stream levels had begun to recede.

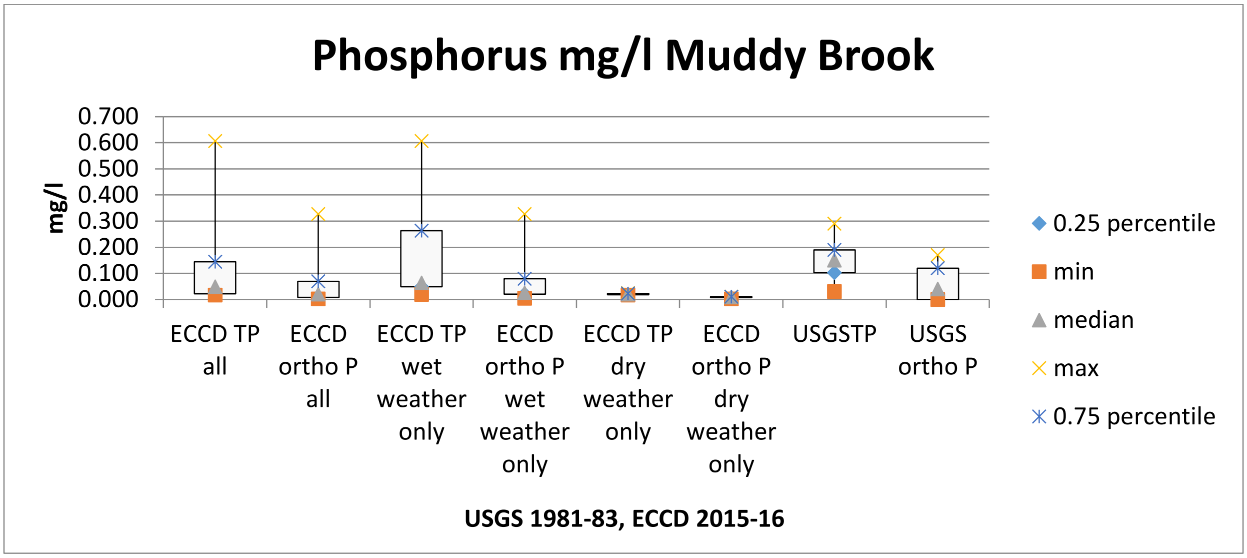

Figure 27: Box and Whisker chart comparing ECCD Phosphorus data from 2015-16 to USGS data from 1981-83 from Muddy Brook.

The above chart demonstrates there continues to be high levels of phosphorus in Muddy Brook upstream of Roseland Lake. This supply of nutrients will continue to support algae blooms in the lake unless controlled. The higher values obtained from the passive stormwater samplers in the fall season may indicate the need to focus on phosphorus reduction strategies during that season of the year. However, comparing the ECCD wet weather data to the USGS TP data, also collected in wet weather, the median value is lower for the ECCD data set, indicating an overall decline in TP concentrations in Muddy Brook in relation to wet weather sampling events.

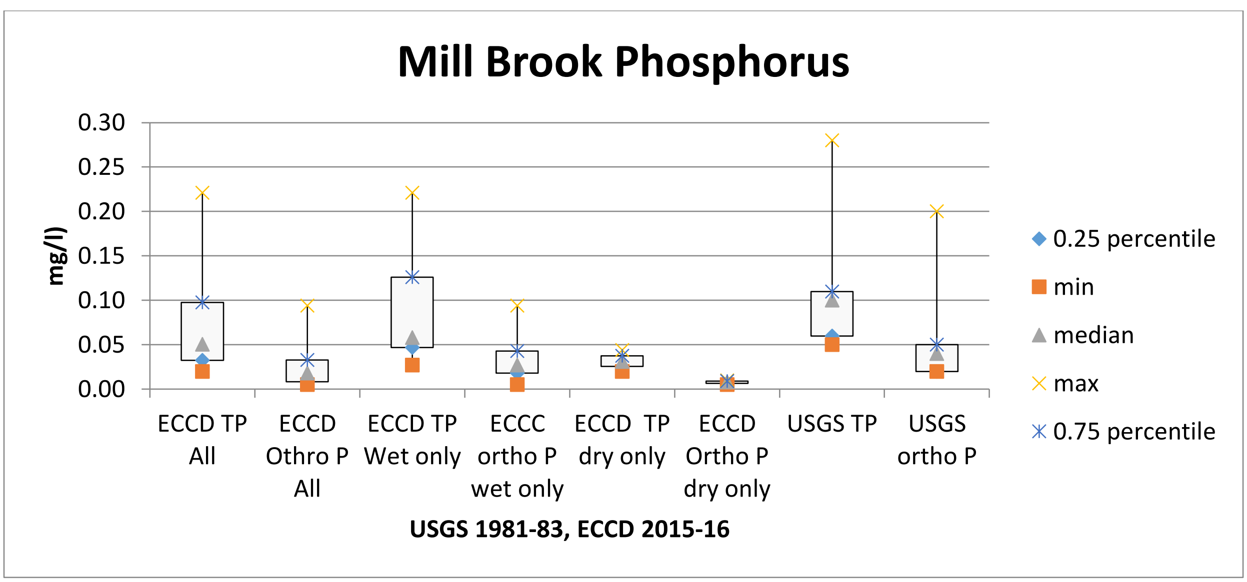

Figure 28: Box and Whisker chart comparing ECCD Phosphorus data from 2015-16 to USGS data from 1981-83 from Mill Brook

As the chart above indicates, when compared to the USGS sample set collected in 1981-83, samples collected in 2015-16 in Mill Brook showed a decrease in Total Phosphorus concentrations related to wet weather sampling events.

Nonpoint Source Controls: Pollutant Trapping by Maintained Inlet Devices

Table 15: Land cover coeffients for TP

Land Use	$mg/m^2/yr$
Forest	4.3
Agriculture	17.7
Urban	80.8

Land use models, supported by actual field data, demonstrate that more pollution runs off developed (Urban) land than the same amount of agricultural land. Forested land usually exports the least amount of pollutants. Developed land includes land with impervious cover, turf grass and barren land. Agricultural land includes crop fields and other grasses. Forest land includes coniferous forest, deciduous forest and wetland forests. The phosphorus runoff coefficients displayed in Table 15were developed by DEP (Becker).

The majority of the Roseland Lake watershed that is located in Thompson, CT and Southbridge, MA is comprised of large contiguous blocks of undeveloped forest land. Stormwater runoff from impervious cover is currently not a major concern for these portions of the watershed. If the watershed in these two communities is inappropriately developed, especially on land with steep slopes, there is a risk that the additional development could be detrimental to the water quality in the Roseland Lake/Little River watershed. Forested land cover changes and forestry operations should incorporate sound water quality BMPs to reduce TSS and nutrient loadings to receiving waters

The majority of the Roseland Lake watershed is in Woodstock, CT. Developed land in the form of impervious cover associated with roadways, parking lots and roof tops in this rural community remain under 10%. The Woodstock Highway Department and State of Connecticut Department of Transportation conduct street sweeping and storm drain sump maintenance annually. The Woodstock road system does not have a well-developed stormwater infrastructure. Stormwater leak-off from roadways is a common stormwater management design, discharging untreated stormwater from the road surface, often directly into wetlands and streams. Many roads predate the Regulations of Connecticut State Agencies Sec. 19-13-B32 Sanitation of Watersheds.

- For future development, Woodstock Planning and Zoning regulations should be carefully reviewed to assure compliance with the stormwater discharge requirements of Sec. 19-13-B32 Sanitation of Watersheds.
- To reduce nonpoint source pollution flowing into the tributary streams of Roseland Lake, the Town of Woodstock should voluntarily conduct a review of its stormwater discharge infrastructure and develop a plan to retrofit infrastructure that directly discharges into streams. Local volunteers can be trained to assist with this effort.
- Where possible, the Woodstock Town Highway Department should look for opportunities to break up long stormwater flow paths and divert stormwater into several small infiltration areas.
- For its historic and scenic dirt roads, it is recommended that the Woodstock Highway Department consult with a relevant expert on methods for maintaining unpaved roadways to develop long-term maintenance and stormwater management plans.

- In areas where regularly inspected and maintained green infrastructure is impractical to reduce NPS pollution, install structural retrofits such as stormwater filter inserts, hydrodynamic separators and deep sump catch basins that are properly and routinely maintained.

Nonpoint Source Controls: Pollutant Trapping by Buffers and Swales

Figure 29: Peckham Brook upstream of Dugg Hill Road in Woodstock, CT

Figure 30: English Neighborhood Brook upstream of Route 197 in Woodstock, CT

It is recommended that pollutant trapping by use of vegetated riverside buffers and swales be increased, particularly along reaches of English Neighborhood Brook, North Running Brook, May Brook and Peckham Brook. Pictured to the left are residential properties where the land has been cleared to the stream channel.

The use of wider vegetated buffers along agricultural fields is recommended along multiple streams upstream of Roseland Lake. As part of a Comprehensive Nutrient Management Plan, the USDA NRCS recommends a minimum 35-foot vegetated buffer between agriculture fields and the high-water mark of a stream channel.

The majority of the Roseland Lake shoreline is minimally developed with significant protected open space along its shoreline, including Roseland Park and property owned by the Wyndham Land Trust. The majority of lakefront residential properties are located on the eastern shore of the lake. Lakeside buffer plantings should be encouraged, especially on steep slopes. Limbing-up of mature trees to improve the scenic vista is recommended rather than removing them. Maintaining lawn to the lake shoreline should be discouraged. Enforcement of existing Woodstock Wetland Regulations and a focused Education and Outreach Campaign by the Woodstock Conservation Commission regarding the environmental function of riparian buffers are recommended.

Vegetated swales are broad, shallow channels with a dense stand of vegetation covering the side slopes and bottom. Swales are used to collect and infiltrate stormwater.

Nonpoint Source Controls: Pollutant Trapping by Detention

Multiple dairy farms in the Roseland Lake watershed have been working with ECCD and the USDA Natural Resources Conservation Service to improve their manure management and silage leachate control systems, contributing their own funds or in-kind labor to match funding from federal sources.

Manure storage tanks, silage bunkers with leachate collection systems, manure lagoons and agricultural settling ponds are examples of detention systems that trap pollutants and have been installed in the watershed.

Using aerial photographs, it is possible to detect deficiencies in agricultural controls where open manure lagoons are undersized for the volume of waste and stormwater runoff that drain into them. Continued efforts to reach out to the farmers and offer financial assistance to improve their wastewater detention facilities is important. See *Little River Watershed Protection Fund* on page 68.

Nonpoint Source Controls: Pollutant Trapping by Infiltration

Infiltration of stormwater is an effective means to remove contaminants from stormwater runoff. Infiltrating stormwater recharges groundwater supplies and prevents heated stormwater runoff from impacting aquatic life in streams. ECCD, working with the Town of Woodstock and volunteers from the community, installed a stormwater bioretention rain garden at the Woodstock Arboretum, resolving a decades-old stormwater runoff/erosion problem in the park downslope of the parking lot of the former Town Hall.

The Woodstock Planning and Zoning Regulations should be reviewed for compliance with the 2004 CT Stormwater Quality Manual and the 2011 Low Impact Development Appendix (or its successor).

The Woodstock road drainage systems should be reviewed to identify opportunities to infiltrate stormwater runoff and reduce erosion where possible, especially on the town's unpaved road network. Examples include:

- interrupt stormwater flow on unpaved roads by installing water bars to divert water to infiltration areas where possible
- install velocity reducers, energy dissipaters and/or rock line roadside ditches to reduce the erosive flow of water
- extend the blade on the road grader used to regrade dirt roads to avoid the development of a gravel berm that prevents stormwater runoff from reaching the designed flow path/infiltration areas in roadside swales
- consult with a relevant expert on best management plans for unpaved road maintenance.

Roseland Park is on the western shore of Roseland Lake. Much of the shoreline is maintained as grass up to a retaining wall with an interrupted tree canopy overhead. Within the park, there are overland drainage areas that flow toward Roseland Lake. The Roseland Park management should consider interrupting drainage channels with rain gardens to encourage stormwater infiltration.

The Woodstock Conservation Commission should continue its education and outreach efforts to promote low impact development strategies outlined in the 2013 appendix to the 2004 CT Stormwater Manual as well as the Connecticut Sediment and Erosion Control Guidelines (as amended).

Nonpoint Source Controls: Pollutant Trapping by Constructed Wetlands

The USDA Natural Resources Conservation Service Conservation Practice Standard Code 656 describes a constructed wetland and acceptable reasons for installing one. A constructed wetland is typically installed where wetland function can be created or enhanced to provide treatment of wastewater or other agricultural runoff.

An intermittent stream flows through a drainage swale behind several dairy farms near Dugg Hill Road. There may be the potential to install a series of constructed wetlands or elevated bio-swales in this drainage path to intercept barnyard runoff and manure storage overflow that drains through the swale toward Peckham Brook.

Nonpoint Source Controls: Pollutant Trapping by Agricultural Best Management Practices

Little River has been designated as a National Water Quality Initiative (NWQI) Watershed by the USDA Natural Resources Conservation Service (NRCS). This designation allows the NRCS to target assistance to help Environmental Quality Incentive Program (EQIP) enrolled farmers and ranchers improve water quality in the watershed. The water quality data collected upstream of Roseland Lake indicate that water quality is improving, but there is still need of additional improvement, especially in the watersheds of several smaller streams with high concentrations of agricultural activities. To assure that the implementation of agriculture Best Management Practices and pilot studies of untried BMPs continues, it is recommended that the NWQI status of the watershed be prioritized so NRCS and its partners will continue to have funding to support nutrient management projects and the expansion of the healthy soil initiative in the watershed. The NRCS has a suite of recommended practices available to achieve goals of individual Comprehensive Nutrient Management Plans. The following practices are suggested but not exclusively promoted.

Adopt Healthy Soil Practices

Many of the larger dairy farms in the watershed have adopted healthy soil practices including no-till farming methods and use of diverse winter cover crops. By maintaining a continuous healthy root system year-round, the soil is less erodible, requires less nutrients and is rich in biological organisms. NRCS and its partners should continue to promote healthy soil practices to expand the acreage of fields using this soil management strategy. As an example, diverse cover crops are used to cycle nutrients and sequester nitrogen, requiring less inputs onto fields. In addition, soils are able to infiltrate and cycle nutrients into the available plant biomass, reducing nutrient-laden effluent from leaving fields.

Use Appropriate Soil Testing Methods

Soil testing before addition of nutrients is a standard practice. Healthy Soil practices build organic nitrogen in the soil that is converted to a crop usable form through natural processes. Conventional soil testing measures Nitrate and Ammonium Nitrogen and the tests indicate nitrogen immediately available to plants, but do not necessarily indicate how much stored nitrogen in the soil may later be liberated from the soil though natural microbial action. This may contribute to an over-application of soluble nitrogen forms that drain off or through the soil before it is available to crops. New soil health analysis techniques (Haney Test or Cornell Test) are available that consider more than available soluble nutrients, but also pools of available nutrients, microbial activity, the carbon:nitrogen balance and water extractable carbon (Haney, Rick). Changing the soil assessment method may lead to a reduction of excess nutrient applications to crop fields, which will save money and reduce nutrient runoff. A pilot study to compare soil test results and crop productivity in local soils and farming practices may benefit the watershed. The cost of a Haney Soil Health Test is approximately $50 per test plus shipping. The cost of a Cornell Healthy Soil test is $60/sample plus shipping.

Reduce Use of Glyphosate in the Watershed

As part of the NRCS Healthy Soil Initiative, agricultural producers in the watershed are encouraged to switch to no-till farming and to plant diverse winter cover crops to maintain a living root in the soil as long as possible. In spring, herbicides such as glyphosate are used to burn down winter cover crops and corn is planted through the plant residue, which remains in place and acts as mulch against weeds and to reduce soil erosion.

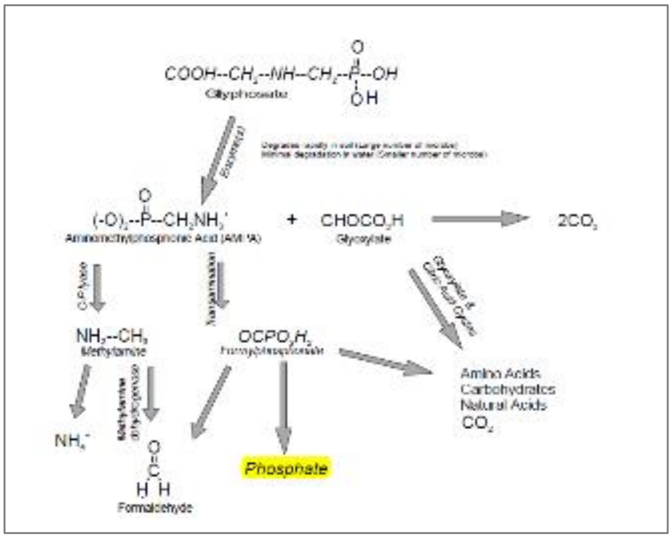

Figure 31: Glyphosate degradation pathway (Schuette)

Research shows that glyphosate breaks down and becomes inactive, but one of the breakdown products is phosphate (see Figure 31). According to the document, *Environmental Fate of Glyphosate*, the "Glyphosate competes with inorganic phosphorus for soil binding sites and the degree of binding depends on available binding sites" (Schuette).

Ohio Sea Grant has been funding research to study the potential impact of glyphosate on cyanobacteria blooms in Lake Erie. Since the passage of the Clean Water Act in 1972, water quality in Lake Erie had been improving. However, a recent increase in harmful algae blooms has led the researchers at Bowling Green State University to link the increased use of glyphosate on fields planted with genetically-modified glyphosate-resistant crops with higher summer temperatures, and concluded this may be contributing to increases in HABs in Lake Erie. In a laboratory setting, using the breakdown products of glyphosate as their only nutrient source, the researchers were able to grow certain cyanobacteria species found in Lake Erie. Researchers are working to create new pollution models to account for the breakdown products of glyphosate as an imported phosphorus source impacting water quality in freshwater systems. The models may help planners and regulators to better understand if the impact of glyphosate use warrants more attention and possible control (Ohio State University).

While the link to HABs to glyphosate use in Ohio has been established, there has been no study to demonstrate that cyanobacteria in freshwater in Connecticut have the same capacity to survive on glyphosate derivatives. If nutrient reductions from other sources fail to reduce the frequency of cyanobacteria blooms in Roseland Lake, this potential source of phosphorus should be investigated. If the amount of glyphosate used on fields cannot be reduced, it may be necessary to account for this source of phosphorus in the nutrient supplement schedules in the future.

Expand Use of Precision Planting Equipment

With funding provided by CT DEEP through an EPA Clean Water Act § 319 NPS grant, ECCD was able to assist a Woodstock farmer to purchase precision planting equipment that is able to plant corn through a standing cover crop. Using this equipment, the cover crop remains in place longer. In 2017, the farmer was able to use half the amount of Glyphosate to burn down the cover crop before the corn emerged from the ground. Expanded use of precision planting technology will reduce the amount of time soil is exposed to wind and rain erosion, and will reduce the amount of Glyphosate applied upstream of Roseland Lake.

Expand use of Roller Crimper

A roller crimper is a mechanical means to interrupt seed production of winter cover crops/green manure. It is designed to roll over the cover crop in spring prior to seed formation. The blades on the crimper also lay down the cover crop, creating a mulch through which cash crops can be directly planted. The mulch helps to retain soil moisture and adds to the organic content of the soil as it decomposes. By using mechanical means to knock down the winter cover crops, it reduces or eliminates the need to use herbicides, such as glyphosate, on the field.

Intercept Tile Drainage Systems and Install Water Treatment Systems

Tile drains are subsurface drainage systems approved by NRCS as a conservation practice. They consist of conduit installed beneath the ground to collect and/or convey excess water. The agricultural benefits of a tile drainage system:

- maintain the water table at a proper level for healthiest plant growth
- keep soil voids free of excess water, which permits air flow and allows important biological processes to take place in soil
- minimize inefficient equipment operation caused by wet areas.

While tile drain systems have allowed farmers to access their fields earlier in the season and extend the growing season, it was later learned that they are excellent conveyors of contaminants such as N, P and fecal bacteria. These contaminants leach through the soil and are not filtered out before reaching the tile drainage outlets. In many cases, the outlet consists of a pipe discharging directly into an adjacent surface drainage ditch or wetland.

Multiple current agricultural BMPs focus on reducing soil erosion and runoff at the soil surface. Research completed in Ohio and Indiana, led by USDA-ARS scientists, estimated that on average nearly 50% of both ortho-phosphorus and total phosphorus discharged from fields via the tile drain system. Tile drainage is now implicated as a significant source of phosphorus impacting inland fresh water quality. Financially, the amount of phosphorus loss from runoff through a tile drainage system would not be an economic concern to most dairy farmers in the Roseland Lake watershed who tend to have more manure than land on which to spread it, but this source of phosphorus can have a major impact on water quality. Once phosphorus enters into a tile drainage system, it bypasses opportunities to bind with soil particles and is discharged into nearby waterways (Fisher).

In 2017, ECCD installed a woodchip bioreactor at the outlet of a tile drained field in South Woodstock. For one year beginning in spring 2018, ECCD staff will be collecting water quality data to determine the effectiveness of the system to reduce ammonia nitrogen, nitrate, nitrate nitrogen and organic nitrogen, total phosphorus, ortho-phosphorus and *E. coli* bacteria. If this pilot project demonstrates woodchip bioreactors to be an effective means of nutrient and pathogen reduction in the Connecticut climate, it would be a valuable BMP to intercept and treat high-nutrient discharges of additional tile drainage outlets located in other locations in the watershed. If the woodchip bioreactor is not an effective means to reduce phosphorus, a secondary filtering activity such as an iron fortified sand filter should be evaluated for inclusion as part of a treatment train. The iron in the sand will bind with the phosphorus, removing it from the effluent.

Create an Inventory of Existing Tile Drainage Systems in the Roseland Lake Watershed

It is unknown how many tile drainage systems were installed in the agricultural fields upstream of Roseland Lake. The practice was more popular prior to modern electronic data filing systems. An important first step to addressing the nutrients that originate as effluent from tile drainage systems, impacting the water quality of Roseland Lake, is to create a database identifying the locations of these systems. This information can be obtained by interviewing landowners, current and retired NRCS staff and/or by reviewing archived paper files that may be warehoused. The highest priority for installation of tile drainage water treatment systems should be on fields that drain toward or into streams with high nutrient concentrations. This includes Muddy Brook below English Neighborhood Brook and fields that drain into the tributaries that flow into Muddy Brook below English Neighborhood Brook. NRCS and/or its Conservation Technical Assistance (CTA) partners could complete this task.

Alternate Tile Drain Drainage Water Management

In tile-drained fields, it is possible to control the groundwater level in the field by installation of structures at the tile drain outlet. By use of removable stop logs, or weirs, a field can be drained prior to field operations that require dryer conditions, and managed to hold more water with its associated nutrients at times when dryer conditions prevail (Fisher). “For maximum water quality benefit during the period from post-harvest through pre-planting (so, from the fall, through the winter and into spring), the current recommendation is to set the control structure outlet elevation within six (6) inches of the field surface. Approximately two weeks prior to the start of field operations in the spring, the control structure outlet elevation is lowered enough to allow the affected fields to sufficiently dry out, so that farm equipment can navigate across and operate in the fields, and so that planting can commence. During the growing season, the outlet control structure is managed so that the water table in the affected fields stays relatively close to, but below, the roots of growing plants. This typically involves raising the outlet control structure to something above the pre-planting elevation described above, then periodically lowering the elevation through the season, as the roots of the growing plants extend deeper underground” (Michigan Department of Environmental Quality).

Use Aerway aerator technology carefully

No-till practices may influence phosphorus broadcast at the surface to stay within the top half inch of soil, which allows the phosphorus levels to build up near the soil surface. No-till practices also encourage macropores to form in the soil. These macropores are beneficial to soil health, but may also create a direct conduit to the tile drainage system (Fisher).

ECCD, funded by grants from CT DEEP through the US EPA Clean Water Act § 319 NPS grant program, purchased two Aerway cultivator units that are shared by multiple farmers in the Little River watershed. The Aerway tines, when set at a 90° angle to the soil surface, are designed to create macropores in compacted soil to increase air and water movement through the soil without a major disturbance of the soil structure. Edge-of-field monitoring on a treatment and control field demonstrated the surface runoff volume was greatly reduced in the treated field compared to the control field. At the time of this study, ECCD staff was not aware of the potential for the enhanced soil macropores created by the Aerway tines to facilitate drainage through the soil into tile drainage systems. It is unknown if the treatment field used in the Aerway field trial is drained via a tile drainage system. It is recommended to review the fields where the Aerway technology is utilized to determine if there are tile drainage systems in place and further consider the unintended potential of the impacts of the technology.

The Aerway equipment has also been used during dry fall weather to lightly incorporate cover crop seeds too improve their fall germination. This practice could be expanded with the caveat that the tines remain at a 90° angle to the soil surface. If the tines are reset to a 45° angle, the pass over the soil disturbs the soil in a similar way to harrowing, which is detrimental to soil health (Covino).

Develop a farmer cooperative/equipment sharing network

Small farms may lack the capital to invest in the new equipment necessary to convert to healthy soil practices. Rather than each farm owning its own equipment, create a means for farms to share equipment where feasible. An example of this is two Aerway cultivators purchased by ECCD with funding support from EPA Clean Water Act § 319 funds through the CT DEEP that is shared by several farms in the Roseland Lake/Little River watershed.

Explore phosphorus recovery methods to extract phosphorus from animal manure as a means to reduce over-application of phosphorus on agriculture fields by manure spreading

Technologies that extract phosphorus from animal manure are in development. The extracted phosphorus can be exported from the watershed as a value-added product rather than a waste product, ending the one-way transport of phosphorus into the watershed.

Examples of practices that can extract phosphorus, while also killing pathogens in manure and other farm waste, for potential export from the watershed include:

- Aerobic manure composting system.
- Anaerobic manure digestion for methane harvesting and power production.
- P removal through centrifugal action.

Study the impacts of diverse cover crops on migratory Canada geese

It has been observed that Canada geese seem to avoid foraging on crop fields planted with diverse cover crops that include plants that might be radishes. Although a low priority, there may be a benefit to studying cover crop diversity in order to identify plants that have low browsing appeal to Canada geese.

Review local land use regulations for compliance with state statutes

Woodstock is a “farm friendly” community, passing a Right to Farm Ordinance at a Town Meeting in 2000. In addition to the multiple agribusinesses in town, hobby farms and back yard chicken coops are also popular. A review of the Woodstock Zoning and Inland Wetland Regulations, and a follow-up conversation with staff at the Woodstock Building Office, revealed there are no minimum acreage requirements for large animals, nor are there any required setbacks from water resources for animal waste storage facilities. It is recommended that the Woodstock Planning and Zoning Commission review its regulations and revise them to be in compliance with the Public Health Code of the State of Connecticut Section 19-13-B32 Sanitation of Watersheds and consider minimum acreage requirements for large animals in consultation with NRCS and the UConn Cooperative Extension System.

Non-Point Source Control through Open Space Protection

In the 2016 Annual Water Quality Report (PWS #CT116011) produced by the Putnam Water Pollution Control Authority, the Little River Diversion Source Water Assessment ranked the overall susceptibility rating for source water derived from the Roseland Lake/Little River watershed as high. This assessment was made in part because “less than 1% of the land is owned by the water system and less than 5% exists as open space.” The assessment report advises Putnam “to increase ownership or control the watershed area whenever land becomes available for purchase.”

The Town of Putnam should work with local land trusts or the Town of Woodstock Open Space Acquisition and Farmland Preservation Committee to develop a critical watershed land open space plan for the Little River watershed, and become a funding partner for land preservation in the watershed.

The Putnam WPCA in conjunction with Putnam Board of Selectmen or designee may also consider accepting conservation easements on open space land within the Little River watershed that has been set aside as open space as a result of the Woodstock Planning and Zoning Open Space Subdivision Regulations.

Develop an Intermunicipal Transfer of Development Rights Program

Another means to achieve the open space goal is to develop a Transfer of Development Rights program with the towns of Woodstock, Thompson and Pomfret, CT and Southbridge, MA to protect land that is within the watershed upstream of the Little River diversion. When land is developed, and that land will be served by the Putnam Water Supply, then in exchange, critical watershed land upstream of the Little River Water Treatment Plant should be protected from development. This can be done by requiring the direct purchase and preservation of the undeveloped land upstream of Roseland Lake. An alternate plan may be to require a transaction fee in lieu of making an open space purchase. The fee in lieu of payment can be made to a Little River Watershed Protection Fund and earmarked for open space preservation.

Nonpoint Source Controls: Pollutant Trapping by Managing Septic Systems

The sewer service region in the Roseland Lake watershed extends to Woodstock Academy with the sewer line extended to their campus in 2012. The majority of the homes and businesses in the watershed are served by on-site wastewater management systems and the Town of Woodstock Water Pollution Control Authority has a policy to discourage new hookups to the sewer system.

Develop a Septic System Maintenance Tracking System

There is no tracking system to ensure septic systems in the watershed are maintained or compliant with current health code requirements. The Board of Directors of the Northeast District Department of Health has rejected a request to be responsible for a septic system maintenance tracking program (phone communication with Susan Starkey, Director of NDDH). The Putnam Watershed Inspector or the Woodstock Water Pollution Control Authority should consider being responsible for this task.

Voluntarily dye test septic systems near the lake

Working with the Northeast District Department of Health, homeowners living near the Roseland Lake shoreline could voluntarily conduct dye tests of their septic systems to verify they are not having an impact on water quality in Roseland Lake. The current subdivision regulations in Woodstock require an effective lot size of 2.5 acres. This is, in part, to allow for adequate separating distances for on-site water and wastewater infrastructure and ample land for a septic system reserve area. Prior to zoning in Woodstock, smaller lot sizes were permitted. On the southeast shoreline of Roseland Lake is the Roseland Terrace subdivision. It was built in the 1950s. The subdivision is served by a community well and all homes have on-site waste disposal. A coarse grain stratified drift aquifer deposit, which is rated highly permeable for septic systems, underlies the neighborhood. Unknown to the homeowner, a septic system located in highly permeable soils may leach nitrates and phosphates into the groundwater. Newer technologies that incorporate

Figure 32: Roseland Terrace subdivision on the southeast shoreline of Roseland Lake.

phosphorus and nitrogen reduction should be encouraged when older septic systems in this subdivision are in need of replacement.

Enforce 50 foot Septic System Setback

A review of the Woodstock wetland and zoning regulations, and follow-up conversations with the Delia Fey, Woodstock Planner, revealed that local regulations do not address Public Health Code of the State of Connecticut Section 19-13-B32-b, the setback requirement for the placement of an onsite wastewater disposal system. The town staff defers all matters related to requirements for onsite waste disposal to the Northeast District Department of Health. The Sanitarian assigned to service Woodstock by NDDH stated that building lots pre-existing the 1977 code were permitted to install systems within 25 feet of a watercourse, but newer lots are required to observe the 50 foot setback requirement. For repair permits issued to homes that predate the 1977 code, a variance can be issued by the Sanitarian if necessary to fit a system onto a lot. To remove confusion over the setback required under state statutes, it is recommended that the Woodstock Planning and Zoning Commission review its regulations and revise them to comply with Section 19-13-B32-b, requiring a setback from streams of 50 feet for septic systems in a drinking water supply watershed.

Request a Zoning Change in Southbridge

The Town of Southbridge Zoning Regulations do not currently recognize the Little River watershed as a contributory area to a surface drinking water supply intake. The Health Department director stated in a phone interview he would consider enforcing the stricter Title 5 Regulations for septic system setbacks from streams in the Little River watershed if he knew a permit being reviewed was in a public drinking water supply watershed (Pellitier). Southbridge has designated the watershed upstream of its own surface water drinking supply as a Watershed Protection District. The Town of Putnam WPCA should consider petitioning Southbridge Zoning Officials to implement a zone change for the undeveloped land in the Little River watershed and designate it as a Watershed Protection District.

Provide Education and Outreach to the general public on septic system management

The Woodstock Conservation Commission initiated an education and outreach campaign regarding septic system maintenance and water conservation strategies in September 2017 by distributing septic system record keeping file folders printed with information on septic system management. They also use their website www.WoodstockConservation.org as a means for education and outreach. This effort should be continued. The Northeast District Department of Health and the Putnam WPCA should also promote septic system best management practices.

Continue to provide funding assistance for Septic System Upgrades

The Town of Woodstock participates in the Housing Rehabilitation Loan Program to assist income-eligible homeowners with major home repairs, including septic system updates. Currently, the Housing Rehabilitation Loan Program funds up to $25,000 as a loan to income-eligible homeowners that must be paid back eventually. All eligible low-income applicants can receive a loan, 50% of which is deferred until the property transfers ownership. The other 50% of the loan is on a no-interest basis paid over ten years in monthly installments. Under the program, very low-income applicants may be eligible for loans which are deferred 100% until the property transfers ownership. To enable homeowners with limited financial means to replace a failing septic system, the Town of Woodstock should continue to participate in this program.

Point Source Controls

A point source of pollution is an effluent pipe where pollution is concentrated and released into the environment. In Connecticut, it is unlawful to discharge industrial or sanitary wastewater into a waterbody upstream of a public drinking water supply inlet. If any illicit point sources are located, it is required they be eliminated.

During the course of the water quality study, ECCD staff was alerted by a local resident of a potential greywater discharge somewhere upstream of the sampling location in English Neighborhood Brook. ECCD staff twice witnessed soap suds in the brook during sampling events. This was reported to the Putnam Watershed Inspector and to the NDDH Woodstock Sanitarian.

> Report Illicit Discharges
>
> Putnam WPCA (860) 963-6800
>
> NDDH (860) 774-7350

The public should be encouraged to report suspected illicit discharges or failing septic systems in the watershed to the Putnam Water Pollution Control Authority (WPCA) and the Northeast District Department of Health (NDDH), so follow-up action can occur.

Additional Actions for Successful Lake Management Outcomes

Develop a Roseland Lake/Little River Healthy Watershed Collaborative

In order to coordinate implementation of the Roseland Lake Management Plan, it is highly recommended to establish a Roseland Lake/Little River Healthy Watershed Collaborative. The Collaborative should be comprised on watershed stakeholders outlined in Table 11 on page 63 and meet twice annually to report on activities related to implementation of this Roseland Lake Management Plan. Recommended roles and responsibilities of the stakeholders are outlined in Table 11.

In order to assist agriculture producers that lack the grant match resources, or to contribute to land conservation efforts, it is recommended to establish a Little River Watershed Protection Fund. The funds can be applied as match for EQIP cost share projects or other grant programs by economically distressed farmers in the Little River watershed, or matching funds for the CT DEEP's Open Space and Watershed Land Acquisition Grant or other grant programs for the purchase of critical watershed land upstream of the Putnam water supply inlet as permanent open space. Potential sources of revenue for this fund may include:

- the US EPA Healthy Watershed Initiative or other grants for funding to support oversite of the establishment of this initiative and potential seed funding for the Little River Watershed Protection Fund
- the Town of Putnam WPCA should consider adding a water surcharge to its water customer's bills to continuously add to this watershed protection trust fund
- create a new intermunicipal Transfer of Developments Rights program to incorporate a transaction fee for new development that will be connected to the Putnam public drinking water supply
- solicit private contributions from residents and businesses owners in Putnam who benefit from clean water.

To manage these funds, develop a committee to review applications submitted to the specially designated Little River Watershed Protection Fund. The fund could potentially be managed by the Eastern Connecticut Community Foundation or another regional non-profit entity.

SECTION 8: IN-LAKE MANAGEMENT STRATEGIES

History of In-lake Management Strategies in Roseland Lake

> Unless the sources of nutrients in Roseland Lake are reduced, there will continue to be serious algae blooms. However, focusing on watershed management alone will not be enough. In-lake management methods will be necessary, too.

The Town of Putnam relies, in part, on Little River as a source of drinking water. The Putnam Water Pollution Control Authority (WPCA) has been granted a withdrawal permit to continue its withdrawal. It was issued on 10/15/13 and will expire on 10/22/38, when they will have the option to renew the permit.

There are many types of herbicides and algaecides available to control aquatic weeds and algae blooms. The CT DPH and the CT DEEP maintain a Memorandum of Agreement (MOA) (DPH LOG #2013-1502) regarding the issuance of Aquatic Pesticide Permits by the CT DEEP in aquatic environments upstream of a surface drinking water supply intake. A full copy of the MOA is available in Appendix E.

As stewards of the water supply, the Putnam WPCA is required to routinely inspect the watershed for threats to water quality. Under a CT General Permit issued by the CT DEEP, they had also been granted a permit waiver as a water company to apply algaecide to upstream waterbodies as needed. This practice was used to control algae blooms that caused taste and odor problems, and increased water treatment costs at its water treatment plant. WPCA chose to use Copper Sulfate ($CuSO_4$) to control algae in Roseland Lake as recommended in the 1978 publication "The Causes of Algae Growth in Roseland Lake, Woodstock, CT" (CT DEP).

The Putnam WPCA is required to and has abided by the treatment limitations placed on $CuSO_4$, as outlined in the MOA, upstream of its drinking water supply surface intake from Little River. No official records could be found as to when the Putnam WPCA began $CuSO_4$ algaecide treatments in Roseland Lake and downstream in Shepherds Pond. However, author Eileen Jokinen, in *Freshwater Snails of Connecticut,* dates the start of the practice around 1980.

In February 2017, the US EPA enacted revised rules under the National Pollutant Discharge Elimination System (NPDES) which required the Town of Putnam WPCA to apply, through the CT DEEP, for a federal permit to treat Roseland Lake with algaecides. The Putnam WPCA, working through a contractor, has applied for its permit to continue algaecide applications in Roseland Lake and Shepherds Pond. The permit application was reviewed for potential impacts on a species of freshwater snail, the disc gyro snail, *Gyradualus circumstriatus,* which is listed as a special concern species in the Connecticut Natural Diversity Data Base (NDDB). The permit was not granted. The DEEP NDDB office is requiring a Roseland Lake snail survey before a permit for $CuSO_4$ will be considered.

Prior to 2004, stands of Common Reed, *Phragmites australis,* impacted the fringes of the littoral zone of Roseland Lake. Rodeo (glyphosate) was used along the shoreline on the *Phragmites.* The above-ground stems *w*ere subsequently mulched or burned. A number of stakeholders funded the *Phragmite*s control project. CT DEEP conducted the glyphosate treatments. The most recent spot treatment of *Phragmites* along the Roseland Lake shoreline was conducted in September 2017.

The Need for In-Lake Management

The implementation of in-lake management strategies will be beneficial to Roseland Lake if the phosphorus contribution from sediments is >25%, and necessary if the phosphorus contribution from sediments is >50% (Solitude Lake Management). In-lake water quality and soil sediment data collected in 2015 and 2016 showed that during the summer, in-lake sources of phosphorous range from 42 – 52%. The duration that lake sediments are exposed to anoxic conditions varies from year to year. Without carefully considered in-lake treatment to prevent Harmful Algae Blooms in Roseland Lake, cyanobacteria blooms that are a threat to human health and the ecology of the lake will continue.

Section 8-1: Herbicides and Algaecides: An Overview

There are many types of herbicides and algaecides available to control aquatic weeds and algae blooms. The CT DPH and the CT DEEP maintain a Memorandum of Agreement (DEEP/DPH MOA) regarding the issuance of Aquatic Pesticide Permits by the CT DEEP in aquatic environments upstream of a surface drinking water supply intake. A full copy of the EDEEP/DPH MOA is available in Appendix D.

Algaecides are ideally used as an algastatic (preventative treatment) to inhibit the growth of algae prior to the onset of a severe algae bloom. Although algaecides will temporarily reduce the algae concentration in the lake, their use is not a long-term solution to the nutrient enrichment that is the underlying cause of algae and cyanobacteria blooms. Without a better understanding of the environmental consequences of algaecide use, the US EPA does not encourage the use of algaecides in drinking water sources (US EPA).

Treatment with Copper

Copper sulfate ($CuSO_4$) is generally a non-selective contact herbicide commonly used to treat lakes and ponds to manage algae blooms. $CuSO_4$ is listed in the DEEP/DPH MOA as a Group 1 permissible herbicide for use upstream of a drinking water supply intake, with the condition that the total dissolved copper concentration shall not exceed 1.3 ppm.

There are short- and long-term impacts of repeated use of $CuSO_4$ to combat algae blooms in lakes (Hansen).

Short-term impacts of CuSO4

- $CuSO_4$ is an algaecide that will kill algae temporarily;
- dead algae sinks to the bottom where its decomposition depletes dissolved oxygen in the hypolimnion;
- it is a short-term solution and recovery of the algal population can occur within 7 to 21 days;
- may cause fish kills due to oxygen depletion;
- impacts non-target species of invertebrates due to copper toxicity;
- if cyanobacteria is dominant, the rapid breaking open of their cells could release cyanotoxins that may contaminate the water supply.

Long-term impacts:

- copper accumulation in the sediments;
- increased tolerance by certain species of algae may require higher copper sulfate dosages;
- shifting of species from green algae to cyanobacteria and from game fish to rough fish;

- reduction of rooted emergent and submerged plants;
- reduction of benthic macroinvertebrates (snails, mussels, bryozoan colonies, insects).

Mary Rogalski, a Yale PhD Candidate, conducted a study in 2015 on the impact of metal pollution in lake sediments on hatching Daphnia eggs, for which she documented copper concentrations in Roseland Lake sediments. The resulting graphs demonstrate a dramatic increase of copper metal in the lake's sediments (Rogalski). As an additional reference point, sediment analysis was independently performed by the USGS in 1983, as part of its evaluation of the watershed. As a result of that sampling, copper concentrations were reported at 8 µg/g (mg/kg) (Kulp).

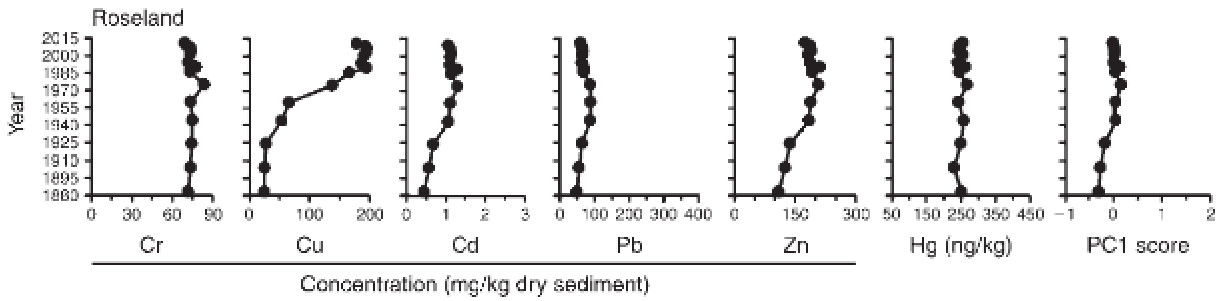

Figure 33: Metal concentrations in Roseland Lake Sediments (2015)

Identification of mat-forming algae species

In the littoral zone of the lake, mat-forming algae can form quickly and float to the surface. Identification of the mat-forming algae species has not been conducted in Roseland Lake. It is possible that a type of mat-forming cyanobacteria, *Lyngbya*, may be present in the lake, as noted by Eileen Jokinen during her snail inventory (Jokinen). There are types of *Lyngbya* that form protective sheaths around their cells, making them more resistant to $CuSO_4$ treatments unless a surfactant is added to the treatment. If it is determined that this form of *Lyngbya* is both present in Roseland Lake and a nuisance algae species, then the addition of the required surfactant may be necessary if $CuSO_4$ is a chosen treatment option (McNally).

Treatment with Sodium Carbonate Peroxyhydrate

Sodium carbonate peroxyhydrate (GreenClean) is a form of hydrogen peroxide. It is sold in either a solid or liquid form. It can be used on a broad range of filamentous and planktonic algae.

Sodium carbonate peroxyhydrate is listed as a Group 1 permissible herbicide for use upstream of a drinking water supply intake in the Connecticut DEEP/DPH MOA. It is more expensive to use than $CuSO_4$ and is not as effective at controlling algal blooms. However, it is more cost-effective to use as an algal bloom preventative (algastatic) agent. The product fully degrades within 24 hours and has less environmental impact than $CuSO_4$ (Biosafe Systems LLC). Since it is non-toxic to invertebrates when used at the recommended dose, there should be less conflict when using sodium carbonate peroxyhydrate near the habitat of a snail of special concern. However, if the product is used during a toxin-forming cyanobacteria bloom, the potential to release the toxins from the cells upon their death is the same as for $CuSO_4$.

Treatment with Flumioxazin

Flumioxazin (Clipper) is an herbicide that is registered for use with aquatic plants. It also controls some forms of filamentous algae. Tests on bluegill and rainbow trout indicate that Flumioxazin is slightly to moderately toxic to fish. Flumioxazin is moderately to highly toxic to aquatic invertebrates, with possible impacts below the labeled maximum rate of 400 ppb (parts per billion). It is practically non-toxic to birds, small mammals and bees (WI DNR). Under the DEEP/DPH MOA, Flumioxazin is a Group 3 Limited use chemical. Conditions required for its use include:

- the applicant demonstrates that there is a specific need for the chemical
- the DEEP and DPH conduct specific reviews as part of the treatment application
- the maximum permissible application is not exceeded
- the applicant may be required to comply with additional conditions.

The Commissioner of the DPH, or a designee, makes final decision whether to issue a permit to apply Flumioxazin.

With the potential for a special concern species of snail in Roseland Lake, Flumioxazin, with its high toxicity to invertebrates, is not recommended.

Pre-treatment/post-treatment Water Quality and Cyanobacteria Tracking

Before any treatment of Roseland Lake with any algaecide, the water should be analyzed to determine the type and density of algae, especially if the lake is being treated for cyanobacteria. If cyanobacteria is present, another test may be advisable to determine the concentration of toxins in the cyanobacteria prior to treatment. If toxins are detected, a post-treatment sample should be analyzed to determine if the concentration of cyanotoxins has changed.

In a presentation at a 2016 Lakes Management Workshop, Dr. Kenneth Wagner of Water Resource Services, stressed the need for continued in-lake monitoring as part of a proper lake management program. His presentation, *Identification, Ecology and Control of Nuisance Freshwater Algae*, emphasized that the proper time to treat a lake for cyanobacteria is before the bloom occurs. Otherwise, if the cyanobacteria contain cyanotoxins, those cyanotoxins will be released into the water as the dying cells break open. To determine if cyanobacteria are present, Roseland Lake monitoring should include cyanobacteria tracking through a combination of visual assessments and microscopic examination, or use of florescence equipment to assess algal pigment to determine whether pigments associated with cyanobacteria are present. Continued in-lake monitoring (for nutrients, Chlorophyll A, dissolved oxygen, temperature, pH, conductivity, and secchi depth) would also be useful to track treatment effectiveness. Using data to predict conditions that warn an algae bloom is pending, a pre-bloom treatment could be recommended that would require less algaecide and reduce the risk of releasing cyanotoxins into the water column.

Chemical Control of Aquatic Plants

At the time this plan was written, less than 30% of the lake surface was affected by aquatic plants, which are not currently considered a nuisance in Roseland Lake. If conditions change, there are limitations in Connecticut on what treatment methods are permitted upstream of an inlet to a public drinking water supply surface treatment facility. Refer to the CT DEEP/DPH MOA outlining permitted and non-permitted herbicides, found in Appendix E. The following treatment options are approved for treatment of aquatic nuisance plants.

Treatment with Fluridone

Fluridone (Sonar) is an herbicide used to control aquatic rooted plants. Fluridone is included in the DEEP/DPH MOA as a Group 2 permitted herbicide in Connecticut. Fluridone may be approved for use in waterbodies greater than 0.25 mile upstream of the distribution reservoir. It is not used as an algaecide.

Treatment with Triclopyr

Triclopyr (Renovate) is an herbicide used to control aquatic rooted plants. It is not used as an algaecide. Tryclopyr is not recommended for use in a lake with an outlet or in moving water (WI DNR). Tryclopyr is a Group 3 Limited use herbicide that may be approved for use in Connecticut if:

- the applicant demonstrates that there is a specific need for the chemical
- the DEEP and DPH conduct specific reviews as part of the treatment application
- the maximum permissible application is not exceeded
- the applicant may be required to comply with additional conditions.

The Commissioner of the DPH, or a designee, makes the final decision as whether to issue a permit to apply triclopyr.

Treatment with Glyphosate

Rodeo (Glyphosate) has been used to control of *Phragmites* along the shoreline of Roseland Lake. Glyphosate is listed as a Group 2 permitted herbicide and its use is restricted to greater than 0.5 miles upstream of a drinking water reservoir. Downstream water testing is required after use of the product.

The breakdown products of glyphosate include phosphate, which is being studied for potentially contributing to algae blooms in other watersheds, as previously discussed.

Other Herbicides

Herbicides not specifically mentioned in the Memorandum of Agreement between the CT Department of Public Health and the CT Department of Energy and Environmental Protection are not approved for use upstream of a public drinking water supply surface intake in Connecticut.

Section 8-2: Non-herbicide In-lake Management Practices

The following tables outline accepted in-lake management strategies that have been used for various purposes. The benefits and limitations of each practice are described briefly. ECCD recommends that a Certified Lake Manager be consulted to help select the best method or methods to prevent future harmful blooms of cyanobacteria in Roseland Lake.

Disclaimer: The Eastern Connecticut Conservation District does not endorse any specific techniques or products outlined in these tables.

Table 16: In-lake Nutrient Reduction/Harmful Algae Bloom Prevention Strategies

Waterbody management measures to prevent HABs	Description	Benefits	Limitations/practical uses in Roseland Lake
Hydraulic Controls Dilution and Flushing	Diverting water from a low-nutrient water source into and through a lake as a means of diluting and flushing nutrients from the higher-nutrient lake water.	Flushing may wash out surface algae and replace higher-nutrient lake water with lower-nutrient dilution water.	The nearest river source for diversion water is the Quinebaug River. The Quinebaug River is a waste-receiving stream. Its diversion to a drinking water supply watershed would not be permitted in Connecticut. Roseland Lake is located in a significant sand and gravel deposit which may be a high yielding aquifer. Groundwater withdrawn downstream of the lake may be a source to pipe in on the upstream end of the lake as needed when conditions favor cyanobacteria growth. Permitting required. The cost of lake dilution and flushing would be extremely high.
Hydraulic Controls Diversion	Drainage channels or pipes used to divert nutrient-rich waters to the downstream side of lakes.	Reduces the nutrient input to the lake.	Depending on the project, major engineering may be required at great expense and other receiving waters may be affected by the nutrient-rich water. Permitting required. Diverting streams would eliminate a water supply to the lake and may interfere with fish runs.
Hydraulic Controls Hypolimnetic withdrawal	Use of siphons to remove nutrient- rich water from the hypolimnion.	Reduces nutrients and eliminates some of the low-oxygen water.	Siphoning from the bottom of the lake may disrupt the lake ecology by interrupting lake stratification.

		May reduce the period of anoxic conditions in the bottom of the lake, which in turn would reduce phosphorus available to support cyanobacteria blooms.	This technique can have severe impacts on downstream receiving waters which receive the nutrient-enriched waters. Water treatment before discharge would be required. Discharges into stream upstream of a drinking water intake are limited to discharges from public or private drinking water treatment systems, dredging and dewatering, emergency and clean water discharges. Permitting required. Cost: Extremely high
Phosphorus Inactivation Alum treatments	Aluminum sulfate (alum) is used to inactivate phosphorus in lake sediments (sediment inactivation). Alum can be applied annually in small doses (micro-floc injection) to precipitate phosphorus from the water column.	Alum works by binding with the active inorganic phosphorus ions, preventing them from being in solution. In the water, this material precipitates out and sinks to the bottom as “floc”. On the sediment surface, it prevents the release of soluble phosphorus by binding with it. Aluminum sulfate (Alum) treatments are permissible upstream of a drinking water supply intake in Connecticut under the condition that the dissolved aluminum concentration does not exceed 0.2 ppm.	The length of effectiveness for a total sediment treatment is reduced in lakes where phosphorus inputs from the watershed are not under control. Estimated cost $200,000 (Solitude Lake Management). Micro-floc injection is predicted to be effective for 3 – 5 times the lake retention time. (Retention time in Roseland Lake is estimated to be 25 days during the HAB season) Estimated cost $9 – 10K per year. Retreatment required annually but may eventually lead to sediment inactivation (Solitude Lake Management). Permitting required.

Artificial circulation- Epilimnetic circulators	Epilimnetic circulators continuously circulate the water in the upper layer of the lake and are theoretically effective at disrupting the buoyancy and vertical migration of cyanobacteria.	This technology is approved for deployment in drinking water reservoirs as well as recreational lakes. This technology targets cyanobacteria while not impacting other organisms that make up the biotic community. Epilimnetic circulators are promoted as a means to prevent the seasonal advantage of cyanobacteria over other forms of phytoplankton. Newer technologies are solar powered and do not need onshore mechanics and power supply.	This technology does not reduce the nutrients in the lake. If the technology fails, conditions that favor cyanobacteria will quickly return. The biomass of algae and/or aquatic plants is not reduced, but shifted to another form. May be a conflict of lake use for ice fishing or skating, unless seasonally decommissioned. Estimated cost: $150,000+ There would also be an annual service fee for this technology (Medora Corporation). The life span of the technology is unknown. Permitting required. Additional staff salary cost for water quality monitoring, system inspection and management.
Artificial circulation- Whole lake circulation	This process is a technique for introducing more oxygen to the entire lake by limiting stagnation and elimination of temperature zones in the lake. It is used in lakes <20 feet deep. Variations include surface aerators, bottom diffusers and water pumps.	By increasing the concentration of dissolved oxygen in the water, it prevents the release of phosphorus from the bottom of the lake. May reduce the amount of time algae are exposed to light for photosynthesis. Enhances habitat for certain fish and other aquatic organisms.	May eliminate cold water habitat by eliminating temperature stratification. Requires on-shore site for the pumps, air compressors and access to a power supply. May be a conflict of lake use for ice fishing or skating, unless seasonally decommissioned. Additional staff salary cost for water quality monitoring, system inspection and management. Permitting required.

			The estimated range of cost for 20 years of application at a hypothetical 100-acre lake is $70,000 to $400,000 (Wagner).
Artificial circulation-Hypolimnetic circulation	Hypolimnetic aeration is accomplished using a specially designed, self-contained, underwater cylinder composed of inside and outside chambers, both open at the bottom. Air is pumped to the bottom of the inside chamber. The rising air bubbles carry the bottom water to the top of the cylinder where it is aerated. The newly oxygenated water then is cycled down the outside chamber and released at the lake bottom.	This technology is approved for deployment in drinking water reservoirs as well as recreational lakes. By enriching the hypolimnion with oxygen, it prevents the release of phosphorus stored in the sediment. Properly managed, it shouldn't interfere with the temperature zones in the lake, allowing for both cool water and warm water habitat. Newer technologies are solar powered and do not need onshore mechanics and power supply.	This technology does not reduce the nutrients in the lake. If the technology fails, conditions that favor cyanobacteria will quickly return. In shallow lakes, it may interfered with the temperature zones in the lake. May be a conflict of lake use for ice fishing or skating, unless seasonally decommissioned. Additional staff salary cost for system inspection and management. Permitting required. No price estimate obtained for this technology.
Conventional Dry Dredging	Dry dredging requires diverting flow into the lake to bypass the lake long enough to dry the sediments so they can be mechanically removed by heavy equipment.	Removes the nutrient rich sediments stored in the bottom of the lake. Will reduce internal loading of phosphorus. Will make the lake deeper, increase flood control.	This would require diverting inflow to the lake from Muddy Brook, Mill Brook and all intermittent streams, which is not practical. Aquatic life in the lake would need to be relocated during the process. Permitting required. Cost: $20/yd^3$ (Wagner)
Conventional Wet Dredging	Uses heavy equipment from shore or a barge to dig out soft sediment from the bottom of the lake.	Removes the nutrient rich sediments stored in the bottom of the lake.	May lose of some biological components of the lake.

		Will reduce internal loading of phosphorus. Will make the lake deeper, increase flood control.	Increased turbidity downstream if lake outflow is not controlled. Requires an upland site for temporary sediment storage/dewatering. Potential shoreline disruption by heavy equipment. Permitting required. Cost: up to \$20/yd^3 (Wagner)
Hydraulic or Pneumatic Dredging	Uses a specialized hydraulic dredge to syphon a slurry of water and sediment from the bottom of the lake.	Removes the nutrient-rich sediments stored in the bottom of the lake. Will reduce internal loading of phosphorus. Using pumps, the dewatering staging site does not need to be in the immediate shore area. Water from dewatering can be returned to the lake. Will make the lake deeper, increase flood control.	May lose some biological components of the lake. Requires an upland site for temporary sediment storage/dewatering. Use of geotextile tubes for dewatering can save space. Permitting required. Cost: up to \$20/yd^3 (Wagner)
Mechanical Harvesting	Uses a floating mechanical weed harvester to cut and collect nuisance aquatic vegetation. The equipment can also be used to collect and remove floating algae scum and mats from the surface of the lake.	May reduce taste and odor problems and reduce clogging of the intake at the water treatment plant. Removes biomass from the lake that would otherwise add to the	Equipment is slow moving, taking a lot of time to cover the surface of the lake. Requires an onshore containment site to store and dewater the collected material prior to disposal.

		nutrients stored at the bottom of the lake. Makes the lake aesthetically more pleasing.	Requires the purchase of $60 – 70K of equipment (internet) and hiring an operator, or ~~a~~ hiring a contractor to respond on demand.
Aquatic Dyes	Dyes are used to block light and limit aquatic plant and algae growth.		Aquatic dyes are not permitted for use in drinking water reservoirs.
Floating Treatment Wetlands	Floating mats with holes are planted with emergent wetland plants and floated on the water surface. The plants are grown hydroponically. The plant roots take up nutrients from the water during the growing season. The artificial wetlands are anchored in several feet of water to prevent the roots taking hold in the lake sediments.	Wetland plants remove nutrients from the water and store them in their biomass. The root systems provide habitat for aquatic organisms and capture particles. Floating wetlands reduce light penetration below them. At the end of the growing season, the plants are harvested and composted off site, permanently removing those nutrients from the lake. The harvested material may help supply “green” ingredients for local agriculture composing operations.	This system is better for nitrogen uptake, but also removes phosphorus. Islands need to be structured with a Canada goose barrier. Anchor lines need to allow for fluctuating water levels to prevent the islands from being submersed in rising water levels. Effectiveness depends on the area covered and the number of plants. Permitting required.
Barley Straw	Barley straw, when it decomposes in water, releases a chemical that may inhibit the reproduction of certain forms of cyanobacteria.	Barley straw has been demonstrated to control algae densities in small ponds. Preferably added to shallow, moving water or lake-side digesters.	Barley straw is not a registered herbicide. Its use would require an inland wetland permit. Adding material to the water will increase the biological oxygen demand as the material decomposes unless removed at the end of the season.

Bacterial Additives and Biological Controls	Certain selected or engineered bacteria that grow in aquatic environments have the ability to out compete algae for available nutrients in the water.	Limited data is available to evaluate the effectiveness of this process.	May not be effective on cyanobacteria. Use of bacterial additives is not listed as permitted on the DEEP/DPH MOA as an allowed product in CT.
Removal of Bottom Feeding Fish	Bottom feeding fish such as carp and bullheads can release a lot of nutrients as they feed and digest their food. Reduction in their populations can in some cases improve water quality.	May increase water clarity and reduce nutrients.	A detailed survey of the density of the fish would be required. As a natural lake with no fish passage barriers, any fish removed would quickly be replaced from upstream/downstream areas. Permitting required.
Sonification	Sonification is a technology that uses sound waves of varying frequencies to interfere with algae reproduction.	Shore-mounted units need a power source and have limited range. Solar powered floating units have been developed that cover larger areas. Some even have on-board monitoring equipment and data can be accessed remotely. Sonification does not disrupt other organisms in the biotic community.	The technology requires line-of-site access to the water where the algae is growing, meaning aquatic plants or boat dock/pier structures or any other solid object would block the sound waves. Use of sonification does not reduce the nutrient concentration in the lake. If the units stop functioning, the nutrients in the hypolimnion are still available to support algae blooms. Permitting required. Cost: $150,000 (LG Sonic)

In-lake Management for Nuisance or Aquatic Invasive Plants

The following table includes in-lake management methods used for nuisance or aquatic plant management. They are not used for algae control in lakes. At the time this plan was prepared, aquatic plants in Roseland Lake were not at the nuisance level, and there are no reports of aquatic invasive plants, but aquatics plants in the lake may reach nuisance levels if lake management is effective at controlling cyanobacteria blooms without addressing nutrient inputs.

Table 17: In-lake Management for Nuisance or Aquatic Invasive Plants

Waterbody management measure to manage nuisance aquatic plants	**Description**	**Benefits**	**Limitations/practical uses in Roseland Lake**
Rotovation	This device is used to remove rooted aquatic plants. It is like a rototiller mounted on a barge.	Disrupts the entire plant, including the root system. Can be completed by a contractor.	Plants may spread by fragmentation. Habitat disturbance. Increases the biological oxygen demand in the water if plants are not removed. Permitting required. Cost: varies by area served.
Benthic Barriers	Benthic barriers are also known as weed mats. They are used to physically cover the bottom of a lake in shallow areas and act as barriers to aquatic plant growth.	Non-chemical means to deter aquatic weed growth in small areas. Can be installed with manual labor in small areas.	Can smother shellfish resources (mussels) if present. Can be labor intensive to maintain. Permitting likely required.
Drawdown	By lowering the water level in the lake over winter, a lake drawdown exposes aquatic plants to freezing and thawing, killing the plants.	A non-chemical means to control aquatic weed growth in the littoral zone.	Since Roseland Lake is a natural lake, there is no mechanism with which to conduct a drawdown.

Shade Covers	Surface shading is a means of weed control in small areas. Polyethylene sheets can be floated on the water to prevent aquatic weed growth and removed when water access is needed. Shoreline trees are a natural form of shade cover.	Two – three weeks of cover may be an effective non-chemical means to control aquatic weeds. The product can be removed and stored to allow access for boating. May provide temporary cover for fish hiding from predators.	Wind and waves may cause displacement of the shade covers. May temporarily impede aquatic animals from gaining access to shore areas. Permitting likely required.
Food Web Biomanipulation -Herbivorous Fish	(Sterile) grass carp can be used to control aquatic plants. They feed on aquatic plants and can reduce nuisance of invasive aquatic vegetation in ponds.	This is a non-chemical means to reduce the biomass of nuisance aquatic and invasive plants. Once introduced in the proper density, herbivorous fish can reduce aquatic plant biomass for up to 5 years.	Use of fish to reduce aquatic plant biomass does not reduce the nutrients available in the aquatic system. It may lead to a shift to higher algae populations. A permit is required before any fish can be released into the water. Places in the watershed where grass carp have been released are required to have a means to keep them from escaping. Any effort to contain fish in Roseland Lake would be a fish passage barrier to native fish populations.
Food Web Biomanipulation –Herbivorous Invertebrates	Certain aquatic plants, like European milfoil, are targeted by a specific weevil that attacks the root system. The potential to find similar biological controls for other aquatic invasive species is possible.	At this time, there are no benefits for this method of aquatic weed control in Roseland Lake.	Permitting required.

Section 9: Five Year Action Plan

ECCD developed a proposed five year action plan for implementing watershed nutrient reduction strategies and adopting appropriate in-lake management strategies necessary to improve the water quality of Roseland Lake. By addressing the nutrient sources causing algae blooms in Roseland Lake, not only will there be a reduced threat of negative health impacts from contact with or consumption of the water, and reduced costs to treat the water before being distributed to the public, but the habitat quality in lake will improve for many different species as a result. There are many strategies that can be initiated quickly at no or low cost. Others strategies will take longer from planning, fund raising and final implementation.

The Roseland Lake Five Year Action Plan can be found in Appendix E

Section 10: Conclusion

Roseland Lake has been the recipient of upland runoff since its formation over 10,000 years ago. Good water quality in the lake is essential for both humans and the ecosystem. Human activity in the watershed has accelerated the natural aging process of the lake. This activity predates colonization by European settlers.

The expected trophic state for Roseland Lake is eutrophic and possibly hypereutrophic, based on the ratio of the size of the watershed to the surface area of the lake. Water quality data collected by ECCD for this study indicates the lake varies from mesotrophic/eutrophic to highly eutrophic. Nutrients from anthropogenic sources that run off the land or enter the lake through groundwater are accelerating the aging process. Of particular concern is the amount of phosphorus that enters the lake each year as nonpoint source pollution. Watershed modeling estimates that nearly 3000 pounds of phosphorus enters Roseland Lake every year from the surrounding watershed. Some of this phosphorus may flow through the system, but a portion of it is deposited on the lake bottom via sedimentation, and a percentage is taken up by algae and accumulates in the lake's sediment after the algae die. In-lake monitoring has determined that this legacy phosphorus is a major source fueling algae blooms in Roseland Lake. During the summer months, when lake and tributary water levels are low, and water temperatures are high, the water retention time in the lake is prolonged. This provides cyanobacteria an advantage over other forms of algae. The ability to alter their buoyancy inside their cells lets cyanobacteria move up and down in the water column to access nutrients released from the bottom when the hypolimnion becomes anoxic in the summer. Cyanobacteria also are capable of obtaining nitrogen from N_2 gas once in-lake supplies of NO_3-N are exhausted. Blooms of cyanobacteria are harmful to both humans and the diverse aquatic life in the lake. It is important that steps be taken to prevent harmful algae blooms in Roseland Lake. Watershed management is critically important, especially reducing the amount of phosphorus entering Roseland Lake. However, watershed management alone will not prevent HABs. In-lake measures are necessary.

There are many different strategies to improve water and habitat quality in Roseland Lake outlined in this plan. An important first step is to form a Roseland Lake/Little River Healthy Watershed Collaborative that will meet, share their collective knowledge and provide updates on actions taken. The next step the Putnam WPCA and other Roseland Lake Stakeholders should take is to evaluate each strategy for its cost, practicality, limitations, environmental impact and duration.

The restoration of Roseland Lake will be a long-term process, but the resulting benefits will be well-worth the time, effort and cost. When the Roseland Lake/Little River Collaborative begins to meet, the development of a vision statement will help direct the focus of this effort.

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Appendix A

Sec. 19-13-B32. Sanitation of watersheds

Unless specifically limited, the following regulations apply to land and watercourses tributary to a public water supply including both surface and groundwater sources.

(a) As used in this section, ''sewage'' shall have the meaning found in section 19-13-B20 (a) of the public health code:

''Toxic metals'' shall be arsenic, barium, cadmium, chromium, lead, mercury and silver and the salts thereof:

''high water mark'' shall be the upper limit of any land area which water may cover, either standing or flowing, at any time during the year and

''watershed'' shall mean land which drains by natural or man-made causes to a public drinking water supply intake.

(b) No sewage disposal system, cesspool, privy or other place for the deposit or storage of sewage shall be located within one hundred feet of the high water mark of any reservoir or within fifty feet of the high water mark of any stream, brook, or watercourse, flowing into any reservoir used for drinking purposes.

(c) No sewage disposal system, cesspool, privy or other place for the deposit or storage of sewage shall be located on any watershed, unless such facility is so constructed that no portion of the contents can escape or be washed into the stream or reservoir.

(d) No sewage shall be discharged on the surface of the ground on any watershed.

(e) No stable, pigpen, chicken house or other structure where the excrement of animals or fowls is allowed to accumulate shall be located within one hundred feet of the high water mark of a reservoir or within fifty feet of the high water mark of any watercourse as above mentioned, and no such structure shall be located on any watershed unless provision is made in a manner acceptable to the commissioner of health for preventing manure or other polluting materials from flowing or being washed into such waters.

(f) No toxic metals, gasoline, oil or any pesticide shall be disposed of as a waste into any watercourse tributary to a public drinking water supply or to any ground water identified as supplying a public water supply well.

(g) Where fertilizer is identified as a significant contributing factor to nitrate nitrogen occurring in excess of 8 mg/l in a public water supply, fertilizer application shall be made only under current guidelines established by the commissioner of health in cooperation with the state commissioner of agriculture, the college of agriculture of the University of Connecticut and the Connecticut agricultural experiment station in order to prevent exceeding the maximum allowable limit in public drinking water of 10.0 mg/l for nitrite plus nitrate nitrogen.

(h) Where sodium occurs in excess of 15 mg/l in a public drinking water supply, no sodium chlorine shall be used for maintenance of roads, driveways, or parking areas draining to that water supply except under application rates approved by the commissioner of health, designed to prevent the sodium content of the public drinking water from exceeding 20 mg/l.

(i) The design of storm water drainage facilities shall be such as to minimize soil erosion and maximize absorption of pollutants by the soil. Storm water drain pipes, except for crossing culverts, shall terminate at least one hundred feet from the edge of an established watercourse unless such termination is impractical, the discharge arrangement is so constructed as to dissipate the flow energy in a way that will minimize the possibility of soil erosion, and the commissioner of health finds that a discharge at a lesser distance is advantageous to stream quality. Special protections shall be taken to protect stream quality during construction.

(Effective August 2, 1977)

Appendix B MA SMART Monitoring Program Water Quality Screening Chart

SMART Monitoring Program
Water Quality Screening Chart

Indicator Group		**Excellent**	**Good**	**Fair**	**Poor**
Biology[1.]					
Plankton		No Blooms	Infrequent Blooms	Periodic Blooms	Frequent/Prolonged Blooms
Periphyton	Chlorophyll a	≤ 2 µg / cm^2 ave. ≤ 7 µg / cm^2 max.		≤6 µg / cm^2 ave. ≤ 20 µg /cm^2 max. >40 % cover in riffle by green macroalgae	>6 µg / cm^2 ave. >20 µg /cm^2 max. >40 % cover in riffle by green macroalgae
Macrophyton		Non-natives absent		Non-natives present	Non-natives Dominant
Macroinvertebrates	% Reference RBP III	Non Impacted ≥ 83%	Slightly Impacted 54-79%	Moderately Impacted 21-50%	Severely Impacted <17%
Fish (Rivers)	Taxa Composition Cold Water Fishery	Dominated by intolerant fluvial fishes	Dominated by intolerant or moderately tolerant fluvial fishes and cold water species well represented (>10%).	Cold water species not well represented (<10%).	Absence of cold water species.
	Taxa Composition Warm Water Fishery	Dominated by intolerant or moderately tolerant fluvial fishes	Dominated by intolerant or moderately tolerant fluvial fishes.	Dominated by tolerant fluvial species, or by macrohabitat generalist species.	General absence (<10%) by fluvial species.
	Target Fish Community	The most dominant species identified in an applicable TFC are present and dominant		The most dominant species identified in an applicable TFC are missing, or if present are low in numbers or proportion.	

SMART Monitoring Program
Water Quality Screening Chart

Indicator Group		Excellent	Good	Fair	Poor
Chemistry[2,3,4]					
Dissolved Oxygen	Cold Water (Fall 10/1-11/30)	≥ 8 mg/l (≥ 11mg/l)	6-8 mg/l (9-11 mg/l)	5-6 mg/l (8-9 mg/l)	< 5mg/l (< 8 mg/l)
	Warm Water (Spring 3/1-6/30)	≥ 6 mg/l (≥ 6.5 mg/l)	5-6 mg/l (5.5-6.5 mg/l)	4-5 mg/l (5.0-5.5 mg/l)	< 4 mg/l (< 5 mg/l)
	Winter 12/1-2/28	91-110% saturation	71-90% saturation	50-70% saturation	< 50% saturation
pH	Standard Units	6.5-8.0 Δ 0.5	6.5-8.5 Δ 0.5	6.0-9.0 Δ 1.0	< 6.0 or > 9.0 Δ 1.5
Temperature	Cold Water	< 15°C (59°F)	15-20°C (59-68°F)	> 20-23.8°C (68-75°F)	> 23.8°C (75°F)
	Warm Water	< 23.8°C (75°F)	24-26.6°C (75-80°F)	> 26.6-28.3°C (80-83°F)	> 28.3°C (83°F)
Conductivity	Umho/cm	≤ 120	80% > 120	50% > 240	20% > 360
Suspended Solids		1-10 mg/l	10-25 mg/l	25-80 mg/l	> 80 mg/l
Nutrients					
Total Phosphorus as P	Lakes -low	< 10 ug/l	10-15 ug/l	15-25 ug/l	> 25 ug/l
	med	<15 ug/l	15-25 ug/l	25-50 ug/l	> 50 ug/l
	high	< 25 ug/l	25-50 ug/l	50-75 ug/l	> 75 ug/l
	Rivers VIII	< 10 ug/l	10-15 ug/l	15-25 ug/l	> 25 ug/l
	XIV	< 25ug/l	25-50 ug/l	50-75 ug/l	> 75 ug/l
Total Nitrogen as N	Lakes-low	< 0.3 mg/l	0.3-0.6 mg/l	0.6-0.9 mg/l	> 0.9 mg/l
	med	< 0.4 mg/l	0.4-0.7 mg/l	0.7-1.0 mg/l	> 1.0 mg/l
	high	< 0.6 mg/l	0.6-0.9 mg/l	0.9-1.2 mg/l	>1.2 mg/l
	Rivers VIII	< 0.3 mg/l	0.3-0.6 mg/l	0.6-0.9 mg/l	> 0.9 mg/l
	XIV	< 0.6 mg/l	0.6-0.9 mg/l	0.9-1.2 mg/l	> 1.2 mg/l

SMART Monitoring Program
Water Quality Screening Chart

		Excellent	Good	Fair	Poor
Habitat[1.]					
RBP II, III, IV	% Reference	≥ 90%	75-88%	60-73%	< 58%
Substrate/Cover	Composition	> 50%	25-49%	10-24%	< 10%
	Embedded	0-25%	25-50%	50-75%	> 75%
Geomorphology	Alterations	None	< 40%	40-80%	> 80%
	Deposition	< 5%	5-30%	30-50%	> 50%
Riparian Zone	Width	> 60 ft.	40-60 ft.	20-40 ft./gaps	< 20 ft.
	Bank Erosion	< 5%	5-30%	30-60%	> 60%
Flow[7.]					
Volume	Net Loss	None	< 7Q10	≥ 7Q10	≥ 0.5 ABF
Channel Status	% Full	100%	75-100%	25-75%	< 25%
Flow Pattern	Δ Reference Stream				
	Low flow duration	< 5%	< 10%	< 15%	< 20%
	Seasonal base flows	< 10%	< 15%	< 20%	< 25%
	High flow pulse frequency	< 10%	< 20%	< 30%	< 50%
	Small flood magnitude	< 10%	< 25%	< 40%	< 50%
	Large flood magnitude	< 15%	< 25%	< 40%	< 50%

SMART Monitoring Program
Water Quality Screening Chart

Indicator Group		Excellent	Good	Fair	Poor
Toxics[5]					
Ambient Toxicity	% Survival	100%	75-100%	50-75%	< 50%
Effluent Toxicity		LC 50 >Permit Limit = "Concern"			
Specific Chemicals	US EPA Criteria		< Chronic Level	≥ Chronic Level	≥ Acute Level
Chlorine			11 ug/L	11-19 ug/L	19 ug/L
Ammonia -N	Lakes (average)	< 0.15 mg/l	0.15-0.3 mg/l	0.3-0.5 mg/l	> 0.5 mg/l
	Rivers (average)	< 0.3 mg/l	0.3 – 0.5 mg/l	0.5-1.0 mg/l	> 1.0 mg/l
Sediments[8]					
Mercury	mg/kg		≤ 0.18	0.19-0.35	≥ 0.36
Other Metals		< TEC	TEC- PEC	> PEC	≥ 2 X PEC
Total PCB's	ug/kg		≤ 60	61-120	≥120
Pesticides			≤ TEC	>TEC	≥ 2 X TEC
PAH's			≤ TEC	>TEC	≥ 2 X TEC
Nutrients	TOC (%)	0.1	1	2-10	10
	TKN (ppm)	55	550	551-4,800	4,800
	TP (ppm)	60	600	601-2,000	2,000
Toxicity Test		100%	75-100%	50-75%	< 50%
Bioaccumulation			None Evident	Limited Advisory	Full Advisory
Fish Tissue					
Advisories		Data below advisory levels		Limited Advisory-targeted population and /or species: P1 (all species) P1 (species) P2 (species) P3 (species)	Full Advisory-general population, all species: P4, P5, P6

SMART Monitoring Program
Water Quality Screening Chart

Indicator Group		Excellent	Good	Fair	Poor
Bacteria[6]					
Fecal Coliform* /100ml	Geometric mean	≤ 20	≤ 200	≤ 1,000	> 1,000
	Maximum	≤ 40	≤ 400	≤ 2,000	> 2,000
E. coli*/100ml	Geometric mean	≤ 12	≤ 126	≤ 630	> 630
	Maximum	≤ 24	≤ 235	≤ 1,260	> 1,260
Enterococci*/100ml (marine water)	Geometric mean	≤4	≤ 35	≤ 175	> 175
	Maximum	≤10	≤104	≤ 350	> 350
Aesthetics					
Oil and Grease		None Objectionable		Visible sheen, deposits or odors	
Taste and Odor		None Objectionable		Offensive odors (rotten egg, sewage, chemical, musty)	
Clarity	Rivers	> 4 feet	4-3 feet	3-2 feet	< 2 feet
	Lakes	>15 feet	10-15 feet	4-10 feet	< 4 feet
Turbidity	Weekly Average	0-1 NTU	1-5 NTU	5-10 NTU	> 10 NTU
Color	PCU	0-30	30-50	50-70	> 70
Nuisance Vegetation	Plants	< 50% coverage		50-75% coverage	> 75% coverage
Nuisance Vegetation	Periphyton	<40 % cover in riffle by green macroalgae		>40 % cover in riffle by green macroalgae	
Trash/Debris		None Objectionable		Nuisance trash, debris, scum or other matter	

*** When "good" criteria are met during dry weather conditions but not during wet weather conditions the waterbody is assessed as "fair".**

SMART Monitoring Program
Water Quality Screening Chart

Notes on SMART Water Quality Screening Criteria:

The purpose of this chart is to aid in the review of data for the SMART Water Quality Report Card. The Report Card uses a simple color-coded system to report water quality in one of four status categories: excellent, good, fair or poor. Since many constituents do not have numerical criteria it can be difficult to assign them to a particular status level. This chart uses the existing database and best professional judgment to determine an expected range of values for each status category. The values are primarily for rivers although some lake values are included. These can be used to screen large data sets and quickly flag areas for more extensive review. It is important to note that these values are not enforceable water quality standards, nor are they intended to replace scientific judgments or site-specific considerations.

1. In the **Biology and Habitat Indicator Groups,** RBP II, III, IV and V refer to the US EPA Rapid Bioasssessment Protocols as modified by MassDEP.
2. For applying **Dissolved Oxygen** values in cold water fisheries use fall values during the period of 10/1-11/30. In warm water fisheries use spring values during the period 3/1-6/30. In all cases use winter values during the period 12/1-2/28.
3. **Nutrient** data should be used in context with other pertinent data (diurnal dissolved oxygen, diurnal pH, Plankton, Periphyton, Macrophyton and turbidity) to determine if a water quality problem exits. Lake nutrient regions –the Nashua, Suasco, and Blackstone SMART stations are in the high nutrient region, the Millers, Chicopee, and F&Q are in the intermediate region. River ecoregions –the Millers SMART stations are in EPA ecoregion VIII, the Blackstone, Nashua, Suasco, Chicopee, and F&Q stations are in EPA ecoregion XIV.
4. For large data sets in the **Chemistry** and **Nutrient Indicators Groups**, where you determine that an occasional high or low value will cause no serious harm, the prescribed values should not be exceeded in greater than 20% of the values of any 20 consecutive samples nor in three consecutive samples.
5. The term **Ambient Toxicity** refers to a standard toxicity test (standard organisms and duration) run with ambient water, not effluent.
6. For **Bacteria** data the **Geometric Mean** is the nth root of the product of five or more samples. Use the **Maximum** value for data sets with fewer than five samples.
7. For **Flow** data, the **Net Loss** is a value calculated from a water budget on a defined drainage area. The net loss is the sum of the water losses minus the sum of water gains (from water withdrawals, water distribution systems, wastewater collection systems and wastewater discharges). The **7Q10** is the lowest flow to be expected for 7 consecutive days during a 10-year period. The **ABF** is the aquatic base flow (usually the August median flow).
8. **Sediments**-TEC= threshold effects concentration, PEC = probable effects concentration, in accordance with the freshwater sediment screening benchmarks for the Massachusetts Contingency Plan (MassDEP).
9. **Fish Tissue**- advice codes in the Freshwater Fish Consumption Advisory List, Ma. Dept. of Public Health, Center for Environmental Health.

Appendix C
Roseland Lake Nutrient Loading Calculations and Modeling

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December 20, 2017

This effort to estimate phosphorus loads to Roseland Lake uses multiple modeling approaches ranging from model approaches which require very little site-specific data, through an analysis of flow, water chemical and sediment chemical data collected for this project.

Lake Morphology Empirical Model

In the 1960s water quality concerns lead to the passage of the Clean Water Act and the construction of improved treatment systems at public wastewater treatment facilities. During this time it was established that phosphorus was the most common limiting nutrient controlling algal biomass production in freshwater lakes. As part of an international study of lakes by the Organization for Economic Cooperation and Development (OECD) a mathematical relationship was established between lake morphometric features, phosphorus loading and phosphorus concentration. This relationship was established by Vollenweider[i] as:

$$P_V = \frac{Lp}{q_s\left(1 + \sqrt{\tau_W}\right)}$$

Where:

$$q_s = \frac{z}{\tau_W}$$

Pv = Phosphorus concentration in lake estimated by Vollenweider equation (mg/L);
Lp = annual phosphorus load per lake area, (grams/m2/year);
τ_W = hydraulic residence time (yr);
q_S = hydraulic overflow rate (m/yr);
= average depth (m)

Several other mathematical relationships have been develop similar to one described above (Kirchner and Dillon 1975[ii], Jones and Bachmann 1976[iii]). It is important to remember that this general relationship is based on hundreds of lakes from across the globe but is approximately predictive for any single lake. Using the following parameter estimates model predicted loading is calculated.

Table 1. Empirical Model parameters

Parameter	Value	Unit	Source
P	0.023	mg/L	Sample result 4/13/16
z	3.1	m	DEP, 1991[iv]
τ_W	8	Days	DEP, 1991

In addition to model uncertainty the model inputs selected can be varied to examine how sensitive the prediction is to each parameter. Using the parameter estimates listed above and solving for the annual load is 3.4 g/m^2/yr. The following table describes changes to parameters and the subsequent change in load estimate.

Table 2. Empirical Model results for estimated phosphorus loading

	Lp (g/m^2/yr)	Kg P/yr	Lbs P/yr
Base estimate	3.73	1451	3199
Increase residence time ($\tau_{W} =$ 24 days)	1.24	483	1065
Reduce mean depth (z = 2.5 m)	2.75	1068	2355
Increase estimated in-lake concentration (P = 0.03 mg/L)	4.87	1892	4172

As shown in Table 2 the empirical loading estimates can vary significantly based on the estimates of site conditions. These loading estimate due; however, provide an additional range to compare watershed based loading estimates to.

Watershed Land Use Models

An estimation of spring lake phosphorus concentrations based on land use conditions was developed using a set of 33 Connecticut Lakes where water quality data was collected from 1974-1978 and land use information is from 1970 aerial photographic analysis (Norvell et al 1979[v]). This equation is:

$$eTP = \frac{(Q + 1.2)}{(Q + 12)}\,(170U + 54\,A + 10W)/D$$

and

$$D = \frac{Q}{WA/SA}$$

where:

eTP = estimated spring Total Phosphorus (µg/L)
Q = water load on the lake (m/yr)
D = water export (m/yr)
WA/SA = Watershed Area to Lake Surface Area Ratio
U = fraction of watershed in urban or residential land use
A = fraction of watershed in agricultural land use
W = fraction of watershed forested land use

This equation includes an estimation of residence time effects also included in the Vollenweider model and land use nutrient export. The 170, 54 and 10 factors associated with the land use types are a representation of their annual export as mg/m^2.

Table 3. Roseland Lake model parameters and results from Norvell et al (1979)

Land Use Year	eTP (µg/L)	WA/SA	Q (m/yr)	U	A	W

1970	42.0	221	139	0.025	0.329	0.648
2010	56.2	209	139	0.128	0.229	0.617

Roseland Lake had the highest percent agricultural land use of the 33 lakes in the Norvell et al study and the estimated total phosphorus (eTP = 42 (µg/L)) was greater than the reported 33 (µg/L) measured concentration.

Land use cover type estimations for the watershed are available based on 2010 aerial photography. The land use areas for each sub-watershed are presented in Table 4.

Table 4. 2010 land use cover type by sub-watershed in acres

Sub-watershed	***Agricultural Field***	***Barren Land***	***Coniferous Forest***	***Deciduous Forest***	***Developed***	***Forested Wetland***	***Non-forested Wetland***	***Other Grasses***	***Turf & Grass***	***Water***	***Total***
Upper Mill Brook	146	0	46	438	35	17	14	8	16	0	720
English Neighborhood	365	2	595	1431	250	198	63	55	110	30	3100
Gravelly Brook	313	2	96	471	107	24	0	5	88	3	1108
Lower Mill	722	2	191	545	238	71	3	30	120	105	2028
May Brook	226	0	20	23	46	0	0	27	35	0	378
Muddy Brook 2-4	298	6	222	299	75	37	2	14	46	10	1009
Muddy Brook 4-5	79	1	50	161	48	17	0	3	42	4	406
Muddy Brook US-5	449	8	1755	1653	298	346	15	42	99	86	4751
North Running Brook	389	3	26	527	102	31	9	17	79	23	1207
Peckham Brook	431		118	135	61	12		3	50	12	823
Lake Shoreline	105	1	97	275	81	25	3	10	39	107	743
Muddy Brook DS-1	256	6	407	377	85	62	5	17	49	13	1275
Taylor Brook	333	3	41	1003	136	78	11	35	51	6	1696
Golf course Brook	69	0	5	64	31	0	0	1	29	0	199
Total	4181	36	3668	7402	1595	917	125	268	854	398	19443
Model Classification[1]	A	U	F	F	U	F	-	A	U	-	

1 This assignment of GIS-based land use classes to one of three nutrient export classes (A = Agriculture, F = Forested, U = Urban/Developed) is adopted from Becker and Dunbar, 2009[6].

Both the 1970 and 2010 eTP values are greater than observed spring surface concentrations of total phosphorus. The Connecticut Agricultural Experiment Station results from May 1974 range from 30-34 (µg/L). Results from May 2015 were between 38-45 (µg/L) and results from April and May of 2016 range from 23-33 (µg/L).

The increase in percentage of developed land in the watershed in the past 40 years is typical for Connecticut and is suspected to be causing increasing eutrophication in CT lakes (Field et al 1996[vii]). Improvements in land management, particularly in agriculture in the Roseland Lake watershed is occurring in part to reduce loading rates from agricultural land use areas.

A 2009 publication. 'Connecticut Methodology for Freshwater Nutrient Management Technical Support Document' (Becker and Dunbar, CTDEP). Presents a watershed land use method for assessing lake phosphorus concentration and estimations for how adoption of best management practices (BMPs) can reduce loading. This study included more recent watershed sampling to develop export coefficients that more likely represent current conditions in the watershed compare to the Norvell et al export coefficients from the 1970s. The model equation from the CT Methodology is:

$$eP - load = \sum_{i=1}^{n} A_i c_i$$

where:

eP-load = Estimated land cover P load
A = area for land cover type *i*
c = export coefficient for cover type *i* at a20% storm change condition

The export rates per cover type in this study were determined based on watershed studies in Connecticut (not in Roseland Lake watershed). The rates determined in CT in the 2009 study are lower than those found by the Norvell et al analysis using 1970s land use and water quality data. This does suggest that BMPs in watersheds are reducing export rates. Urban and agricultural land continue to export phosphorus at a much higher rate based on the 2009 study. While the general trend in export rate decline from the 1970s to 2010 can be noted, the methods of the two studies are different. An over 50% decrease in the forest land export values is likely a result of the different study approach rather than solely a change in the forest land nutrient export. Replacing the coefficients for A, F and U in the Norvell et al, (1979) equation with the export coefficients for the 2009 CTDEP study results in an eTP value of 23 µg/L which is within the range of measured spring concentrations.

Table 5. Connecticut-derived land use phosphorus export coefficients

	DEP, 2009		Norvell, et al. 1979	
Land Use	lbs/ac/day	mg/m²/yr	lbs/ac/day	mg/m²/yr
Agriculture	$4.33*10^{-4}$	17.7	$1.32*10^{-3}$	54
Forest	$1.04*10^{-4}$	4.3	$2.44*10^{-4}$	10
Urban	$1.98*10^{-3}$	80.8	$4.16*10^{-3}$	170

Using the land cover areas from Table 4 above and the CTDEP (2009) equations, load estimates from each of the sub-watershed are calculated.

Table 6. Sub-watershed P load based on watershed area land use. Land use data from 2010 (Table 4) and loading coefficient from CTDEP (2009).

	Estimated Annual Phosphorus Load (lbs P/yr)			
Sub-watershed	**Urban/Developed**	**Agricultural**	**Forest**	**Total**
Upper Mill Brook	37.1	24.35	19.0	80
English Neighborhood	261.0	66.40	84.4	412
Gravelly Brook	141.7	50.32	22.4	214
Lower Mill	260.2	118.86	30.6	410
May Brook	58.7	40.02	1.6	100
Muddy Brook 2-4	91.5	49.34	21.2	162
Muddy Brook 4-5	66.0	13.03	8.6	88
Muddy Brook US-5	292.4	77.61	142.5	513
North Running Brook	133.4	64.26	22.1	220
Peckham Brook	79.9	68.61	10.1	159
Lake Shoreline	88.0	18.18	15.1	121
Muddy Brook DS-1	100.5	43.03	32.1	176
Taylor Brook	137.0	58.09	42.6	238
Golf course Brook	43.2	11.07	2.6	57
Total	1791	703	455	2949

The watershed loading estimation from the 2010 land use data is approximately 2,950 lbs P/yr. This estimate is within the range of loads obtained using the Vollenweider equation with varying inputs (1,065-4,172 lbs P/yr see Table 2).

Watershed Loading – Direct Measurement

Direct measurement of watershed loading can be made by knowing the flow rate and phosphorus concentration in tributary streams. This study included stream stage measurement and the development of flow rating curves (see report by Mauri Pelto). Measurements of stream flow and stream phosphorus concentrations were examined at Peckham Brook and Mill Brook with samples and gage measurements made before and after rain events.

Table 7. Stage measurements and flow volumes from Peckham and Mill Brook

	Peckham Brook		Mill Brook	
Date	Gage (ft)	Flow (CFS)	Gage (ft)	Flow (CFS)
9/30/2015	4.84	7.92	4.11	28.22
10/27/2015	4.34	0.42	3.88	15.37
10/29/2015	4.64	2.46	4.46	71.12
4/25/2016	4.58	1.73		
4/26/2017	-			
4/27/2016	4.6	1.94		
11/14/2016	4.44	0.76		
11/16/2016	4.51	1.15		

Using the measured concentrations and flows from Peckham Brook instantaneous loading values are calculated. To compare these instantaneous loads to the watershed loading model results these loads have been converted to lbsP/year units.

Table 8. Watershed loading calculations at Peckham Brook sampling events

Date	Sample	Total P (mg/L)	Flow (CFS)	Instantaneous load (lbs P/yr)
10/27/15	Pre (Grab)	14	0.42	12
10/29/15	Passive	800		3869
10/29/15	Post	584	2.46	2824
4/25/15	Pre	18		61
4/27/16	Post	24	1.94	92
11/14/16	Pre	14	0.76	21
11/15/16	Passive	184		416
11/16/16	Post	99	1.15	224

As shown in Table 4 the watershed load of Peckham Brook estimated by land use is 159 lbs P/yr. Base flow loads in this brook were measured to be less than that annual load while storm events which include sediment transport were generally higher than the watershed average. The largest storm event in October 2015 had both the highest total phosphorus concentrations and highest flows. This demonstrates that storm runoff and sediment transport can be a major element of the annual load for tributaries to the lake. High flows also reduce the Roseland Lake residence time which will transport more of the in-lake nutrients further downstream. The measured loads at Peckham Brook appear to support the land use load estimate for this sub-basin but the measured values also show that loading from the watershed can be very variable based on weather and seasonal conditions. Even during base flow stream conditions higher flow volumes in November 2016 result in nearly double the phosphorus load with the same stream water concentration.

Internal Phosphorus Loading

Phosphorus loading into lakes can be removed either by discharge of water out of the lake, biological uptake, or sedimentation in the lake. Sedimentation is typically occurring through biological uptake and sedimentation (by algae, plants and higher level consumers) or adsorption to particular matter and sedimentation. In shallow sediments biological decomposition and changing redox conditions can cause the release of phosphorus from the sediment back to the overlying waters. The development of anoxic conditions in sediments and bottom water promotes the release of iron-bound phosphorus. Summer monitoring of Roseland Lake finds anoxic conditions and elevated phosphorus and has for decades. Those observations have led to this effort to quantify internal loading and watershed loading to help guide future efforts for loading reduction.

This release of phosphorus back to surface waters is referred to as an internal load. The quantification of internal load has been described by Nürnberg (1987)[viii]

$$L_{int} = AF \times RR$$

where:

L_{int} = Internal Phosphorus Load (mg P/m^2 summer)
AF = Anoxic Factor (days/summer)
RR = Anoxic Aerial Release Rate (mg P/m^2 day)

This model develops a load to the lake using an estimation of the area and duration of anoxic sediment, which is termed the anoxic factor Nürnberg (1995)[ix].

$$AF = \frac{duration\ of\ anoxia\ (days) \times anoxic\ sediment\ area\ (acres)}{lake\ surface\ area\ (acres)}$$

To develop an estimate of anoxia area the area of the lake at three foot depth intervals was estimated based on a CTDEEP bathymetric map[x] (Table 9).

Table 9. Estimated lake surface area by water depth intervals

Depth (ft)	**Area (acres)**
Surface (0)	96
3	76.8
6	64
9	57.6
12	38.4
15	19.2
18	9.6

The duration of anoxia and anoxic sediment area was estimated based on the water column profiling data from 2015 and 2016. The area of anoxia was frequently below 12 feet based on the monitoring results. Duration of anoxia was estimated as 136 days in 2015 and 74 days in 2016. The calculated AF values are present in Table 8 below.

The release rate of phosphorus from anoxic sediment is estimated from the total sediment phosphorus concentration using the equation develop by Nürnberg (2005)[xi]

$$RR = 0.8 + 0.76\log(TP_{sed})$$

where:
RR = Anoxic Aerial Release Rate (mg P/m^2 day)
TP_{sed} = sediment total phosphorus concentration (mg P/g dry wt sediment)

Sediment samples were collected at five locations in the lake in October 2016 and analyzed for total phosphorus (see Solitude report). The concentrations ranged from 1.93 to 3.02 mgP/gram dry wt sediment with an average of 2.48 mgP/g dry wt.

Using the calculated values for AF and RR for Roseland Lake the estimated values for internal load (L_{int}) are presented in Table 10.

Table 10. Range of anticipated internal loads as express by L_{int} based on AF and RR values

AF values	days/summer
2015 (136 days, 38.4 acres)	54.4
2016 (74 days, 38.4 acres)	29.6
Average AF (15 days 38.4 acres)	42
RR values	mg P/ m^{2}day
Maximum measured sediment total P (3.02 mgP/g)	14.6
Minimum measured sediment total P (1.93 mgP/g)	10.4
Average measured sediment total P (1.93 mgP/g)	12.6
L_{int} values	mg P/m^2 summer
Maximum AF x RR	795
Minimum AF x RR	308
Average AF x RR	528
Summer load in Roseland Lake	lbs P/summer
Max L_{int}	681
Min L_{int}	264
Average L_{int}	453

Using the estimated land use watershed load of 2,950 lbs P/yr the internal load represents between 8-19% of a total annual load with an average 135 contribution. Because the internal is only released during the summer it accounts for 21-55% of the P-load during five months of the summer and fall when anoxia is likely to occur.

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Appendix D Tributary Water Quality Monitoring Results

2015/16 Roseland Lake Tributary Data as assessed by the UCONN Center for Engineering and Environmental Science Laboratory

Mill Brook

Date	9/10/15	9/11/15	9/11/15	9/30/15	10/27/15	10/29/15	10/29/15	4/25/16	4/26/16	4/27/16	11/14/16	11/15/16	11/16/16
TN mg/l	NSS	NSS	0.938	1.296	0.287	0.777	0.788	0.355	NSS	0.460	0.382	0.746	0.731
organic N mg/l	NSS	NSS	0.309	0.0564	0.284	0.700	0.634	0.205	NSS	0.240	0.030	0.480	0.496
nitrate N mg/l	NSS	NSS	0.614	0.682	0.003	0.074	0.144	0.090	NSS	0.220	0.084	0.238	0.230
TP mg/l	NSS	NSS	0.058	0.221	0.020	0.141	0.111	0.044	NSS	0.027	0.031	0.057	0.037
Ortho P mg/l	NSS	NSS	0.027	0.094	0.010	0.035	0.051	0.008	NSS	0.005	0.005	0.022	0.014
TSS mg/l	NSS	NSS	3	35	8	38	13	6	NSS	2	8	6	ND

Little River

Date	9/10/15	9/11/15	9/11/15	9/30/15	10/27/15	10/29/15	10/29/15	4/25/16	4/26/16	4/27/16	11/14/16	11/15/16	11/16/16
TN mg/l	0.457	NSS	0.469	0.712	0.731	0.725	0.741	0.676	NSS	0.676	0.968	3.980	1.166
organic N mg/l	0.401	NSS	0.401	0.401	0.464	0.491	0.512	0.352	NSS	0.339	0.625	3.644	0.798
nitrate N mg/l	0.017	NSS	0.011	0.278	0.129	0.130	0.145	0.311	NSS	0.329	0.271	0.279	0.311
TP mg/l	0.037	NSS	0.048	0.048	0.040	0.054	0.120	0.038	NSS	0.030	0.049	0.443	0.07
Ortho P mg/l	0.037	NSS	0.014	0.016	0.012	0.015	0.016	0.006	NSS	0.007	0.005	0.102	0.022
TSS mg/l	2	NSS	3	5	7	10	ND	7	NSS	7	4	45	8

Muddy Brook

Date	9/10/15	9/11/15	9/11/15	9/30/15	10/27/15	10/29/15	10/29/15	4/25/16	4/26/16	4/27/16	11/14/16	11/15/16	11/16/16
TN mg/l	1.911	1.831	2.044	1.946	1.389	1.524	1.007	1.078	0.998	0.903	1.282	2.924	0.8575
organic N mg/l	0.354	0.395	0.471	0.75	0.454	1.303	0.776	0.323	0.282	0.228	0.238	1.540	0.451
nitrate N mg/l	1.52	1.382	1.54	1.052	0.928	0.216	0.227	0.746	0.701	0.664	1.039	0.978	0.407
TP mg/l	0.023	0.064	0.055	0.263	0.019	0.357	0.144	0.017	0.019	0.022	0.024	0.606	0.049
Ortho P mg/l	0.011	0.021	0.021	0.155	0.011	0.079	0.069	0.003	0.005	0.005	0.008	0.327	0.025
TSS mg/l	ND	4	3	24	8	7	3	2	ND	ND	ND	36.000	ND

Peckham Brook

Date	9/10/15	9/11/15	9/11/15	9/30/15	10/27/15	10/29/15	10/29/15	4/25/16	4/26/16	4/27/16	11/14/16	11/15/16	11/16/16
TN mg/l	NSS	NSS	NSS	2.171	**2.948**	**4.580**	4.295	**3.766**	NSS	3.665	3.438	2.624	3.512
organic N mg/l	NSS	NSS	NSS	0.896	**0.608**	**2.521**	2.060	**0.698**	NSS	0.38	0.278	1.044	0.944
nitrate N mg/l	NSS	NSS	NSS	1.238	2.337	**2.033**	2.209	**3.054**	NSS	3.272	3.16	1.577	5.557
TP mg/l	NSS	NSS	NSS	0.244	0.014	**0.800**	0.584	0.018	NSS	0.024	0.014	0.184	0.099
Ortho P mg/l	NSS	NSS	NSS	0.1	0.013	**0.389**	0.449	0.008	NSS	0.009	0.008	0.032	0.082
TSS mg/l	NSS	NSS	NSS	54	5	138	5	3	NSS	3	ND	56.000	ND

USGS Data 1981-83 (Kulp)

Muddy Brook										
Date	10/27/1981	12/2/1981	6/2/1982	6/6/1982	8/9/1982	11/5/1982	2/3/1983	3/19/1983	3/19/1983	4/24/1983
TN mg/l	0.950	1.200	1.300	1.100	2.800	1.800	2.000	1.900	1.600	1.700
organic N mg/l	0.490	0.460	0.530	0.230	1.400	1.300	0.900	0.510	0.490	0.530
nitrate N mg/l	0.400			0.590	1.120	0.500	0.800	1.100	0.800	1.000
TP mg/l	0.030	0.190	0.120	0.100	0.250	0.190	0.290	0.110	0.100	0.180
Ortho P mg/l	ND	0.120	0.040	0.040	0.170	0.120	0.110	0.000	0.000	0.000
TSS mg/l		88	240	134	7	22	265	164	103	28
Mill Brook										
Date	10/27/1981	12/2/1981	6/2/1982	6/6/1982	8/9/1982	11/5/1982	2/3/1983	3/19/1983	3/19/1983	4/24/1983
TN mg/l	NSS	0.970	1.000	0.900	30.000	1.300	1	1.100	1.000	2.400
organic N mg/l	NSS	0.230	0.580	0.310	30.000	0.870	0.450	0.470	0.430	1.500
nitrate N mg/l	NSS				0.470	0.390	0.490	0.490	0.490	
TP mg/l	NSS	0.110	0.080	0.110	0.050	0.100	0.120	0.060	0.050	0.280
Ortho P mg/l	NSS	0.100	0.040	0.020	0.050	0.020	0.040	0.030	0.020	0.200
TSS mg/l	NSS									
Little River										
Date	10/27/1981	12/2/1981	6/2/1982	6/6/1982	8/9/1982	11/5/1982	2/3/1983	3/19/1983	3/19/1983	4/24/1983
TN mg/l	NSS	0.750	0.800	1.100		0.900	1.500	1.100	0.900	0.900
organic N mg/l	NSS	0.220	0.440	0.470	0.860	0.630	0.850	0.420	0.210	0.280
nitrate N mg/l	NSS			0.490		0.190	0.590	0.590	0.590	
TP mg/l	NSS	0.070	0.060	0.080	0.040	0.070	0.100	0.030	0.030	0.040
Ortho P mg/l	NSS	0.090	0.020	0.030	0.030	ND	0.040	0.010	0.020	0.010
TSS mg/l	NSS	23	27	12	4	37	30	15	7	3

NSS No Sample Sent

ND Not Determined

Roseland Lake Tributary Data as Assessed by the Department of Public Health Laboratory in Rocky Hill

Mill Brook US Stone Bridge Road (Mill-01)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	NSS	NSS	0.58		ND	NSS	0.9		ND	NSS	0.21		ND	NSS	1
Organic N	NSS	NSS	<0.6		<0.6	NSS	0.68		<0.6	NSS	<0.6		<0.6	NSS	0.76
Nitrate N	NSS	NSS	0.58		ND	NSS	0.22		<0.1	NSS	0.21		<0.1	NSS	0.24
TP	NSS	NSS	0.065		0.016	NSS	0.11		0.024	NSS	0.022		0.017	NSS	0.039
TSS	NSS	NSS	<4		<4	NSS	5		<4	NSS	<4		<4	NSS	<4
Little River US Stone Bridge Road (LR-01)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	ND	NSS	0.62		0.31	0.24	0.83		0.31	NSS	0.31		0.87	1.59	1.5
Organic N	<0.6	NSS	0.62		<0.6	<0.6	<0.6		<0.6	NSS	<0.6		0.75	1.3	1.2
Nitrate N	<0.1	NSS	<0.1		0.15	0.12	0.16		0.31	NSS	0.31		0.31	0.29	0.3
TP	0.039	NSS	0.04		0.04	0.045	0.076		0.024	NSS	0.028		0.058	0.09	0.077
TSS	<4	NSS	<4		<4	<4	4		5	NSS	4		<4	8	5
unnamed intermittent stream by the baseball field (UN-01)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	NSS	NSS	NSS		NSS	NSS	0.85		0.48	NSS	0.41		0.89	1.14	0.76
Organic N	NSS	NSS	NSS		NSS	NSS	0.71		<0.6	NSS	<0.6		<0.6	0.77	0.62
Nitrate N	NSS	NSS	NSS		NSS	NSS	0.13		0.48	NSS	0.41		0.89	0.37	0.14
TP	NSS	NSS	NSS		NSS	NSS	0.11		0.013	NSS	0.011		0.013	0.11	0.045
TSS	NSS	NSS	NSS		NSS	NSS	5		<4	NSS	<4		<4	10	5
unnamed intermittent stream by the golf course (UN-02)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	NSS	NSS	NSS		NSS	NSS	1.13		0.2	NSS	0.26		NSS	1.51	NSS
Organic N	NSS	NSS	NSS		NSS	NSS	0.83		<0.6	NSS	<0.6		NSS	0.82	NSS
Nitrate N	NSS	NSS	NSS		NSS	NSS	0.3		0.2	NSS	0.26		NSS	0.61	NSS
TP	NSS	NSS	NSS		NSS	NSS	0.11		0.013	NSS	0.011		NSS	0.2	NSS
TSS	NSS	NSS	NSS		NSS	NSS	10		<4	NSS	<4		NSS	9	NSS
Muddy Brook US Roseland Park Road/Roseland Lake (MB-01)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	1.7	NSS	1.6		1.2	2.03	1.32		0.62	NSS	0.68		1.1	1.82	1.05
Organic N	<0.6	NSS	<0.6		<0.6	1.3	1		<0.6	NSS	<0.6		<0.6	0.74	0.74
Nitrate N	1.7	NSS	1.6		1.2	0.73	0.32		0.62	NSS	0.68		1.1	0.82	0.42
TP	0.012	NSS	0.012		0.016	0.36	0.16		0.016	NSS	0.018		0.024	0.14	0.051
TSS	<4	NSS	<4		<4	34	7		<4	NSS	<4		<4	<4	<4

North Running Brook US Muddy Brook (NRB-01)

Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	NSS	13	8.8		ND	1.65	1		0.89	NSS	0.99		0.53	NSS	0.75
Organic N	NSS	13	6.6		<0.6	0.97	0.92		<0.6	NSS	<0.6		<0.6	NSS	0.64
Nitrate N	NSS	<0.1	<0.1		<0.1	0.68	<0.1		0.89	NSS	0.99		0.53	NSS	0.11
TP	NSS	2.5	1.4		0.074	0.21	0.14		0.017	NSS	0.021		0.081	NSS	0.074
TSS	NSS	32	11		<4	40	8		<4	NSS	<4		20	NSS	<4

Muddy Brook US North Running Brook (MB-02)

Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	1.70	NSS	1.60		1.20	1.73	0.99		0.60	0.80	0.58		1.10	1.69	1.09
Organic N	<0.6	NSS	<0.6		<0.6	1.6	0.6		<0.6	<0.6	<0.6		<0.6	0.7	0.64
Nitrate N	1.70	NSS	1.60		1.20	ND	0.39		0.60	0.50	0.58		1.10	0.99	0.45
TP	0.027	NSS	0.028		0.018	0.500	0.170		0.016	0.093	0.017		0.023	0.041	0.047
TSS	34	NSS	<4		<4	77	15		<4	<4	<4		<4	6	<4

Peckham Brook US Dugg Hill Road (PB-01)

Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	2.9	NSS	3.14		3	5.1	3.6		3.5	NSS	3.6		3.5	2.9	3.78
Organic N	<0.6	NSS	0.74		<0.6	2.1	1.3		<0.6	NSS	<0.6		<0.6	1	0.88
Nitrate N	2.9	NSS	2.4		3	3	2.3		3.5	NSS	3.6		3.5	1.9	2.9
TP	0.031	NSS	0.120		0.011	0.680	0.540		0.015	NSS	0.020		0.010	0.120	0.110
TSS	6	NSS	14		ND	10	76		ND	NSS	ND		ND	36	ND

May Brook US Woodstock Road (MAY-01)

Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	4.400	NSS	2.400		4.100	13.150	3.300		3.900	NSS	3.500		4.300	1.320	3.200
Organic N	1	NSS	1.1		<0.6	12	1.5		<0.6	NSS	<0.6		<0.6	1	0.9
Nitrate N	3.4	NSS	1.3		4.1	1.8	1.8		3.9	NSS	3.5		4.3	0.32	2.3
TP	0.120	NSS	0.076		0.024	7.600	0.470		0.024	NSS	0.020		0.022	0.160	0.110
TSS	33	NSS	6		<4	1590	<4		<4	NSS	<4		<4	7	<4

Muddy Brook DS Woodstock Road US Gravelly Brook (MB-04)

Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	0.19	NSS	0.11		ND	ND	0.6		ND	NSS	ND		ND	ND	0.72
Organic N	<0.6	NSS	<0.6		<0.6	<0.6	0.6		<0.6	NSS	<0.6		<0.6	<0.6	0.72
Nitrate N	0.19	NSS	0.11		<0.1	<0.1	<0.1		<0.1	NSS	<0.1		<0.1	<0.1	<0.1
TP	0.027	NSS	0.066		0.041	0.210	0.088		0.019	NSS	0.019		0.028	0.038	0.039
TSS	<4	NSS	6		<4	64	2		<4	NSS	<4		<4	6	<4

Gravelly Brook US Cady Lane (GB-01)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	NSS	NSS	NSS		NSS	NSS	NSS		0.22	0.14	NSS		ND	0.22	ND
Organic N	NSS	NSS	NSS		NSS	NSS	NSS		<0.6	<0.6	NSS		ND	ND	ND
Nitrate N	NSS	NSS	NSS		NSS	NSS	NSS		0.22	0.14	NSS		<0.1	0.22	<0.1
TP	NSS	NSS	NSS		NSS	NSS	NSS		0.096	0.009	NSS		0.009	0.052	0.026
TSS	NSS	NSS	NSS		NSS	NSS	NSS		<4	<4	NSS		<4	18	<4
English Neighborhood Brook US Route 169 (ENB-01)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	0.23	NSS	0.23		ND	ND	ND		ND	ND	ND		ND	0.15	0.1
Organic N	<0.6	NSS	<0.6		<0.6	<0.6	<0.6		<0.6	<0.6	<0.6		<0.6	<0.6	<0.6
Nitrate N	0.32	NSS	0.32		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1		<0.1	0.15	0.1
TP	0.025	NSS	0.04		0.03	0.11	0.044		0.012	0.015	0.012		0.016	0.055	0.022
TSS	<4	NSS	<4		<4	21	<4		<4	<4	<4		<4	5	0.055
Muddy Brook US Route 197 and US English Neighborhood Brook (MB-05)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	ND	0.66	ND		ND	ND	0.68		ND	NSS	ND		0.65	1	0.8
Organic N	<0.6	0.66	<0.6		<0.6	<0.6	<0.6		<0.6	NSS	<0.6		0.65	1	0.7
Nitrate N	<0.1	<0.1	<0.1		<0.1	<0.1	0.68		<0.1	NSS	<0.1		<0.1	<0.1	0.1
TP	0.060	0.081	0.074		0.029	0.100	0.120		0.030	NSS	0.028		0.040	0.060	0.047
TSS	8	5	<4		<4	5	<4		<4	NSS	<4		<4	<4	<4
Taylor Brook US Pulpit Rock Road (TB-01)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	1.9	NSS	2.8		0.55	0.31	1.08		ND	NSS	0.43		0.46	1.33	1
Organic N	0.66	NSS	1.1		<0.6	<0.6	0.75		<0.6	NSS	<0.6		<0.6	0.95	0.7
Nitrate N	0.41	NSS	1.7		0.55	0.31	0.33		0.42	NSS	0.43		0.46	0.38	0.3
TP	0.270	NSS	0.150		0.020	0.240	0.170		0.023	NSS	0.024		0.029	0.067	0.055
TSS	27	NSS	12		<4	29	5		<4	NSS	<4		6	<4	<4
Mill Brook DS New Sweden Road US Quasset Lake outlet (MILL-02)															
Date	9/10/15	9/11/15	9/11/15		10/27/15	10/29/15	10/29/15		4/25/16	4/26/16	4/27/16		11/14/16	11/15/16	11/16/16
TN	0.65	NSS	ND		ND	ND	0.68		ND	NSS	0.15		0.69	0.72	0.91
Organic N	0.65	NSS	<0.6		<0.6	<0.6	0.68		<0.6	NSS	<0.6		0.69	0.72	0.64
Nitrate N	ND	NSS	<0.1		<0.1	<0.1	<0.1		<0.1	NSS	0.15		<0.1	<0.1	0.27
TP	0.130	NSS	0.160		0.064	0.180	0.140		0.035	NSS	0.038		0.029	0.042	0.044
TSS	5	NSS	9		<4	23	6		<4	NSS	<4		<4	<4	<4

NSS = No Sample Sent

ND = Non Determined

Appendix E Roseland Lake Management Plan Five Year Action Plan

	Roseland Lake **5 Year Action Plan - *2018 to 2022***			
	Overarching Goal: ***To reduce nutrients from NPS sources to restore and preserve Roseland Lake and its tributaries so that they fully support all uses, including source-water for drinking, recreational contact and habitat for aquatic-life.***			
	Please refer to Sections 7 and 8 in the Roseland Lake Management Plan for a complete list of recommendations	**Priority ***	**Partners**	**Status**
2018				
Goal:	**Raise Stakeholder Awareness and Involvement by Implementing a Watershed Management Information and Education Campaign**			
Activities:	Adopt the Roseland Lake Management Plan as an additional planning document for the town	H	Putnam, Woodstock	
	Education and outreach on residential property NPS management	M	Woodstock Conservation Commission, Putnam WPCA, NDDH	
	Promote healthy soil initiative to farms not currently using soil health practices	M	NRCS, ECCD, TLGV, and Woodstock Agricultural Commission	
	Promote Agriculture best management practices and support pilot initiatives focused on improved water quality in Roseland Lake	M	NRCS, DEEP	
Goal:	**Conduct additional research and surveys to better inform lake management approach**			
Activities:	Consult with a Certified Lake Manager on best options for in-lake management strategies in Roseland Lake	H	Putnam WPCA	
	Initiate the highway stormwater infrastructure inventory and evaluation	M	Woodstock Highway Department	
	Initiate spring and summer nutrient baseline monitoring in Roseland Lake	H	Putnam WPCA	
	Initiate and support cyanobacteria monitoring program in Roseland Lake	H	Putnam WPCA, The Last Green Valley	
	Conduct snail inventory in Roseland Lake and the surrounding streams that would be impacted by algaecide	H	Putnam WPCA	
	Conduct an agricultural tile drain inventory	M	NRCS	
	Track down potential illicit discharges into English Neighborhood Brook and Peckham Brook and enforce remediation	H	Putnam WPCA watershed inspector, NDDH	
Goal:	**Facilitate Review and Revisions of Land-use/zoning Regulations**			
Activities:	Review and revise local zoning ordinances for compliance with the Public Health Code Sanitation of Watershed rules	M	Woodstock Planner, Woodstock PZC	

	Petition Southbridge to consider a zone change to enforce larger septic system setbacks from perennial streams in the Little River watershed	M	Putnam WPCA	
Goal:	**Develop Stakeholder Group and Watershed-wide Initiatives to Support restoration Efforts**			
Activities:	Initiate the creation of a Roseland Lake Healthy Watershed Collaborative	H	Putnam Town Administrator	
	Seek funding assistance to support Roseland Lake Healthy Watershed Collaborative Coordinator	H	Putnam Town Administrator	
	Initiate the development of an open space protection priority plan	M	Roseland Lake Healthy Watershed Collaborative, Putnam WPCA, Woodstock Open Space Land Acquisition and Farmland Preservation Committee, The New Roxbury Land Trust, Wyndham Land Trust	
	Initiate a Little River Watershed Protection Fund and explore means raise revenues for the fund	M	Putnam WPCA	
Goal:	**Implement in-lake management protocol as advised by a certified lake manager**			
Activities:	Implement in-lake management protocol as advised by a certified lake manager. Seek funding assistance if necessary.	H	Putnam WPCA	- -
	Please refer to Sections 7 and 8 in the Roseland Lake Management Plan for a complete list of recommendations	**Priority ***	**Partners**	**Status**
2019				
Goal:	**Raise Stakeholder Awareness and Involvement by Implementing a Watershed Management Information and Education Campaign**			- -
Activities:	Education and outreach on residential property NPS management	M	Woodstock Conservation Commission, Putnam WPCA, NDDH	- -
	Continue to promote healthy soil initiative to farms not currently using soil health practices	M	NRCS, ECCD, TLGV, and Woodstock Agricultural Commission	- -
	Promote Agriculture best management practices and support pilot initiatives focused on improved water quality in Roseland Lake	M	NRCS, DEEP	- -
Goal:	**Conduct additional research and surveys to better inform lake management approach**			- -
Activities:	Continue water quality and cyanobacteria monitoring in the lake to track effectiveness of in-lake implementation. Continuosly evaluate the functioning of the selected in-lake practice.	H	Putnam WPCA	- -
	Complete tile drain inventory and seek funding to assist with remediation project	M	NRCS, ECCD	- -

	Complete the highway stormwater infrastructure inventory and evaluation. Begin process to prioritize retrofits. Seek funding to implement highest priority projects.	M	Woodstock Highway Department	- -
Goal:	**Develop Stakeholder Group and Watershed-wide Initiatives to Support restoration Efforts**			- -
Activities:	Hire or assign responsibilities to a Roseland Lake/Little River Healthy Watershed Collaborative Coordinator. Organize meetings at least biannually with other Roseland Lake stakeholders to review status of the recommendations in the Roseland Lake Management Plan	H	Putnam Town Administrator	- -
	Develop an oversite committee and develop criteria for scoring applications for funding assistance through the Little River Watershed Protection Fund	M	Roseland Lake Healthy Watershed Collaborative	- -
	Initiate negotiations for the creation of an intermunicipal Transfer of Development Rights program	M	CEOs Putnam, Woodstock	- -
Goal:	Non-point Source Control - Agriculture			- -
Activities:	Continue to work with local agribusiness to implement appropriate NRCS practices for nutrient management	M	NRCS, CT DEEP, US EPA, ECCD	- -
	Please refer to Sections 7 and 8 in the Roseland Lake Management Plan for a complete list of recommendations	**Priority ***	**Partners**	**Status**
2020				
Goal:	**Raise Stakeholder Awareness and Involvement by Implementing a Watershed Management Information and Education Campaign**			
Activities:	Education and outreach on residential property NPS management	M	Woodstock Conservation Commission, Putnam WPCA, NDDH	-
	Continue to promote healthy soil initiative to farms not currently using the practice	M	NRCS, ECCD, TLGV, and Woodstock Agricultural Commission	-
	Promote Agriculture best management practices and support pilot initiatives focused on improved water quality in Roseland Lake	M	NRCS, DEEP	
Goal:	**Conduct additional research and surveys to better inform lake management approach**			
Activities:	Continue to monitor water quality and cyanobacteria inn Roseland Lake to evaluate the effectiveness of the in-lake management measures. If the management measures chosen are not effective, seek an alternate method in consultation with a certified lake manager.	H	Putnam WPCA	-
Goal:	**Non-point Source Control - Agriculture**			

		Priority *	Partners	Status
Activities:	Continue to work with local agribusiness to implement appropriate NRCS practices for nutrient management	M	NRCS, CT DEEP, US EPA, ECCD	
	Please refer to Sections 7 and 8 in the Roseland Lake Management Plan for a complete list of recommendations	**Priority ***	**Partners**	**Status**
Goal:	**Non-point Source Control - Developed land**			
Activities:	Implement stormwater retrofit activities at highest priority areas. Continue to seek funding for additional implementation work	M	Woodstock Highway Department	- -
	Look for opportunities to purchase and protect from development land in the Roseland Lake watershed	M	Putnam WPCA, Woodstock Open Space Land Acquisition and Farmland Preservation Committee, The New Roxbury Land Trust, Wyndham Land Trust	- -
2021				
Goal:	**Raise Stakeholder Awareness and Involvement by Implementing a Watershed Management Information and Education Campaign**			
Activities:	Education and outreach on residential property NPS management	M	Woodstock Conservation Commission, Putnam WPCA, NDDH	-
	Continue to promote healthy soil initiative to farms not currently using the practice	M	NRCS, ECCD, TLGV, and Woodstock Agricultural Commission	-
	Continue to support cyanobacteria monitoring program in Roseland Lake			
	Continue to monitor Roseland Lake to evaluate the effectiveness of the in-lake management measures. If the management measures chosen are not effective, seek an alternate method in consultation with a certified lake manager.	H	Putnam WPCA	-
Goal:	**Develop Stakeholder Group and Watershed-wide Initiatives to Support restoration Efforts**			
Activities:	Continue to work with local agribusiness to implement appropriate NRCS practices for nutrient management	M	NRCS, CT DEEP, US EPA, ECCD	- -
	Continue to look for opportunities to purchase and protect from development land in the Roseland Lake watershed	M	Putnam WPCA, Woodstock Open Space Land Acquisition and Farmland Preservation Committee, The New Roxbury Land Trust, Wyndham Land Trust	- -
	Non-point Source Control - Developed land			- -
	Implement stormwater retrofit activities at highest priority areas. Continue to seek funding for additional implementation work	M	Woodstock Highway Department	
	Look for opportunities to purchase and protect from development land in the Roseland Lake watershed	M	Putnam WPCA, Woodstock Open Space Land Acquisition and Farmland Preservation Committee, The New Roxbury Land Trust, Wyndham Land Trust	

2022				
Goal:	**Raise Stakeholder Awareness and Involvement by Implementing a Watershed Management Information and Education Campaign**			
Activities:	Education and outreach on residential property NPS management	L	Woodstock Conservation Commission, Putnam WPCA, NDDH	
Goal:	Continue to promote healthy soil initiative to farms not currently using the practice	M	NRCS, ECCD, TLGV, and Woodstock Agricultural Commission	- -
Activities:	**Conduct additional research and surveys to better inform lake management approach**			
	Continue to monitor water quality and cyanobacteria in Roseland Lake to evaluate the effectiveness of the in-lake management measures. If the management measures chosen are not effective, seek an alternate method in consultation with a certified lake manager.	H	Putnam WPCA	- -
	Continue biannual meetings of the Roseland Lake Little River Healthy Watershed Collaborative	**M**	Putnam WPCA	- -
	Continue to work with local agribusiness to implement appropriate NRCS practices for nutrient management	M	NRCS, CT DEEP, US EPA, ECCD	- -
	Continue to look for opportunities to purchase and protect from development land in the Roseland Lake watershed	M	Putnam WPCA, Woodstock Open Space Land Acquisition and Farmland Preservation Committee, The New Roxbury Land Trust, Wyndham Land Trust	- -
			- -	- -
			- -	
			- -	
			- -	
				Status
	Completed Activities			
	Activity		**Partner(s)**	

Subject to periodic review and revision.

H - high priority activity M - medium priority activity L - low priority activity

Appendix F Roseland Lakes Nutrient Monitoring Quality Assurance Protocol Plans (QAPP)

Roseland Lake Nutrients Monitoring QAPP

Roseland Lake Sediment Sampling QAPP

Roseland Lake Nutrients Modeling QAPP