Source Water Phosphorus Reduction Feasibility Plan

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Prepared for:

City of Newport Water Division
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Prepared by:

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NEIWPCC
New England Interstate Water Pollution Control Commission

NARRAGANSETT BAY ESTUARY PROGRAM

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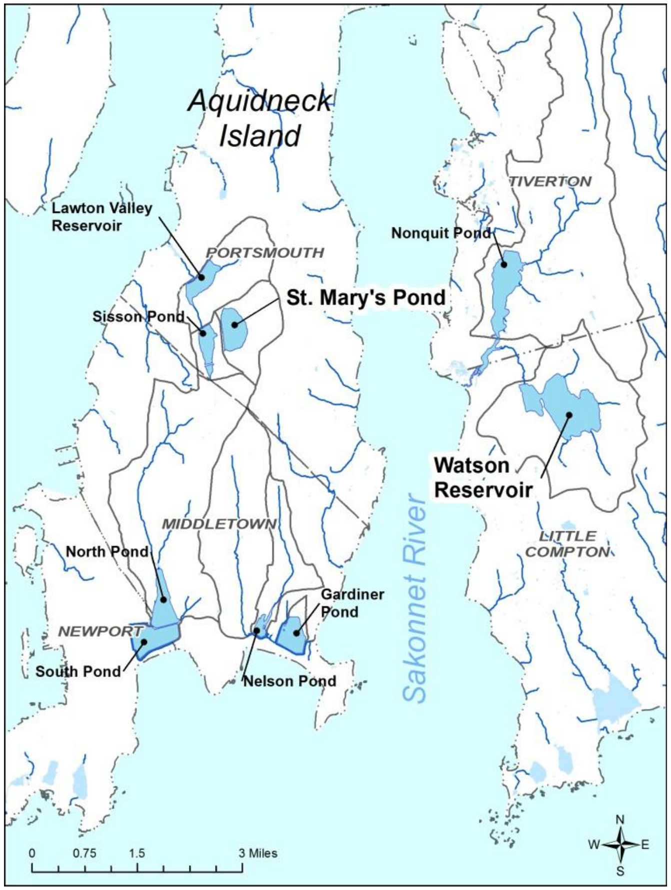
Water Quality Challenges

Cyanobacteria blooms, also often called harmful algal blooms (HABs), have been reported with increasing frequency worldwide, including in southern New England and the Narragansett Bay watershed. HABs have the potential to impact both human and aquatic health, food web production, and ecosystem services; and are a water quality concern for freshwater lakes and ponds and estuaries (Falconer and Humpage, 2005; Havens, 2008). The U.S. Environmental Protection Agency and the Centers for Disease Control have been raising awareness of cyanobacteria, the potential negative health and environmental impacts of blooms, and the need to manage nutrients to better control bloom formation. Within the Narragansett Bay watershed, Rhode Island, Massachusetts, and Connecticut have all initiated monitoring plans and/or guidance for monitoring of HABs. Evidence of the widespread prevalence of HABs in Rhode Island alone is indicated by Rhode Island Department of Environmental Management (RIDEM) state-wide monitoring of HABs. 2011 and 2012 monitoring results found 62% of the samples collected during that two-year period exceeded the RI Health Advisory Guidance of 70,000 cells/ml (ESS Group Inc., 2013). Projections of water quality impacts due to climate change indicate that HABs will likely increase due to warmer water temperatures and increased nutrient inputs to waterbodies.



St. Mary's Pond and Watson Reservoir & Watersheds

Purpose of this Study

The Newport Water Division (NWD) has also monitored cyanobacteria in the system of nine reservoirs and ponds that comprise the water supply. The NWD system serves Newport, Middletown, and a portion of Portsmouth, as well as supplying water to the Portsmouth Water & Fire District and Naval Station Newport. The watershed area of the NWD water supply covers approximately 21 mi^2 across 5 municipalities, with a wide variety of land uses. Like other freshwater lakes and ponds in the region, the NWD source waters have experienced algal blooms as a result of historic and ongoing nutrient inputs and were identified by RIDEM as impaired due to total organic carbon (TOC) and phosphorus (RIDEM, 2015). In 2011-2012, NWD retained Fuss & O'Neill to monitor nutrients, clarity, bacteria, chlorophyll a, cyanobacteria, and the algal toxin, microcystin. Ranking the water quality observed in these ponds during that study, St. Mary's Pond and Watson Reservoir (shown at left) are among those with the greatest risk for bloom formation based on average and median total phosphorus, the number of samples with cyanobacteria counts greater than 20,000 cells/ml and the ratio of cyanobacteria to total algae.

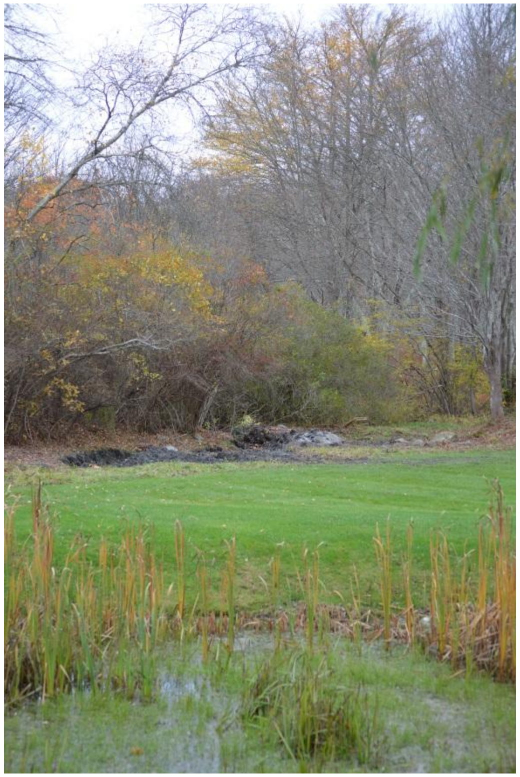
Goals of this Study

It is well documented that cyanobacteria abundance is limited by nutrient and light availability, and there is generally a strong relationship between phosphorus concentration and cyanobacteria concentrations. Therefore, HABs are a symptom of nutrient pollution. While in-lake treatment with algaecides or nutrient inactivation techniques is possible, these are short-term solutions. A sustainable solution requires the identification of nutrient sources and development of management strategies to reduce and mitigate nutrient loading to surface waters.

In 2015, the NWD received a grant from the Narragansett Bay Estuary Program (NBEP) funded through the United States Environmental Protection Agency (EPA), specifically EPA's Southern New England Program for Coastal Watershed Restoration, to conduct a study to assess potential phosphorus reduction in sources waters of the NWD water supply, focusing on St. Mary's Pond and Watson Reservoir and their watersheds. This project is directly applicable to the Southern New England Coastal Watershed Restoration Program because it:

- brings together public and private stakeholders to collaborate on initiatives to protect, enhance and restore watersheds,
- adopts a holistic, systems-based approach to watershed and lake management, and
- advances protection, enhancement, and restoration of clean water, healthy diverse habitats, and associated populations of aquatic dependent organisms.

The relationship between the goals of the Southern New England Coastal Watershed Restoration Program and this study are illustrated in Table 1.1.


Tributary stream to Watson Reservoir in the Sakonnet Vineyard.


Oakland Farms neighborhood in the St. Mary's Pond Watershed


Cows at pasture in the St. Mary's Pond Watershed

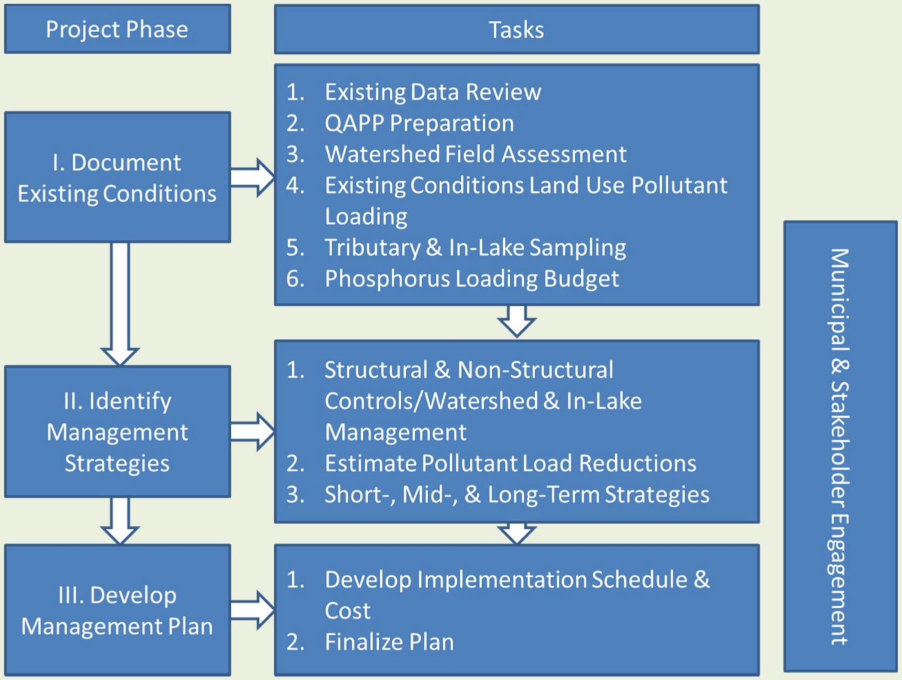
Table 1.1 Summary of Shared Goals

Southern New England Coastal Watershed Restoration Program Goals		Goals of this Project
Focus on nutrient pollution & address phosphorus impairment to freshwater systems	→	Focuses on quantifying and mitigating phosphorus loading to freshwaters with existing elevated phosphorus levels and subsequent algal blooms.
Develops designs or plans to prevent nutrient pollution	→	Develops a plan to reduce phosphorus loading that will serve as a demonstration project for other NWD reservoirs and water bodies throughout the region.
Supports program building	→	Involvement of stakeholders builds capacity to address nutrient pollution within these groups, as well as NWD.
Local implementation	→	Identifies specific projects to be implemented locally within the Watson Reservoir and St. Mary's Pond watersheds.
Regional transferability	→	Plan results will be transferable to other NWD reservoirs and other surface water bodies with similar land use and nutrient loading issues within the region.
Invests strategically	→	Identifies the most feasible and cost-effective strategies for structural and non-structural controls for phosphorus loading.
Within a nutrient impacted waterbody	→	Watson Reservoir and St. Mary's Pond have been identified by RIDEM as phosphorus-impacted freshwaters.
Results in improved coordination and increased capacity of government and watershed organizations	→	Involvement & support of the project stakeholders will result in improved coordination and increased local/regional capacity to address nutrient loading.
Improves habitat degradation/ecosystem services	→	Reduction of phosphorus loading and subsequent reduction of HABs will improve habitat and enhance ecosystem services including fishing, recreational, aesthetic values and improve drinking water source water quality.
Measurable goals	→	Goal is reduced nutrient loading and algal blooms - Phosphorus concentrations in tributary streams and water bodies and cyanobacteria concentrations can be monitored and quantified.

Summary of Study Approach

The project design is based on the EPA's methodology for watershed-based planning (USEPA, 2008) which has proven to be an effective framework for prioritizing and managing efforts to both restore degraded water quality and protect watershed health. This approach comprehensively assesses pollutant sources and helps to identify and, working together with project stakeholders, prioritize management efforts to address those sources. This process has been used successfully for lake and pond watershed planning (e.g., Maine DEP, 2013). This approach will be complemented by use of assessment and management techniques specific to lakes and ponds and outlined in the US EPA's *Lake and Reservoir Restoration Guidance Manual* (USEPA, 1990). The flow chart in Box 1.1 breaks down the project design to show the major phases and tasks used to perform the project.

Box 1.1 – Study Approach



The results of this study are presented in this report and detailed information about methods can be found in the accompanying Technical Appendices. **Section 2 – Watson Reservoir and St. Mary's Pond and Their Watersheds** provides a description of the study area. A brief review of the historic water quality data for the waterbodies and their watersheds is presented in **Section 3 – Water Quality in the Watersheds and Waterbodies**. The estimation of nutrient loading is described in **Section 4 – Nutrient Sources**. **Section 5** presents **Management Strategies** to achieve nutrient reduction and **Section 6** outlines a prioritized **Implementation Plan** and identified opportunities for transferability within the Narragansett Bay watershed.

Stakeholders

- Newport Water Division
- Town of Portsmouth
- Natural Resource Conservation Service (NRCS)
- Aquidneck Land Trust (ALT)
- Sakonnet Preservation Association (SPA)

2 - Watson Reservoir & St. Mary's Pond & Watersheds

Overview

Watson Reservoir and St. Mary's Pond are two of nine surface water reservoirs used by the Newport Water system, which supplies residents of Newport, Middletown, and a small section of Portsmouth with potable water. In addition to these municipalities, water from the Newport Water System is provided wholesale to the Portsmouth Water & Fire District and the Naval Station in Newport. St. Mary's Pond is located on Aquidneck Island in the town of Portsmouth, RI and Watson Reservoir is located in Little Compton, RI (Figure 2.1 and Figure 2.4).

The overall treatment capacity of the Newport Water system is 16 million gallons per day (MGD). The nine surface water reservoirs within the Newport Water System have a total capacity of approximately 4.3 billion gallons, with 3.9 billion usable gallons. Watson Reservoir is the largest of all the reservoirs within the Newport Water System, with a storage capacity of 1,755.1 MG of which 1,677.4 MG is usable storage. The smaller St. Mary's Pond has a storage capacity of 565.3 MG of which 403.0 MG is usable storage. St Mary's Pond receives water from Watson Reservoir via a pipeline that runs under the Sakonnet River. Water is pumped from Watson Reservoir to St. Mary's Pond via the Sakonnet River Pumping Station where it is then conveyed to the Lawton Valley Water Treatment Plant (WTP) by way of the St. Mary's Pumping Station (Pare Corporation, 2014; RIDEM, 1993)

The Watson Reservoir Watershed is located primarily in Little Compton, RI with less than two percent of the watershed in Tiverton, RI. The watershed area totals approximately 2,296 acres which includes approximately 379 acres for Watson Reservoir itself, with the remaining 1917 acres draining to the reservoir. The reservoir receives water from direct runoff and several small unnamed tributaries and Pachet Brook. Land surface elevations in the Watson Reservoir watershed range from 48 feet to 162 feet above sea level.

Table 2-1. Watershed Quick Facts

	Watson Reservoir	St. Mary's Pond
Watershed Area[1]	2,296 acres; 3.59 mi^2	523 acres; 0.82 mi^2
Elevation	Highest: 162 Lowest:48	Highest: 268 Lowest:178
Impervious Cover	3.6%	8.3%
Major Land Uses	Forest: 53.3% Agricultural: 28.1% Residential: 14.0% Other: 4.6%	Forest: 23.3% Agricultural: 37.0% Residential: 29.9% Other: 9.8%
Population[2]	556 persons	500 persons

[1] Includes 378.9 acres for Watson Reservoir and 111.4 acres for St. Mary's Pond waterbodies

[2] Population was estimated from the number of dwelling units in the E911 layer multiplied by 2.7 persons per household.

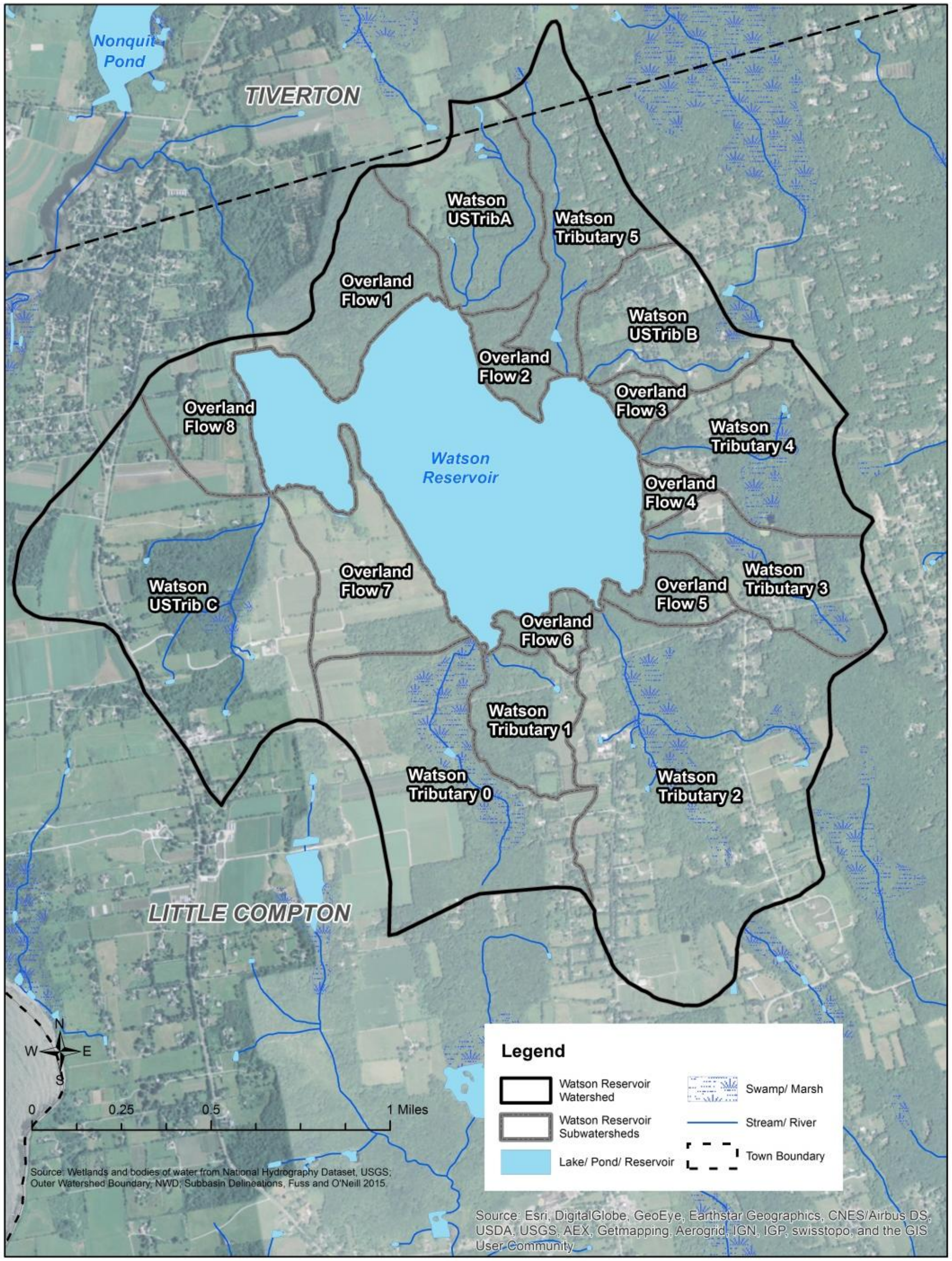
What is a Watershed?

A watershed is a basin that catches rain and snow and drains into a central waterbody. All of the land within the watershed is part of it, and watersheds often contain smaller "subwatersheds." The land, waterbodies, aquifers, people, habitat, and infrastructure are interrelated within a watershed system. Changes in one part of the watershed can affect other parts.

St. Mary's Pond is located in Portsmouth, RI and receives inflow from its own drainage area as well as water pumped across the Sakonnet River from Nonquit Pond and Watson Reservoir (RIDEM, 1993). St. Mary's Pond watershed is 523 acres which includes the 111.4 acre pond. Land area draining to the pond is approximately 411.4 acres. Excess water spilling from St. Mary's Pond dam is collected in Sisson Pond. Land surface elevations in the St. Mary's Pond watershed range from 178 feet to 268 feet above sea level.

Watson Reservoir

The Harold E. Watson Reservoir was completed in 1960 by the construction of a dam on Pachet Brook. The surface area of the reservoir is approximately 379 acres (RIGIS, 2011) and a recent bathymetric survey of the reservoir shows maximum capacity of approximately 1750 MG (Apex Engineering, 2008). The waterbody has a northwest-southeast orientation, following the path of the former Pachet Brook streambed. Maximum depth in the reservoir is approximately 25 feet, and average depth is 14.4 feet. Soft sediment depth within the reservoir was measured in 2015 as part of this study and depths ranged from 0 to 2.5 feet, with a mean depth of 0.62 feet. The overall volume of soft sediment within Watson Reservoir was estimated at 373,701



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

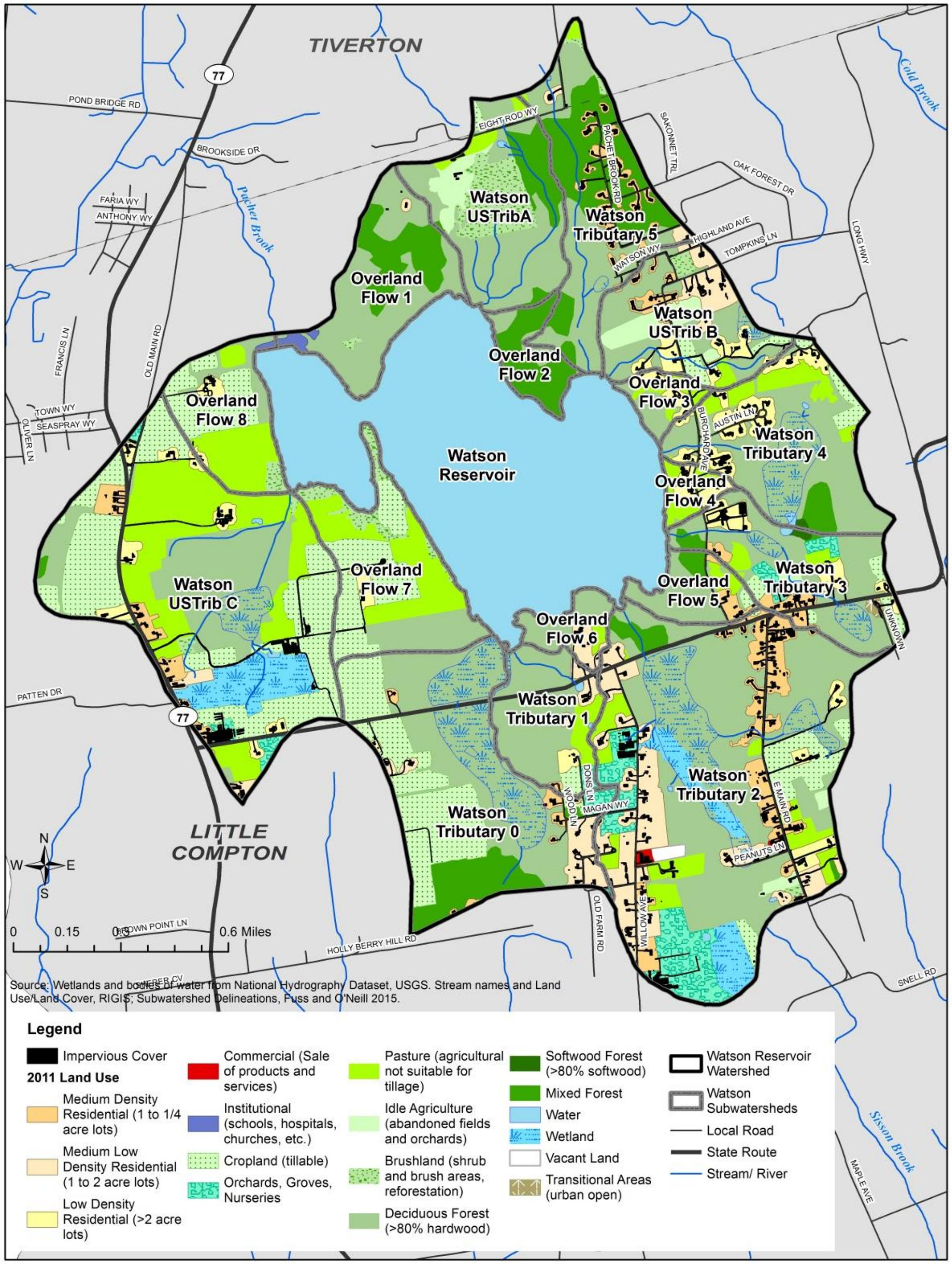
Figure 2.1 Watson Reservoir Watershed

cubic yards. (For more detail on soft sediment data collection and volume calculations see Section 3 and Technical Appendix B.)

Watson Reservoir Watershed

Watson Reservoir Watershed is 3.6 square miles or 2,296 acres in size, including 379 acres for the Reservoir itself. The total area draining to the reservoir is 3.0 square miles or 1,917 acres. There were nine small tributaries that contribute flow to the reservoir and eight small overland flow areas identified through field reconnaissance and available mapping. The drainage areas associated with these subwatersheds range from 65.1 acres to 402.7 acres in size. Overland flow areas range from 14.7 to 152.1 acres in size.

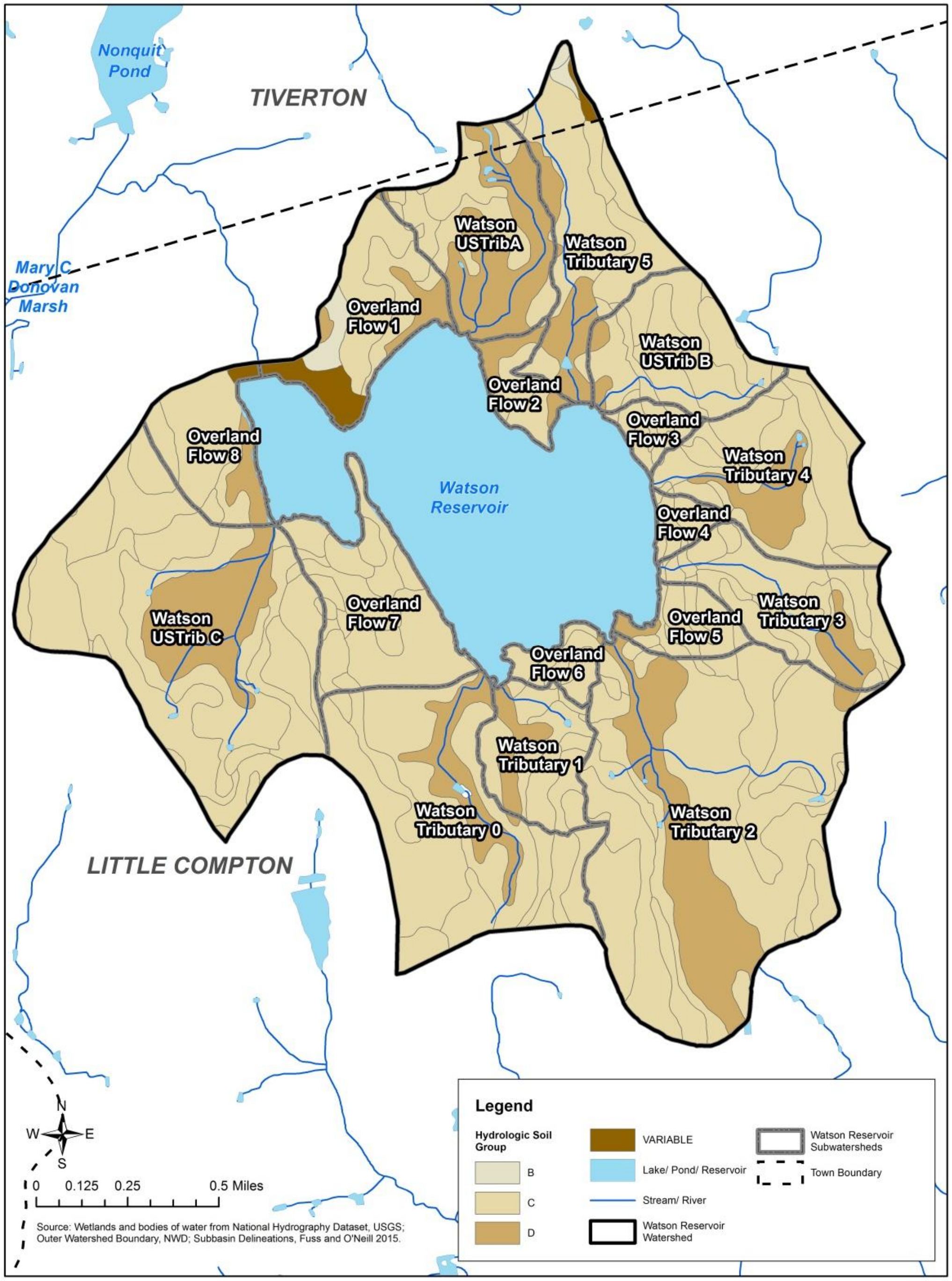
Land use within the watershed (Table 2.1 and Figure 2.2) was determined using the 2011 Land Use/Land Cover data set available from Rhode Island Geographic Information System website (RIGIS, 2015).The Watson Reservoir watershed is primarily forested (1,021.2 acres), which includes deciduous forest (>80% hardwood), softwood forest (>80% softwood), mixed forest, and brush land (shrub and brush areas, reforestation). Agricultural land use (538.9 acres) includes cropland (14.2 percent), pasture (11.1 percent), and



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS. Stream names and Land Use/Land Cover, RIGIS; Subwatershed Delineations, Fuss and O'Neill 2015.

Figure 2.2 Watson Reservoir Watershed Land Use & Impervious Cover orchards, groves, and nurseries (2.9 percent). Residential land use (268.6 acres) within the watershed includes low density residential (>2 acre lots), medium low density residential (1 to 2 acre lots), and medium density residential (1 to ¼ acre lots).

To estimate nutrient loading from the watershed, low density residential and medium-low density residential land use classes were grouped into the same category Low Density Residential – LDR (<1 du/acre) (du = dwelling unit) (see Section 4). Low density residential comprised 9.4 percent (180.4 acres) of the watershed and medium density residential comprised 4.6 percent (88.2 acres) of the watershed. Other land use categories within the watershed total 4.6 percent (87.9 acres) of the watershed and include: wetlands, water, idle agricultural, institutional, commercial, vacant land, and transitional areas. Wetlands are the largest land use class in this category at 2.6 percent (49.2 acres); all additional land use classes within the other category total 2.0 percent (38.7 acres) of the watershed.



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015.

Figure 2.3 Watson Reservoir Watershed Hydrologic Soil Groups

Impervious cover for the Watson Reservoir Watershed was estimated at 3.6 percent overall from the impervious surfaces data set available from RIGIS (2015). This data set is available statewide and represents impervious surfaces in Rhode Island in both 2003-2004 and 2011. For estimating pollutant loading (Section 4) an impervious value for each land use class in each watershed was determined (see Technical Appendix D). These estimates provide the average percent of imperviousness within a land use class and ranged from 0 to 100 percent. The 100 percent value was for a 3.1 acre parcel of institutional space. Another high impervious value (59.2 percent) was calculated for a 2.3 acre commercial land use area in the watershed. Excluding these parcels, percent impervious values ranged from 0.0 to 23.9 percent. Low impervious values, 3 percent or less, were seen for most land use classes. Residential areas ranged from 14.2 to 23.4 percent impervious (Figure 2.2)

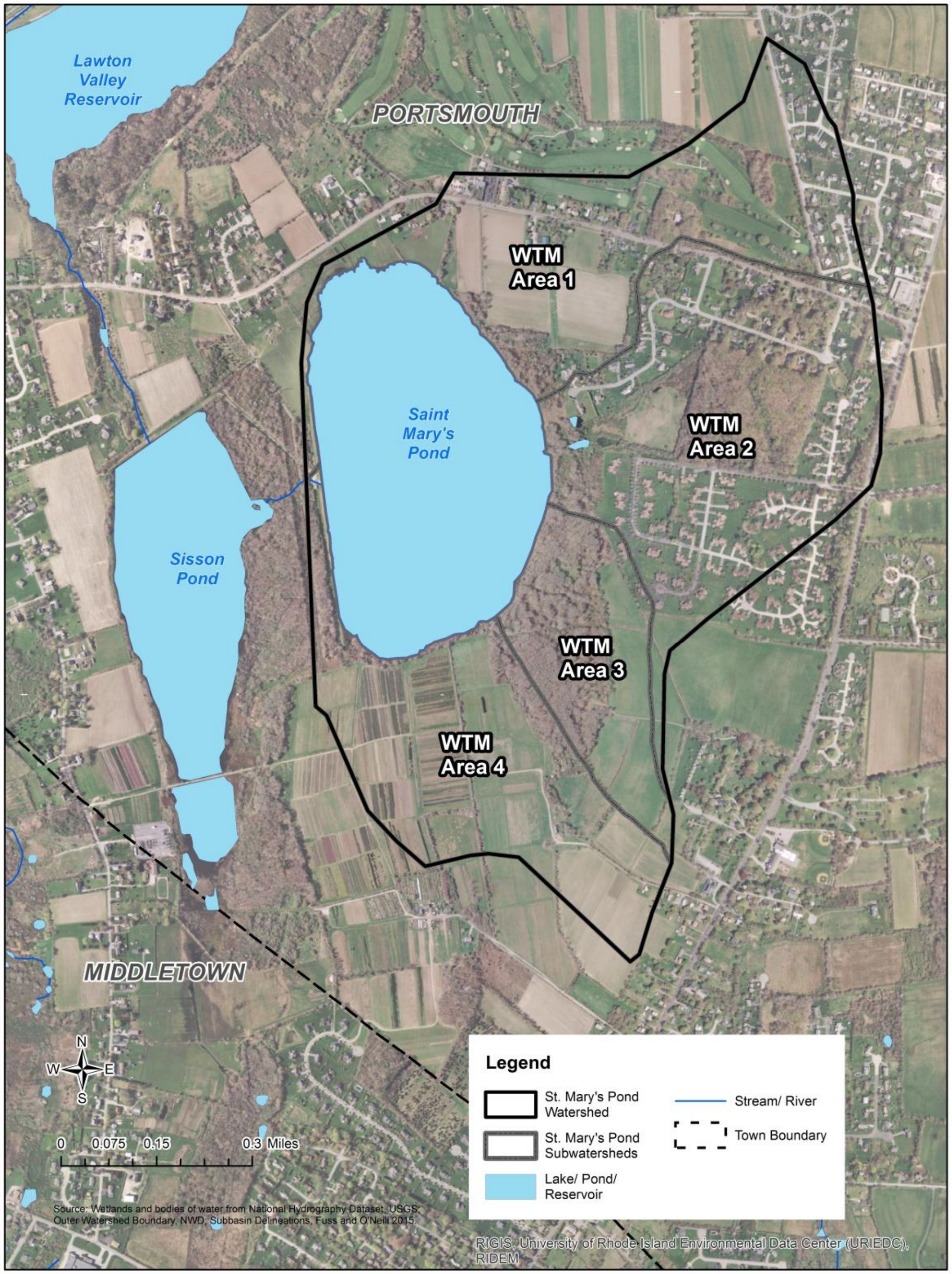
The hydrologic soil groups (HSGs) within the watershed was determined from the 2014 Rhode Island Soil Survey Program data set available from RIGIS (2015). The HSG classification system places a soil type into a specific group based on the soil's runoff characteristics. HSGs are important when considering low impact development (LID), best management practices (BMPs) and on-site wastewater treatment system (i.e., septic system) requirements. Possible categories include group A, B, C, and D. Infiltration rates decrease from A to D, with A having the highest infiltration rate and D having a very low infiltration rate and the highest runoff potential (Phillips, 2015). The predominant hydrologic soil groups within the Watson Reservoir Watershed are HGS C at approximately 79 percent, 1,516 acres, of the watershed. HSG D was 19 percent, 368 acres, of the watershed; HSG B was a minor soil type within the watershed at 0.6 percent, 12.5 acres (Figure 2.3). The dominance of C soils in the watershed means that a high percentage of the rain falling in the watershed will become stormwater runoff since these soils have a slow infiltration rate.

St. Mary's Pond

St. Mary's pond is 111 acres in size, with an estimated volume of approximately 565 MG based on data collected as part of a bathymetric survey (Apex Engineering, 2008). The Pond is relatively shallow, with a maximum depth of approximately 5-6 feet. Soft sediment depths within the pond, measured in the summer of 2015, ranged from 0 to 2.5 feet with a mean depth of 0.93 feet. The overall volume of soft sediment within St. Mary's Pond was estimated at 161,099 cubic yards. (For more detail on soft sediment data collection and volume calculations see Section 3 and Technical Appendix B.) Aerators are currently installed in the western side pond near the dam. St. Mary's Pond receives inflow from its own drainage area as well as water pumped across the Sakonnet River from Nonquit Pond and Watson Reservoir. No perennial tributaries were identified during field reconnaissance of the St. Mary's Pond watershed. Any excess water that spills over the dam at St. Mary's Pond is collected in Sisson Pond (RIDEM, 1993).

St. Mary's Pond Watershed

St. Mary's Watershed is 0.82 square miles or 523 acres in size, including approximately 111 acres for the pond itself (Figure 2.4). The total area draining to the pond is 0.6 square miles or 412 acres. For



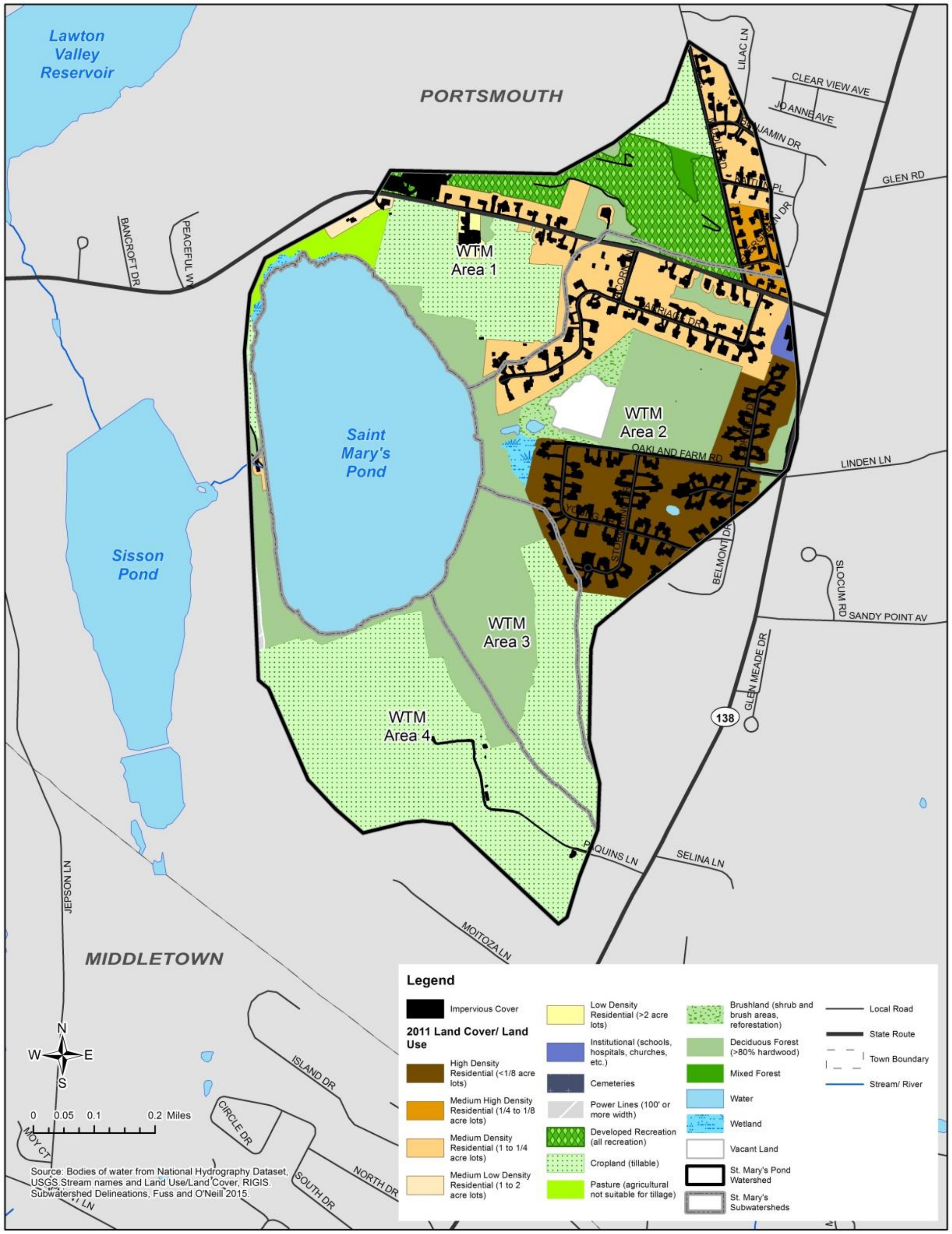
Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015

RIGIS, University of Rhode Island Environmental Data Center (URIEDC), RIDEM

Figure 2.4 St. Mary's Pond Watershed

pollutant loading modeling purposes (Section 4), the watershed was divided up into four separate areas based on elevation contours and stormwater drainage systems. The drainage areas associated with these ‘subwatersheds’ or watershed treatment (WTM) areas range from 50.6 acres to 142.5 acres in size (Figure 2.4).

Land use within the St. Mary’s Pond watershed (Table 2.1 and Figure 2.5) is primarily agricultural (152.3 acres) and residential (122.8 acres). Agricultural land use includes cropland (27.2 percent) and pasture (1.4 percent). Residential land use within the watershed includes low density residential (>2 acre lots), medium low density residential (1 to 2 acre lots), medium density residential (1 to ¼ acre lots), medium high density residential (1/4 to 1/8 acre lots) and high density residential (<1/8 acre lots). To estimate nutrient loading from the watershed, low density residential and medium-low density residential land use classes were grouped into the same category Low Density Residential – (LDR- <1 du/acre), medium density residential remained a single category (MDR-1-4 du/acre) and medium high and high density residential were grouped into a single category – high density residential (HDR- > 4 du/acre) (see Section 4). Low density residential comprised 0.9 percent (3.6



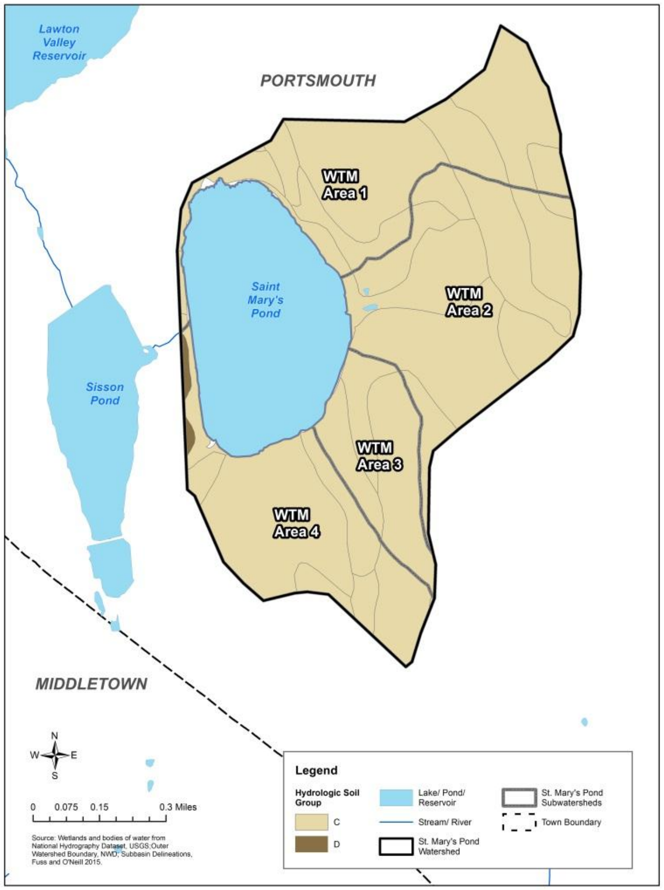
Source: Bodies of water from National Hydrography Dataset, USGS Stream names and Land Use/Land Cover, RIGIS. Subwatershed Delineations, Fuss and O'Neill 2015.

Figure 2.5 St. Mary’s Pond Watershed Land Use & Impervious Cover acres); medium density residential comprised 14.8 percent (61.2 acres), and high density residential comprised 14.1 percent (58.1 acres) of the watershed.

Forested land (95.9 acres) includes deciduous forest (>80% hardwood), mixed forest, and brush land (shrub and brush areas, reforestation). Other land use categories within the watershed total 9.8 percent (40.3 acres) of the watershed including wetlands, water, developed recreation, vacant land, institutional, and power lines. Developed Recreation is the largest land use class in this category at 7.2 percent (29.6 acres). All additional land use classes within the other category total 2.6 percent (10.8 acres) of the watershed (Figure 2.5).

Impervious cover for St. Mary's Pond was estimated at 8.3 percent from the impervious surfaces data set available from RIGIS (2015). Percent impervious values for St. Mary's Pond ranged from 0.0 to 33.0 percent. Low impervious values, 4 percent or less, were seen for most land use classes. Institutional land use had a percent impervious value of 22.0 percent while Developed Recreation had a percent impervious value of 11.9 percent. Residential areas ranged from 25.5 to 33.0 percent impervious (Figure 2.5). Impervious surfaces tend to accumulate pollutants and contribute a greater runoff volume. Thus, higher percentages of impervious cover result in a higher potential for pollutant loading.

The HSGs within the watershed were determined from the 2014 Rhode Island Soil Survey Program data set available from RIGIS (2015). As in the Watson Reservoir Watershed, the predominant hydrologic soil group within the St. Mary's Pond Watershed is Hydrologic Group C (99.4 percent, 409.4 acres). The remaining soils were Hydrologic Group D at 0.6 percent (2.3 acres) of the watershed (Figure 2.6).



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS;Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015.

Figure 2.6 St. Mary's Pond Watershed Hydrologic Soil Groups

3 - Water Quality in the Watersheds and Waterbodies

> Limnologists and lake managers have developed a general consensus about freshwater lake responses to nutrient additions, that essentially an ambient total phosphorus (TP) concentration of greater than about 0.01 mg/L and/ or a total nitrogen (TN) concentration of about 0.15 mg/L is likely to predict blue-green algal bloom problems during the growing season.
>
> - *Nutrient Criteria Technical Guidance Manual, Lakes and Reservoirs* (USEPA, 2000)

Watson Reservoir and St. Mary's Pond have experienced frequent algal blooms over the past several years. Phosphorus (P), an essential nutrient for plants and animals, can become detrimental to surface water quality at excessive levels. Phosphorus is usually the "limiting nutrient" in freshwaters, which means that relatively small amounts can increase algae growth. The EPA recommends that total phosphorus (TP) concentrations in surface water reservoirs should not exceed 0.01 mg/L (U.S. Environmental Protection Agency (USEPA), 2000). Rhode Island surface water quality criteria set the criteria for TP at 0.025 mg/L (Rhode Island Department of Environmental Management, Office of Water Resources, 2009).

Excessive nutrient levels are associated with harmful algal blooms (HABs) or cyanobacteria blooms. The U.S. EPA and Centers for Disease Control (CDC) have been raising awareness of cyanobacteria, its potential negative health and environmental impacts, and the need to better manage nutrients within the environment to prevent the formation of HABs. The Rhode Island Department of Environmental Management (RIDEM) state-wide monitoring of HABs in 2011 and 2012 found that 62% of the samples collected during the period exceeded the RI Health Advisory of 70,000 cells/ml. (ESS Group Inc., 2013). A monitoring study conducted by Fuss and O'Neill in 2011-2012 found that Watson Reservoir and St. Mary's Pond were among the reservoirs with the greatest risk for bloom formation based on average and median TP values, the number of samples with high cyanobacteria counts (> than 20,000 cells/ml) and the ratio of cyanobacteria to total algae (Fuss and O'Neill, 2014).

Several prior studies have been conducted to monitor and characterize water quality conditions in St. Mary's Pond and Watson Reservoir. These studies include monitoring of the NWD water supply reservoirs in 2011 and 2012 by Fuss and O'Neill, sampling in 2014 by RIDEM, ambient water quality monitoring by RIDEM, sediment monitoring by RIDEM, and an on-going study by RIDEM known as the Source Water Protection Initiative.

Recommended EPA lake and reservoir nutrient reference conditions for the ecoregion containing Rhode Island are TP = 0.08-0.20 mg/L and TN = 0.32-0.41 mg/L

- *Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria, Lakes and Reservoirs in Nutrient Ecoregion XIV (USEPA, 2001)*

Historic Water Quality Information

Historic water quality information is available for the NWD reservoirs from data collected over the last several years by the RIDEM and others. Review of this information is useful to help characterize the degree and extent of nutrient concentrations within the NWD drinking water reservoirs and help target strategies to reduce sources of nutrient loading to these drinking water sources. Prior studies are briefly summarized below, with an emphasis on TP concentrations.

2011-2012 Sampling

In 2011 and 2012, Fuss and O’Neill conducted bi-weekly monitoring of water quality at 11 sampling stations within the City of Newport water supply, including St. Mary’s Pond and Watson Reservoir. Nutrient data collected during this study included total phosphorus (TP), phosphate, nitrite, nitrate, and total Kjehldahl nitrogen (TKN). None of the sampling locations were consistently below the RIDEM TP criteria of 0.025 mg/L throughout 2011 or 2012. Watson Reservoir showed a spike in TP levels in October 2011 of approximately 0.13 mg/L and again in July of 2012 of over 0.35 mg/L. St. Mary’s Pond showed TP levels consistently below 0.05 mg/L throughout 2011 while 2012 showed values closer to 0.10 mg/L with a spike of ~0.24 mg/L in July of 2012 (Fuss and O'Neill, 2013). Algal enumeration and identification in 2012 indicated that cyanobacteria species dominate the algal composition in both reservoirs in June through October, with cyanobacteria cell counts ranging from 160 – 84,323 cells/mL in Watson Reservoir and 0 – 102,791 cells/mL in St. Mary’s Pond.

RIDEM 2014 Sampling

The RIDEM conducted surface water and sediment sampling of the Newport Water Departments nine surface water reservoirs between May 6th and May 15th, 2014. The primary objective of the sampling was to determine background copper and phosphorus concentrations in the surface water and sediments of each reservoir prior to seasonal application of copper sulfate and before stratification (Rhode Island Department of Environmental Management, 2013; Rhode Island Department of Environmental Management, 2014). Data collection included a water column profile at the deepest location of each reservoir. In addition to the water column profile, water samples were collected one meter below the surface and one meter above the bottom and analyzed for dissolved and total copper, water hardness, and dissolved and total phosphorus. Sediment samples from the deepest part of each reservoir were taken and analyzed for total copper and total phosphorus (Rhode Island Department of Environmental Management, 2013; Rhode Island Department of Environmental Management, 2014).

Water chemistry results from the spring 2014 sampling showed elevated phosphorus levels at both St. Mary’s Pond and Watson Reservoir. Total Phosphorus levels at the surface and at depth varied from 0.035 to 0.043 mg/L at St. Mary’s Pond and 0.024 to 0.028 mg/L at Watson Reservoir (surface and depth measurements, respectively). Particulate phosphorus levels ranged from 0.02 to 0.025 mg/L at St. Mary’s Pond and 0.019 to 0.023 mg/L at Watson Reservoir (surface and depth, respectively). Levels of dissolved copper exceeded both the acute and chronic criteria at St. Mary’s Pond while these exceedances were not observed at Watson Reservoir. The data suggests that residual levels of copper remain elevated in the water column even after the cessation of seasonal applications of copper sulfate at St. Mary’s Pond. Elevated concentrations of copper in the sediment also suggest that bottom sediments may be a continuous source of dissolved copper to the water column (Rhode Island Department of Environmental Management, 2014).

Sediment samples from Watson Reservoir and St. Mary’s Pond had Total Phosphorus (TP) levels of 91 and 351 mg/kg, respectively and Total Copper levels of 9.2 and 1430 mg/kg, respectively. Total Copper levels at St. Mary’s Pond exceeded all freshwater sediment quality guidelines considered by RIDEM in their review (Rhode Island Department of Environmental Management, 2014).

RIDEM Source Water Protection Initiative

The RIDEM instituted a Source Water Protection Initiative for the Newport Water Supply Reservoirs in coordination with the Rhode Island Department of Health (RIDOH) to ensure that the water quality in each of the NWD’s nine reservoirs is suitable for drinking water using conventional water treatment. As part of this initiative the RIDEM conducted bi-weekly monitoring of the nine reservoirs from May through October 2015 to better understand the water quality within the source water reservoirs. Data collected from this monitoring effort will be used to determine acceptable phosphorus levels, determine necessary reductions in phosphorus discharged to the reservoirs, identify the pollution sources contributing to the degraded water quality, as well as identifying watershed and stormwater management alternatives that will aid in the restoration of the water quality within the reservoirs (Rhode Island Department of Environmental Management, unknown).

The proposed approach to establish allowable phosphorus loads will include evaluating the causative relationship between nutrients and algal growth and total organic carbon (TOC). The desired outcome will be establishing a target phosphorus concentration that reduces algal growth and TOC concentrations to a level that supports drinking water and total aquatic life uses. Existing phosphorus loads will be estimated using available water quality data and various desktop watershed models. Loads will include the portion resulting from internal cycling of phosphorus from sediments.

The results of the study have not yet been published, but review of the raw data provided by RIDEM allows for a summary of the water quality findings relative to the key nutrients TP and TN and dissolved oxygen (DO) which is critical for release of phosphorus from lake bottom sediments. A total of 12 sampling events were conducted at each waterbody on an approximately bi-weekly basis from early May to early October. As with the field work for this this study, samples were collected by RIDEM at the deepest location within each waterbody in accordance with the Quality Assurance Project Plan (QAPP) developed for the project and available at http://www.dem.ri.gov/pubs/data.htm.

In Watson Reservoir, samples consistently showed TP increasing with depth in the water column, with the highest TP value (0.073 mg/L) measured on September 8, 2015. All measured TP values were greater than the value of 0.01 mg/L that is typically indicative of supporting algal blooms, but were less than the value of 0.08 mg/L that is the lower level of the ambient reference values for lakes in this ecoregion. Mean and median values calculated from samples collected at all depths were 0.02 mg/L and 0.018 mg/L, respectively. Mean and median TN values calculated from samples taken at all depths were 0.66 mg/L and 0.603 mg/L and all TN values collected were greater than the value of 0.15 mg/L that is typically indicative of conditions supporting algal blooms as well as the reference ecoregion range of 0.32-0.41 mg/L. The highest TN concentration observed was 2.2 mg/L from a sample collected at depth on September 8, 2015. DO values in the reservoir decreased from top to bottom, with the initial anoxic reading (i.e., DO<2 mg/L) observed on June 17, 2015. The anoxic zone at the bottom of the reservoir grew over the season, peaking in early September when the lower 1.25 meters of the reservoir had DO values less than 2 mg/L and reached a minimum of 0.05 mg/L.

In St. Mary’s Pond, water quality profiles tended to be fairly uniform, likely a result of the shallow depth of the pond, potential for wind mixing, and use of aerators in the location of maximum depth where sampling occurred. TP values peaked in late August 2015 at 0.206 mg/L at the surface and 0.0181 mg/L at depth. Mean and median values of all samples collected were 0.067 mg/L and 0.048 mg/L and all values were greater than 0.01 mg/L, which is typically indicative of supporting algal blooms. Values did not exceed 0.08 mg/L until August 25, 2015. TN values also peaked in late August and were generally higher than TN values observed in Watson Reservoir. Mean and median TN values were 1.23 mg/L and 1.215 mg/L, respectively, and all values were above the ecoregion ambient water reference range of 0.32-0.41 mg/L. The highest measured TN value was 3.26 mg/L from a surface sample collected in August. DO values never reached anoxic conditions, with the lowest value (4.21 mg/L) recorded at depth in August 2015.

Data Collected from this Study

From the spring through the early fall of 2015, Fuss and O’Neill collected water and sediment samples within St. Mary’s Pond and Watson Reservoir watersheds. A Quality Assurance Project Plan (QAPP) was developed by Fuss and O’Neill with assistance from the NWD laboratory to support the in-lake and tributary monitoring, field assessment, secondary data collection, and modeling for this project. The QAPP was reviewed and approved by NEIWPCC and EPA.

Tributary and in-lake sampling was done on six separate dates at St. Mary’s Pond and Watson Reservoir (Table 3.1).

In addition, in-lake sediment sampling of surficial sediments was conducted in June of 2015. The water quality and sediment sampling (Table 3.2) was conducted to support the assessment of existing trophic status of these water bodies and to quantify nutrient loading from input tributaries and bottom sediment.

The tributary streams were sampled 6 times (coincident with in-lake sampling) for nutrients, flow, and in situ water quality parameters. In-lake sampling was done at the deepest location within each pond at the surface and depth, as well as the thermocline (if present) or the midpoint of the water column. Parameters measured on site included water temperature, dissolved oxygen (DO), conductivity, and Secchi disk depth (transparency). Additional testing was done by a certified laboratory on each sample for nutrients, alkalinity, turbidity and selected metals necessary to estimate in-lake phosphorus loading from sediments. Samples were collected starting in mid to late spring to show conditions as the pond enters the summer, and monthly from April through September to show any potential change in release of phosphorus from the bottom sediments (Fuss and O'Neill, 2014).

Table 3-1. Tributary and In-Lake Sampling Dates at St. Mary's Pond and Watson Reservoir

Sampling Event	Date
Event 1	April 29, 2015
Event 2	May 27, 2015
Event 3	June 17, 2015
Event 4	July 22 & 24, 2015
Event 5	August 26, 2015
Event 6	September 23, 2016

Table 3-2. Sampling Parameters at St. Mary's Pond and Watson Reservoir

Tributary and Outlet Sampling Locations		In-Lake Sampling Locations	
In-Situ Measurement	Laboratory Measurement	In-Situ Measurement	Laboratory Measurement
Water Temperature Dissolved Oxygen Conductivity Flow	Total Phosphorus Total Nitrogen Nitrate+Nitrite Ammonia-Nitrogen	Water Temperature Dissolved Oxygen Conductivity Secchi Transparency Redox Potential*	Total Phosphorus Total Nitrogen Nitrate+Nitrite Ammonia-Nitrogen Alkalinity Turbidity Total Iron*

*Measured if anoxic conditions present.

In-lake sediment sampling consisted of two components: 1) probing of the pond and reservoir bottoms to determine the distribution of soft sediments that interact with the overlying water area and 2) sampling of the surficial sediments. A map showing the distribution of soft sediment and thickness created as part of this study can be found in Technical Appendix B. Sediment sampling consisted of surficial sampling at three locations at each water body based upon sediment distribution to evaluate potential for phosphorus loading from in-lake sediments. Composite samples were well homogenized and tested by a certified laboratory for phosphorus, solids, and organic content.

All of the data collected both in-situ and through laboratory analysis is included in Technical Appendix A. The discussion below focuses on phosphorus, nitrogen and dissolved oxygen.

Watson Reservoir and Watershed

In addition to water quality sampling at the deepest location in Watson Reservoir, 6 tributary locations were identified for sampling in the watershed (Figure 3.1). Of the 6, Tributary 5 in the northeastern part of the watershed, did not have sufficient flow for sampling during any of the 6 sampling events. TP and TN concentrations in each of

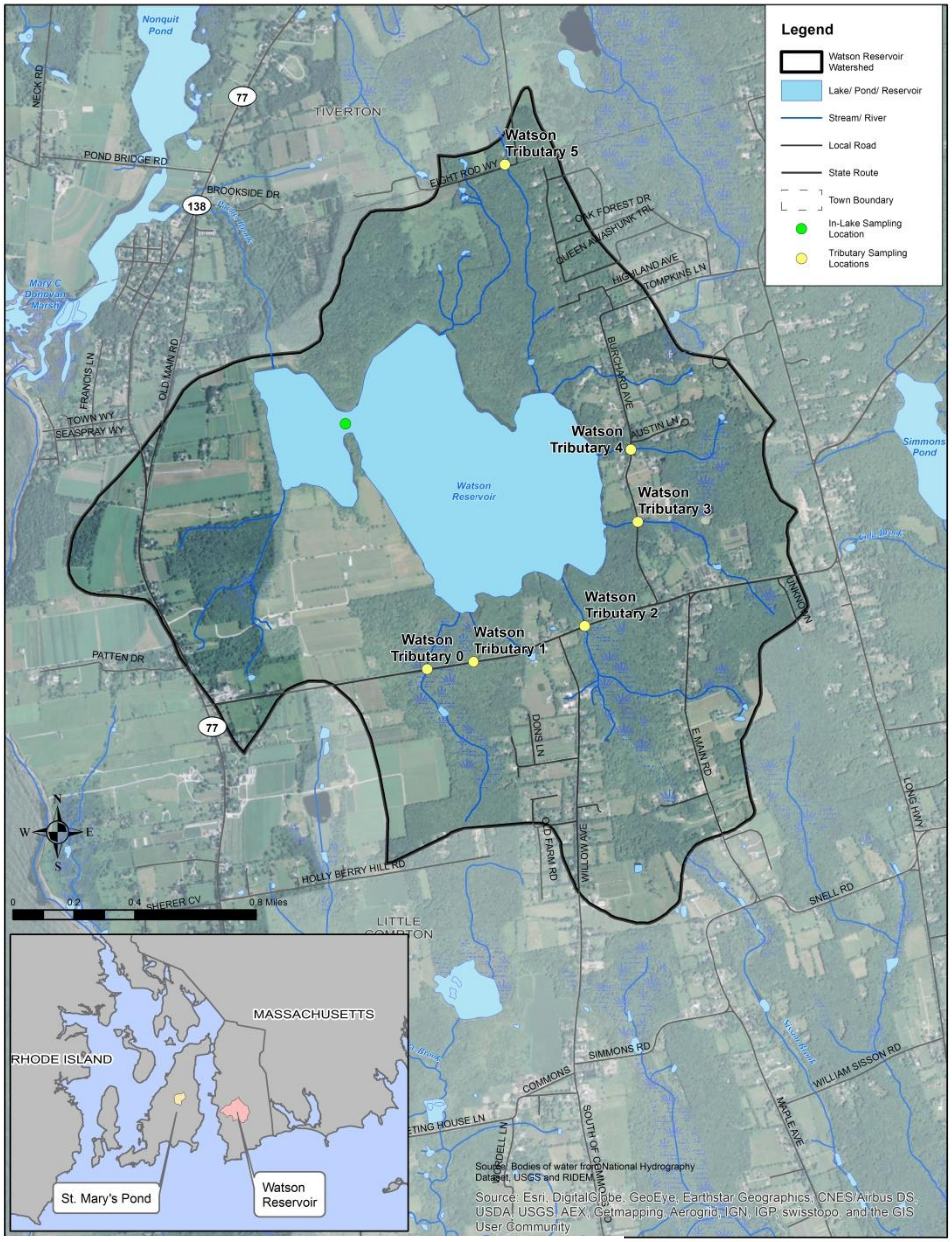


Figure 3.1 Watson Reservoir Sampling Locations

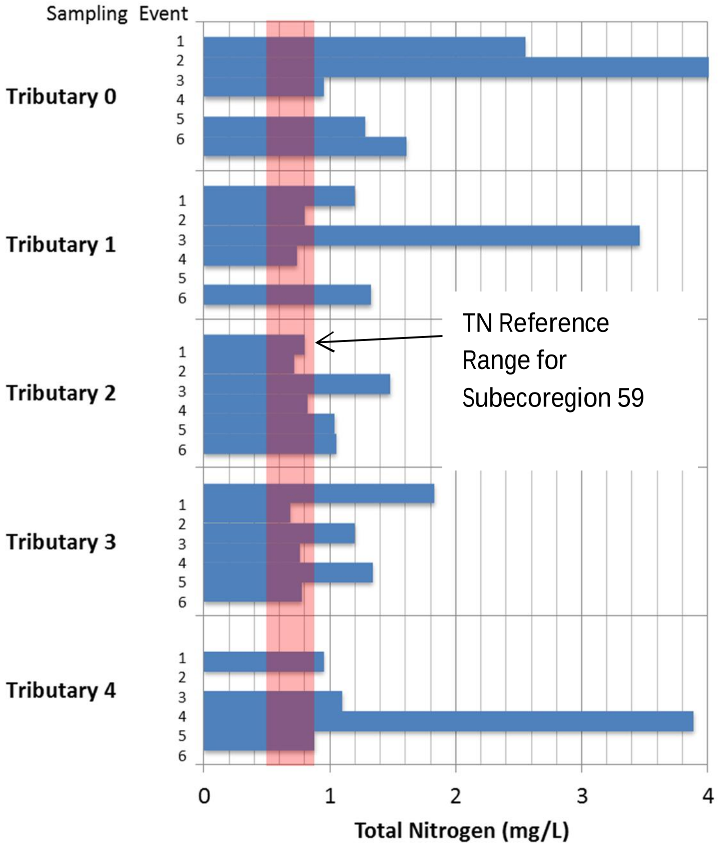


Figure 3.2 TN Concentrations in Tributary Streams

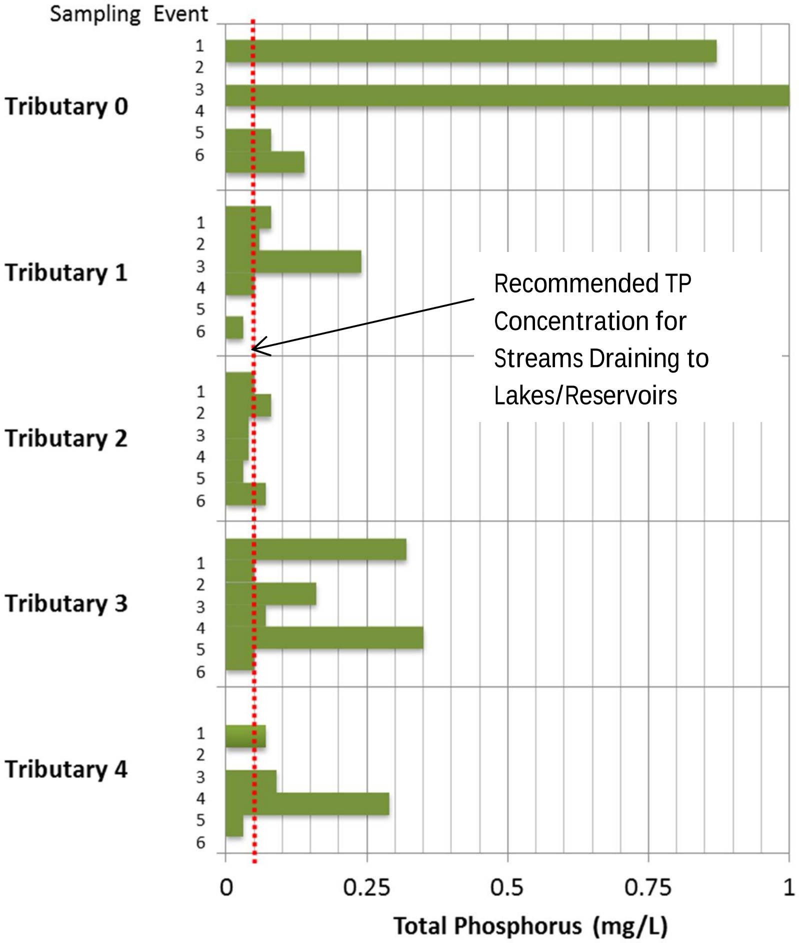


Figure 3.3 TP Concentrations in Tributary Streams

the tributaries is shown in Figure 3.2 and 3.3. TP concentrations in many tributary streams exceeded the recommended concentration of 0.05 mg/L for tributaries discharging to lakes and reservoirs, especially in Tributaries 0, 3 and 4. Multiple samples showed TN concentrations above the reference range of 0.48 – 0.87 mg/L for subecoregion 59 of EPA Ecoregion XIV (USEPA, 2000), with all samples collected from Tributary 0 and Tributary 4 above the reference range.

Sampling results within the Reservoir were generally consistent with results obtained in prior years by other researchers. TP concentrations tended to increase with depth and peaked in late July at 0.62 mg/L. All samples collected had TP concentrations greater than 0.01 mg/L and 5 of the 6 sampling events had bottom TP concentrations greater than the reference value of 0.08 mg/L, indicating generally elevated TP concentration in the reservoir and conditions capable of supporting algal blooms. (Figure 3.4)

TN concentrations in Watson Reservoir tended to increase with depth in the water column starting in mid-June and peaking in August at 6 mg/L. All TN concentrations were above the 0.15 mg/L concentration that in generally indicative of conditions supporting algal blooms and for most of the sampling events, TN concentrations were greater than the reference value of 0.32 mg/L for the USEPA Ecoregion containing Rhode Island. (Figure 3.5)

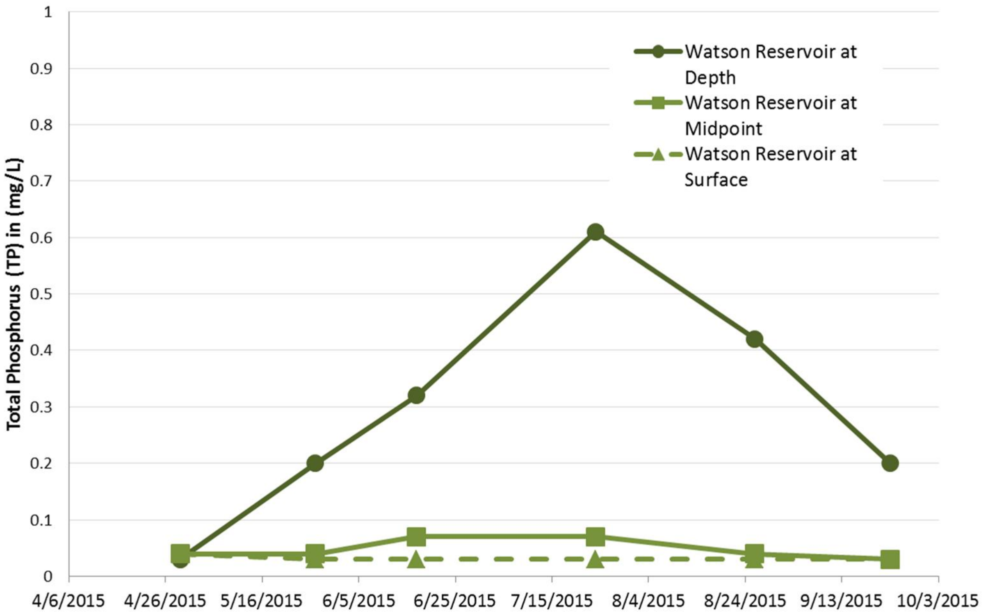


Figure 3.4 TP Concentrations in Watson Reservoir

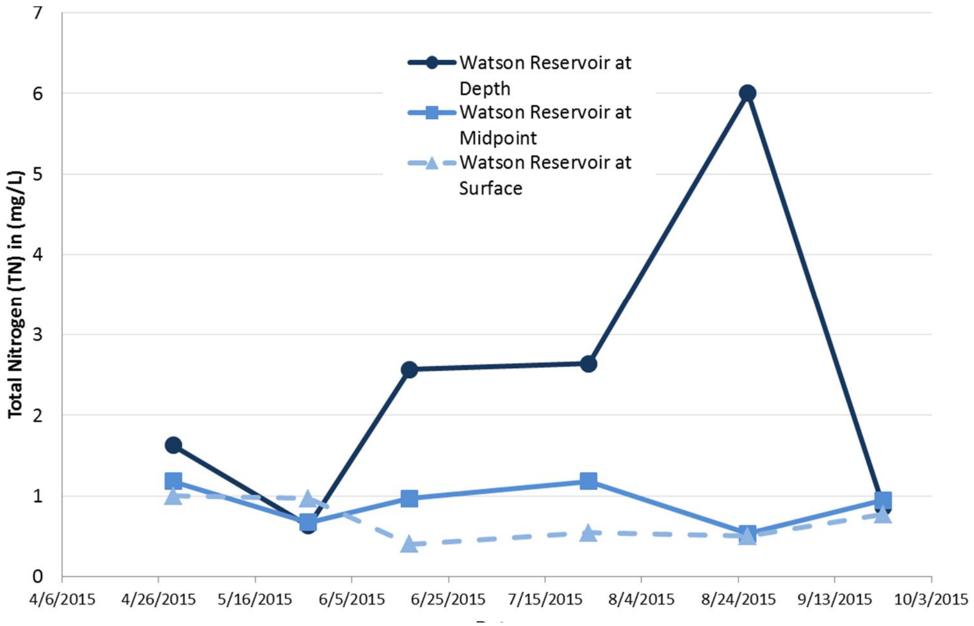


Figure 3.5 TN Concentrations in Watson Reservoir

DO profiles at the early, mid- and late-season sampling show the significant gradient that develops in the summer, leading to anoxic conditions at depth in Watson Reservoir. Later in the fall, the reservoir becomes mixed, but DO concentrations remain lower than in the spring. (Figure 3.6)

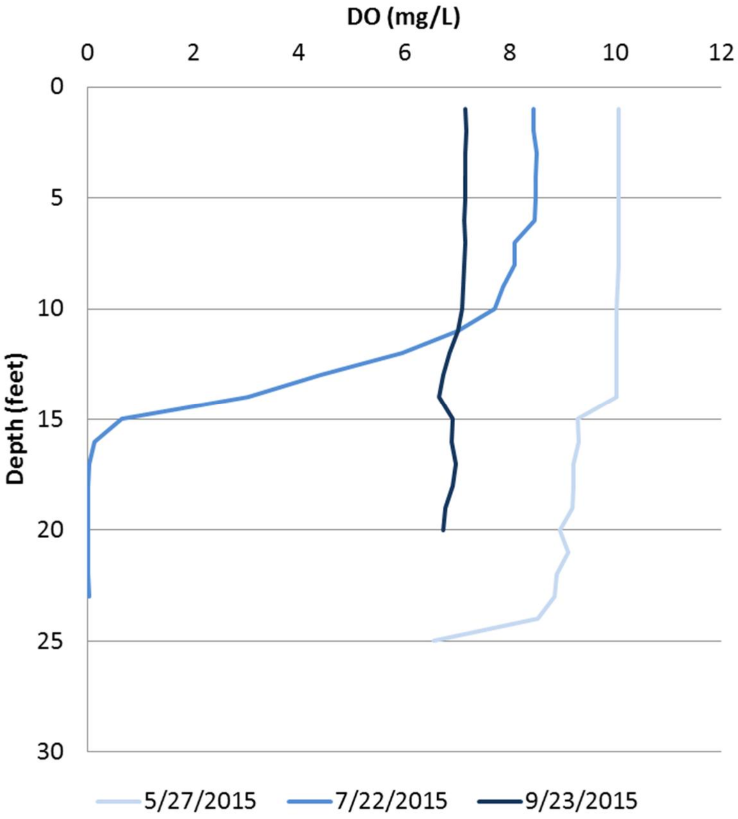


Figure 3.6 DO Profiles in Watson Reservoir

TP concentration is sediment samples collected from Watson Reservoir (Figure 3.7) in June 2015 were 1170 mg/kg, 1100 mg/kg, and 864 mg/kg. These values are higher than the TP concentration reported (91 mg/kg) for the one sample collected by RIDEM in Spring 2014. The lowest sediment TP concentration was measured in sediment collected from the easternmost sampling site in the reservoir. Available sediment phosphorus (P), which is the sum of loosely-bound and iron-bound P, is elevated but not atypical, ranging from 372.6 mg/kg to 552.2 mg/kg. Both solids and organic content are moderate and consistent across sampling locations, with percent solids ranging from 21.5 to 33.2 percent and organic matter ranging from 17.5 to 36.4 percent.

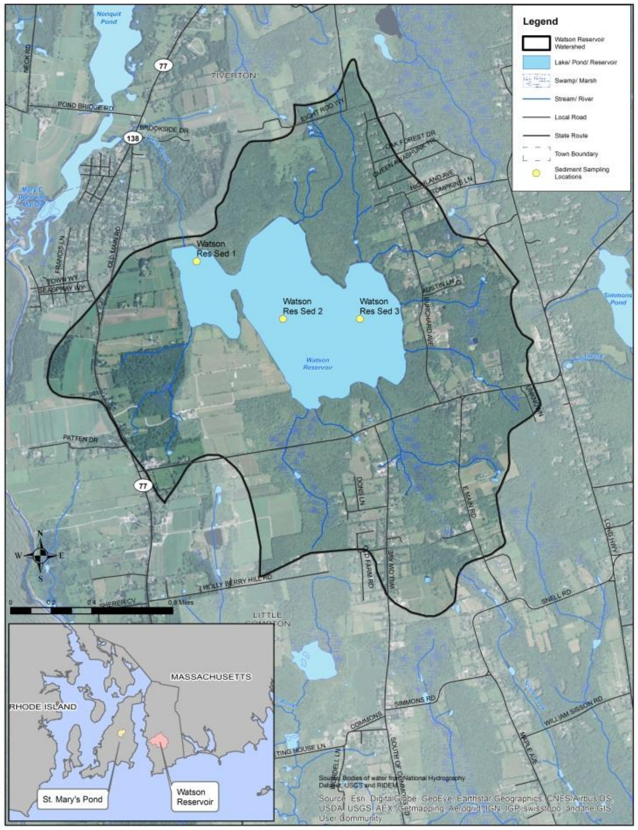


Figure 3.7 Sediment Sampling Locations in Watson Reservoir

St. Mary's Pond and Watershed

Water quality sampling consisted of in-lake sampling only since field reconnaissance in the spring of 2015 did not reveal any perennial tributary streams. TP and TN concentrations show higher values than those observed in samples collected from Watson Reservoir, which is consistent with findings of other studies of the two waterbodies. TP values tend to increase with depth and peaked in August when bottom values reached 3.8 mg/L. Like Watson Reservoir, all samples collected had TP concentrations greater than 0.01 mg/L and samples collected in July, August, and September had TP concentrations greater than the reference value of 0.08 mg/L, indicating generally elevated TP concentration in the pond and conditions capable of supporting algal blooms. (Figure 3.8) TN concentrations also increased with depth, with the highest concentration observed at depth in July, and all values exceeded the ecoregion reference value of 0.32 mg/L. Average TN concentrations over the study period were 1.19 mg/L at the surface and 2.2 mg/L at depth (Figure 3.9)

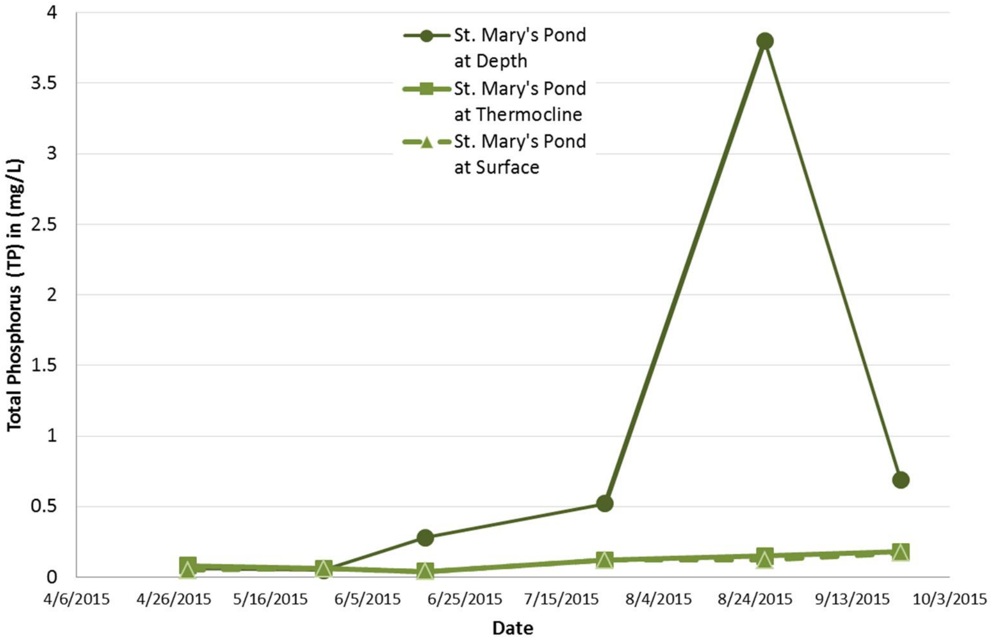


Figure 3.8 TP Concentrations in St. Mary's Pond

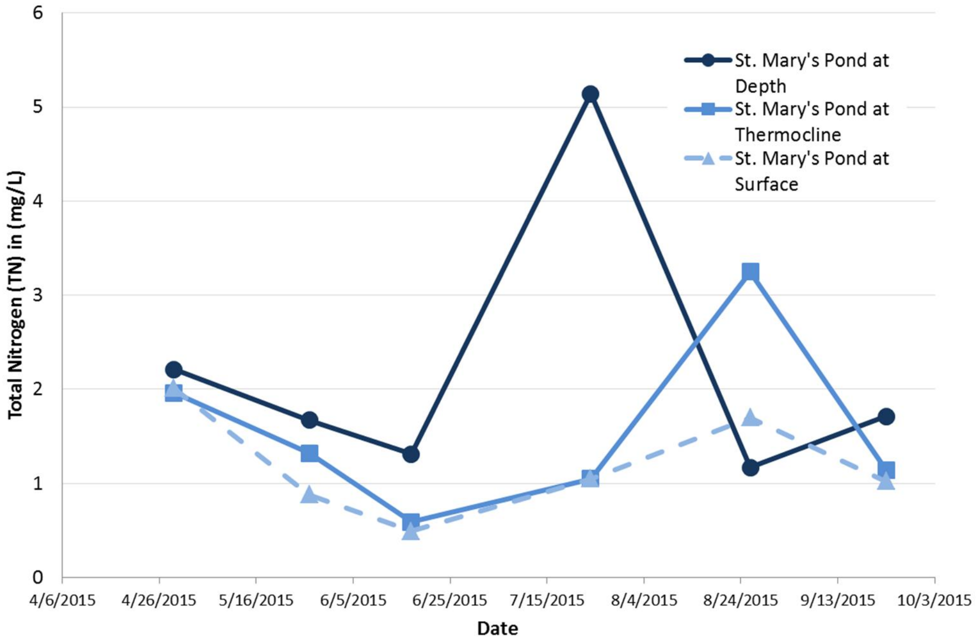


Figure 3.9 TN Concentrations in St. Mary's Pond

The shallowness of the pond, combined with the aerators in the sampling area, likely contributed to the relatively uniform DO profile throughout the sampling season. Although temporal changes in DO were observed, with the lowest DO values present in mid-summer, little variation in DO with depth was observed and no anoxic measurements were recorded during the 6 sampling events (Figure 3.10).

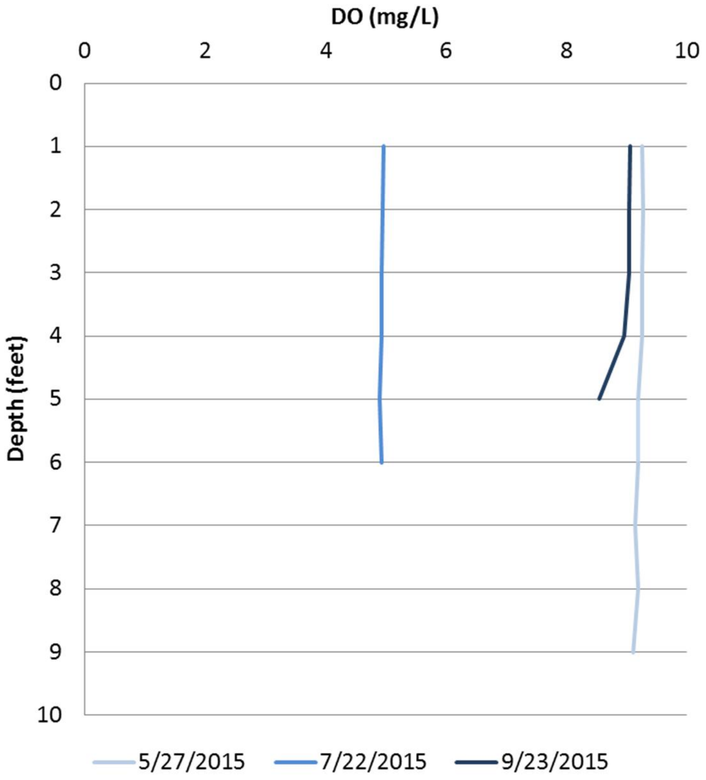


Figure 3.10 DO Profiles in St. Mary's Pond

Sediment TP concentrations in St. Mary's Pond were similar to Watson Reservoir and range from 1010 mg/kg to 1920 mg/kg. These values differ from data collected by RIDEM in 2014 in that Watson and St. Mary's have similar TP concentrations (St. Mary's was three times higher in the RIDEM samples) and are also higher in magnitude. Interestingly, the available sediment P ranges from 547. 8 mg/kg to 960.1 mg/kg and is relatively high and also greater in magnitude than available sediment P observed in Watson Reservoir, a result which would be consistent with the differences between St. Mary's Pond and Watson Reservoir observed in the RIDEM sediment samples. As in Watson Reservoir, both solids and organic content are moderate and consistent across sampling locations, with percent solids ranging from 23.4 to 33.4 percent and organic matter ranging from 20 to 23.1 percent.

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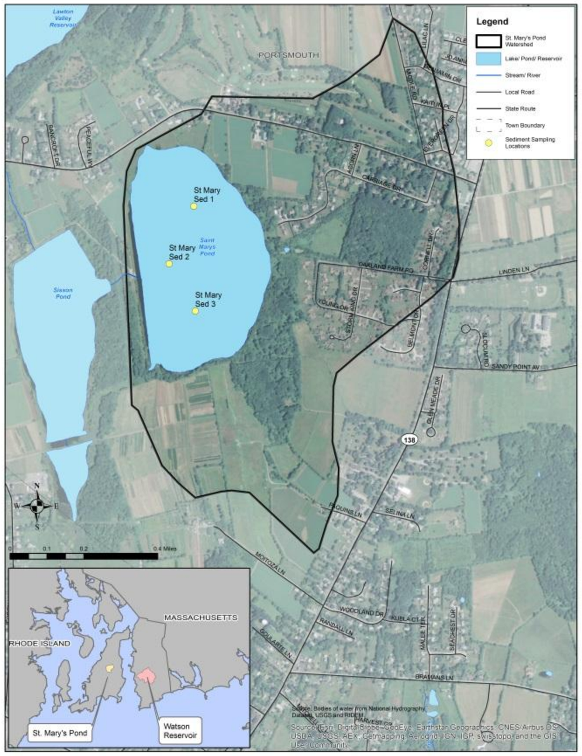


Figure 3.11 Sediment Sampling Locations in St. Mary's Pond

Conclusions

Both historic water and sediment quality data for Watson Reservoir and St. Mary’s Pond and data collected as part of this study indicated TP concentrations in the waterbodies that are above desirable concentrations, typical for meotrphic and eutrophic waterbodies, and have the potential to support algal blooms. This finding is consistent with the designation by RIDEM of both waterbodies as impaired for fish and wildlife habitat due to elevated phosphorus concentrations. TP concentrations in sediment, and available sediment P, are elevated in both waterbodies, indicating the potential for release of P from bottom sediment under appropriate conditions. In addition, tributary streams to Watson Reservoir have elevated TP and TN concentrations, indicating nutrient sources are present in the watershed and being discharged to the reservoir. Although no tributaries to St. Mary’s Pond were sampled, it is likely that elevated TP and TN concentrations would be found in surface water runoff to the Pond.

4 - Nutrient Sources

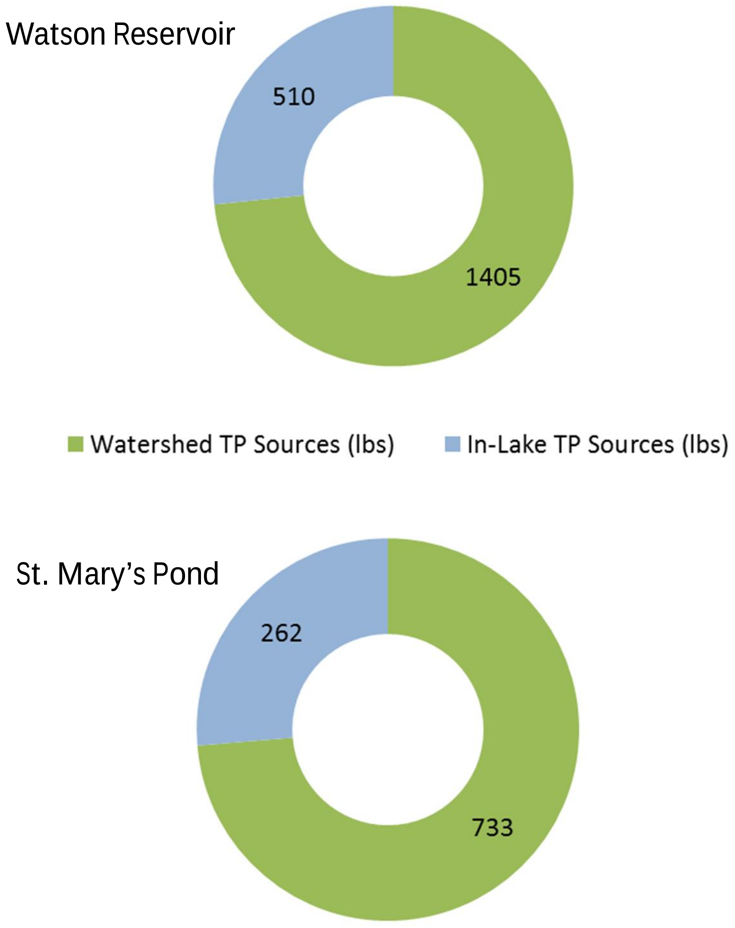


Figure 4.1 Relative Phosphorus Sources

Overview

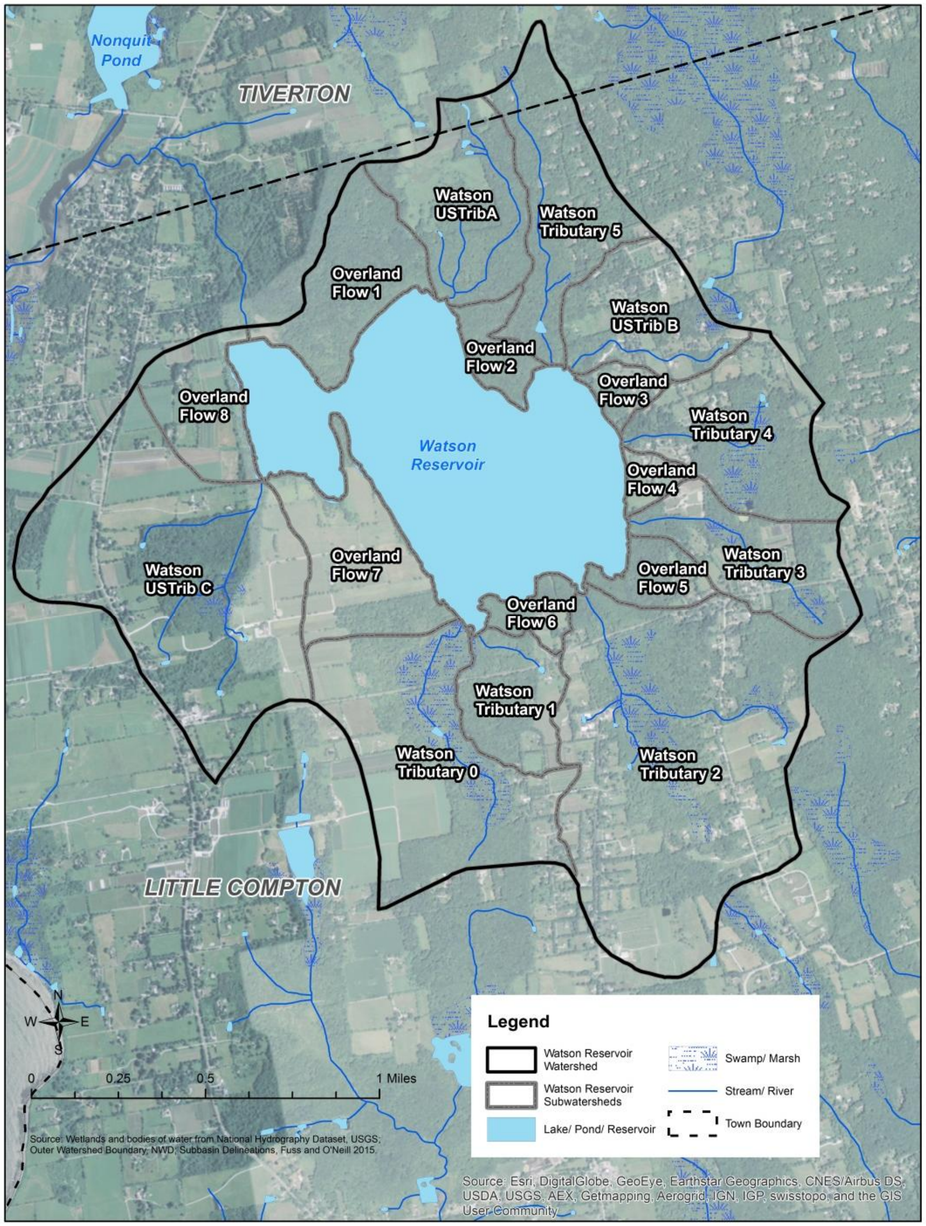
Sources of phosphorus to Watson Reservoir and St. Mary's Pond were assessed through a combination of field data collection and analysis and watershed modeling. Understanding the relative magnitude of sources is critical to identifying and prioritizing management actions to reduce nutrient contributions (also called nutrient "loading"). The assessment described in detail below indicated that external (watershed) sources are the primary contributor to loading in each waterbody compared to internal (in-lake sediment) sources (Figure 3.1).

The Watershed Treatment Model (WTM), developed by the Center for Watershed Protection, was used to estimate the annual load of total phosphorus (TP) to in the Watson Reservoir and St. Mary's Pond watersheds.

The basis of the WTM is a pollutant loading calculation developed by Schueler (1987) called the Simple Method. Based on user-specified input describing characteristics of the watershed, the WTM estimates total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), and fecal coliform bacteria (FC) loads from various land uses. Land uses modeled for the Watson Reservoir Watershed include: low and medium density residential (LDR and MDR), commercial, institutional, agricultural (cropland, pasture and orchards, groves, and nurseries) forest, rural, water, and wetland. Land uses modeled for St. Mary's include: low, medium, and high density residential (LDR, MDR, and HDR), institutional, developed recreation, agricultural (cropland and pasture), forest, rural, water and wetland. Residential, commercial, institutional, and similar developed land use classes were modeled using event mean concentrations (EMCs). Agricultural and other rural land use classes were modelled using annual loading rates and runoff coefficients

(Caraco, 2013). Runoff coefficients for Cropland and Pasture were taken from the Virginia Erosion and Sediment Control Handbook (Virginia Erosion and Sediment Control Handbook, 1980). (For details on Event Mean Concentrations and Runoff Coefficients see Technical Appendix D). Annual rainfall for the watersheds was estimated at 48.6 inches from data available for Tiverton, RI (U.S. Climate Data, 2015).

The Watson Reservoir and St. Mary's Pond Watersheds were divided into subwatersheds for the purposes of modeling. The Watson Reservoir watershed was modeled using 9 subwatersheds and 4 overland flow areas (Figure 4.2). Overland flow areas are areas within the watershed where runoff drains directly to the receiving waterbody, whereas runoff in subwatersheds flows to a stream that then discharges to the reservoir. Subwatershed boundaries for Watson Reservoir were determined using a combination of subwatersheds generated from the USGS tool Stream Stats and 2-foot elevation contours based on the 2011 LIDAR data (RIGIS). As discussed in Section 3, tributaries in six of the nine subwatersheds were sampled for water quality data during the spring and summer of 2015 (Figure 3.1). St. Mary's Pond atershed was modelled as 4 direct drainage areas, referred to as watershed



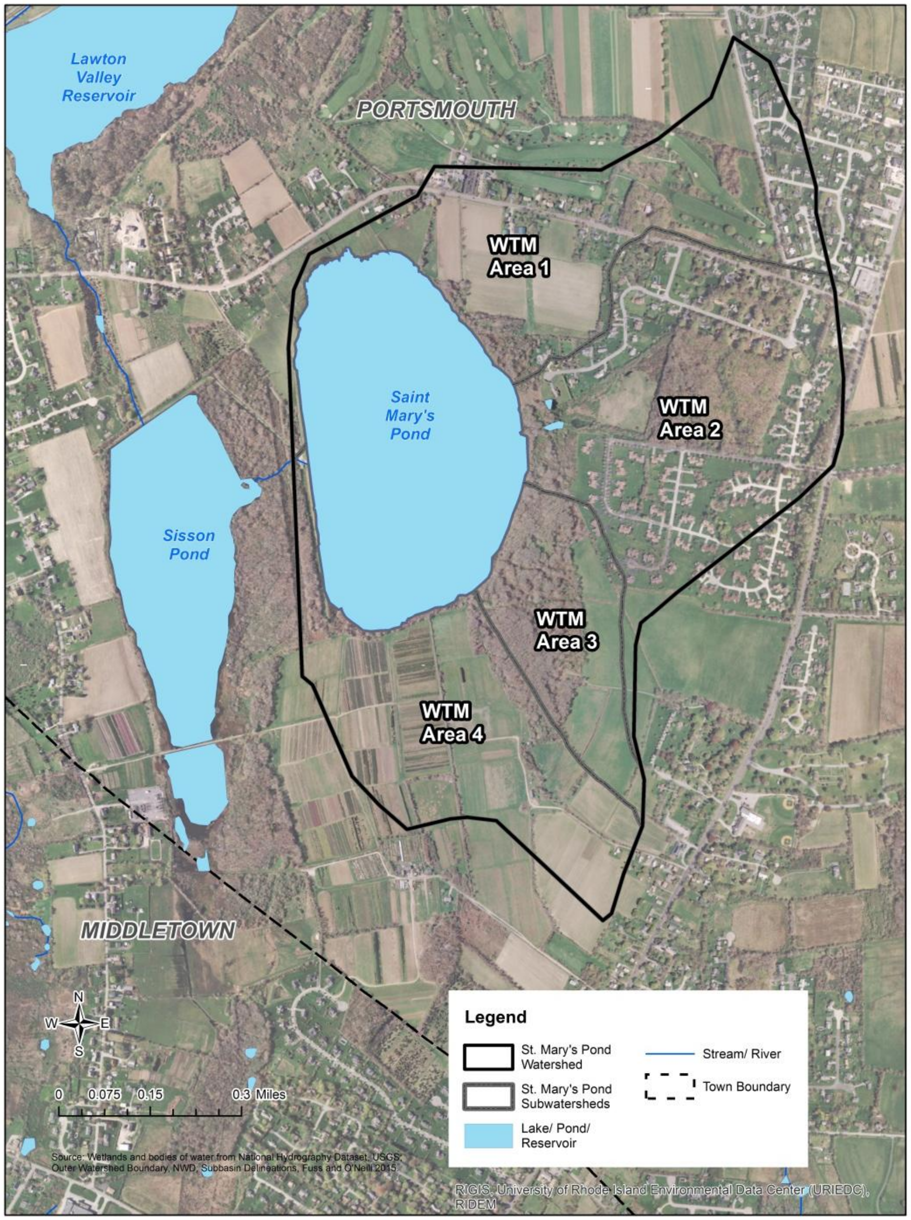
Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 4.2 Watson Reservoir Watershed

treatment areas in Figure 4.3. The watershed treatment areas were delineated based on the 2011 LIDAR data and inferred stormwater catchment areas reviewed in the field.

In addition to pollutants generated from land uses, the WTM estimates pollutant loads from other sources (secondary sources) that may be present, but are not necessarily associated with a particular land use. These secondary sources may include on-site sewage disposal systems (OSDS), sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), illicit connections, urban channel erosion, livestock, winter-time road sanding, and non-stormwater point sources. For both Watson Reservoir and St. Mary's Pond Watersheds, no public sewer system is present; therefore SSOs and CSOs are not part of the secondary load. Illicit connections to storm drains were assumed to be zero and urban channel erosion was set to zero. Factors affecting the loads calculated for OSDSs include distance from a reservoir or tributary, soil type, and density of residential development. To determine the number of residences within 100 feet of a water body, the National Hydrography Dataset of streams and surface water bodies was buffered by 100 feet and intersected with the E911 Layer available from RIGIS.



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015.

RIGIS, University of Rhode Island Environmental Data Center (URIEDC), RIDEM

Figure 4.3 St. Mary's Pond Watershed

(For additional information on model input, GIS data layers and assumptions refer to Technical Appendix D).

There are pastured cows in the St. Mary's Pond watershed; however, the loads associated with these animals are included in the pasture EMC values and were not calculated separately in the livestock section of the secondary loads spreadsheet. The livestock load calculations only apply to animals in feed lot situations. Winter time road sanding was estimated by calculating an application rate for road sand multiplied by the lane miles within the each watershed. TSS loads associated with road sanding are affected by not only the amount of impervious surfaces of the roadway (acres) but also the percentage of the road that is either open or closed. Open sections of roadway are those areas that do not have stormwater drains and catch basins that collect sand and other debris that wash off the pavement. A closed section is a section of roadway that drains directly to a storm drain with catch basin and conveys stormwater flows directly to an outfall. From field assessments of the Watson Reservoir Watershed there is only a small section of the watershed in the subwatershed associated with Tributary 5 where road runoff drains to catch basins. Residential sections of the St. Mary's Pond watershed in WTM areas 1 and 2 drain to stormwater drains/catch basins with outfalls that discharge upstream of St. Mary's Pond.

In addition to primary and secondary loads, the WTM model also estimates reductions and/or additions to pollutant loads based on management activities occurring within the watershed. These management practices may include turf management, pet waste education, erosion and sediment control at construction sites, street sweeping and catch basin cleanouts, existing best management practices (BMPs), and riparian buffers.

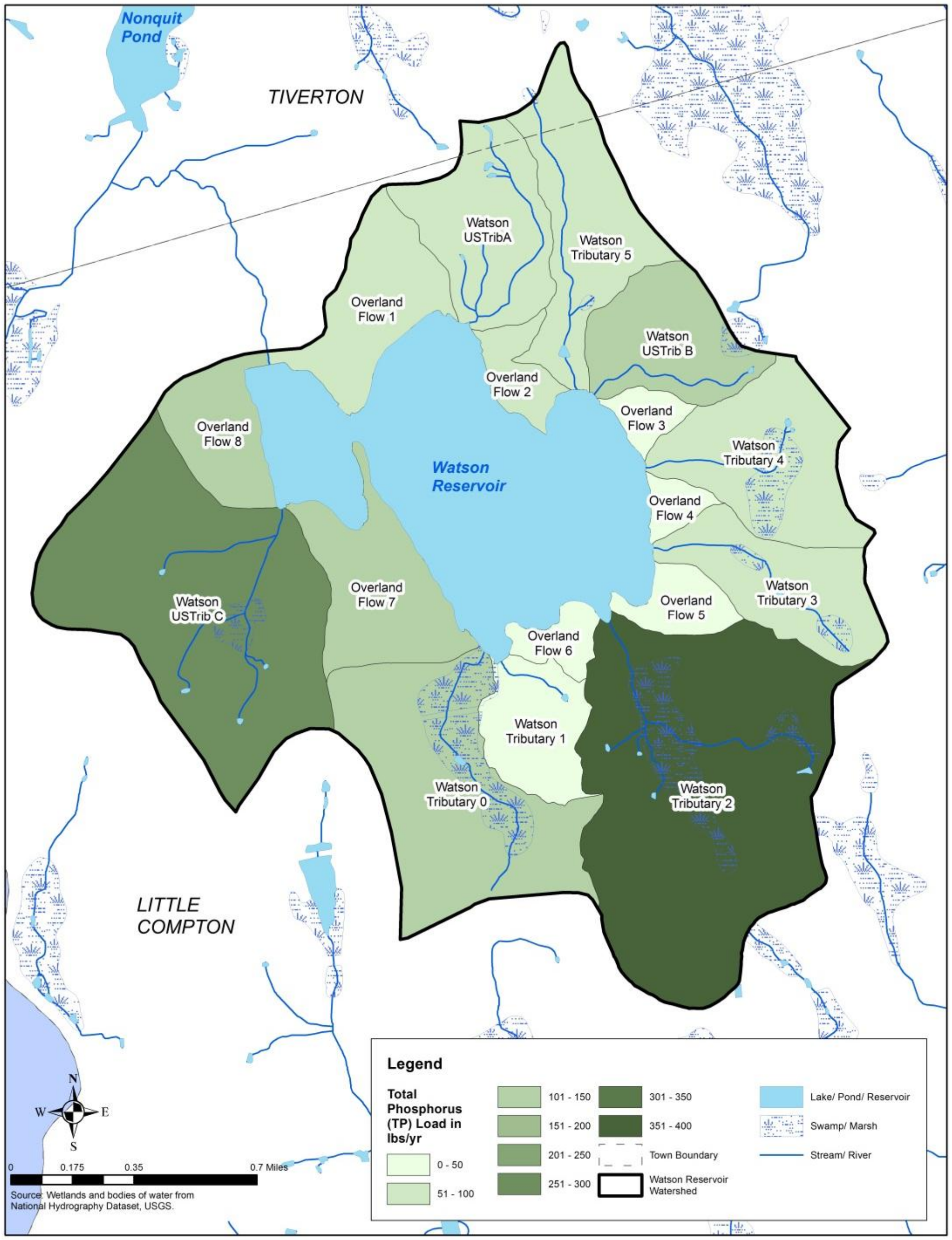
Existing management practices within the Watson Reservoir Watershed and St. Mary's Pond Watershed included existing forested areas modeled as vegetative buffers with a low maintenance factor, turf management in residential areas, and catch basin cleaning. Existing forested areas within each watershed either along the waterbody edge or tributary streams were estimated from the RIGIS Land Use/Land Cover data available from RIGIS. For additional details on model assumptions refer to Technical Appendix D.

When reviewing modeling results it is important to remember that the estimated loads are not calibrated to existing conditions since insufficient data exists to perform calibration and that the estimated loads do not incorporate any attenuation from sedimentation or biological processes as runoff and streamflow move through the watershed. As a result, they likely represent conservative estimates of nutrient loading in the watersheds.

Modeling Results – Loads and Yields

Watson Reservoir

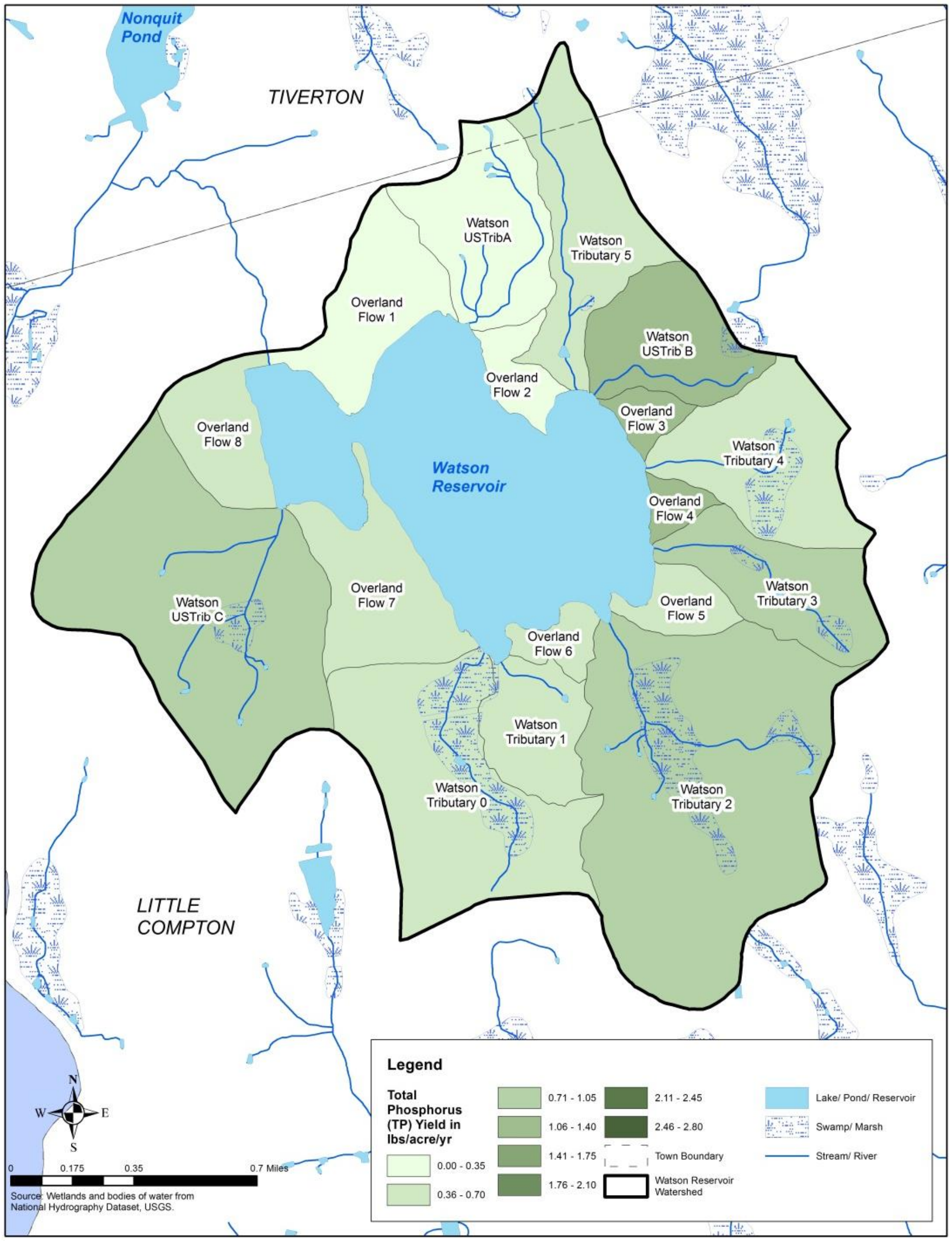
Existing Loads to Watson Reservoir are the sum of primary and secondary sources plus existing management practices, all of which are defined and described above. The estimated existing Total Phosphorus (TP) watershed load to Watson Reservoir is 1,405 lbs/year. Evaluation of TP loading by land use type shows that agricultural land uses (cropland, pasture, and orchard, groves, and nurseries) dominate the TP loading, accounting for approximately 40% of the TP from primary sources, with residential land uses accounting for an additional 30%. Total Phosphorus (TP) loads within the modeled subwatersheds range from 18 lbs/year (Overland Flow Area 4) to 408 lbs/year of TP (Watson Tributary 2). Estimated loads based on sampling data collected (see Section 2), show reasonable agreement with modeled results in the Tributary 3 and Tributary 4 subwatersheds, but are lower than the modeled results for the Tributary 2 subwatershed. The latter observation may be due to attenuation in the wetland system in the Tributary 2 subwatershed which is not accounted for in the WTM. Total Nitrogen (TN) Loads within the modeled subwatersheds range from 116 lbs/year (Overland Flow Area 4) to 2,802 lbs/year of TN (Watson Tributary 2).



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS.

Figure 4.4 Watson Reservoir Watershed Total Phosphorus Loads

Since the magnitude of a load is partially a function of subwatershed area modeled, in order to compare pollutants between the different subwatersheds a better estimate of the relative pollutant runoff is the yield, which is lbs/acre/year. TP yields are highest in some overland flow area adjacent to the watershed and lowest in some forested areas of the watershed (Tributary 0 subwatershed area areas in the northeast corner of the watershed). The average existing yield to the Watson Reservoir was 0.7 lbs/acre/year of TP, higher than the 0.1-0.2 lbs/acre/year estimated by the USGS SPARROW model for the region, and 6.1 lbs/acre/year for TN. The spatial distribution of yield values are similar for both TP and TN, and ranged from 0.2 to 1.3 lbs/acre/year for TP and 1.3 to 7.9 lbs/acre/year for TN in Watson Tributary A and Overland Flow Area 4, respectively.



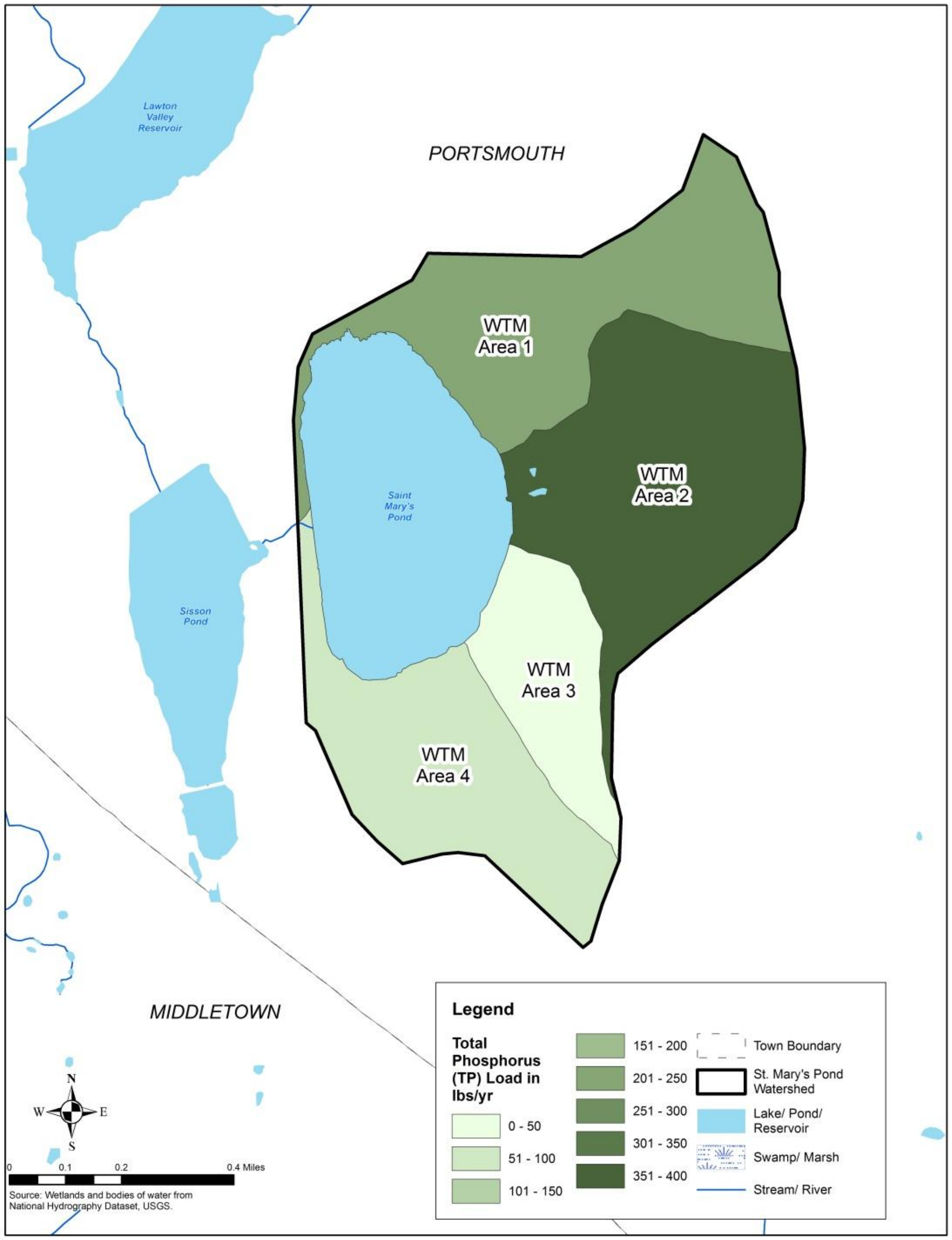
Source: Wetlands and bodies of water from National Hydrography Dataset, USGS.

Figure 4.5 Watson Reservoir Watershed Total Phosphorus Yields

St. Mary's Pond

As with Watson Reservoir, existing loads to St. Mary's Pond are the sum of primary and secondary sources plus existing management practices. Existing loads to St. Mary's Pond are 733 lbs/year of TP and 4,358 lbs/year of TN. In St. Mary's Pond watershed, residential land use dominates the phosphorus loading at nearly 63% of the existing phosphorus load by land use. Total Phosphorus (TP) loads within the modeled subwatersheds range from 33 lbs/year (WTM Area 3) to 399 lbs/year of TP (WTM Area 2).

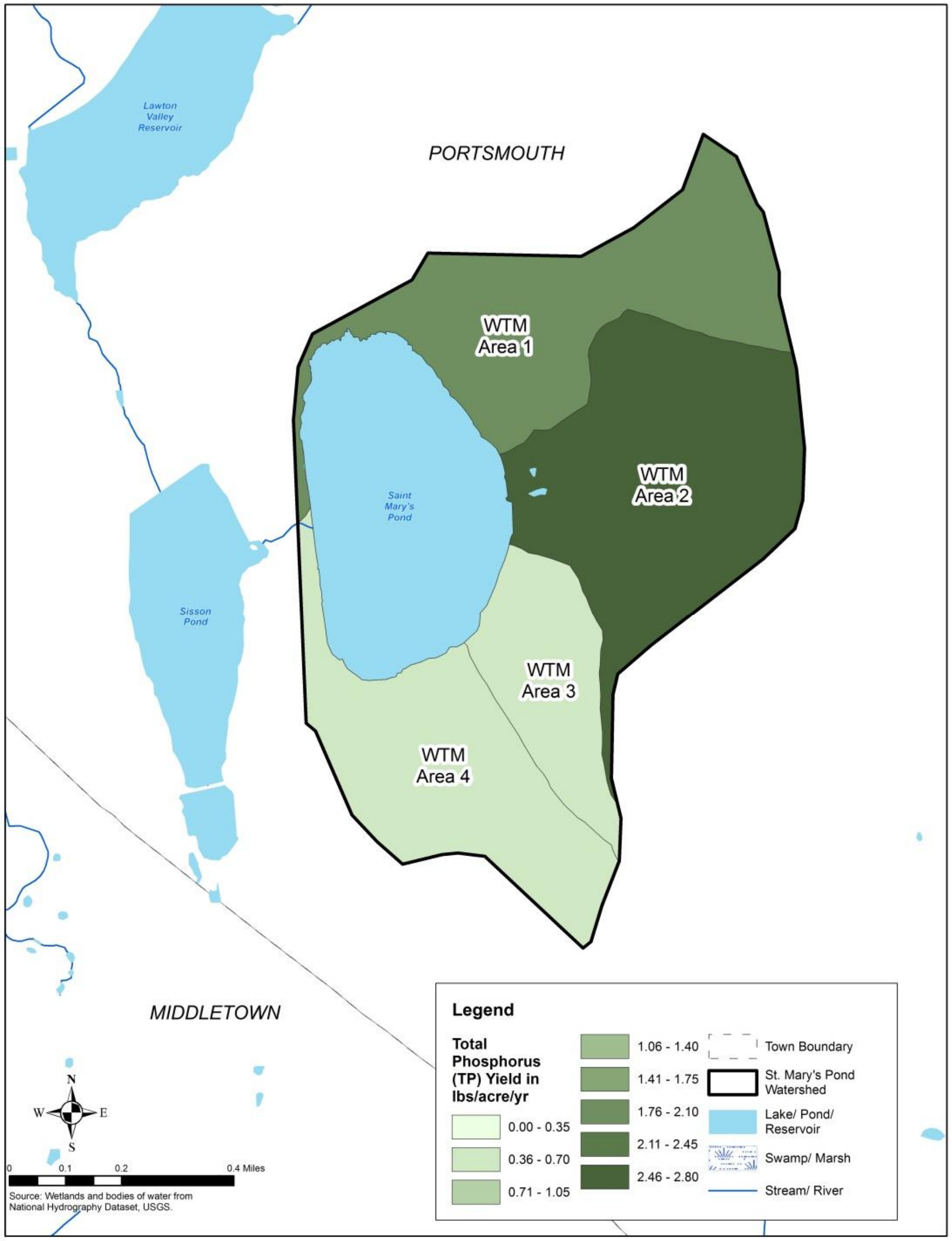
The highest loads and yields are observed in WTM Area 2, the area containing the residential subdivisions at Carriage Drive and Oakland Farms. WTM Area 1, the subwatershed along Union Street, including the Green Valley Country Club golf course, has the second highest estimated load and yield. TP yields estimated by the USGS SPARROW model for the region estimate watershed-wide TP yields of 0.1-0.5 lbs/ac/yr. Although these values are lower than those observed in WTM Area 1 and 2, they are closer to values estimated by the WTM for subwatershed Areas 3 and 4 (0.6 lbs/acre/yr), which are dominated by agricultural land and forest. Total Nitrogen (TN) loads within the modeled subwatersheds range from 363 lbs/year



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS.

Figure 4.6 St. Mary's Pond Watershed Total Phosphorus Loads

(WTM Area 3) to 1,562 lbs/year of TN (WTM Area 2) and follow a similar spatial pattern as the TP loads and yield.



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS.

Figure 4.6 St. Mary's Pond Watershed Total Phosphorus Yields

Internal Nutrient Loading

During winter and spring thermal stratification, when any mixing is limited to surface waters, the lower waters of a lake (hypolimnion) can become anoxic due to chemical and biological activity associated with the breakdown of organic matter by microbes (Wetzel, 1983). This can also occur right at the sediment-water interface of shallow lakes during calm conditions as releases have been documented in waters as shallow as 20 cm (Søndergaard et al., 2013). In anoxic conditions, sediments that have acted as a nutrient sink with oxygen present will release P into the lower waters that may eventually influence the productivity of the upper waters through mixis. Parameters such as organic content, and content of iron (Fe), aluminum (Al), manganese (Mn), calcium (Ca), clay and other elements with the capacity to bind and release phosphorus (P) may all influence sediment–water interactions and determine the amount of P released (Søndergaard et al., 2003). Forms of mobile P, consisting of the loosely-sorbed and Fe-P redox sensitive fractions, are most likely to contribute to internal P loading (Pilgrim et al. 2007) thus the sediment samples for this study were analyzed for total, loosely-sorbed and Fe-bound P fractions.

There are 4 different ways to estimate internal phosphorus load for a lake (Holdren et al., 2001): 1) Net (and gross) estimates from an extensive phosphorus budget through mass balance of inflows, outflows and internal fluxes on an annual basis. This requires at least monthly measurements of P entering the waterbody, P leaving the waterbody and the P concentration and volume of each lake strata (epilimnion, metalimnion and hypolimnion); 2) Partially net estimates from in-situ P increases accumulating in the hypolimnion during summer; 3) Partially net estimates from the in-situ P increases at fall turnover. Both Method 2 and Method 3 above are usually overestimates in that they do not account for all settling and sediment sequestering that will occur at and after the sediments become oxic. 4) Gross estimates from measured or estimated sediment phosphorus release rates and the measured or estimated anoxic area and time (i.e., the anoxic factor of Nürnberg 1988). With the scope of this study limited to spring through fall sampling, Method 2 was selected as the best approach to estimate internal nutrient loading.

With sampling dates covering late April through late September (see Section 3), post-spring mixis through fall turnover conditions were monitored. This allowed for documenting the accumulation of nutrients in the lower waters as they became anoxic and also allowed for insight into how much of the gross internal load was settled and sequestered. In the 6 months of sampling in 2015, anoxia occurred in the bottom waters on two sampling dates: July 22 and August 26. Dissolved oxygen profiles allowed for the calculation of anoxic areas and volumes using the GIS bathymetry data (See Technical Appendix C). Gross internal P load was determined by calculating the hypolimnetic load as the difference in concentration between the bottom water and upper water TP for the measured anoxic water volume (as concentration * volume = load) divided by the relative volume of the anoxic zone to the oxic lake volume. It was assumed the winter internal load for St Mary Pond and Watson Reservoir were negligible given the low spring P concentrations measured and most other studies have found this also to be the case as P release is reduced in low temperatures (Nürnberg et al., 2013).

For Watson Reservoir, the gross internal load was calculated as 320 lbs P by July 22 increasing to 457 lbs P by August 26. The anoxic lake volume extended to about 20 percent of the lake in late July and 28.5 percent in late August. As the net load is typically 28 to 50 percent of the gross loading (Cooke et al., 1993) and given that there was a reduction of TP concentration from 420 ppb to 200 ppb in the hypolimnion of Watson from late August to late September, this suggests at least a 53 percent retention factor (possibly more) that would predict the net internal loading of about 218 lbs P which comes to approximately 13.4 percent of the total annual load (the majority of the TP load for Watson Reservoir load coming from external sources). Checking these calculations using Method 4 (above) and using equations in Nürnberg et al. (2012) yielded an estimate of 41 days of anoxia in Watson Reservoir and an anoxic factor 23.8 days. Using estimations of sediment release rates based on regressions from Nürnberg (1988) and the average iron-bound TP in the Watson Reservoir sediment analyses results in a rate of 6.5 mg P/m^3 day. Multiplying the anoxic factor by the sediment release rate and the area of the lake results in a gross internal loading estimate of 510 lbs TP that compares well to the 457 lbs calculated from the hypolimnetic measurements.

Estimation of internal loading in St. Mary’s Pond is more challenging given its very shallow depth (mean of 6.2 feet) and connection with other waterbodies including input from Watson Reservoir. In addition, most sampling was done within the area where aerators are in use and thus much of the water column in that area is destratified. Only a very small volume of water was assumed to be anoxic (essentially the water just at the sediment water interface and possibly up to a foot above). While Watson had a moderate iron (Fe) to TP ratio indicating TP could be bound and sequestered, the ratio in the St. Mary’s Pond sediments was low. In addition, current and historical use of copper sulphate for algae control has most likely contributed sulphur to the sediments that can compete with P binding to Fe. From the sediment analyses results, it appears that St. Mary’s Pond has a higher TP release rate than Watson Reservoir, 10.7 vs 6.5 mg P/m^3 day.

Using the in-situ bottom TP method as was done for Watson Reservoir, the internal gross loading for St. Mary’s Pond was estimated at 115.5 lbs TP which represents only 13.6 percent of the annual loading. Using the fall turnover method (Method 3 above) however yields a gross estimate of 262 lbs P which would represent a more reasonable 26 percent of the annual P load to the lake. Unlike Watson Reservoir, St. Mary’s Pond TP concentration stayed very high in the bottom waters even in late September and both mid-lake and surface TP concentrations increased significantly, indicating very low P settling and retention. Thus, the 262 lbs estimate should not be reduced by any factor given these circumstances. This may still be an underestimate of loading, since measurements were not taken in the non-aerated sections of the lake. It should also be noted that whole lake TP flux from month to month during the June through September period was quite dynamic with very high lake-wide TP mass by late August that was significantly reduced in September.

Overview

Nutrient management strategies can be broadly placed into two categories – watershed management and in-lake management. As illustrated in Figure 5.1, phosphorus sources to a waterbody consist of three major components:

- Atmospheric deposition
- External contributions (or “loading”) from the watershed
- Internal contributions from bottom sediments in the waterbody.

Of those sources, external loading from the watershed and internal loading from bottom sediments are the two that can be managed. Atmospheric deposition is part of larger regional concerns and cannot be controlled at the watershed scale. While addressing both internal and external nutrient contributions are important for the long-term protection of water quality, the prioritization of management recommendations for these two sources differs from one waterbody to the next. The relative contribution of loading from each source is an important consideration. In addition, without watershed management to control external loading, nutrients delivered to the waterbody will become part of the internal loading. Consequently, controlling external loading from watershed sources is always an important element to increase the longevity of effectiveness of any in-lake management actions.

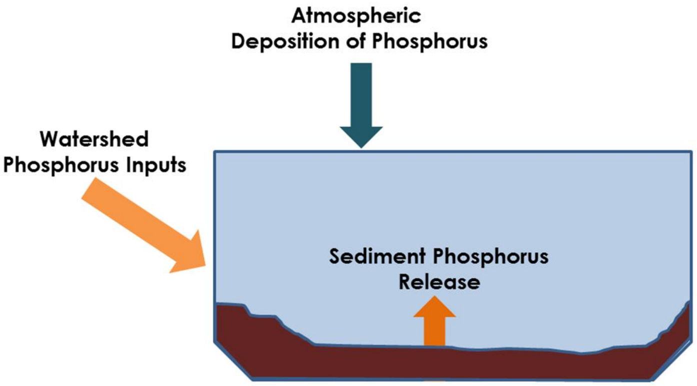


Figure 5.1 Phosphorus Sources

Watershed Best Management Practices

Best Management Practices (BMPs) are methods, structures or techniques that have been identified to be the most practical and effective means to prevent or treat pollution before it reaches a waterbody. BMPs can be both structural, such as an infiltration systems, and non-structural, such as a public education program aimed at cleaning up after pets. BMPs can be tailored to specific audiences, sites or pollutants of concern depending on individual site constraints and are typically recommended in combination to maximize positive impacts. Both types of management strategies were considered in this study.

While there is a large universe of BMPs, this project focuses on those management practices that most effectively address nutrient removal and are best suited for the individual activities and physical conditions of these two watersheds. The pool of potential BMPs was narrowed using a combination of modeling and water quality sampling information, field reconnaissance, and information on soils, land use and ownership. The summary Tables 5.1 and 5.2 outline the environmental benefits of the BMPs (e.g., water quality, habitat, etc.) considered while also identifying some of the limitations associated with each practice. Overall implementation cost and maintenance requirements, where applicable, were also evaluated and included in the summary tables.

Table 5.1 Non-Structural Best Management Practices

Type	Description	Water Quality Benefits			Opportunities	Limitations	Cost
		Nutrients	Sediment	Bacteria			
Riparian Buffer 	A riparian buffer is a vegetated area adjacent to a water body, usually forested, which helps shade and partially protect it from the potential impacts of adjacent land uses. It plays a key role in reducing the negative effects of stormwater and can help to improve water quality in associated streams, rivers, and lakes.	●●●	●●●	●●●	Funding and technical support through the Natural Resource Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) Riparian buffers, regardless of width, can provide excellent habitant enhancement benefits for multiple species of plants, insects and animals.	May require land acquisition which can be expensive. Buffer efficiency is directly tied to buffer width for both nutrient and sediment removal efficiency. Sweeney and Newbold (2014) suggest buffers be >30m in width to protect physical, chemical and biological integrity of small streams.	$$$
Nutrient Management (fertilizer, manure, irrigation) 	Nutrient Management programs aim to manage the amount, source, placement and timing of fertilizers, manure, and soil amendments to agricultural landscapes in order to minimize cost and protect natural resources.	●●●	●●	●	Funding and technical support through: -NRCS EQIP Program -RCPP-regional Conservation Partnership Program -NRCS Agricultural Management Assistance Program (AMA)	Requires "buy-in" from property owner(s) to be effective. A proper Nutrient Management Plan typically involves soil testing which can increase overall cost.	$$$

Type	Description	Water Quality Benefits			Opportunities	Limitations	Cost
		Nutrients	Sediment	Bacteria			
Street Sweeping 	Street sweeping is a BMP that has been implemented for some time as a requirement of NPDES programs. There have been some more recent studies suggesting that more frequent sweeping and the type of equipment used to complete the sweeping can have additional positive effects while offering a cost-effective means to improve stormwater quality.	●●	●●●	●●	Can improve neighborhood aesthetics. Target more frequent sweeping (and catch basin cleaning) in areas of heavier sediment accumulation.	Increasing the frequency of sweeping will have obvious impacts on overall program cost. The type of sweeper has shown to have an effect on overall removal efficiency. Vacuum-assisted and regenerative air sweepers have been found to be more effective. These sweepers are not as common as mechanical sweepers and are typically more costly.	$$
Residential Education (Lawn Care, Pet Waste Management, Septic Maintenance) 	Residential educational programs can be extremely cost effective mechanisms to reach out and help change behaviors that have a negative impact on water quality. Programs can have several messages but the most common typically involve pet waste management, septic system maintenance and lawn/turf management.	●●●	●	●●●	Opportunities for targeted campaigns exist where pet licensing is a requirement. Can improve neighborhood aesthetics.	Hard to quantify any improvements due solely to a pet waste management program. Requires public buy-in to be effective. Can require frequent maintenance (i.e., waste disposal, refreshing waste bag stations).	$

Key for Table 5.1

	Water Quality Benefits	Construction Cost
High	●●●	$$$
Medium	●●	$$
Low	●	$

Table 5.2 Structural Best Management Practices

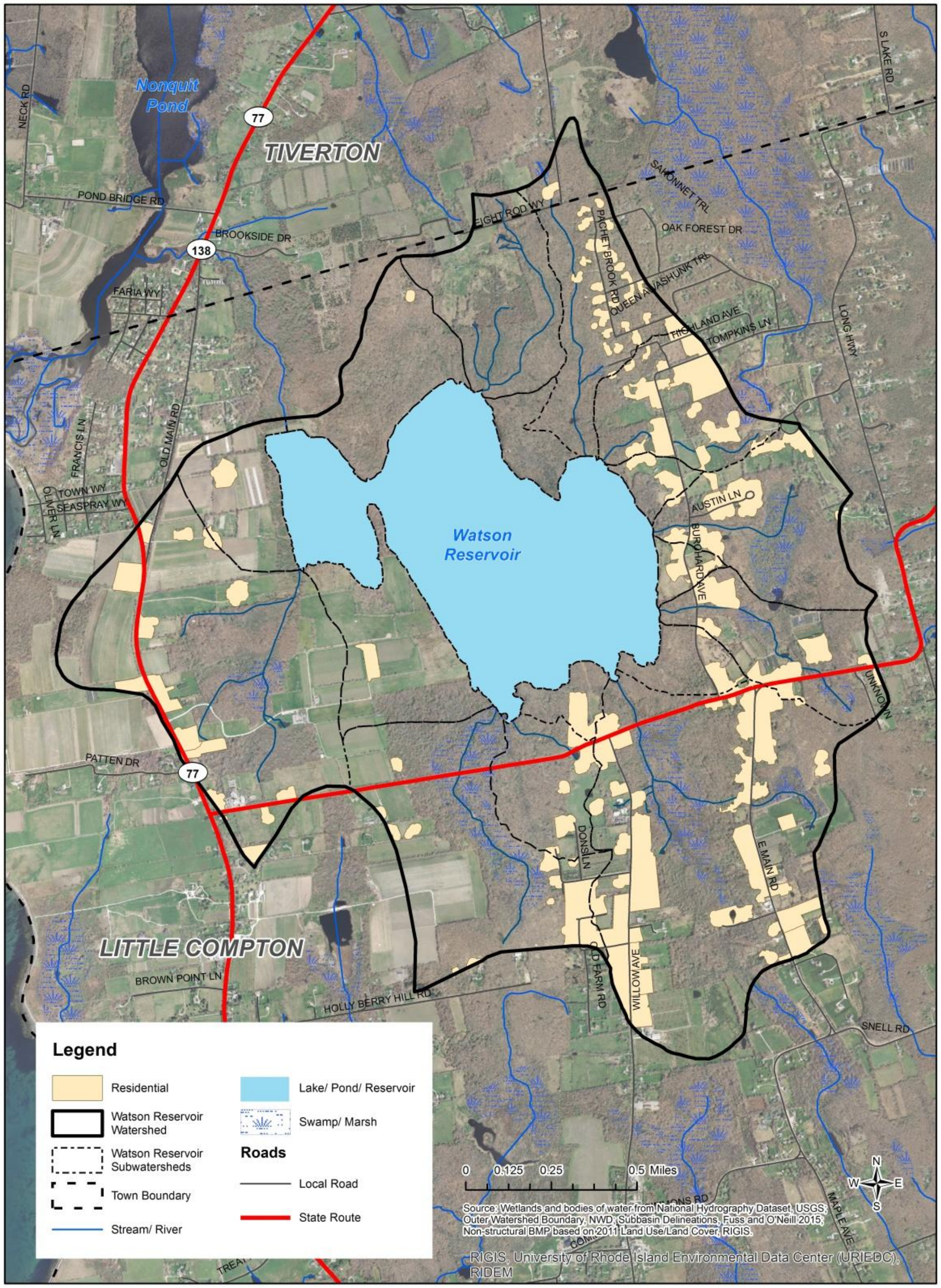
Type	Description	Water Quality Benefits				Opportunities	Limitations	Cost	Maintenace
		TP	TN	TSS	Bact				
Infiltration/Filtering Practices	Infiltration practices store the water quality volume (WQV) in the void spaces of a trench or open chamber before it is infiltrated into underlying soils. Filtering practices treat stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a surface or underground media matrix.	●●●	●●	●●	●●●	Funding opportunities may exist through the Section 319 Grant program, as well as other local grant programs that target stormwater BMPs.	Infiltration practices are ideally located in areas with highly permeable soils (infiltration rates of >0.5 in/hr). Typically requires separation from seasonally high ground water. Ideally not placed under pavement or concrete for easier maintenance.	$$$	🪏🪏🪏
Wet Vegetated Treatment Systems (WVTS)	A surface wet stormwater basin that provides water quality treatment primarily in a shallow vegetated permanent pool. A wet stormwater basin that provides water quality treatment primarily in a wet gravel bed with emergent vegetation.	●●●	●●●	●●	●●●	Funding opportunities may exist through the Section 319 Grant program, as well as other local grant programs that target stormwater BMPs. Wetland systems can provide both aquatic and terrestrial habitat improvements.	Requires contributing drainage areas of 5-10 acres. Substrate needs to be maintained in a saturated condition which means this practice is best in areas with a high water table and a shallow depth to groundwater. Due to sizing requirements, this practice typically requires a larger amount of available space than other practices which could restrict siting.	$$	🪏🪏

Type	Description	Water Quality Benefits				Opportunities	Limitations	Cost	Maintenace
		TP	TN	TSS	Bact				
Linear Bioretention	Linear bioretention, or open channel systems, are vegetated open channels that are explicitly designed to capture and treat the full WQV within dry or wet cells formed by check dams or other means. These include both Dry and Wet Swales.	●●●	●●●	●●	●●	Funding opportunities may exist through the Section 319 Grant program as well as other local grant programs that target stormwater BMPs. Wet Swales can also provide some habitat benefits.	Grass species selected for Dry Swales need to be appropriate for the environmental setting and be able to withstand high velocities at times along with inundation. Little habitat benefit unless the channel is designed as a Wet Swale Wet Swales provide more phosphorus removal than Dry Swales.	$	🪏

Key for Table 5.2

	Water Quality Benefits	Construction Cost	Maintenance Requirements
High	● ● ●	$$$	🪏🪏🪏
Medium	● ●	$$	🪏🪏
Low	●	$	🪏

Opportunities for both structural and non-structural BMPs exist in the Watson Reservoir and St. Mary's Pond watersheds. Figure 5.2 and Figure 5.3 identify areas in the watersheds where opportunities for Residential Education exist. Residential land use comprises a relatively small percentage (14 percent) of the Watson Reservoir watershed, but educating residents about lawn care, pet waste practices, and septic system maintenance is estimated to potentially reduce annual TP loads by 85 lbs and TN loads by 401 lbs (6 percent of the overall existing watershed TP and TN loads) if education was to be conducted at all residential areas throughout the watershed. In the St. Mary's Pond watershed where residential land use is nearly one-third of the watershed, the potential for annual TP and TN load reduction is 50 lbs (7 percent) and 241 lbs (6 percent), respectively.



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015; Non-structural BMP based on 2011 Land Use/Land Cover, RIGIS.

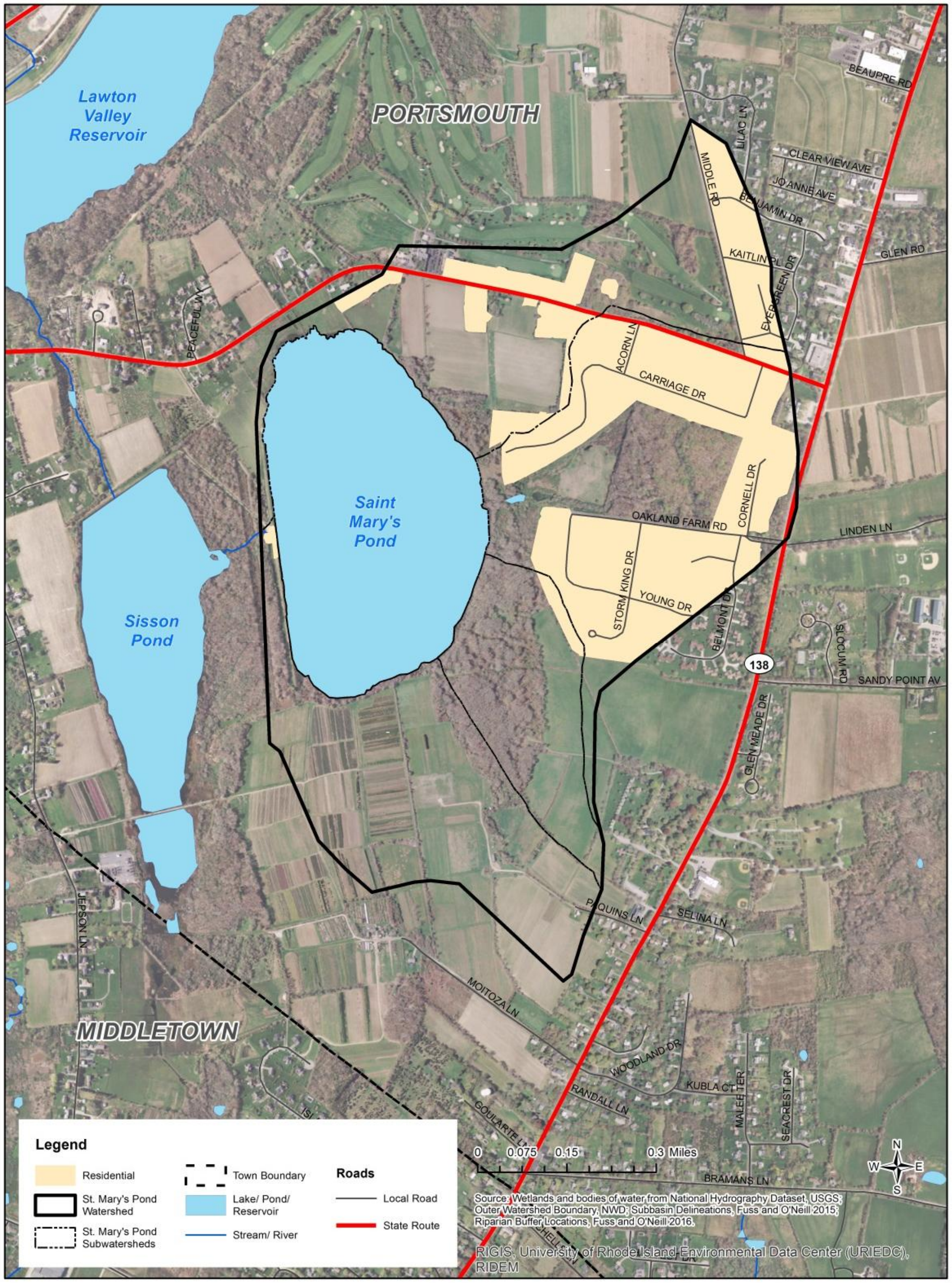
RIGIS, University of Rhode Island Environmental Data Center (URIEDC), RIDEM

Figure 5.2 Residential Education Opportunities Watson Reservoir Watershed

Table 5.3 Estimated Nutrient Reduction from Residential Education – Watson Reservoir Watershed

Residential Education Management Practice	Total Phosphorus Reduction (lbs/yr)	Total Nitrogen Reduction (lbs/yr)
Septic System Maintenance	6	37
Lawn Care	77	351
Pet Waste Disposal	2	13
Total	85	401

Education programs tend to be cost-effective for nutrient reduction and also increase overall awareness and support for other actions (including installation of structural BMPs) to improve water quality throughout the watershed. Costs for residential education programs can vary widely, and because of this, cost-effectiveness is often not included for education programs (e.g., DNREC, 2012), but work in the James River watershed in Virginia provides an approximate cost-benefit for pet waste education of $3.36/lb of TP removed and Versar (2011) found residential lawn care education in the Patuxent River watershed in Maryland to be a cost-effective BMP for TP removal at $272/lb. A combined pet waste and lawn care education program in the Great Seneca Creek watershed in Maryland



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015; Riparian Buffer Locations, Fuss and O'Neill 2016.

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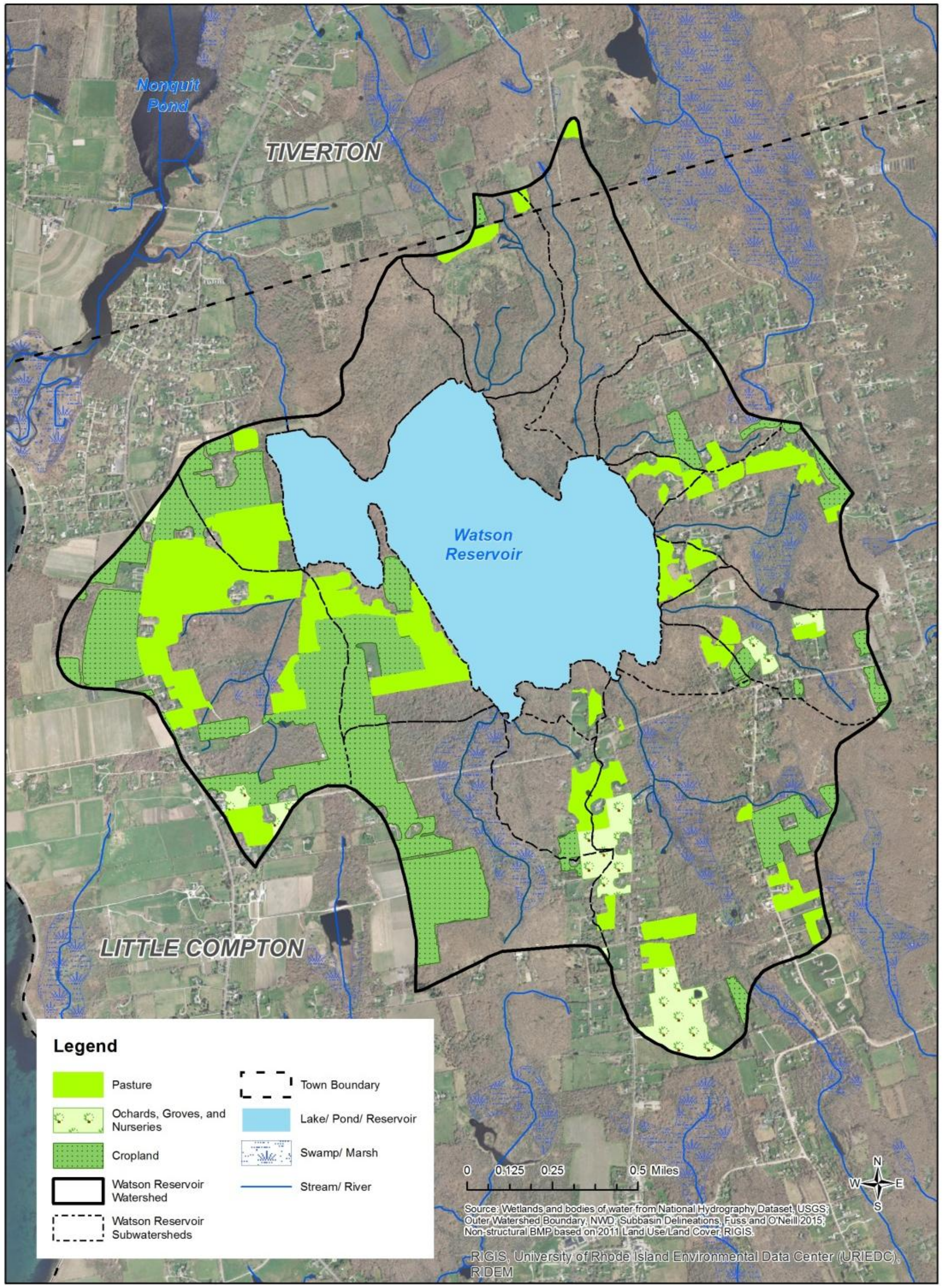
Figure 5.3 Residential Education Opportunities St. Mary's Pond Watershed estimated the cost per dwelling unit of $15 and the overall cost per pound of TP removed of $298/lb (Versar, 2012). While cost-effectiveness is a function of the educational elements involved and number of households reached, these values from recent studies provide an estimate of the potential cost-effectiveness of residential education programs in the St. Mary's Pond and Watson Reservoir watersheds. Other non-structural practices like street sweeping were considered, but were found to be relatively minor in terms of reductions in nutrient loading due to the limited number of roads within the watersheds.

Table 5.4 Estimated Nutrient Reduction from Residential Education - St Mary's Pond Watershed

Residential Education Management Practice	Total Phosphorus Reduction (lbs/yr)	Total Nitrogen Reduction (lbs/yr)
Septic System Maintenance	8	48
Lawn Care	40	181
Pet Waste Disposal	2	12
Total	50	241

Agricultural land use is nearly one-third of the land use in the Watson Reservoir watershed and 37 percent in the St. Mary's Pond watershed, so nutrient management at agricultural operations, and the Green Valley Golf Course in the St. Mary's Pond watershed has a potentially significantly effect on nutrient loading (Figure 5.4 and 5.5). Because of the potential variation in the effectiveness of nutrient management, two scenarios were considered, one with a nutrient (TP, TN) reduction of 25 percent and a second with a nutrient reduction of 75 percent (Rao et al., 2009; Santhi, et al., 2006). Assuming a 25 percent to 75 percent reduction in nutrient loading, total annual phosphorus loads could be reduced by 7 to 22 percent in the Watson Reservoir watershed and by 4 to 13 percent in the St. Mary's Pond watershed compared to existing conditions if implemented at all agricultural areas. Costs associated with nutrient management are site-specific and will vary based on the crops produced and management practices used. Bonham et al. (2006) provides one of the few published estimates of cost-effectiveness of nutrient management and estimates $415-486/lb of phosphorus reduction for a variety of farm types.



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015; Non-structural BMP based on 2011 Land Use/Land Cover, RIGIS.

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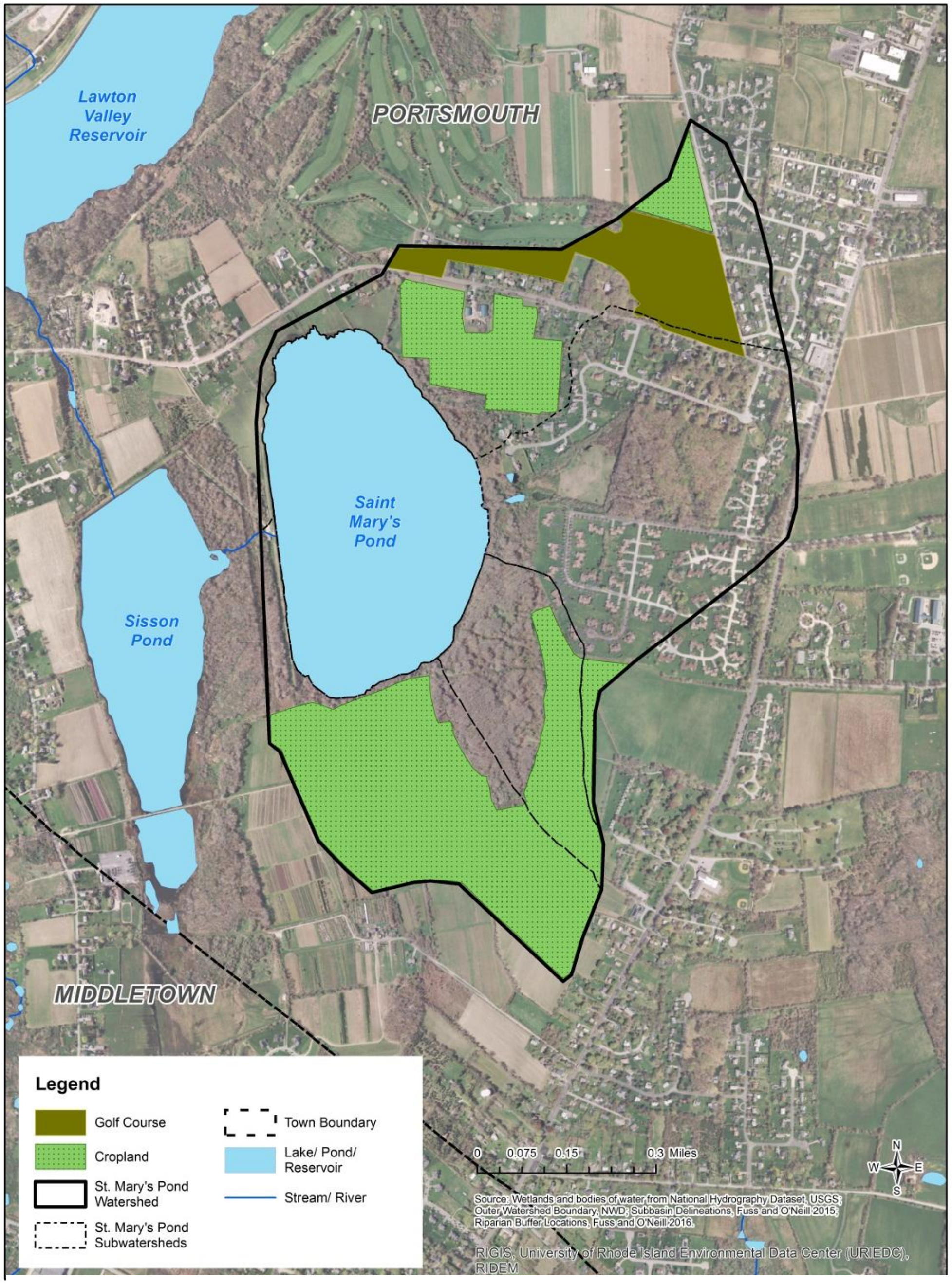
Figure 5.4 Nutrient Management Opportunities Watson Reservoir Watershed

Watson Reservoir Watershed
Nutrient Management Estimated Pollutant Removal*

25% Reduction
Total Phosphorus ≈ 102 lbs/year
Total Nitrogen ≈ 1,152 lbs/year
Total Suspended Solids ≈ 156,273 lbs/year

75% Reduction
Total Phosphorus ≈ 306 lbs/year
Total Nitrogen ≈ 3,455 lbs/year
Total Suspended Solids ≈ 468,820 lbs/year

*removal based on 25% and 75% reduction in “Primary Loads” from agricultural land use in the WTM.



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015; Riparian Buffer Locations, Fuss and O'Neill 2016. RIGIS, University of Rhode Island Environmental Data Center (URIEDC), RIDEM

Figure 5.5 Nutrient Management Opportunities St. Mary's Pond Watershed

St. Mary's Pond Watershed
Nutrient Management Estimated Pollutant Removal*

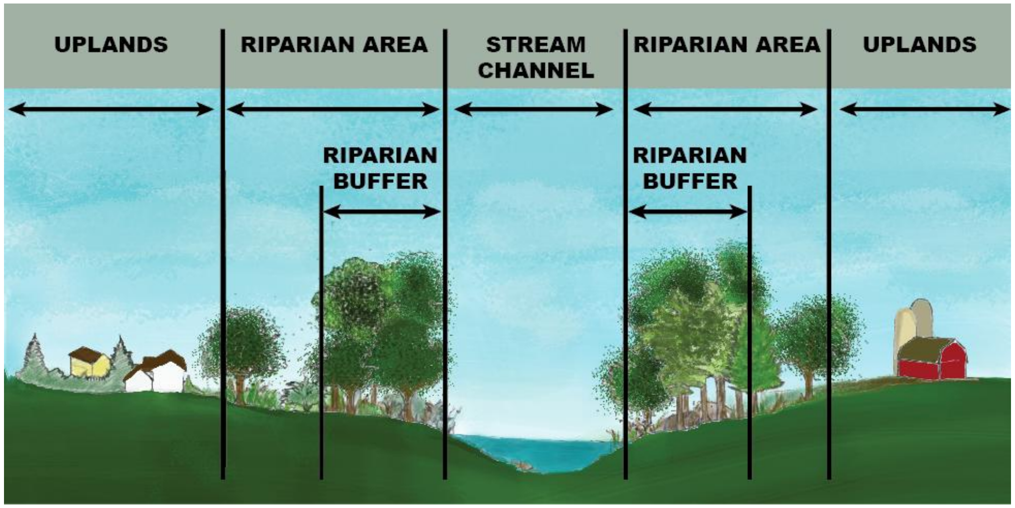
25% Reduction
Total Phosphorus ≈ 32 lbs/year
Total Nitrogen ≈ 330 lbs/year
Total Suspended Solids ≈ 35,312 lbs/year

75% Reduction
Total Phosphorus ≈ 96 lbs/year
Total Nitrogen ≈ 990 lbs/year
Total Suspended Solids ≈ 105,935 lbs/year

*removal based on 25% and 75% reduction in "Primary Loads" from agricultural land use and golf course in the WTM.

Vegetative buffers around Watson Reservoir and St. Mary's Pond were considered as non-structural BMPs. A vegetated or riparian buffer is an area of trees and shrubs adjacent to a water body that can help intercept nutrients, sediments, pesticides and other pollutants in surface, and shallow subsurface, runoff (NRCS, 1997). Riparian buffers play an important role in protecting water quality and providing critical wildlife habitat along stream corridors and surrounding lakes. While there is some variability in the scientific literature regarding the width of the buffer needed to protect water quality and habitat, there is consensus that, typically, the wider the buffer the more protective of the resource the buffer becomes (Sweeney, 2014; Rhode Island Legislative Task Force, 2014).

In Rhode Island, the freshwater wetland regulations were recently updated to reflect the importance of riparian buffers, although a required or recommended width for riparian buffers has not been established (State of Rhode Island, 2015). Additional guidance on regulatory buffer widths in the State of Rhode Island is expected in 2017. Currently, the State's freshwater wetland regulations have jurisdiction over 100-foot and 200-foot riverbank wetlands. Based on this existing jurisdictional area and the minimum buffer width of 30 meters (~100 feet) suggested by Sweeney (2014) as the minimum needed to protect the physical, chemical and biologic integrity of a waterbody, two buffer widths, 100-foot and 200-foot, were used in this study to evaluate the potential for pollutant removal in these watersheds.



Schematic of Riparian Buffer

Source: USEPA, https://blog.epa.gov/blog/2012/09/around-the-water-cooler-riparian-buffers/

Lack of buffer along St. Mary's Pond

Source: Fuss & O'Neill, 2015

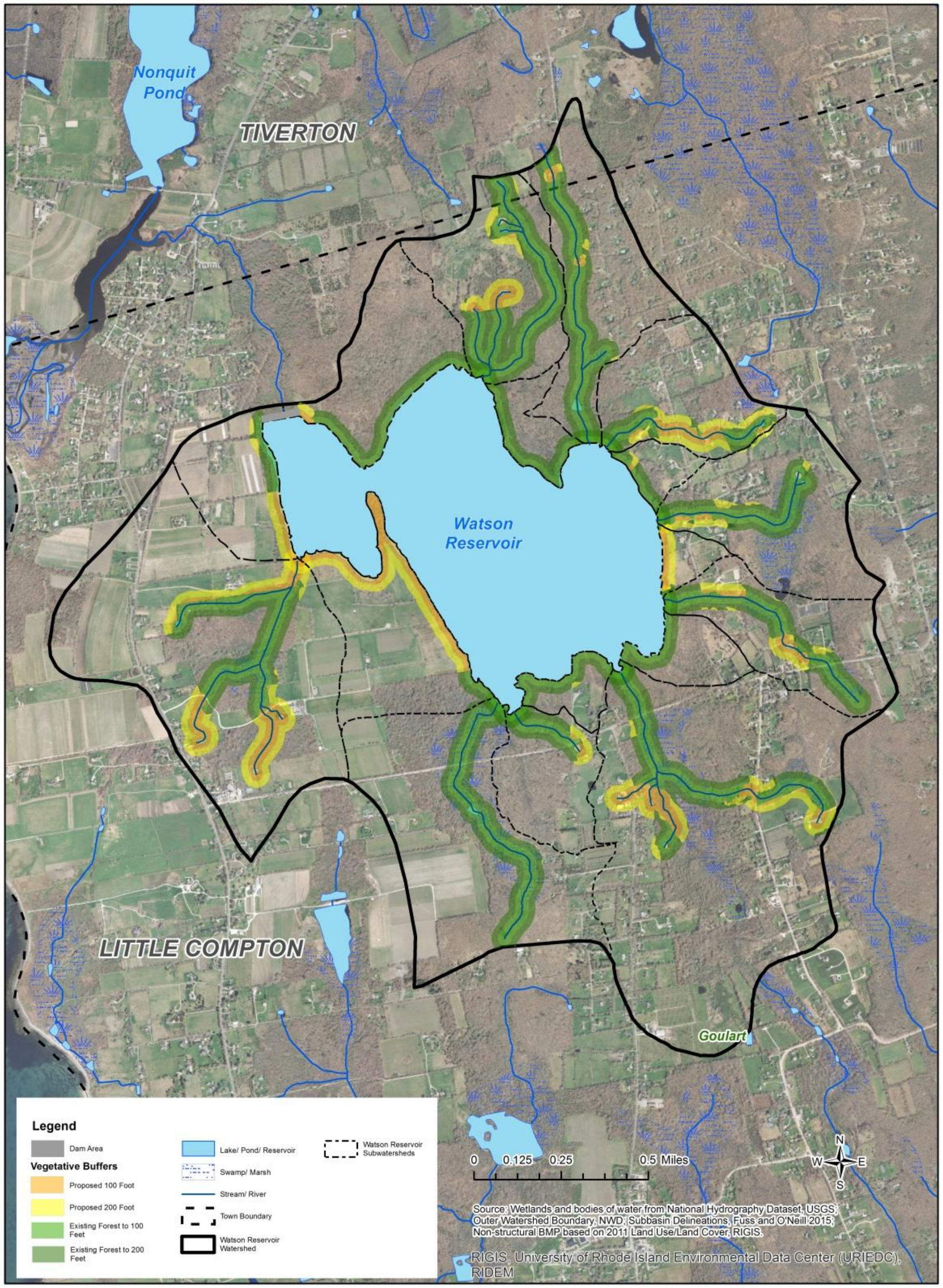
In the Watson Reservoir watershed the forested riparian buffer surrounding the reservoir is largely intact both at the 100-foot and 200- foot widths. Approximately 65% of the 100-foot buffer and 68 percent of the 200-foot buffer are currently mapped as forested based on RIGIS land use/cover mapping (Figure 5.6).

The re-establishment of the buffers in the areas shown in orange (100-foot) and yellow (200-foot) in the figure at right would reduce nutrient loading in both of these watersheds. Watershed pollutant loading model results estimate that if the forested riparian buffer is increased to 100 percent of the reservoir perimeter, excluding the dam area, there could be a 6 to10 percent (90 to 145 lbs) reduction in annual watershed Total Phosphorus loading and a 6 to 8 percent (560 to 888 lbs) reduction in annual Total Nitrogen loading.

Watson Reservoir Watershed
Estimated Pollutant Removal*

100-foot Reservoir Buffer
Total Phosphorus ≈ 90 lbs/year
Total Nitrogen ≈ 560 lbs/year
Total Suspended Solids ≈ 6,275 lbs/year

200-foot Reservoir Buffer
Total Phosphorus ≈ 145 lbs/year
Total Nitrogen ≈ 888 lbs/year
Total Suspended Solids ≈ 9,600 lbs/year
*Assumes 100% forested riparian buffer



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015; Non-structural BMP based on 2011 Land Use/Land Cover, RIGIS.

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Figure 5.6 Vegetative Buffer - Watson Reservoir Watershed

The percentage of forested buffer surrounding St. Mary's Pond is nearly identical to that of Watson Reservoir. Approximately 66 percent of the 100-foot buffer is currently intact and 68 percent of the 200-foot buffer is also considered to be forested. (Figure 5.7) The greater percentage of intact 200-foot buffer compared to the 100-foot buffer is partially attributed to the fact that a portion of the 200-foot buffer is outside of the watershed boundary in the northwestern portion of the watershed. This would decrease the overall area of the 200 foot buffer surrounding the reservoir and since the intact 200-foot buffer is similar in area to the intact 100-foot buffer the percentage of intact 200-foot buffer is therefore higher. If the 100-foot forested riparian buffer was increased to 100 percent, excluding the dam, there could be as much as a 3 percent reduction in annual TP loads (~24 lbs). If the 200-foot buffer was re-established, there could be as much as a 9 percent reduction of the loading (~65 lbs). Similarly, the annual TN load reductions could be 3 to 8 percent (~137 lbs to 361 lbs) with buffer re-establishment

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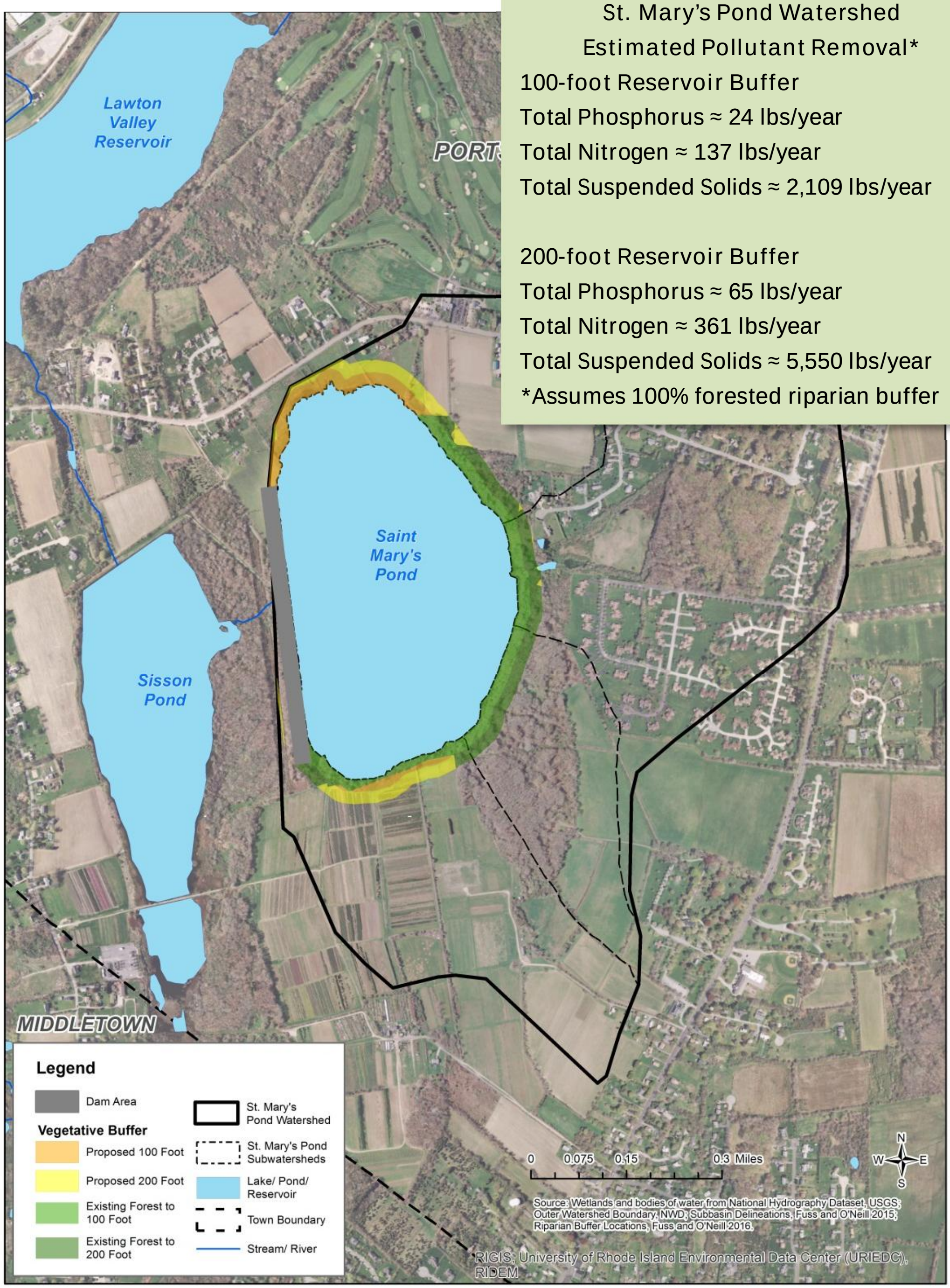

St. Mary's Pond Watershed
Estimated Pollutant Removal*

100-foot Reservoir Buffer
Total Phosphorus ≈ 24 lbs/year
Total Nitrogen ≈ 137 lbs/year
Total Suspended Solids ≈ 2,109 lbs/year

200-foot Reservoir Buffer
Total Phosphorus ≈ 65 lbs/year
Total Nitrogen ≈ 361 lbs/year
Total Suspended Solids ≈ 5,550 lbs/year
*Assumes 100% forested riparian buffer

Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015; Riparian Buffer Locations, Fuss and O'Neill 2016.

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Figure 5.7 Vegetative Buffer – St. Mary's Pond Watershed

Figure 5.8 and Figure 5.9 illustrate locations identified for the potential placement of new structural best management practices or the retrofit of existing stormwater management structures. These locations were selected based on a combination of modeling estimates of loading and field reconnaissance. Recommended BMP types (i.e., bioretenton, etc) are a function of existing infrastructure, soils and soil infiltration capacity, target pollutant (nutrients) and available space. With the exception of land controlled by the Aquidneck Land Trust or the City of Newport in the St. Mary's Pond watershed, structural BMPs have only been recommended in existing roadway rights-of-way. Table 5.4 provides a summary of the potential BMPs by watershed. Each BMP is then described in greater detail on an individual sheet. Potential nutrient reductions associated with the BMPs were estimated using the Watershed Treatment Model (WTM). Information presented for each BMP assumes that 100% of the water quality volume (WQv) is being treated by the BMP. Technical Appendix H contains more detail on the methods of estimating BMP cost-effectiveness.

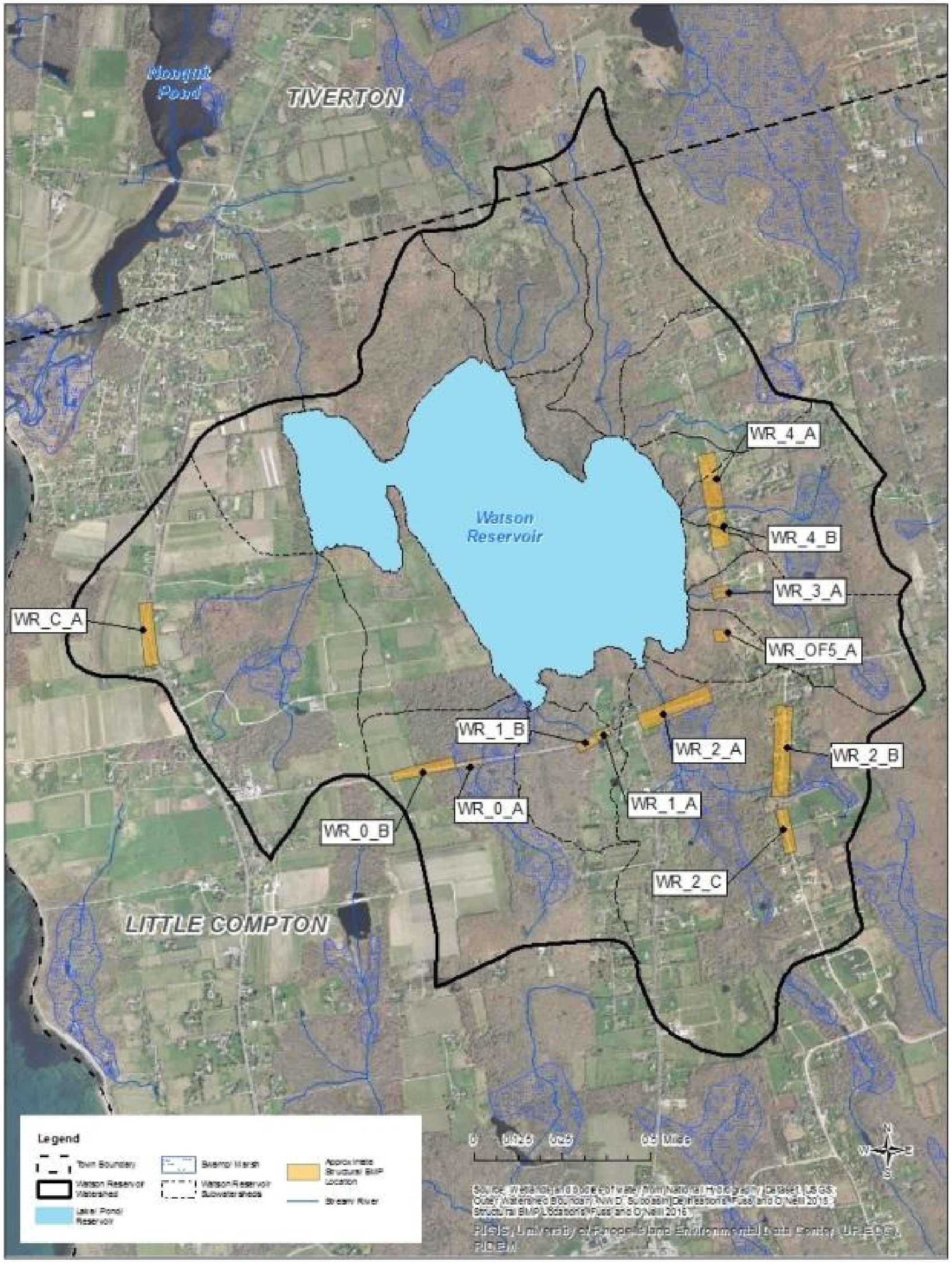
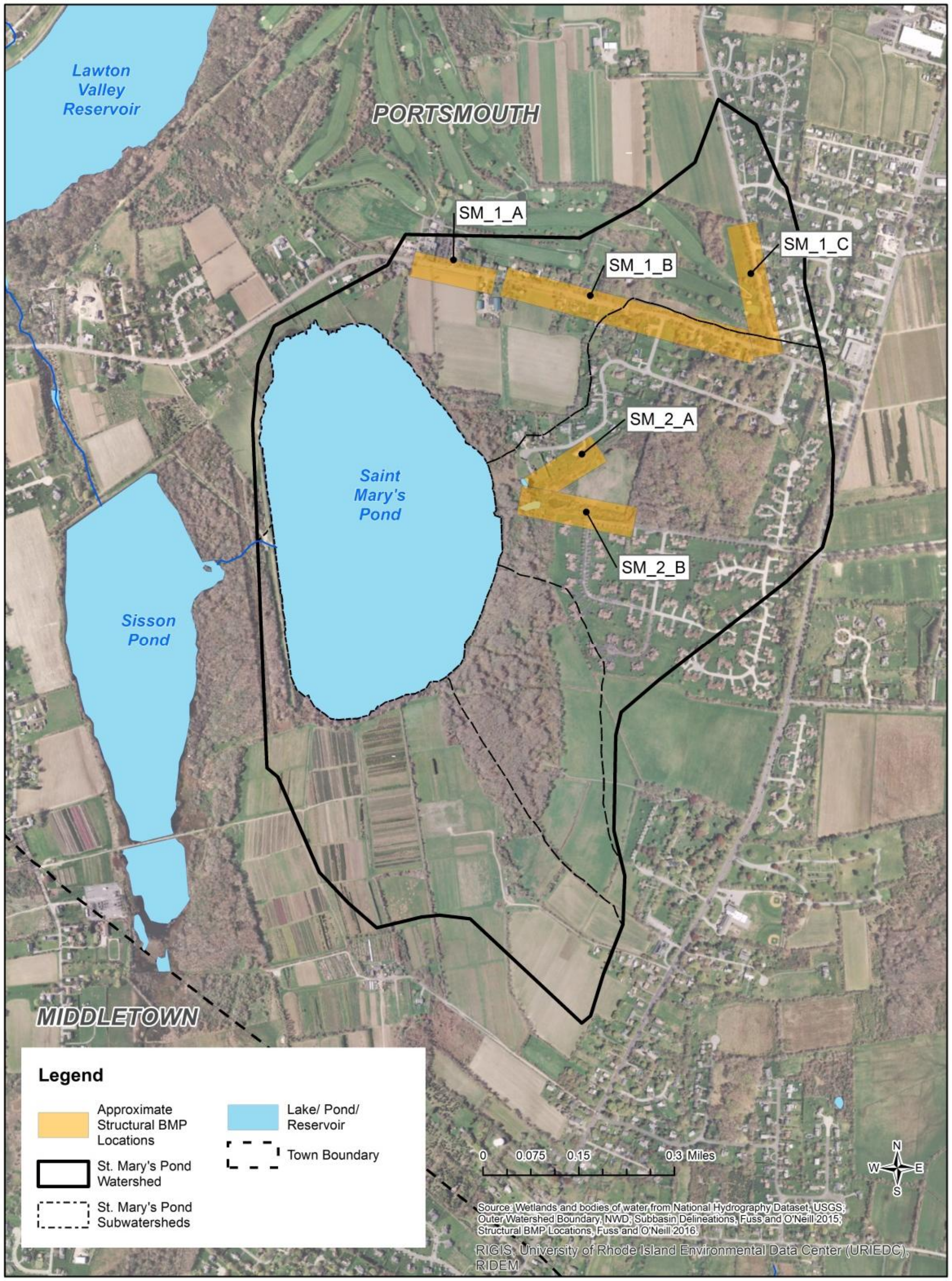


Figure 5.8 Potential Structural BMPs – Watson Reservoir Watershed



Source: Wetlands and bodies of water from National Hydrography Dataset, USGS; Outer Watershed Boundary, NWD; Subbasin Delineations, Fuss and O'Neill 2015; Structural BMP Locations, Fuss and O'Neill 2016.
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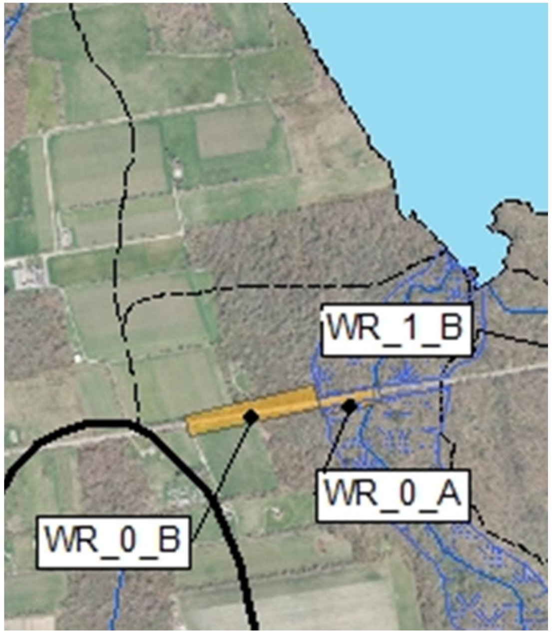
Figure 5.9 Potential Structural BMPs – St. Mary's Pond Watershed

Table 5.5 Potential Structural BMPs

BMP Identifier	Type	Retrofit?
Watson Reservoir Watershed		
WR_0_A	Linear Bioretention	No
WR_0_B	Linear Bioretention	No
WR_1_A	Linear Bioretention	No
WR_1_B	Linear Bioretention	No
WR_2_A	Linear Bioretention	No
WR_2_B	Linear Bioretention	Yes
WR_2_C	Linear Bioretention	Yes
WR_3_A	Bioretention	No
WR_4_A	Linear Bioretention	Yes
WR_4_B	Linear Bioretention	No
WR_C_A	Linear Bioretention	Yes
WR_OF5_A	Bioretention	No
St. Mary's Pond Watershed		
SM_1_A	Linear Bioretention	No
SM_1_B	Tree Filters or Filtration Retrofits	Yes
SM_1_C	Linear Bioretention	Yes
SM_2_A	Bioretention or WVTS	Yes
SM_2_B	Bioretention or WVTS	Yes

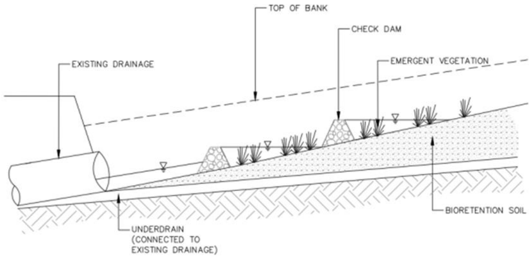
Watson Reservoir Watershed – Peckham Road Linear Bioretention (WR_0_A, WR_0_B)



BMP Locations: WR_0_A, WR_0_B
(Peckham Road, Little Compton, RI)

Proposed Concept: New linear bioretention systems are recommended along the shoulder of the road in the existing right-of-way (ROW) on either side of Peckham Road. These systems would be designed to discharge to a small tributary east of the BMPs. Site constraints at these locations could include slope, width of road ROW and adjacent wetland boundaries.

Linear bioretention, or bioswales, are vegetated open channels with an underlying soil matrix that are designed to capture and treat the water quality volume (WQ_V) within dry or wet cells formed by check dams or other means. Bioswales can be designed to infiltrate stormwater into the underlying soils where soil and subsurface conditions allow or discharge to the existing drainage system using underdrains or overflow catch basins.



Typical Profile of a Roadside Bioswale with Check Dams and Underdrain

Estimated Pollutant Removal
WR_0_A and WR_0_B
Total Phosphorus ≈ 13 lbs/year
Total Nitrogen ≈ 70 lbs/year
Total Suspended Solids ≈ 3943 lbs/year

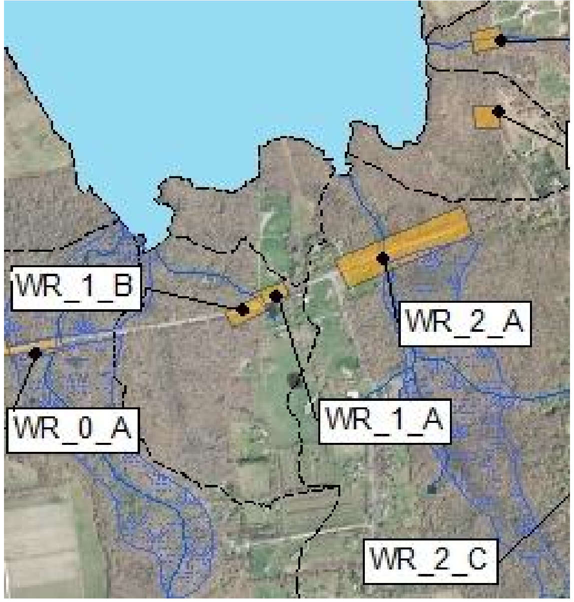
Cost Effectiveness
Total Initial Cost ≈ $44,919
Total Annual Cost ≈ $4,178
Total Phosphorus Removal ($/lb) ≈ $321
Total Nitrogen Removal ($/lb) ≈ $60

BMP Characteristics
Drainage Area ≈ 11.20 acres
Impervious Area ≈ 1.15 acres
WOv ≈ 21.835 ft^3

Approximate Location of WR_0_B
Image Source: Fuss & O'Neill, January 2016

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

Watson Reservoir Watershed – Peckham Road Linear Bioretention (WR_1_A, WR_1_B, WR_2_A)



BMP Locations: WR_1_A, WR_1_B, WR_2_A (Peckham Road, Little Compton, RI)

Proposed Concept: Install linear bioretention at WR_1_A and WR_1_B along the shoulder of the road in the existing right-of-way (ROW). Additionally, install linear bioretention at WR_2_A along the shoulder on both the north and south sides of the road west of the tributary stream and north of the road east of the tributary. Improvements at WR_2_A would also reduce erosion issues at this location. These systems would be designed to outlet to the tributary stream.

Linear bioretention, or bioswales, are vegetated open channels with an underlying soil matrix that are designed to capture and treat the water quality volume (WQV) within dry or wet cells formed by check dams or other means. Bioswales can be designed to infiltrate stormwater into the underlying soils where soil and subsurface conditions allow or discharge to the existing drainage system using underdrains or overflow catch basins.

(L-R) WR_1_B (west of tributary), WR_2_A (east of tributary) (Peckham Road, Little Compton, RI)

Estimated Pollutant Removal

WR_1_A	WR_1_B	WR_2_A
Total Phosphorus ≈ 2 lbs/year	Total Phosphorus ≈ 13 lbs/year	Total Phosphorus ≈ 32 lbs/year
Total Nitrogen ≈ 9 lbs/year	Total Nitrogen ≈ 70 lbs/year	Total Nitrogen ≈ 179 lbs/year
Total Suspended Solids ≈ 48 lbs/year	Total Suspended Solids ≈ 394 lbs/year	Total Suspended Solids ≈ 1,319 lbs/year

Cost Effectiveness

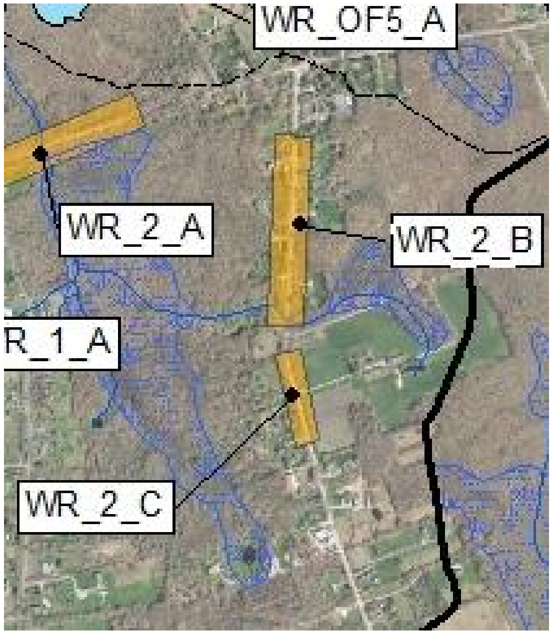
Total Initial Cost ≈ $17,968	Total Initial Cost ≈ $7,421	Total Initial Cost ≈ $154,678
Total Annual Cost ≈ $1,671	Total Annual Cost ≈ $690	Total Annual Cost ≈ $14,386
Total Phosphorus Removal ($/lb) ≈ $836	Total Phosphorus Removal ($/lb) ≈ $53	Total Phosphorus Removal ($/lb) ≈ $450
Total Nitrogen Removal ($/lb) ≈ $186	Total Nitrogen Removal ($/lb) ≈ $10	Total Nitrogen Removal ($/lb) ≈ $80

BMP Characteristics

Drainage Area ≈ 1.25 acres	Drainage Area ≈ 10.05 acres	Drainage Area ≈ 23.74 acres
Impervious Area ≈ 0.46 acres	Impervious Area ≈ 0.19 acres	Impervious Area ≈ 3.96 acres
WQv ≈ 2,225 ft^3	WQv ≈ 18,458 ft^3	WQv ≈ 48,487 ft^3

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

Watson Reservoir Watershed – East Main Road Linear Bioretention (WR_2_B, WR_2_C)



BMP Location: WR_2_B, WR_2_C
(East Main Road, Portsmouth, RI)

Proposed Concept: Install linear bioretention retrofits at WR_2_B and WR_2_C. These practices would be installed along the shoulder of East Main Road in the existing right-of-way and utilize the existing footprint of the swales already at these locations on the eastern side of the road.

Linear bioretention, or bioswales, are vegetated open channels with an underlying soil matrix that are designed to capture and treat the water quality volume (WQV) within dry or wet cells formed by check dams or other means. Bioswales can be designed to infiltrate stormwater into the underlying soils where soil and subsurface conditions allow or discharge to the existing drainage system using underdrains or overflow catch basins.

Estimated Pollutant Removal

WR_2_B	WR_2_C
Total Phosphorus ≈ 14 lbs/year	Total Phosphorus ≈ 52 lbs/year
Total Nitrogen ≈ 76 lbs/year	Total Nitrogen ≈ 279 lbs/year
Total Suspended Solids ≈ 569 lbs/year	Total Suspended Solids ≈ 1,991 lbs/year

Cost Effectiveness

Total Initial Cost ≈ $76,948	Total Initial Cost ≈ $136,710
Total Annual Cost ≈ $7,157	Total Annual Cost ≈ $12,715
Total Phosphorus Removal ($/lb) ≈ $511	Total Phosphorus Removal ($/lb) ≈ $245
Total Nitrogen Removal ($/lb) ≈ $94	Total Nitrogen Removal ($/lb) ≈ $46

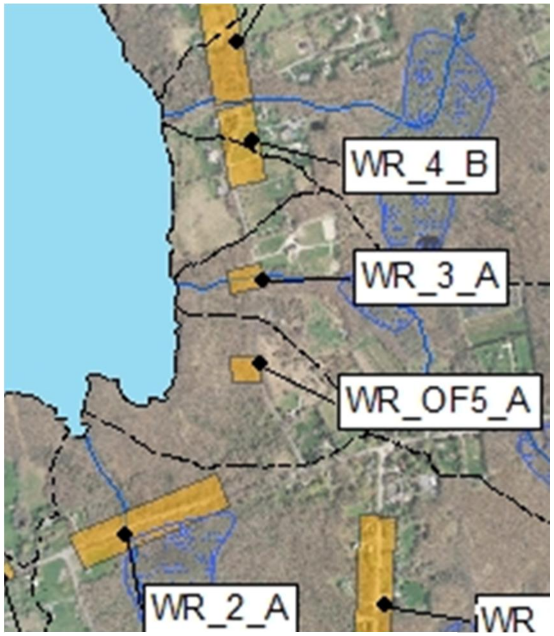
BMP Characteristics

Drainage Area ≈ 10.00 acres	Drainage Area ≈ 38.21acres
Impervious Area ≈ 1.97 acres	Impervious Area ≈ 3.50 acres
WQv ≈ 20,915 ft^3	WQv ≈ 73,172 ft^3

Existing Swale - East Main Road
Source: Fuss & O'Neill, 2016

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

Watson Reservoir Watershed – Burchard Avenue Bioretention (WR_3_A, WR_OF5_A)



BMP Location: WR_3_A, WR_OF5_A
(Burchard Avenue, Little Compton, RI)

Proposed Concept: Install bioretention cells within the public right-of-way (ROW) at both WR_3_A and WR_OF5_A. WR_3_A would be sited southwest of the road/tributary intersection. WR_OF5_A would be located west of Burchard Avenue where an existing piped outfall has created channelized flow from the road to the reservoir. Possible site constraints include depth to groundwater, slope and tree clearing.

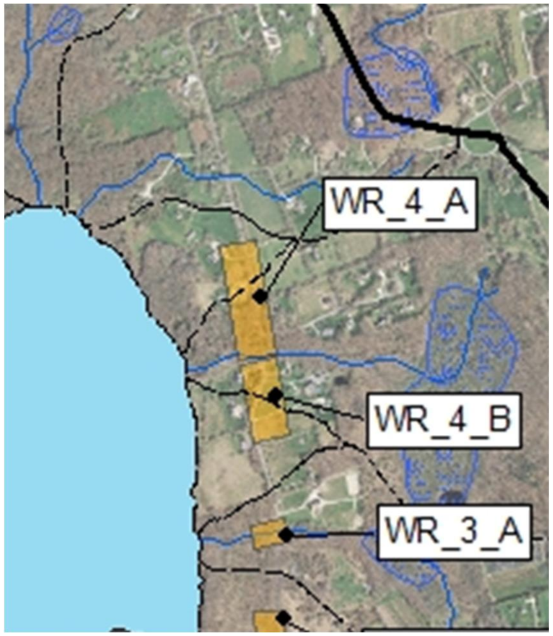
Bioretention cells are characterized by a shallow depression that treats stormwater as it flows through a soil matrix and is returned to the storm drain system or infiltrated into underlying soils or substratum.

Approximate Location of WR_OF5_A
Image Source: Fuss & O'Neill, January 2016

Estimated Pollutant Removal	
WR_3_A	WR_OF5_A
Total Phosphorus ≈ 5 lbs/year	Total Phosphorus ≈ 15 lbs/year
Total Nitrogen ≈ 27 lbs/year	Total Nitrogen ≈ 79 lbs/year
Total Suspended Solids ≈ 188 lbs/year	Total Suspended Solids ≈ 550 lbs/year
Cost Effectiveness	
Total Initial Cost ≈ $9,765	Total Initial Cost ≈ $45,407
Total Annual Cost ≈ $988	Total Annual Cost ≈ $4,594
Total Phosphorus Removal ($/lb) ≈ $198	Total Phosphorus Removal ($/lb) ≈ $306
Total Nitrogen Removal ($/lb) ≈ $37	Total Nitrogen Removal ($/lb) ≈ $58
BMP Characteristics	
Drainage Area ≈ 3.65 acres	Drainage Area ≈ 10.21 acres
Impervious Area ≈ 0.2 acres	Impervious Area ≈ 0.93 acres
WQv ≈ 6,828 ft^3	WQv ≈ 19,899 ft^3

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

Watson Reservoir Watershed – Burchard Avenue Linear Bioretention (WR_4_A, WR_4_B)

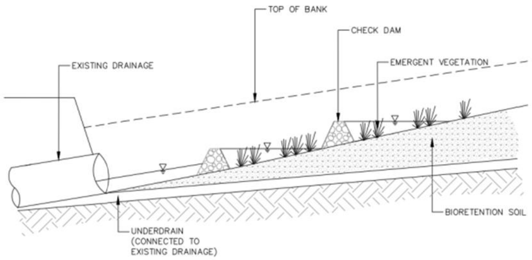


BMP Location: WR_4_A, WR_4_B
(Burchard Ave, Little Compton, RI)

Proposed Concept: Install linear bioretention swales at WR_4_A and WR_4_B. WR_4_A will retrofit the existing swale located on the east side of the road north of the tributary crossing Burchard Avenue. A new bioswale would be installed at WR_4_B along the eastern side of Burchard Avenue, south of the tributary crossing. Potential constraints include depth to ground water, slope and proximity to residential properties.

Linear bioretention, or bioswales, are vegetated open channels with an underlying soil matrix that are designed to capture and treat the water quality volume (WQ_V) within dry or wet cells formed by check dams or other means. Bioswales can be designed to infiltrate stormwater into the underlying soils where soil and subsurface conditions allow or discharge to the existing drainage system using underdrains or overflow catch basins.

Typical Profile of a Roadside Bioswale with Check Dams and Underdrain



Estimated Pollutant Removal

WR_4_A	WR_4_B
Total Phosphorus ≈ 48 lbs/year	Total Phosphorus ≈ 14 lbs/year
Total Nitrogen ≈ 273 lbs/year	Total Nitrogen ≈ 81 lbs/year
Total Suspended Solids ≈ 1,493 lbs/year	Total Suspended Solids ≈ 460 lbs/year

Cost Effectiveness

Total Initial Cost ≈ $126,554	Total Initial Cost ≈ $62,105
Total Annual Cost ≈ $11,771	Total Annual Cost ≈ $5,776
Total Phosphorus Removal ($/lb) ≈ $245	Total Phosphorus Removal ($/lb) ≈ $413
Total Nitrogen Removal ($/lb) ≈ $43	Total Nitrogen Removal ($/lb) ≈ $71

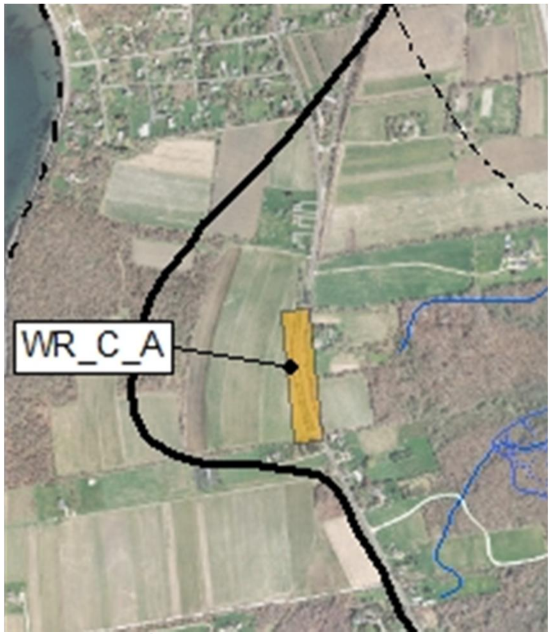
BMP Characteristics

Drainage Area ≈ 34.86 acres	Drainage Area ≈ 10.16 acres
Impervious Area ≈ 3.24 acres	Impervious Area ≈ 1.59 acres
WQv ≈ 67,060 ft^3	WQv ≈ 20,640 ft^3

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

Approximate Location of WR_4_A
Image Source: Fuss & O'Neill, January 2016

Watson Reservoir Watershed – West Main Road Linear Bioretention (WR_C_A)



BMP Location: WR_C_A
(West Main Street, Little Compton, RI)

Proposed Concept: Retrofit an existing swale along West Main Road as a linear bioretention system. Potential constraints include the location of an outlet or discharge point and conflicts with utilities, including overhead wires located within the footprint of the intended practice.

Linear bioretention, or bioswales, are vegetated open channels with an underlying soil matrix that are designed to capture and treat the water quality volume (WQV) within dry or wet cells formed by check dams or other means. Bioswales can be designed to infiltrate stormwater into the underlying soils where soil and subsurface conditions allow or discharge to the existing drainage system using underdrains or overflow catch basins.

Estimated Pollutant Removal

Total Phosphorus ≈ 67 lbs/year

Total Nitrogen ≈ 354 lbs/year

Total Suspended Solids ≈ 2,520 lbs/year

Cost Effectiveness

Total Initial Cost ≈ $139,054

Total Annual Cost ≈ $12,933

Total Phosphorus Removal ($/lb) ≈ $306

Total Nitrogen Removal ($/lb) ≈ $58

BMP Characteristics

Drainage Area ≈ 59.22 acres

Impervious Area ≈ 3.56 acres

WQv ≈ 110,781 ft^3

Typical Bioswale

Source: Pennsylvania Stormwater Manual Section 6.4.8

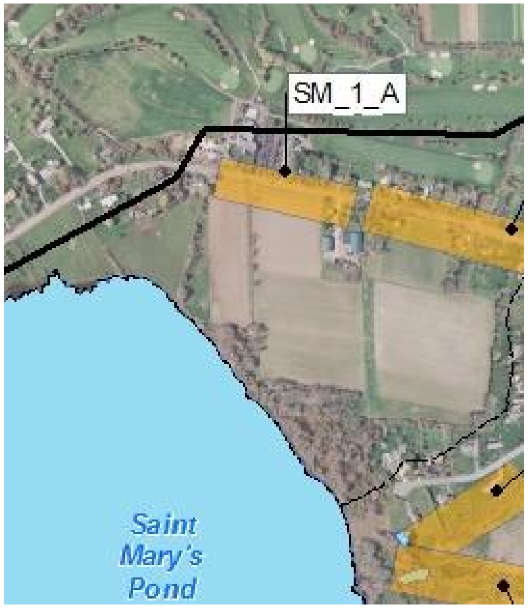
West Main Road ROW

note utility pole

Image Source: Fuss & O'Neill, January 2016

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

St. Mary's Pond Watershed – Union Street Linear Bioretention (SM_1_A)



BMP Location: SM_1_A
(Union Street, Portsmouth, RI)

Proposed Concept: Install a linear bioretention system along the south side of Union Street in the existing right-of-way (ROW). The linear bioretention system would be designed to outlet to the existing storm drainage network.

Linear bioretention, or bioswales, are vegetated open channels with an underlying soil matrix that are designed to capture and treat the water quality volume (WQV) within dry or wet cells formed by check dams or other means. Bioswales can be designed to infiltrate stormwater into the underlying soils where soil and subsurface conditions allow or discharge to the existing drainage system using underdrains or overflow catch basins.

Estimated Pollutant Removal
Total Phosphorus ≈ 11 lbs/year
Total Nitrogen ≈ 61 lbs/year
Total Suspended Solids ≈ 700 lbs/year

Cost Effectiveness
Total Initial Cost ≈ $96,869
Total Annual Cost ≈ $9,010
Total Phosphorus Removal ($/lb) ≈ $819
Total Nitrogen Removal ($/lb) ≈ $148

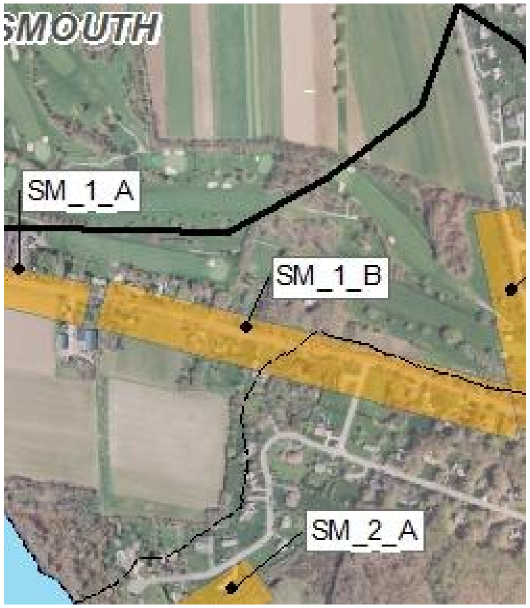
BMP Characteristics
Drainage Area ≈ 6.06 acres
Impervious Area ≈ 2.48 acres
WQv ≈ 17,455 ft^3

Typical Bioswale
Source: Pennsylvania Stormwater Manual Section 6.4.8

Union Street ROW
Image Source: Fuss & O'Neill, January 2016

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

St. Mary’s Pond Watershed – Union Street Filtration Retrofit (SM_1_B)



BMP Location: SM_1_B
(Union Street, Portsmouth, RI)

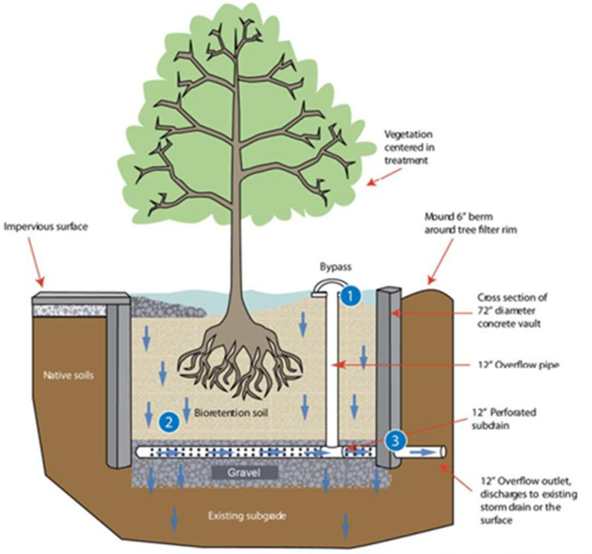
Estimated Pollutant Removal
Total Phosphorus ≈ 66 lbs/year
Total Nitrogen ≈ 195 lbs/year
Total Suspended Solids ≈ 5,901 lbs/year

Cost Effectiveness
Total Initial Cost ≈ $205,195
Total Annual Cost ≈ $20,174
Total Phosphorus Removal ($/lb) ≈ $314
Total Nitrogen Removal ($/lb) ≈ $106

BMP Characteristics
Drainage Area ≈ 43.18 acres
Impervious Area ≈ 3.94 acres
WQv ≈ 84,804 ft^3

Proposed Concept: Install a series of tree box filters or similar filtration retrofits along Union Street. These practices can be retrofitted to outlet and overflow to the existing stormwater infrastructure along the street. Topographic barriers and poorly draining soils in this area make this type of retrofit the most viable alternatives despite the typically higher costs associated with these practices.

Filtering practices treat stormwater by settling out larger particles in a forebay or sediment chamber, and then filtering stormwater through surface or underground filter media. Filter media can be comprised of various layers and percentages of sand, peat, leaf compost, bioretention soil or gravels depending on site specific constraints and requirements. A tree box filter is a pre-manufactured concrete box which is installed in the ground, filled with soil media, and typically planted with native, non-invasive trees or shrubs. The tree box functions as a compact bioretention system.



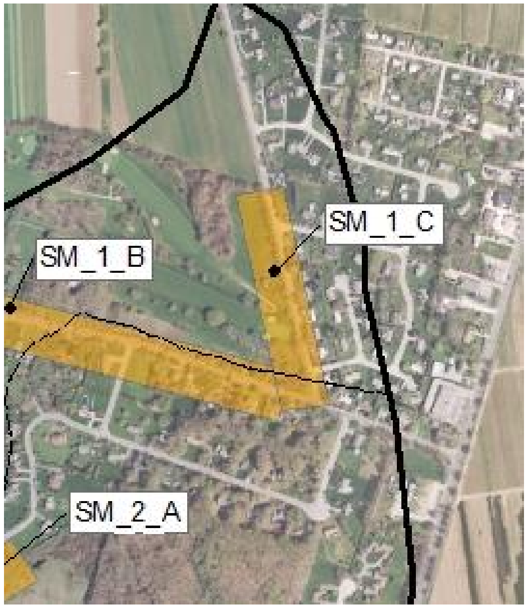
Source: adapted from UNHSC, 2007

Typical Tree Box Filter Cross Section

Example Tree Filter
Source: CTDEEP,
http://www.ct.gov/deep/cwp/view.asp?A=2719&Q=567354

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

St. Mary's Pond Watershed – Middle Road Linear Bioretention (SM_1_C)



BMP Location: SM_C_1
(Middle Road, Portsmouth, RI)

Proposed Concept: Retrofit the existing drainage swale on the eastern side of Middle Road as a linear biorentention system and install a second linear bioretention system on the west side of the road to help capture the entire water quality volume. These systems would be designed to outlet to the existing storm drainage network.

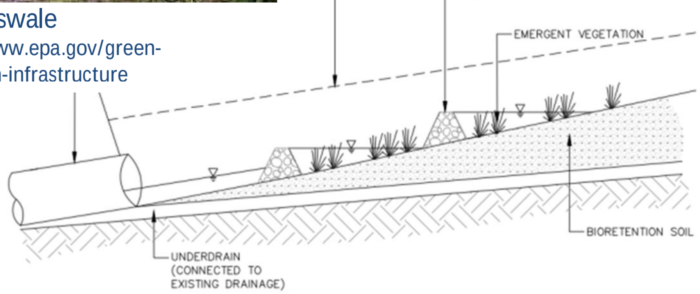
Linear bioretention, or bioswales, are vegetated open channels with an underlying soil matrix that are designed to capture and treat the water quality volume (WQV) within dry or wet cells formed by check dams or other means. Bioswales can be designed to infiltrate stormwater into the underlying soils where soil and subsurface conditions allow or discharge to the existing drainage system using underdrains or overflow catch basins.

Typical Roadside Bioswale

Source: USEPA, https://www.epa.gov/green-infrastructure/what-green-infrastructure

Middle Road ROW

Image Source: Fuss & O'Neill, January 2016



Typical Profile of a Roadside Bioswale with Check Dams and Underdrain

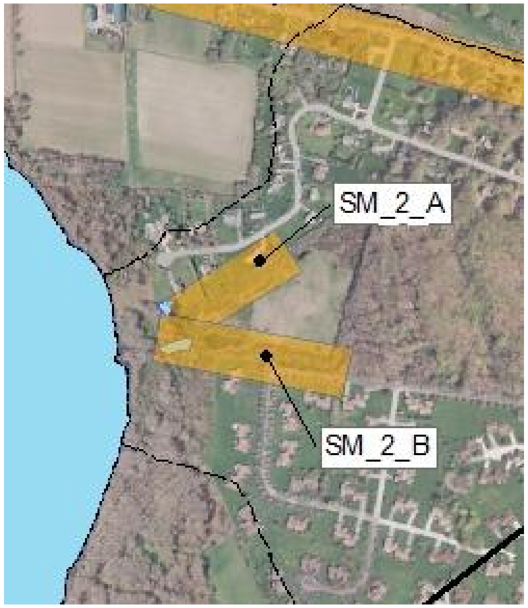
Estimated Pollutant Removal
Total Phosphorus ≈ 29 lbs/year
Total Nitrogen ≈ 163 lbs/year
Total Suspended Solids ≈ 1,775 lbs/year

Cost Effectiveness
Total Initial Cost ≈ $240,219
Total Annual Cost ≈ $22,343
Total Phosphorus Removal ($/lb) ≈ $770
Total Nitrogen Removal ($/lb) ≈ $137

BMP Characteristics
Drainage Area ≈ 18.85 acres
Impervious Area ≈ 6.15 acres
WQv ≈ 44,257 ft^3

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

St. Mary's Pond Watershed – Carriage Drive Bioretention or Wet Vegetated Treatment System (SM_2_A)



BMP Location: SM_2_A
(Carriage Drive, Portsmouth, RI)

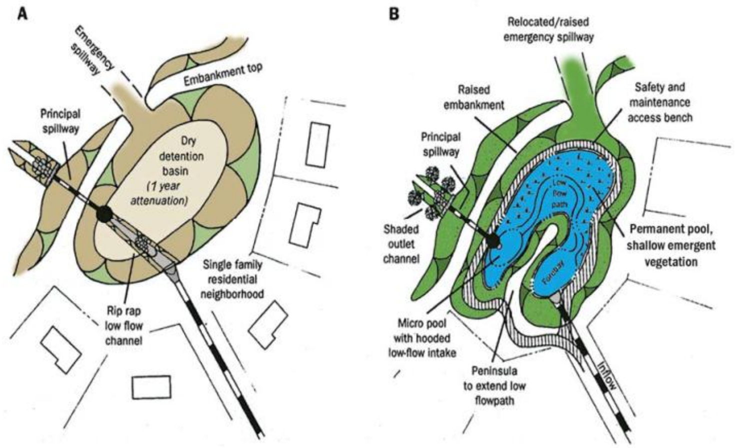
Estimated Pollutant Removal
Total Phosphorus ≈ 77 lbs/year
Total Nitrogen ≈ 234 lbs/year
Total Suspended Solids ≈ 7,194 lbs/year

Cost Effectiveness
Total Initial Cost ≈ $281,566
Total Annual Cost ≈ $26,366
Total Phosphorus Removal ($/lb) ≈ $342
Total Nitrogen Removal ($/lb) ≈ $113

BMP Characteristics
Drainage Area ≈ 41.40 acres
Impervious Area ≈ 9.01 acres
WQv ≈ 89,857 ft^3

Proposed Concept: Retrofit the existing stormwater basin to function as a bioretention system or a Wet Vegetated Treatment System (WVTS) depending on the depth to groundwater and other site constraints at this location. Since the soils in the area are typically poorly-draining, it is likely that a WVTS would be most appropriate.

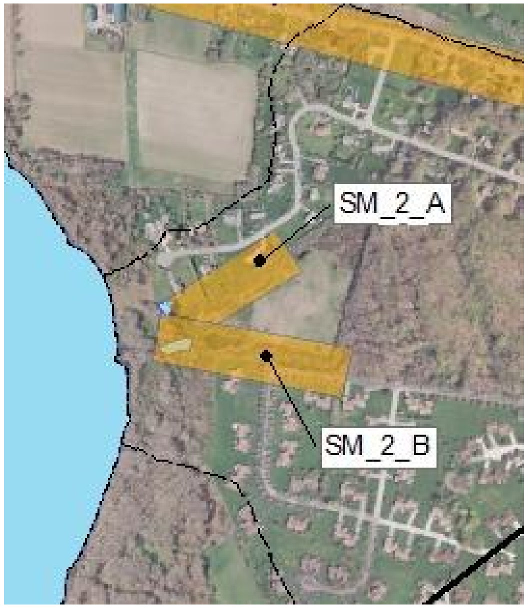
WVTSs are typically wet stormwater basins that provide water quality treatment primarily in a shallow vegetated permanent pool or wet gravel bed with emergent vegetation. Plantings that are part of the WVTS can also provide habitat benefits.



Retrofit of an Existing Detention Basin (A) to a Shallow WVTS (B)
Source: Adopted from CWP, 2007

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

St. Mary’s Pond Watershed – Oakland Farms Bioretention or Wet Vegetated Treatment System (SM_2_B)



BMP Location: SM_2_B
(Oakland Farms, Portsmouth, RI)

Proposed Concept: Retrofit the existing sedimentation basin and stormwater wet pond to function as a large bioretention system or Wet Vegetated Treatment System (WVTS) depending on depth to groundwater and other site constraints at this location. Since the soils in the area are typically poorly-draining, it is likely that a WVTS would be most appropriate.

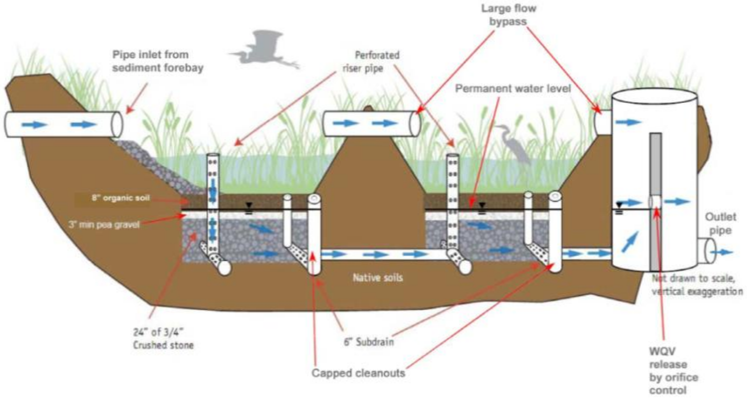
WVTS systems are typically wet stormwater basins that provide water quality treatment primarily in a wet gravel bed with emergent vegetation. Plantings that are part of the WVTS can also provide habitat benefits.

Estimated Pollutant Removal
Total Phosphorus ≈ 131 lbs/year
Total Nitrogen ≈ 404 lbs/year
Total Suspended Solids ≈ 12,501 lbs/year

Cost Effectiveness
Total Initial Cost ≈ $579,382
Total Annual Cost ≈ $54,253
Total Phosphorus Removal ($/lb) ≈ $414
Total Nitrogen Removal ($/lb) ≈ $134

BMP Characteristics
Drainage Area ≈ 69.34 acres
Impervious Area ≈ 18.54 acres
WQv ≈ 156,128 ft^3

Existing Sedimentation Basin
Source: Fuss & O’Neill, February 2016



Adapted from UNHSC, 2009

Typical WVTS Cross Section

Assumptions:
100% of WQv treated by BMP
Initial cost includes design, permitting, and construction
Costs (including maintenance) annualized over 20 year lifespan
WQv = One inch of runoff from the impervious area (RI Stormwater Design and Installation Standards Manual)

In-Lake Management Options

Several options for reducing in-lake sources of phosphorus exist, consisting of physical, chemical, and even biological controls. Biological controls target algal growth, but typicallydon’t remove loading from already existing in-lake sources. In addition, they can potentially have unforeseen habitat and water quality effects. Physical and chemical controls potentially reduce nutrient availability and in some cases, remove the source of phosphorus altogether (Wagner, 2004). Two of the more common management methods (Table 5.6) – dredging, an in-lake physical control, and nutrient inactivation, an in-lake chemical control – were investigated.

Table 5.6 Summary of Selected In-Lake Management Options (Source: Wagner, 2004)

Option	Mode of Action	Advantages	Disadvantages
Dredging	· Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering · Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system · Nutrient reserves are removed and algal growth can be limited by nutrient availability	· Can control algae if internal recycling is main nutrient source · Increases water depth · Can reduce pollutant reserves · Can reduce sediment oxygen demand · Can improve spawning habitat for many fish species · Allows complete renovation of aquatic ecosystem	· Temporarily removes benthic invertebrates · May create turbidity · May eliminate fish community (complete dry dredging only) · Possible impacts from containment area discharge · Possible impacts from dredged material disposal · Interference with recreation or other uses during dredging
Phosphorus Inactivation	· Typically salts of aluminum, iron or calcium are added to the lake, as liquid or powder · Phosphorus in the treated water column is complexed and settled to the bottom of the lake · Phosphorus in upper sediment layer is complexed, reducing release from sediment · Permanence of binding varies by binder in relation to redox potential and pH	· Can provide rapid, major decrease in phosphorus concentration in water column · Can minimize release of phosphorus from sediment · May remove other nutrients and contaminants as well as phosphorus · Flexible with regard to depth of application and speed of improvement	· Possible toxicity to fish and invertebrates, mainly by aluminum at low or high pH · Possible release of phosphorus under anoxia (with Fe) or extreme pH (with Ca) · May cause fluctuations in water chemistry, especially pH, during treatment · Possible resuspension of floc in shallow areas · Adds to bottom sediment, but typically an insignificant amount

Dredging

Dredging is the mechanical removal of accumulated sediment from the bottom of waterbodies, using conventional dry, conventional wet, or hydraulic/pneumatic techniques (Wagner, 2004). Dry dredging involves partially or completely draining of a waterbody and removal of exposed bottom sediments with a bulldozer or other conventional excavation equipment. As the name implies, wet dredging involves excavation of bottom sediment overlain by water. Usually a partial drawdown of the waterbody is done and clamshell dredges, draglines, and other specialized excavation equipment are used. Excavated material is often only 10-30 percent solids and must be placed in an adjacent dewatering area before it can be removed. Hydraulic dredging is also done with water overlying the bottom sediment and typically involves a suction type of dredge that removes the sediments as a slurry. The slurry is pumped to a containment area for dewatering of the sediment. The selection of a dredging methodology depends on a variety of factors including, but not limited to, sediment quality and quantity, ability to control water level, and availability of containment area for dewatering.

Costs associated with dredging depend on the methodology and volume of material to be removed. For the purposes of this study, a cost of $30/cubic yard (cy) of sediment to be removed is a reasonable order of magnitude for comparison with other management methods. As described in Section 2, estimated sediment volumes in Watson Reservoir and St. Mary's Pond are 373,701 cy and 161,099 cy, respectively. Assuming all soft sediment was removed, order of magnitude costs would be $11.2 million for Watson Reservoir and $4.8 million for St. Mary's Pond. It would be possible to conduct a more limited dredging program, especially in the larger Watson Reservoir where sediment depth has greater variation.

Dry Dredging

Source: Fuss & O'Neill, 2013

Alum Treatment

Source: Snohomish County, WA
http://snohomishcountywa.gov/2451/Lake-Ketchum-Restoration

Phosphorus Inactivation

Inactivation of phosphorus in surface bottom sediments can be accomplished by using aluminum, calcium or lanthanum salts to bind phosphorus that is currently bound to iron and can be released from the sediments into the water column under low oxygen conditions. Aluminum is typically the preferred phosphorus inactivator because of its ability to bind phosphorus under the widest range of pH and oxygen conditions. Jar tests are required to determine the doses and ratios of chemicals to be used for treatment. Toxicity to aquatic life is a concern if ambient pH levels are low or elevated.

Costs associated with phosphorus inactivation are on the order of $500-1000/acre (Wagner, 2004). As described in Section 2, the surface areas of Watson Reservoir and St. Mary's Pond are 2,296 and 111 acres respectively. Assuming that only a fraction (two-thirds) of the area of each waterbody was treated for phosphorus inactivation, order of magnitude costs would be $757,680 to $1.5 million for Watson Reservoir and $36,630 to $73,260 for St. Mary's Pond.

Feasibility of In-Lake Management

While dredging would remove accumulated sediment and the associated nutrient reserves for internal loading, it would not reduce ongoing nutrient inputs from the watershed. In addition, dredging introduces operational challenges for a drinking water supply system that are not present in a recreational lake. Phosphorus inactivation is most effective when a substantial portion of the phosphorus load to the waterbody is associated with in-lake sediment sources, which is not the case here. Generally, phosphorus inactivation is only an interim measure and does not replace the need for on-going watershed management to control external sources of nutrients. Only when external (i.e., watershed) phosphorus loads have been controlled to the maximum extent practicable or are a small component of the overall nutrient loading (which is not the case in the Watson Reservoir or St. Mary's Pond watersheds), is phosphorus inactivation identified as the most feasible option (Wagner, 2004).

At this time, given the smaller contribution of in-lake phosphorus loading compared to watershed loading, watershed control of nutrient inputs to both St. Mary's Pond and Watson Reservoir is the focus of the recommendations. Limiting watershed loading is critical to preventing the potential for increased internal loads. Addressing loads at the watershed level also tends to produce multiple benefits to water quality by reducing the watershed loading, not just associated with nutrients, but also sediment and bacteria. As a result, in-lake management options are not currently recommended for nutrient management. Instead, watershed management options should be implemented to reduce watershed sources of nutrients.

A primary goal of this project is the identification of feasible and effective short-, medium-, and long-term management actions to reduce phosphorus loading to Watson Reservoir and St. Mary's Pond and development of an implementation plan. The following important elements were incorporated into the development of the plan:

- Identification of existing nutrient sources and consideration of the relative magnitude of those sources,
- Cost-effectiveness and sustainability of potential management actions to reduce nutrient loading,
- Support for the actions in terms of both initial funding sources and long-term responsibility for management,
- Secondary effects of the action – additional benefits (e.g., habitat enhancement, coordination with regional or state initiatives) or limitations (e.g., lack of long-term support) associated with a management action.

In addition, because the challenges and opportunities in the St. Mary's Pond and Watson Reservoir watersheds are in many ways typical of those in the other Newport Water supply reservoirs and watersheds and throughout the Narragansett Bay Estuary watershed, identifying the transferability of these management methods to other areas is also an important outcome of this project that is highlighted below.

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April 2016 Stakeholder Meeting to review management options

Identifying Sources

Sections 3 and 4 provided a summary of the nutrient sources to Watson Reservoir and St. Mary's Pond. Key findings are:

- For both waterbodies, estimated phosphorus loading from the watershed is greater than that from internal sediments. This indicates that addressing inputs from the watershed is important for both short-term and long-term control of nutrient loading in both waterbodies.
- In the Watson Reservoir watershed, sampling revealed TP concentrations higher than the recommended concentrations (0.05 mg/L) for tributary streams to lakes and ponds in all the sampled tributaries (Figure 6.1). Watershed modeling indicates higher yields of phosphorus from cropland and residential areas compared to other land use types. Overall watershed loading of phosphorus is also dominated by agricultural and residential uses.
- In the St. Mary's watershed, modeling also indicates that cropland and residential areas dominate nutrient loading.

The assessment of nutrient sources to St. Mary's Pond and Watson Reservoir indicates that management activities should focus on reducing loading from residential and agricultural sources in the watersheds.

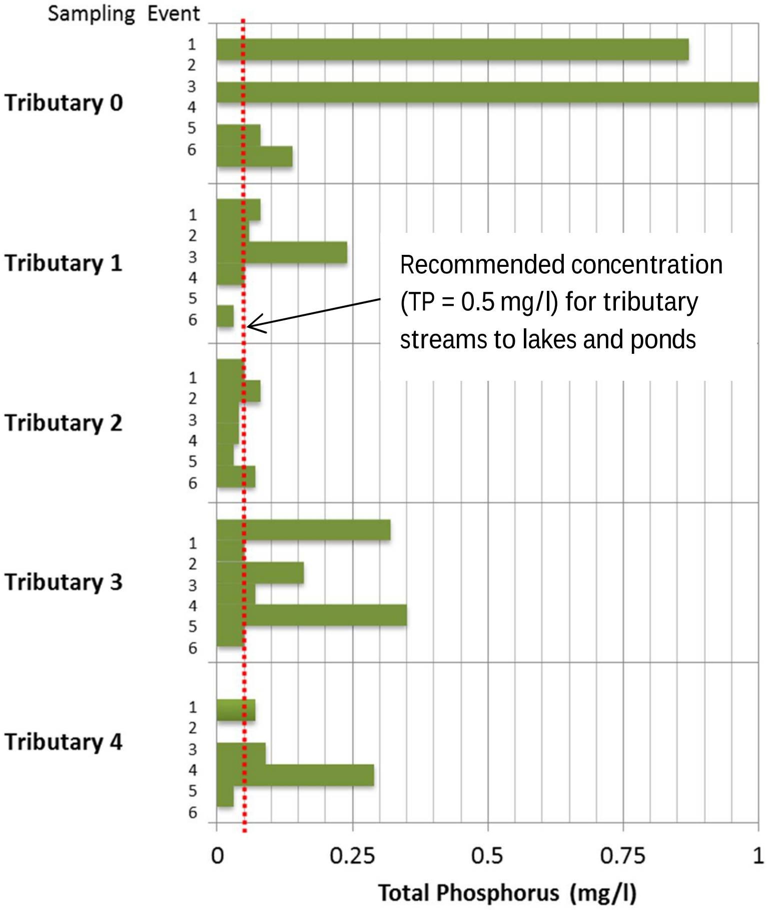

Figure 6.1 Total Phosphorus Concentration in Tributary Streams: April – September 2015
Red line indicates recommended concentration for tributary stream. (See Section 3 for more detail.)

Cost-Effectiveness and Sustainability

Assessing the effectiveness of management practices can focus on the potential to reduce pollutant loads. Figure 6.2 summarizes the potential reductions in total phosphorus and total nitrogen for the structural and non-structural management practices described in Section 5. However, with limited resources, considering the cost-effectiveness of a management measure is also an important consideration. Cost-effectiveness of management practices is usually measured in terms cost of removing a pound of a particular pollutant. For structural BMPs, there are well-established methods for doing this type of calculation (see Technical Appendix H). Figure 6.3 illustrates the anticipated cost-effectiveness, measured in cost per pound of nutrient removed for the structural BMPs identified for each watershed. It should be noted that these costs are preliminary and more detailed design and cost information would be needed for actual implementation of a BMP. However, the methodology used in Technical Appendix H provides a reasonable methodology for preliminary estimates of cost and comparison of BMPs. This analysis, which accounts for both initial costs to construct the BMPs as well as maintenance costs over a 20 year period, indicates that in St. Mary's Pond watershed, cost-effectiveness for phosphorus is greatest

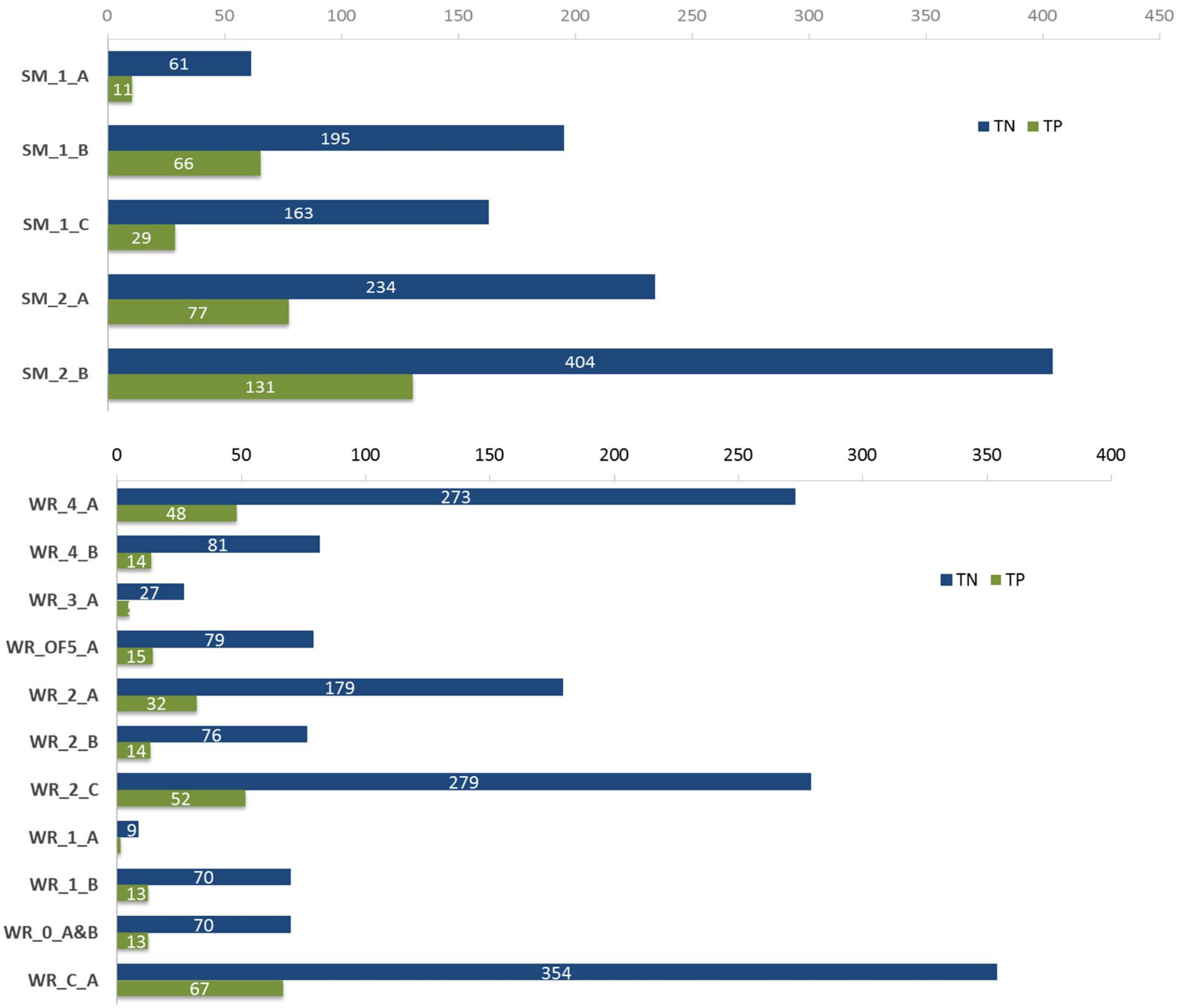

Figure 6.2 Total Phosphorus and Total Nitrogen Removal (lbs) for Structural BMPs in St. Mary's Pond (top) and Watson Reservoir (bottom) watersheds

(i.e., lowest cost per pound of total phosphorus removed) for the retrofits associated with stormwater drainage from Carriage Drive and Oakland Farms and lowest (i.e., highest cost per pound of total phosphorus removed) for the linear bioretention proposed along Union and Middle Road. However, the overall range is narrow, varying from approximately $300/lb to $800/lb on an annual basis.

In the Watson Reservoir watershed, the 20-year structural BMP cost-effectiveness was similar to St. Mary’s Pond because of the similar types of BMPs considered. The cost-effectiveness was typically in the $200/lb to $800/lb range. The linear bioretention (WR_1_B) proposed along Peckham Road was slightly outside of that range at approximately $53/lb on an annual basis. Since BMP costs are a function of the impervious area treated and the type of BMPs are similar throughout the watershed, the costs and cost-effectiveness of the BMPs considered in the St. Mary’s Pond watershed are a function of the impervious area draining to a particular stormwater BMP and potential pollutant removal of the BMP. The relatively narrow range results in less of a distinction in prioritization of BMPs based on 20-year cost effectiveness. Therefore, consideration of a wider range of issues is important for BMP prioritization.

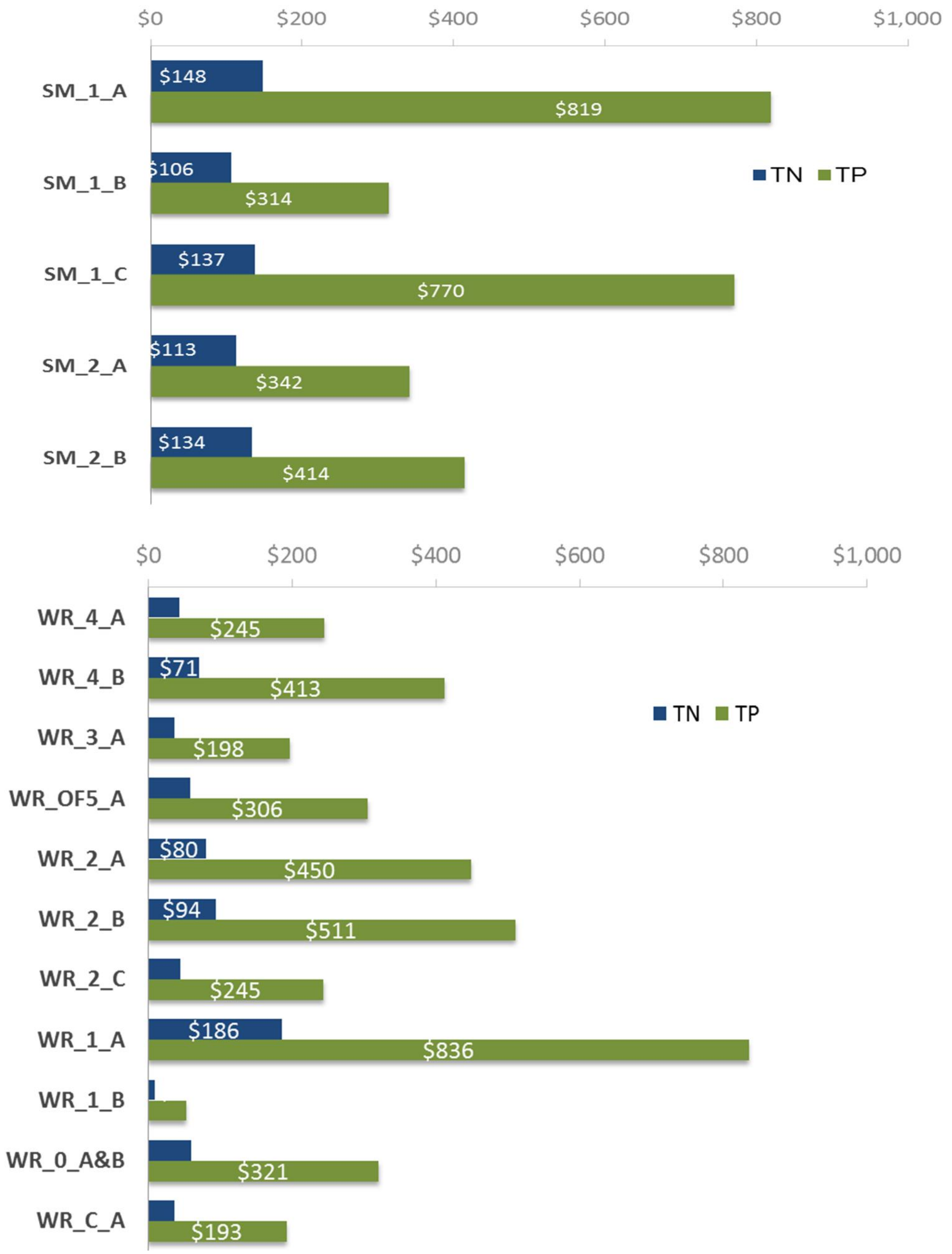

Figure 6.3 Cost Effectiveness ($/lb) for Structural BMPs in St. Mary’s Pond (top) and Watson Reservoir (bottom) watersheds

As discussed in Section 5, assessing the cost-effectiveness of non-structural BMPs can vary widely, so for non-structural BMPs the sustainability of the management practice is an important consideration. Re-establishment and protection of buffers is potentially cost effective because the City of Newport owns much of the land within the immediate buffer to the waterbodies and the maintenance of those areas is relatively self-sustaining once appropriate vegetation is established. Protecting them from re-encroachment and managing invasive species are likely to be on-going requirements, but will remain within the control of the Newport Water Division, making this management action more likely to be sustainable.

Residential education can reap multiple benefits, including strengthening the connection community members feel with the watersheds. In the St. Mary’s Pond watershed, there is the opportunity to leverage the existing relationship that the Aquidneck Land Trust (ALT), a stakeholder in this project, has with the residential communities on Carriage Lane and Oakland Farms. These are the two major residential areas in the watershed, are significant areas of potential phosphorus loading, and are also located adjacent to ALT’s preserved open space area, the Oakland Forest and Meadow. This relationship between the residential areas and the Oakland Forest and Meadow, where potential BMPs SM_2_A and SM_2_B are also located, increases the likelihood of residents to understand the connection between their household actions and the effects on natural resources in their community.

Nutrient management is included as a non-structural BMP in this study. As discussed in Section 5, assigning a cost to nutrient management is not feasible because development of a management plan is site-specific, so the direct comparison with structural BMP costs in this watershed is not practical. However, to the extent that a nutrient management plan will become part of an agricultural operation and can be supported by NRCS, the opportunities for sustainability of those actions can be significant.

Cost-effectiveness is similar for the watershed BMPs considered and tends to be in the range of $200-800 per pound of phosphorus removed. Non-structural practices, for which it is more difficult to establish cost-effectiveness rates, are likely to be sustainable in the St. Mary’s Pond and Watson Reservoir watersheds to the extent that they become part of routine operations (reestablishment and protection of riparian buffers by the Newport Water Division and nutrient management by farms, vineyards, and the golf course) and accepted as important stewardship by the watersheds’ residents (residential education practices).

Oakland Forest & Meadow Trail in St. Mary’s Pond Watershed

Support for Management Actions

Implementation of management actions requires both initial support to institute a program or construct a stormwater management practice and long-term stewardship to ensure that routine maintenance or on-going assessment is happening. These drinking water supply watersheds are somewhat unique in that the water supplier (the City of Newport) owns little of the watersheds. Consequently, support within the watershed communities is key for any management actions that extend beyond the boundaries of the land owned by the City, which is limited to the area immediately surrounding Watson Reservoir and St. Mary’s Pond. Because the definition of effectiveness for this project includes the likelihood of support for the management actions proposed, the project team worked with the stakeholder group to identify types of actions that could have an initial champion, could be eligible for funding, and would be acceptable to the watershed community members by enhancing the community with minimal encroachment or alteration to private property. In some cases, for example the development of nutrient management plans on private property, structural BMPs may become part of the management action. However, no specific structural alternations on privately-owned properly other than the Oakland Forest, were assumed for the development of this implementation plan.

The prioritization process identified structural BMP locations that are within existing municipal or state roadway rights-of-way or on land owned by the City of Newport or project stakeholder, the Aquidneck Land Trust, in order to both identify an initial project champion and also an entity that could assume or assist with on-going maintenance. In addition, emphasis was placed on identifying management practices that would be eligible for state or federal funding programs (e.g., NRCS EQIP, Section 319) for at least initial construction/implementation.

Secondary Effects

Secondary effects are actions which result from, but are not necessarily the primary focus of, a management action. Vegetative buffers are an excellent example of a management practice that reduces nutrient loading, but also provides wildlife habitat and creates a physical exclusion barrier to a water supply. Some of the proposed projects also coordinate with other watershed, regional or state programs or initiatives. For example:

- Work on Union Street which is under the control of the Rhode Island Department of Transportation would align with RIDOT's requirement under their current consent decree with the U.S. EPA which requires RIDOT to develop stormwater control plans that will identify the extent to which RIDOT's roads and structures contribute to runoff to impaired waterbodies, assess best practices to reduce pollution and then implement measures (in some cases including structural controls).
- Retrofits on Middle Road in Portsmouth would coincide with the State Transportation Improvement Plan for repaving of the road in 2018.
- All actions to reduce phosphorus loading would support the anticipated Total Maximum Daily Loads (TMDLs) to be issued by RIDEM for St. Mary's Pond and Watson Reservoir.
- Nutrient management on agricultural land in the watershed will align with NRCS's objectives to assist farmers through their EQIP program and ongoing efforts by NRCS in Rhode Island to assist farmers.
- All actions to reduce nutrient loading are consistent with the State of Rhode Island water resources planning objectives outlined in Rhode Island Water 2030 (RI Division of Planning, 2012).

Both the structural and non-structural management practices recommended have secondary environmental benefits (e.g., reduction of other pollutants, enhancement of habitat) and/or leverage, align with, or support other watershed, regional or state programs or initiatives.

Prioritization & Transferability

Working together with the project stakeholders, management practices discussed in Section 5 were categorized into short- (1-3 year), mid- (3-5 year), and long-tern (5-10 year) windows for implementation. The assignment into those categories took into account the issues discussed above – ability to reduce phosphorus loading, cost-effectiveness, initial and on-going support for the project and secondary considerations regarding coordination with other programs and initiatives. Tables 6.1 and 6.2 outline the prioritized Implementation Plan and note any special considerations that influenced the assignment to a particular timeframe. In addition, opportunities for transferability to other watersheds within the Newport Water Division water supply, as well as throughout the Narragansett Bay Estuary watershed, are also noted.

Conclusion

The Implementation Plan outlined in Tables 6.1 and 6.2 synthesizes information from field investigations, prior studies, pollutant load modeling, and local stakeholder input to identify a roadmap for feasible and cost-effective prioritization of efforts to reduce phosphorus loads to Watson Reservoir and St. Mary's Pond over the next several years. It is expected that these management measures will also support the achievement of any goals for nutrient load reductions identified in the forthcoming TMDLs for St. Mary's Pond and Watson Reservoir. Implementation of specific structural BMPs will require additional site-specific information to support design and construction, but this study has demonstrated the feasibility and potential benefit of structural BMPs in both watersheds. Although external (i.e., watershed) sources currently dominate phosphorus loading in each waterbody, it is important to continue to assess in-lake conditions and internal loading from bottom sediments. Finally, in addition to identifying nutrient reduction strategies for these two watersheds, the management measures presented in the Implantation Plan are widely applicable to other watersheds within the NWD system and throughout the Narragansett Bay Estuary watershed.

Table 6.1 Implementation Plan for Watson Reservoir Watershed

Management Practice	Short-Term (1-3 years)			Mid-Term (3-5 years)		Long-Term (5-10 years)					Considerations	Transferability
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026		
Vegetative Buffers	■	■	■								· Newport Water controls the land immediately adjacent to the water bodies. · Buffers would need to be reestablished in some areas were encroachment has occurred. · Opportunities for public education with signage, etc. · Secondary benefit for reduction of other pollutants and provision of habitat.	· Can be implemented at all NWD reservoirs . · Aligns with efforts by ALT to develop conservation plans identifying priority buffer areas · Aligns with RIDEM guidance for riparian buffers.
Residential Education	■	■	■	■	■						· Residential population is more diffuse than St. Mary's watershed, so a longer implementation period likely. · Partnering with grass-roots conservation association would improve opportunities for success. · Variety of opportunities for scale and scope of education program.	· Since most NWD land is not owned or controlled by the City of Newport, education is an important management practice for all of the water supply watersheds. · Focusing on actions most likely to impact nutrients – pet waste, lawn care, and septic systems – will be most beneficial throughout the NBEW.
Nutrient Management	■	■	■	■	■	■	■	■	■	■	· Opportunity to leverage ongoing work of NRCS to engage farmers in Rhode Island. · Implementation is expected to cover the entire time period due to the number of agricultural operations and the time needed to engage farms and obtain a commitment to a plan.	· Agriculture is present in most of the NWD watersheds and throughout the NBEW, so engaging the agricultural community will be important to watershed-wide water quality issues.

Management Practice	Short-Term (1-3 years)			Mid-Term (3-5 years)		Long-Term (5-10 years)					Considerations	Transferability
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026		
Structural BMPs												· C and D soils in the region favor the use of bioretention, so BMPs identified in this watershed are relevant to other watersheds both in the NWD system and the NBEW.
WR_0_A & WR_0_B				■	■	■					· This BMP offers moderate TP removal and cost-effectiveness, but is located in a watershed with relatively high stream TP concentrations.	
WR_1_A						■	■	■	■	■	· This BMP is the least cost-effective and is a lower priority for implementation.	
WR_1_B					■	■	■				· This BMP offers moderate TP removal and cost-effectiveness.	
WR_2_A	■	■	■								· This BMP offers >30 lbs/yr estimated TP removal and moderate cost-effectiveness.	
WR_2_B					■	■	■				· This BMP offers moderate TP removal and cost-effectiveness.	
WR_2_C	■	■	■								· This BMP offers >50 lbs/yr estimated TP removal and good cost-effectiveness.	
WR_3_A					■	■	■				· This BMP offers low estimated TP removal (<5 lbs/yr) and is among the least cost-effective of the BMPs considered.	
WR_4_A	■	■	■								· This BMP offers >40 lbs/yr estimated TP removal and good cost-effectiveness.	

Management Practice	Short-Term (1-3 years)			Mid-Term (3-5 years)		Long-Term (5-10 years)					Considerations	Transferability
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026		
WR_4_B					█	█	█				· This BMP offers moderate TP removal and cost-effectiveness.	
WR_C_A	█	█	█								· Located on a state road, this BMP could become part of RIDOT's plan to address stormwater quality as part of their existing consent decree with USEPA. · It also has high cost-effectiveness and the highest estimated TP removal of all the BMPs assessed.	
WR_OF5_A					█	█	█				· This BMP offers moderate TP removal and cost-effectiveness.	

Table 6.2 Implementation Plan for St. Mary's Pond Watershed

Management Practice	Short-Term (1-3 years)			Mid-Term (3-5 years)		Long-Term (5-10 years)					Considerations	Transferability
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026		
Vegetative Buffers	■	■	■								· Newport Water controls the land immediately adjacent to the water bodies. · Buffers would need to be reestablished in some areas were encroachment has occurred. · Opportunities for public education with signage, etc. · Secondary benefit for reduction of other pollutants and provision of habitat.	· Can be implemented at all NWD reservoirs. · Aligns with efforts by ALT to develop conservation plans identifying priority buffer areas · Aligns with RIDEM guidance for riparian buffers.
Residential Education	■	■	■								· Opportunity to leverage relationships between ALT and Carriage Drive and Oakland Farms homeowners. · Many opportunities for scale and scope of education.	· Since most NWD land is not owned or controlled by the City of Newport, education is an important management practice for all of the water supply watersheds. · Focusing on actions most likely to impact nutrients – pet waste, lawn care, and septic systems – will be most beneficial throughout the NBEW.
Nutrient Management	■	■	■	■	■	■	■	■	■	■	· Opportunity to leverage ongoing work of NRCS to engage farmers in Rhode Island. · Implementation is expected to cover the entire time period due to the number of agricultural operations and the time needed to engage farms and obtain a commitment to a plan.	· Agriculture is present in most of the NWD watersheds and throughout the NBEW, so engaging the agricultural community will be important to watershed-wide water quality issues.

Management Practice	Short-Term (1-3 years)			Mid-Term (3-5 years)		Long-Term (5-10 years)					Considerations	Transferability
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026		
Structural BMPs												· C and D soils in the region favor the use of bioretention and WVTS, so BMPs identified in this watershed are relevant to other watersheds both in the NWD system and the NBEW.
SM_1_A	█	█	█								· Located on a state road, this BMP could become part of RIDOT's plan to address stormwater quality as part of their existing consent decree with USEPA.	
SM_1_B	█	█	█								· Located on a state road, this BMP could become part of RIDOT's plan to address stormwater quality as part of their existing consent decree with USEPA.	
SM_1_C	█	█	█								· Resurfacing of Middle Road has been included in the RIDOT Transportation Improvement Plan for funding in FY2017.	
SM_2_A			█	█	█						· Although space exists for the installation of a BMP, lack of connection to the existing drainage system makes this a lower priority. A detailed field investigation of drainage in the area would be required prior to any implementation. · Potential exists for a BMP at this site to capture drainage from Carriage Drive that is currently untreated as it drains into Oakland	

Management Practice	Short-Term (1-3 years)			Mid-Term (3-5 years)		Long-Term (5-10 years)					Considerations	Transferability
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026		
											Forest near the eastern shore of St. Mary's Pond.	
SM_2_B	■	■	■								· The opportunity for retrofit of an existing structure and the high pollutant removal potential and cost-effectiveness make this a priority for implementation. · Its location in the ALT-owned Oakland Farms Forest/Meadow also provides public education opportunities for those that visit the open space area.	

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Technical Appendix A – Water Quality Data

In-Lake Samples – Laboratory Testing

Sample Location	Analytical Laboratory	Reporting Limit	St. Mary's Pond at Depth	St. Mary's Pond at Thermocline	St. Mary's Pond at Surface	Watson Reservoir at Depth	Watson Reservoir at Thermocline	Watson Reservoir at Surface	Field Duplicate
Date			**4/29/2015**	**4/29/2015**	**4/29/2015**	**4/29/2015**	**4/29/2015**	**4/29/2015**	**4/29/2015**
Sample Number			01134150320-01	01134150320-02	01134150320-03	01134150320-09	01134150320-10	01134150320-11	01134150320-12
Depth (ft)			9'	4'	1'	24'	8'	1'	Watson 8'
Total Nitrogen (mg/L)	NET	0.03	2.21	1.96	2.01	1.63	1.18	1	0.89
Nitrate (mg/L)	NET	0.03	1.00	0.85	1	0.82	0.37	0.4	0.38
Nitrite (mg/L)	NET	0.007	0.009	0.008	0.007	0.007	0.007	ND	0.007
Ammonia (mg/L)	NET	0.1	ND	ND	ND	ND	ND	ND	ND
Alkalinity (mg/L)	NET	2	8	10	8	8	7	6	6
Turbdity (NTU)	NET	0.1	2.7	2.7	3.2	2.4	2.4	2	2.1
Total Phosphorous (mg/L)	Analytical Balance	0.01	0.06	0.08	0.05	0.03	0.04	0.04	0.05

In-Lake Samples – Laboratory Testing									
Sample Location	**Analytical Laboratory**	**Reporting Limit**	**St. Mary's Pond at Depth**	**St. Mary's Pond at Thermocline**	**St. Mary's Pond at Surface**	**Watson Reservoir at Depth**	**Watson Reservoir at Thermocline**	**Watson Reservoir at Surface**	**Field Duplicate**
Date			**5/27/2015**	**5/27/2015**	**5/27/2015**	**5/27/2015**	**5/27/2015**	**5/27/2015**	
Sample Number			1145150527-01	1145150527-02	1145150527-03	1145150527-05	1145150527-06	1145150527-04	
Depth (ft)			9'	5'	1'	25'	13'	1'	
Total Nitrogen (mg/L)	NET	0.03	1.67	1.32	0.88	0.63	0.67	0.97	
Nitrate (mg/L)	NET	0.03	0.47	0.52	0.38	ND	0.17	0.17	
Nitrite (mg/L)	NET	0.007	ND	ND	ND	ND	ND	ND	
Ammonia (mg/L)	NET	0.1	ND	ND	ND	ND	ND	ND	
Alkalinity (mg/L)	NET	2	17	16	15	11	9	11	
Turbdity (NTU)	NET	0.1	1.3	3.6	3	18	5	3.6	
Total Phosphorous (mg/L)	Analytical Balance	0.01	0.05	0.06	0.06	0.2	0.04	0.03	

In-Lake Samples – Laboratory Testing									
Sample Location	**Analytical Laboratory**	**Reporting Limit**	**St. Mary's Pond at Depth**	**St. Mary's Pond at Thermocline**	**St. Mary's Pond at Surface**	**Watson Reservoir at Depth**	**Watson Reservoir at Thermocline**	**Watson Reservoir at Surface**	**Field Duplicate**
Date			**6/17/2015**	**6/17/2015**	**6/17/2015**	**6/17/2015**	**6/17/2015**	**6/17/2015**	
Sample Number			1297150617-03	1297150617-02	1297150617-01	1297150617-06	1297150617-05	1297150617-04	
Depth (ft)			8'	6'	1'	26'	20'	1'	
Total Nitrogen (mg/L)	NET	0.03	1.31	0.59	0.49	2.57	0.97	0.4	
Nitrate (mg/L)	NET	0.03	0.2	0.19	0.19	0.07	0.07	ND	
Nitrite (mg/L)	NET	0.007	0.007	ND	ND	ND	ND	ND	
Ammonia (mg/L)	NET	0.1	ND	ND	ND	0.3	0.2	ND	
Alkalinity (mg/L)	NET	2	18	18	18	12	10	8	
Turbdity (NTU)	NET	0.1	4.9	1.7	1.6	16	15	4.5	
Iron (mg/L)	NET	0.05	4	0.4	0.29	12.6	5.05	0.18	
Total Phosphorous (mg/L)	Analytical Balance	0.01	0.28	0.04	0.04	0.32	0.07	0.03	

In-Lake Samples – Laboratory Testing

Sample Location	Analytical Laboratory	Reporting Limit	St. Mary's Pond at Depth	St. Mary's Pond at Thermocline	St. Mary's Pond at Surface	Watson Reservoir at Depth	Watson Reservoir at Thermocline	Watson Reservoir at Surface	Field Duplicate
Date			**7/24/2015**	**7/24/2015**	**7/24/2015**	**7/22/2015**	**7/22/2015**	**7/22/2015**	
Sample Number			1297150724-09	1297150724-10	1297150724-11	1297150722-06	1297150722-07	1297150722-08	
Depth (ft)			5.5'	3.5'	1'	23'	19'	1'	
Total Nitrogen (mg/L)	NET	0.03	5.14	1.05	1.05	2.64	1.18	0.54	
Nitrate (mg/L)	NET	0.03	0.04	0.05	0.04	0.04	0.08	0.03	
Nitrite (mg/L)	NET	0.007	ND	ND	0.008	ND	NF	0.007	
Ammonia (mg/L)	NET	0.1	0.4	0.3	0.3	1	0.6	0.2	
Alkalinity (mg/L)	NET	2	26	26	27	34	24	10	
Turbdity (NTU)	NET	0.1	250	13	13	63	12	4.7	
Total Phosphorous (mg/L)	Analytical Balance	0.01	0.52	0.12	0.12	0.61	0.07	0.03	
Iron (mg/L)	NET	0.05	5.24	0.52	0.54	11.7	4.71	0.19	

In-Lake Samples – Laboratory Testing									
Sample Location	**Analytical Laboratory**	**Reporting Limit**	**St. Mary's Pond at Depth**	**St. Mary's Pond at Thermocline**	**St. Mary's Pond at Surface**	**Watson Reservoir at Depth**	**Watson Reservoir at Thermocline**	**Watson Reservoir at Surface**	**Field Duplicate**
Date			**8/26/2015**	**8/26/2015**	**8/26/2015**	**8/26/2015**	**8/26/2015**	**8/26/2015**	
Sample Number			129720150826-01	129720150826-02	129720150826-03	129720150826-04	129720150826-05	129720150826-06	
Depth (ft)			6.5'	5'	1'	22'	13'	.5'	
Total Nitrogen (mg/L)	NET	0.03	1.17	3.25	1.7	6	0.53	0.5	
Nitrate (mg/L)	NET	0.03	0.07	0.15	0.6	ND	0.03	ND	
Nitrite (mg/L)	NET	0.007	ND	ND	ND	ND	ND	ND	
Ammonia (mg/L)	NET	0.1	0.4	0.3	0.3	202	ND	ND	
Alkalinity (mg/L)	NET	2	21	22	20	48	13	13	
Turbdity (NTU)	NET	0.1	105	11	11	17	4.8	5.2	
TKN (mg/L)	NET	1	1.1	3.1	1.1	6.0	0.5	0.5	
Total Phosphorous (mg/L)	Analytical Balance	0.01	3.80	0.15	0.12	0.42	0.04	0.03	
Iron (mg/L)	NET	0.05	1.6	1.14	1.03	13.6	0.41	0.12	

In-Lake Samples – Laboratory Testing

Sample Location	**Analytical Laboratory**	**Reporting Limit**	**St. Mary's Pond at Depth**	**St. Mary's Pond at Thermocline**	**St. Mary's Pond at Surface**	**Watson Reservoir at Depth**	**Watson Reservoir at Thermocline**	**Watson Reservoir at Surface**	**Field Duplicate**
Date			**9/23/2015**	**9/23/2015**	**9/23/2015**	**9/23/2015**	**9/23/2015**	**9/23/2015**	
Sample Number			0132150923-11	0132150923-10	0132150923-09	0132150923-08	0132150923-07	0132150923-06	
Depth (ft)			5'	3'	1'	20'	16.5'	1'	
Total Nitrogen (mg/L)	NET	0.03	1.71	1.14	1.02	0.86	0.95	0.77	
Nitrate (mg/L)	NET	0.03	0.11	0.14	0.12	0.06	0.15	0.07	
Nitrite (mg/L)	NET	0.007	ND	ND	ND	ND	ND	ND	
Ammonia (mg/L)	NET	0.1	0.3	0.2	0.3	0.2	0.2	0.2	
Alkalinity (mg/L)	NET	2	18	17	17	16	16	16	
Turbdity (NTU)	NET	0.1	14	15	16	5.8	5.1	6	
TKN (mg/L)	NET	1	1.6	1	0.9	0.8	0.8	0.7	
Total Phosphorous (mg/L)	Analytical Balance	0.01	0.69	0.18	0.17	0.2	0.03	0.03	

St. Mary’s Pond In-Lake Measurements

4/30/2015	Depth (ft)	Temperature (°C)	pH	Conductivity	DO (mg/l)	Redox Potential (mV)
	1	12.95	7.75	203.4	10.28	
	2	12.97	7.59	203.2	10.23	
	3	12.97	7.62	203.2	10.21	
	4	12.98	7.63	203.1	10.21	
	5	12.97	7.62	203.1	10.21	
	6	12.98	7.63	203.1	10.21	
	7	12.98	7.62	203.1	10.19	
	8	12.97	7.62	203.1	10.17	
	9	12.99	7.61	203.1	10.18	

St. Mary’s Pond In-Lake Measurements

5/27/2015	Depth (ft)	Temperature (°C)	pH	Conductivity	DO (mg/l)	Redox Potential (mV)
	1	18.91	6.43	216.9	9.27	
	2	18.9	6.42	216.8	9.28	
	3	18.89	6.38	216.7	9.26	
	4	18.87	6.37	216.9	9.26	
	5	18.86	6.36	216.8	9.2	
	6	18.83	6.32	216.8	9.19	
	7	18.82	6.31	217	9.15	
	8	18.81	6.22	216.9	9.2	
	9	18.77	6.15	216.5	9.11	

St. Mary’s Pond In-Lake Measurements

6/17/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	21.62	7.24	213.3	9.27	
	2	21.62	7.18	195.9	9.28	
	3	21.62	7.11	196.8	9.26	
	4	21.5	7.02	197.9	9.26	
	5	21.57	6.95	199.9	9.2	
	6	21.55	6.88	200.8	9.19	
	7	21.51	6.76	202.1	9.15	
	8	21.3	6.8	216.9	9.2	

St. Mary’s Pond In-Lake Measurements

7/22/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	26.12	7.04	227.9	4.97	
	2	26.04	7.03	227.9	4.95	
	3	26.02	6.98	227.8	4.94	
	4	25.91	6.92	228.1	4.93	
	5	25.88	6.9	228.3	4.91	
	6	25.76	6.76	228.6	4.94	

St. Mary’s Pond In-Lake Measurements

8/26/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	26.6	7.04	186.8	4.29	134.8
	2.5	26.6	7.04	186.7	4.4	145.9
	3.5	26.6	7.03	186.2	4.43	158.7
	4.5	26.6	7.01	186.3	4.54	166.5
	5.5	26.4	6.96	188.1	3.16	171.6
	6.5	26.3	6.96	190.3	1.77	172.8

St. Mary’s Pond In-Lake Measurements

9/23/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	19.92	7.46	158.1	9.06	
	2	19.91	7.35	158.1	9.05	
	3	19.92	7.22	158.0	9.04	
	4	19.97	7.11	157.8	8.97	
	5	20.07	7.02	157.1	8.55	

Watson Reservoir In-Lake Measurements

4/30/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	12.95	6.61	153	12.03	
	2	12.93	6.68	153.1	12.08	
	3	12.88	6.7	153.1	12.06	
	4	12.83	6.75	153.2	12.07	
	5	12.81	6.78	153.5	12.09	
	6	12.76	6.83	153.9	12.11	
	7	12.67	6.85	153.8	12.08	
	8	12.47	6.86	153.7	12.03	
	9	12.41	6.89	153.8	12.01	
	10	12.37	6.92	153.4	11.93	
	11	12.34	6.93	153.8	11.87	
	12	12.28	6.92	153.8	11.84	
	13	12.26	6.93	154	11.86	
	14	12.24	6.96	154	11.84	
	15	12.24	6.96	154.1	11.79	
	16	12.22	6.95	154	11.76	
	17	12.22	6.97	154.1	11.76	
	18	12.2	6.96	154	11.74	
	19	12.19	6.94	160.9	10.98	
	20	12.18	6.9	157.9	11.2	
	21	12.16	6.83	157.9	11.27	
	22	12.19	6.73	158.3	11.28	
	23	12.19	6.69	157.8	11.28	
	24	12.19	6.69	157.8	11.28	

Watson Reservoir In-Lake Measurements

5/27/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	18.41	6.53	158.7	10.07	
	2	18.41	6.53	158.7	10.07	
	3	18.41	6.53	158.7	10.07	
	4	18.41	6.52	158.7	10.06	
	5	18.41	6.53	158.8	10.06	
	6	18.41	6.5	158.6	10.06	
	7	18.41	6.49	158.7	10.06	
	8	18.41	6.49	158.7	10.06	
	9	18.41	6.49	158.7	10.05	
	10	18.37	6.46	158.7	10.03	
	11	18.37	6.46	158.8	10.02	
	12	18.36	6.46	158.7	10.02	
	13	18.34	6.44	158.8	10.02	
	14	18.28	6.42	158.8	10.02	
	15	18.28	6.12	156.9	9.28	
	16	18.29	6.08	157	9.3	
	17	18.29	6.05	157	9.21	
	18	18.3	6	157	9.21	
	19	18.3	5.97	157	9.18	
	20	18.3	5.87	157.4	8.94	
	21	18.3	5.79	155.8	9.11	
	22	18.31	5.66	155.7	8.88	
	23	18.32	5.62	156.1	8.85	
	24	18.32	5.55	156.1	8.53	
	25	18.35	5.44	156.1	6.56	

Watson Reservoir In-Lake Measurements

6/17/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	22.13	6.41	156.2	8.3	
	2	21.99	6.41	156.7	8.26	
	3	21.93	6.37	156.7	8.31	
	4	21.89	6.38	156.8	8.32	
	5	21.85	6.44	156.9	8.3	
	6	21.72	6.41	157	8.4	
	7	21.66	6.37	157.2	8.36	
	8	21.5	6.35	157.3	8.24	
	9	21.08	6.36	158.1	8.24	
	10	20.8	3.34	157.7	7.75	
	11	20.26	6.33	156.9	7.2	
	12	20.02	6.32	157.3	7.03	
	13	19.79	6.32	157.7	6.82	
	14	19.62	6.3	158	6.69	
	15	19.66	6.31	162.6	6.71	
	16	19.35	6.31	163	6.49	
	17	19.26	6.24	164.1	6.17	
	18	19	6.28	165.3	5.74	
	19	18.45	6.24	166.6	4.97	
	20	18.22	6.23	167.3	4.35	
	21	17.96	6.21	171.1	2.43	
	22	18.15	6.12	171.1	2.45	

Watson Reservoir In-Lake Measurements

7/22/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	26.31	6.77	169.6	8.44	
	2	26.28	9.74	169.6	8.45	
	3	26.21	6.71	176.3	8.51	
	4	26.15	6.68	181.8	8.49	
	5	26.08	6.64	182	8.49	
	6	25.91	6.58	197.4	8.46	
	7	25.76	6.58	143.6	8.1	
	8	25.56	6.57	144.2	8.09	
	9	25.42	6.53	145.7	7.87	
	10	25.14	6.55	147.2	7.72	
	11	24.81	6.67	148.8	7.02	
	12	24.37	6.57	149	5.97	
	13	23.79	6.62	150.3	4.41	
	14	21.03	6.66	165.65	3.03	
	15	20.36	9.72	166.3	0.64	
	16	19.8	6.7	166.8	0.14	
	17	19.42	6.69	169.4	0.03	
	18	19.31	6.67	175.4	0.02	
	19	19.26	6.63	179.9	0.01	
	20	19.29	6.66	184.3	0.01	
	21	19.34	6.62	194.2	0.01	
	22	19.6	6.53	208.9	0.02	
	23	20.32	6.14	233.9	0.03	

Watson Reservoir In-Lake Measurements

8/26/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1.049	27.995	8.97	175.5	9.22	81.8
	2.010	27.967	8.98	175.3	9.22	84.5
	3.082	27.944	8.99	175.3	9.22	87.5
	4.059	27.806	9	175	9.2	91.2
	5.036	27.214	8.96	172.6	9.1	95.8
	6.151	26.854	8.9	170.8	9.03	100.4
	7.184	26.734	8.84	169.9	8.93	105.2
	8.161	26.647	8.75	169.4	8.8	110.2
	9.167	26.595	8.64	168.9	8.59	116.5
	10.072	26.402	8.43	168.3	7.69	129.9
	11.111	26.085	8.25	167.6	6.52	139.6
	12.128	25.487	7.87	165.4	3.83	151.9
	13.068	24.334	7.51	158.3	0.6	152.2
	14.114	22.93	7.26	168.9	0.32	11.1
	15.015	21.995	7.13	183.8	0.25	-48.6
	16.078	21.046	7.01	205.2	0.22	-99.8
	17.127	20.753	6.98	214.4	0.2	-116.9
	18.124	20.673	6.97	217.9	0.18	-127.3
	19.087	20.319	6.97	222.9	0.17	-138.9
	20.081	20.16	6.98	226.1	0.15	-148.8

Watson Reservoir In-Lake Measurements

9/23/2015	Depth (ft)	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Redox Potential (mV)
	1	21.86	6.96	138.7	7.16	
	2	21.80	6.96	138.6	7.17	
	3	21.77	6.96	138.6	7.16	
	4	21.74	6.95	138.7	7.16	
	5	21.71	6.95	138.6	7.15	
	6	21.66	6.95	138.7	7.14	
	7	21.55	6.95	143.2	7.15	
	8	21.53	6.95	143.2	7.14	
	9	21.49	6.94	143.3	7.11	
	10	21.49	6.94	143.5	7.10	
	11	21.46	6.93	143.7	7.02	
	12	21.40	6.92	144.8	6.85	
	13	21.37	6.91	146.6	6.73	
	14	21.34	6.92	145.9	6.65	
	15	21.31	6.76	146.0	6.92	
	16	21.26	6.98	146.3	6.90	
	17	21.19	6.92	146.7	6.98	
	18	21.17	6.89	148.7	6.92	
	19	21.17	6.84	155.2	6.77	
	20	21.17	6.80	163.1	6.73	

Watson Reservoir Tributary Sampling									
	Analytical Laboratory	**Reporting Limit**	**Tributary 0**	**Tributary 1**	**Tributary 2**	**Tributary 3**	**Tributary 4**	**Tributary 5**	**Field Duplicate**
Date			4/29/2015	4/29/2015	4/29/2015	4/29/2015	4/29/2015	4/29/2015	
Sample Number			01134150320-07	01134150320-08	01134150320-06	01134150320-05	01134150320-04	No Flow	
Total Nitrogen (mg/L)	NET	0.03	1.61	1.33	1.05	0.78	0.88		
Nitrate (mg/L)	NET	0.03	0.7	0.93	0.35	0.18	0.08		
Nitrite (mg/L)	NET	0.007	0.007	ND	ND	ND	ND		
Ammonia (mg/L)	NET	0.1	ND	ND	ND	ND	ND		
Total Phosphorous (mg/L)	Analytical Balance	0.01	0.14	0.03	0.07	0.05	0.03		

Watson Reservoir Tributary Sampling									
	Analytical Laboratory	**Reporting Limit**	**Tributary 0**	**Tributary 1**	**Tributary 2**	**Tributary 3**	**Tributary 4**	**Tributary 5**	**Field Duplicate**
Date			5/27/2015	5/27/2015	5/27/2015	5/27/2015	5/27/2015	5/27/2015	**Field Duplicate @ Trib 1**
Sample Number			1145150527-10	No Flow	1145150527-09	1145150527-08	1145150527-07	No Flow	1145150527-11
Total Nitrogen (mg/L)	NET	0.03	1.28		1.04	1.34	3.89		1.18
Nitrate (mg/L)	NET	0.03	0.57		0.44	0.14	0.09		0.47
Nitrite (mg/L)	NET	0.007	0.01		ND	ND	ND		0.014
Ammonia (mg/L)	NET	0.1	ND		ND	ND	ND		ND
Total Phosphorous (mg/L)	Analytical Balance	0.01	0.08		0.03	0.35	0.29		0.05

Watson Reservoir Tributary Sampling									
	Analytical Laboratory	**Reporting Limit**	**Tributary 0**	**Tributary 1**	**Tributary 2**	**Tributary 3**	**Tributary 4**	**Tributary 5**	**Field Duplicate**
Date			6/17/2015	6/17/2015	6/17/2015	6/17/2015	6/17/2015	6/17/2015	**Field Duplicate @ Trib 1**
Sample Number			No Flow	1297150617-11	1297150617-10	1297150617-09	1297150617-07	No Flow	1297150617-08
Total Nitrogen (mg/L)	NET	0.03		0.74	0.82	0.76	1.1		1.3
Nitrate (mg/L)	NET	0.03		0.04	0.22	0.06	ND		ND
Nitrite (mg/L)	NET	0.007		ND	ND	ND	ND		ND
Ammonia (mg/L)	NET	0.1		ND	ND	ND	ND		ND
Total Phosphorous (mg/L)	Analytical Balance	0.01		0.05	0.04	0.07	0.09		0.09

Watson Reservoir Tributary Sampling									
	Analytical Laboratory	**Reporting Limit**	**Tributary 0**	**Tributary 1**	**Tributary 2**	**Tributary 3**	**Tributary 4**	**Tributary 5**	**Field Duplicate**
Date			7/22/2015	7/22/2015	7/22/2015	7/22/2015	7/22/2015	7/22/2015	**Field Duplicate @ Trib 3**
Sample Number			1297150722-05	1297150722-04	1297150722-03	1297150722-02	No Flow	No Flow	1297150722-01
Total Nitrogen (mg/L)	NET	0.03	0.95	3.46	1.48	1.2			1.69
Nitrate (mg/L)	NET	0.03	0.14	0.26	0.97	0.19			0.57
Nitrite (mg/L)	NET	0.007	0.008	ND	0.01	0.009			0.019
Ammonia (mg/L)	NET	0.1	0.4	0.6	0.3	0.3			0.3
Total Phosphorous (mg/L)	Analytical Balance	0.01	1	0.24	0.04	0.16			0.15

Watson Reservoir Tributary Sampling

	Analytical Laboratory	Reporting Limit	Tributary 0	Tributary 1	Tributary 2	Tributary 3	Tributary 4	Tributary 5	Field Duplicate
Date			8/26/2015	8/26/2015	8/27/2015	8/28/2015	8/29/2015	8/27/2015	**Field Duplicate @ Trib 4**
Sample Number			129720150826-12	129720150826-11	129720150826-10	129720150826-09	129720150826-07	No Flow	129720150826-08
Total Nitrogen (mg/L)	NET	0.03	12.2	0.8	0.71	0.68	0.95		1.07
Nitrate (mg/L)	NET	0.03	0.11	0.1	0.11	0.08	0.04		0.06
Nitrite (mg/L)	NET	0.007	0.009	ND	ND	ND	0.009		0.009
Ammonia (mg/L)	NET	0.1	0.1	0.2	ND	ND	ND		ND
Total Phosphorous (mg/L)	Analytical Balance	0.01	--*	0.06	0.08	0.05	0.07		0.07
TKN, mg/L	NET	1	12.1	0.7	0.6	0.6	0.9		1

Watson Reservoir Tributary Sampling

	Analytical Laboratory	Reporting Limit	Tributary 0	Tributary 1	Tributary 2	Tributary 3	Tributary 4	Tributary 5	Field Duplicate
Date			9/23/2015	9/23/2015	9/23/2015	9/23/2015	9/23/2015	9/23/2015	**Field Duplicate @ Trib 3**
Sample Number			0132150923-05	0132150923-04	0132150923-03	0132150923-01	No Flow	No Flow	0132150923-02
Total Nitrogen (mg/L)	NET	0.03	2.55	1.2	0.8	1.83			0.76
Nitrate (mg/L)	NET	0.03	0.05	ND	ND	0.13			0.16
Nitrite (mg/L)	NET	0.007	ND	ND	ND	ND			ND
Ammonia (mg/L)	NET	0.1	0.2	0.6	0.1	ND			ND
Total Phosphorous (mg/L)	Analytical Balance	0.01	0.87	0.08	0.05	0.32			0.11
TKN, mg/L	NET	1	2.5	1.2	0.8	1.7			0.6

Water Quality Sampling Locations

Location Name	Latitude	Longitude		Location Name	Latitude	Longitude
Watson Tributary 0	41.52932	-71.1804		Watson Tributary 4	41.53975	-71.1674
Watson Tributary 1	41.52966	-71.1775		Watson In-Lake	41.54102	-71.1855
Watson Tributary 2	41.53134	-71.1704		St. Mary's In-Lake	41.55444	-71.2729
Watson Tributary 3	41.53631	-71.167				

Notes

NET	=	New England Testing Laboratories
*	=	Result eliminated during QA/QC

Tributary Data

Tributary 0		Latitude	Longitude		
		41.529315	-71.180395		
Date	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Flow Rate (cfs)
4/30/2015	10.85	6.68	279.5	14.34	0.25
5/27/2015	16.45	5.45	344.3	6.28	0.44
6/17/2015	DRY	DRY	DRY	DRY	DRY
7/24/2015	20.11	6.22	344.9	1.58	0.02
8/26/2015	22.4	6.53	314	3.51	0.24
9/23/2015	15.29	6.38	285.2	3.16	0

Tributary 1		Latitude	Longitude		
		41.52966	-71.177455		
Date	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Flow Rate (cfs)
4/30/2015	11.66	6.45	214.1	7.86	Trickle
5/27/2015	DRY	DRY	DRY	DRY	DRY
6/17/2015	--	--	--	--	0.2
7/24/2015	18.86	6.25	2034.3	0.52	0.02
8/26/2015	20.5	5.4	739	1.3	0.02
9/23/2015	16.05	5.64	2776.8	1.91	0

Tributary 2		Latitude	Longitude		
		41.53134	-71.170377		
Date	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Flow Rate (cfs)
4/30/2015	11.45	6.39	325	10.09	0.53
5/27/2015	17.66	6.15	411.1	6.4	0.27
6/17/2015	--	--	--	--	0.0498
7/24/2015	19.63	5.94	489.3	3.66	0.09
8/26/2015	23.3	6.32	406	2.8	0.37
9/23/2015	14.24	6.39	330.4	2.66	0.17

Tributary 3		Latitude	Longitude		
		41.53631	-71.166999		
Date	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Flow Rate (cfs)
4/30/2015	11.44	6.36	227.7	11.01	0.19
5/27/2015	17.63	5.58	177.9	8.72	0.18
6/17/2015	--	--	--	--	0.3325
7/24/2015	20.06	5.91	90.7	5.23	0.02
8/26/2015	22.1	6.22	77.4	5.48	0.1
9/23/2015	15.55	6.04	69	4.62	0.0165

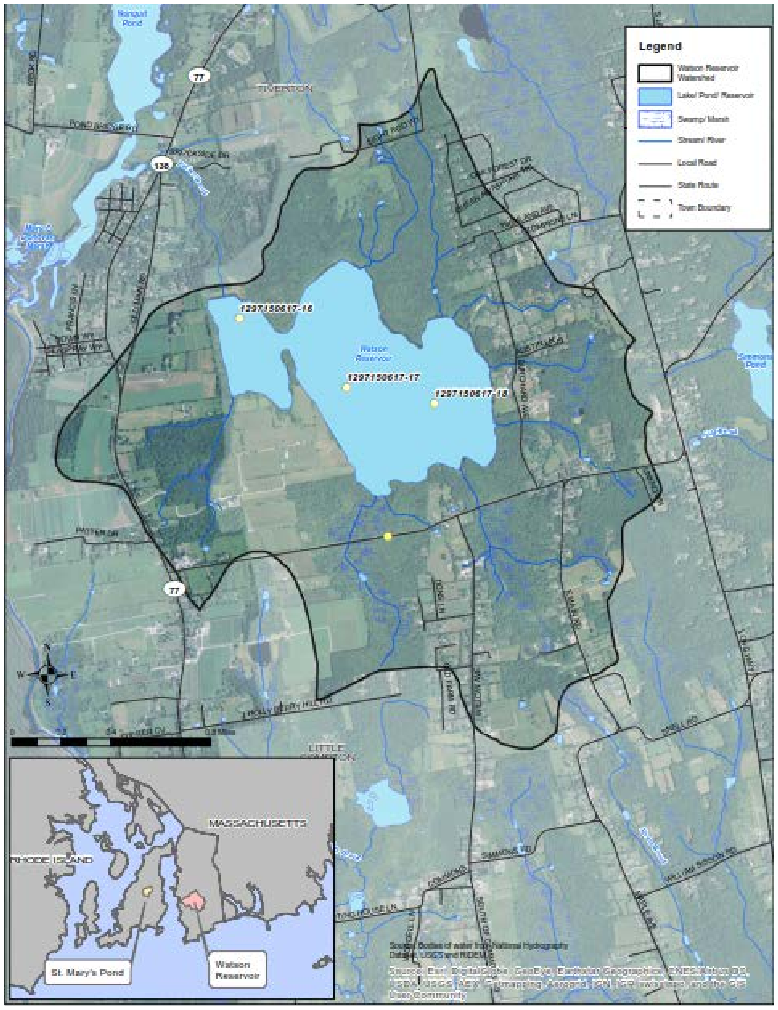
Tributary 4		Latitude	Longitude		
		41.53975	-71.167413		
Date	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Flow Rate (cfs)
4/30/2015	10.5	6.69	56.5	12.12	0.49
5/27/2015	17.7	5.77	60.8	8.85	0.018
6/17/2015	--	--	--	--	1.33
7/24/2015	DRY	DRY	DRY	DRY	DRY
8/26/2015	21.9	4.49	87.8	4.4	0.5
9/23/2015	DRY	DRY	DRY	DRY	DRY

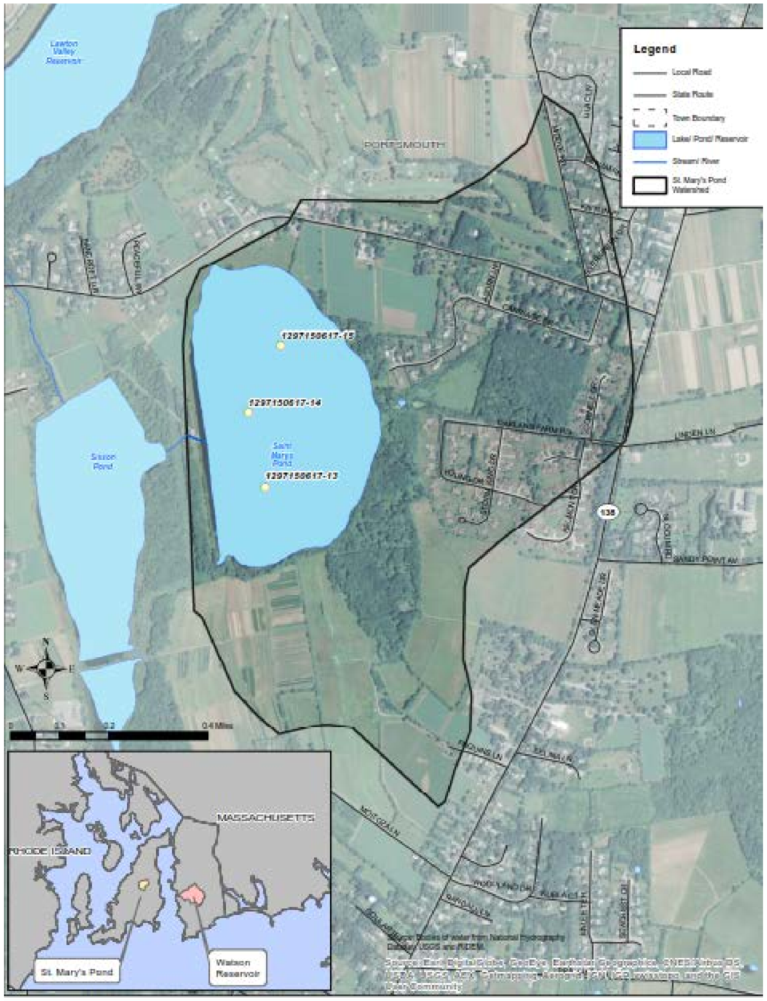
Tributary 5		Latitude	Longitude		
		41.55336	-71.175323		
Date	Temperature (°C)	pH (s.u.)	Conductivity (µS/cm)	DO (mg/l)	Flow Rate (cfs)
4/30/2015	DRY	DRY	DRY	DRY	DRY
5/27/2015	DRY	DRY	DRY	DRY	DRY
6/17/2015	DRY	DRY	DRY	DRY	DRY
7/24/2015	DRY	DRY	DRY	DRY	DRY
8/26/2015	DRY	DRY	DRY	DRY	DRY
9/23/2015	DRY	DRY	DRY	DRY	DRY

In-Lake Sediment Samples

Sample Location	**Analytical Laboratory**	**St. Mary's Pond**	**St. Mary's Pond**	**St. Mary's Pond**	**Watson Reservoir**	**Watson Reservoir**	**Watson Reservoir**
Date		**6/17/2015**	**6/17/2015**	**6/17/2015**	**6/17/2015**	**6/17/2015**	**6/17/2015**
SEDIMENT							
Sample Number		1297150617-13	1297150617-14	1297150617-15	1297150617-16	1297150617-17	1297150617-18
Total Phosphorous (mg/kg)	Analytical Balance	1010	1150	1920	1170	1100	864
Percent Solids (%)	Analytical Balance	33.8	23.4	28.4	33.2	21.5	30.7
Organic Matter (%)	Northeast	21.8	23.1	20	36.4	17.5	24.8
Iron-Bound Phos. (mg/kg)	Northeast	787	534	928	442	531	354
Loosely-sorbed Phos. (mg/kg)	Northeast	54.1	13.8	32.1	25.1	21.2	18.6

Sediment Samples Locations





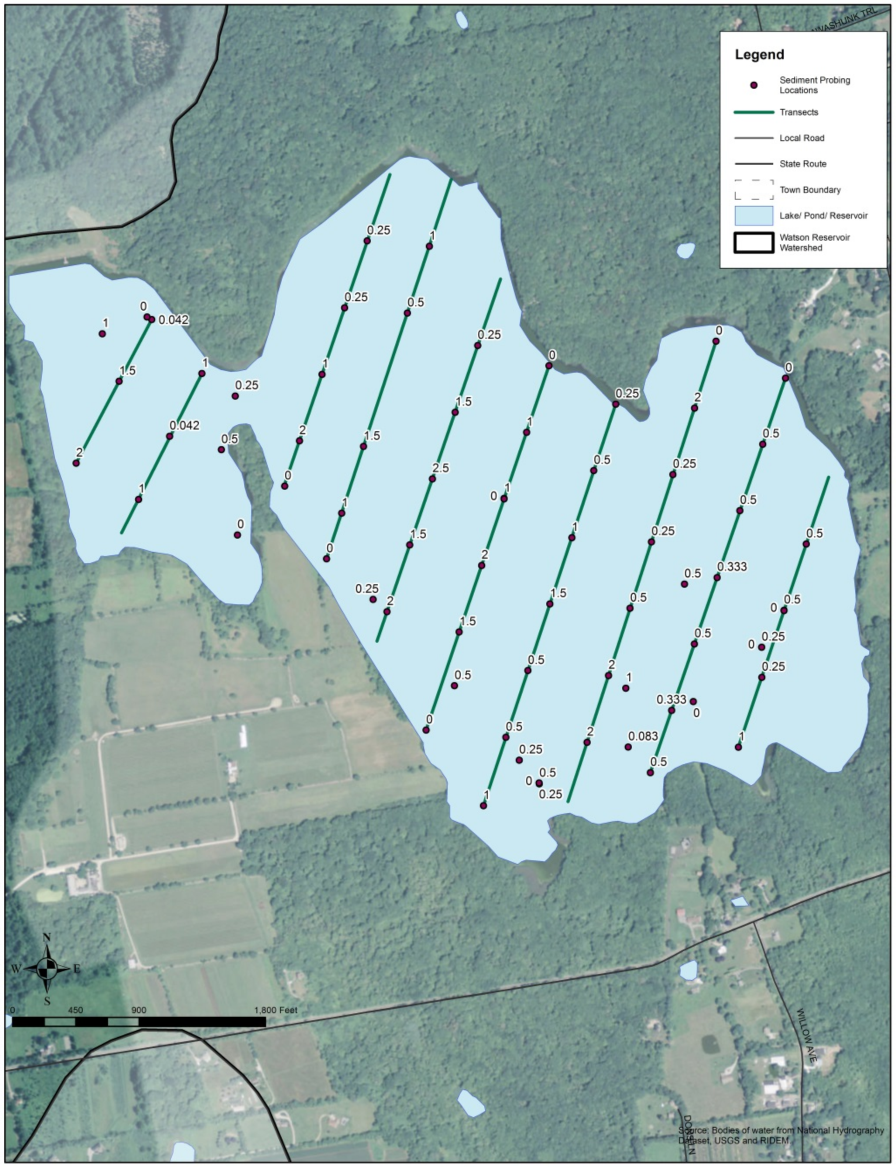
Technical Appendix B – Sediment Depth Calculations

Sediment Depth Probing at Watson Reservoir and St. Mary's Pond

Sediment depth was measured at Watson Reservoir in Little Compton, RI and St. Mary's Pond in Portsmouth, RI in the summer of 2015. Watson Reservoir sediment probing occurred along transects that ran in a southwesterly to northeasterly direction, spaced approximately 500 to 600 feet apart. A total of 70 locations were probed to characterize sediment depth in Watson Reservoir. A square sampling grid was constructed for St. Mary's Pond with sediment probing locations spaced between 300 and 500 feet apart. A total of 48 locations were probed within St. Mary's pond.

Sediment probing was done from a boat using PVC piping, one inch in diameter. Soft sediment depth ranged from 0.0 to 2.5 feet in depth in both water supply areas, with a mean depth of 0.62 feet in Watson Reservoir and 0.93 feet in St. Mary's Pond. In order to calculate a volume of soft sediment in each of the water supply areas, the sediment depth data collected in the field was interpolated using Spatial Analysis tools in ArcGIS 10.2. This interpolated grid was created using kriging (ordinary method, semivariogram model: spherical) which created a continuous grid of sediment depths for both water supply areas. Specific details on how the sediment volume calculations made using Cut/Fill can be found in a article published in October-December 2002 Edition of *ArcUser* (Price, 2002). Estimated soft sediment volumes for Watson Reservoir and St. Mary's Pond were 10,089,924 and 4, 349,663 cubic feet respectively.

Price, M. (2002, October-December). Deriving Volumes With ArcGIS Spatial Analyst. ArcUser. ESRI.



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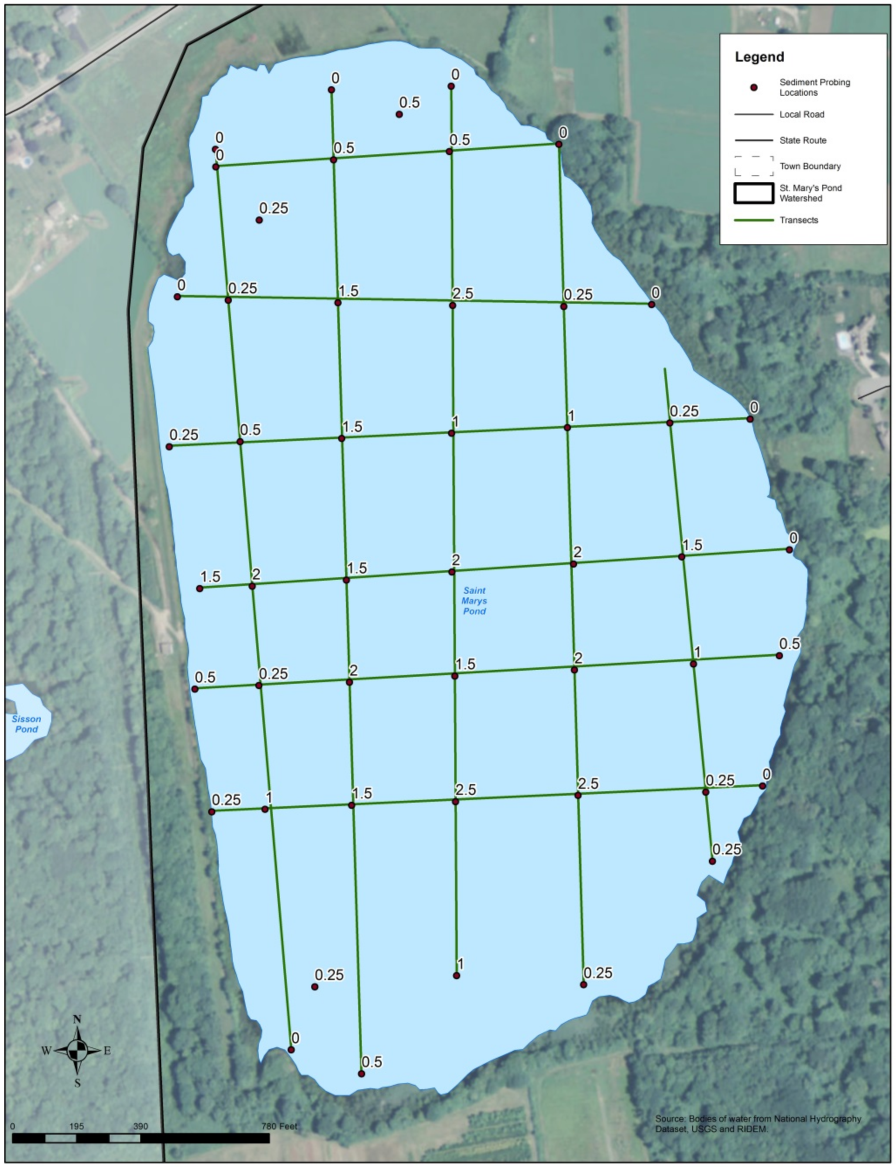

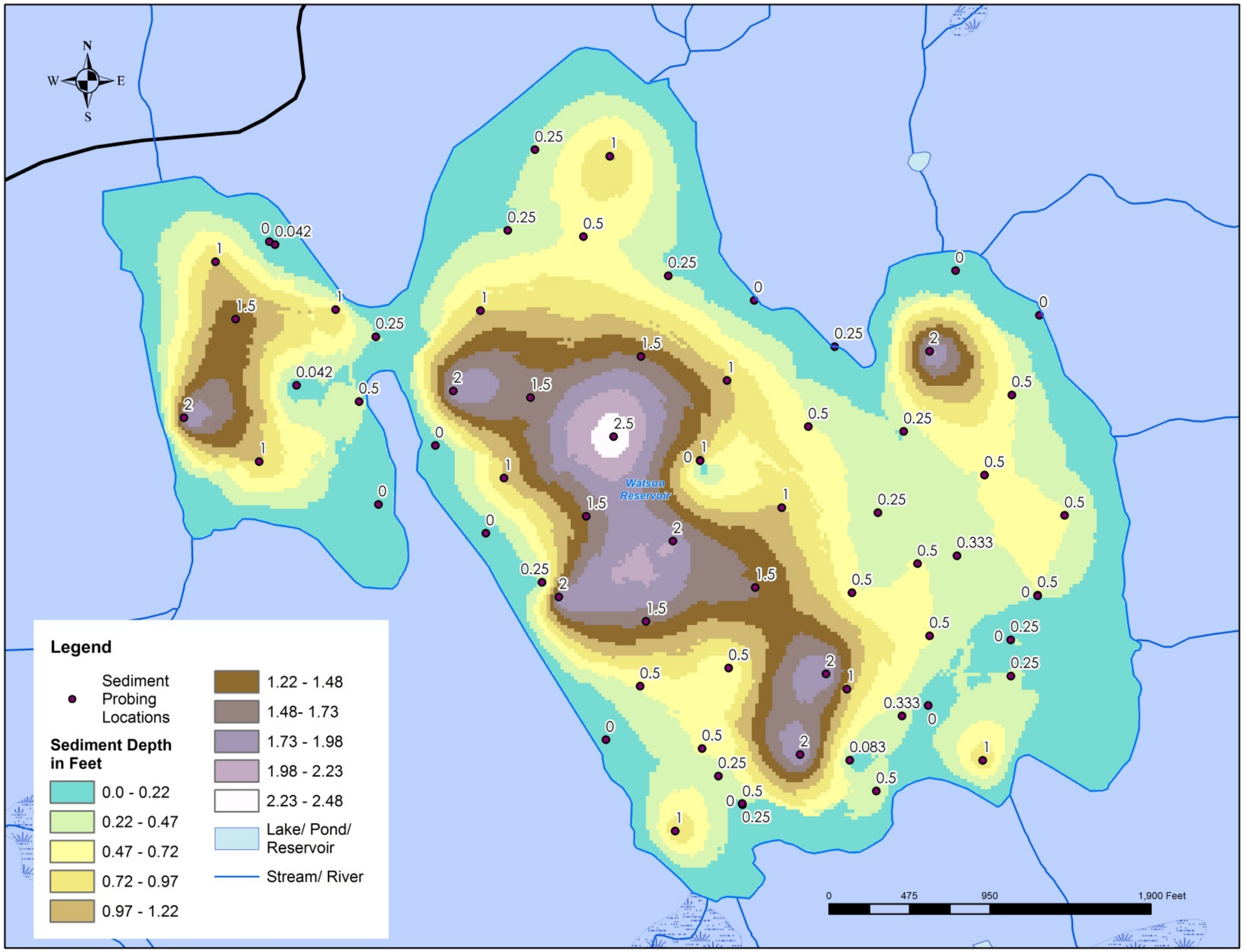
N
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E
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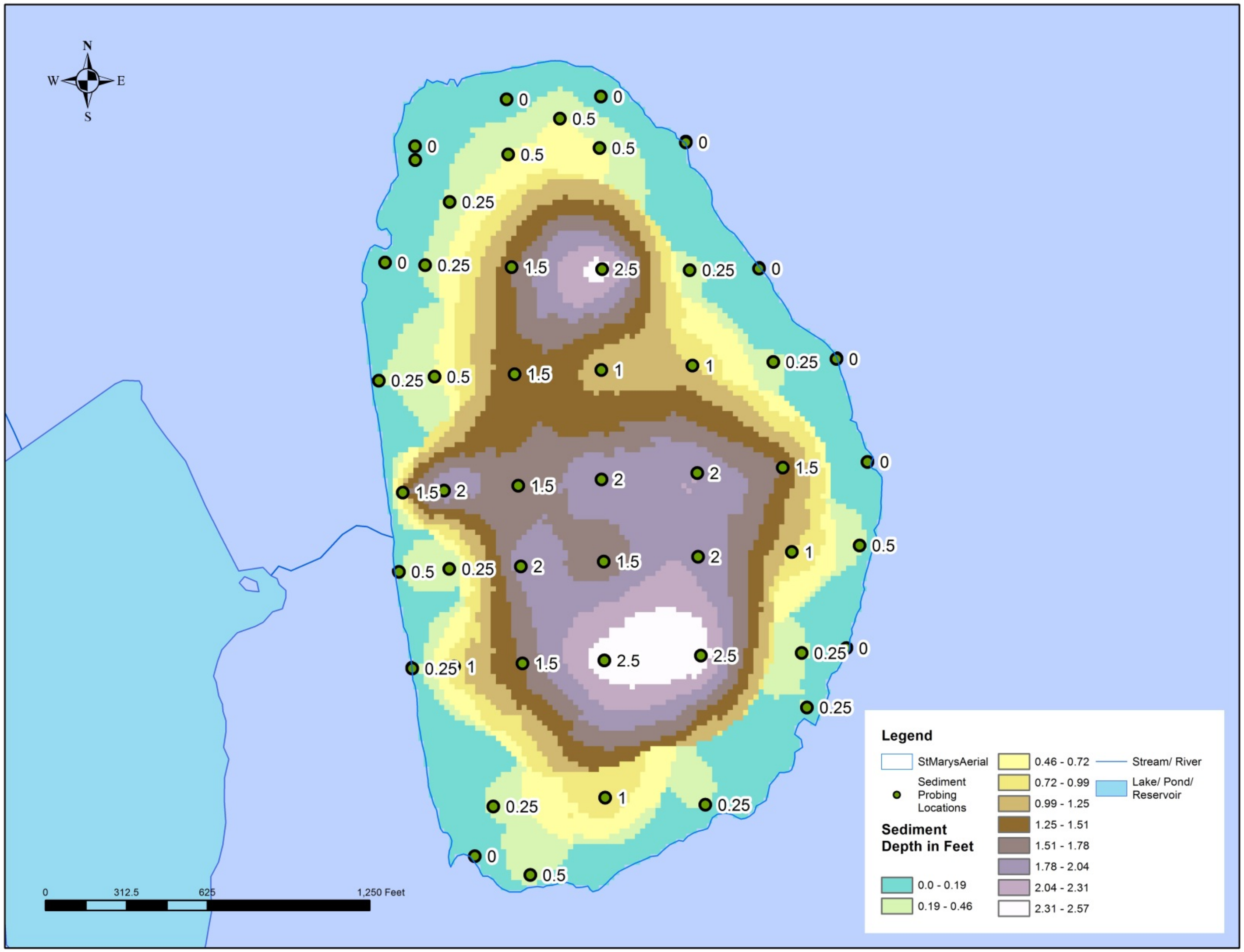
0.25
1
0.25
0.5
0
0.042
1
0.25
0
0
1
1.5
1
0.25
1.5
2
1
0.042
2
1.5
0.5
0.5
0.5
0.25
2.5
0
0
1
1
0.5
1
Watson Reservoir
1.5
0
0.25
0.5
2
0.5
0.333
0.25
2
1.5
0.5
0
0.5
1.5
0.5
0
0.25
0.5
0.5
0.25
2
1
0.333
0
0
0.5
2
0.083
1
0.25
0.5
0.5
0
1
0.25
Legend
● Sediment Probing Locations
Sediment Depth in Feet
0.0 - 0.22
0.22 - 0.47
0.47 - 0.72
0.72 - 0.97
0.97 - 1.22
1.22 - 1.48
1.48- 1.73
1.73 - 1.98
1.98 - 2.23
2.23 - 2.48
Lake/ Pond/ Reservoir
Stream/ River
0
475
950
1,900 Feet


N
W
E
S
0
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0
0.25
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0.25
1.5
2.5
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0.25
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1.5
1
1
0.25
0
1.5
0
1.5
2
1.5
2
2
0.5
0.25
2
1.5
2
1
0.5
0.25
1
1.5
2.5
2.5
0.25
0
0.25
0.25
1
0.25
0
0.5
0
312.5
625
1,250 Feet
Legend
StMarysAerial
Sediment Probing Locations
Sediment Depth in Feet
0.0 - 0.19
0.19 - 0.46
0.46 - 0.72
0.72 - 0.99
0.99 - 1.25
1.25 - 1.51
1.51 - 1.78
1.78 - 2.04
2.04 - 2.31
2.31 - 2.57
Stream/ River
Lake/ Pond/ Reservoir

Technical Appendix C – Oxic and Anoxic Layer Calculations

Calculations of the volume of anoxic water (i.e., water with dissolved oxygen values less than 2 mg/L) were determined using a combination of 2008 bathymetric data available in GIS format from Apex Engineering, a bathymetric survey report conducted by Apex in October of 2008 (Apex Companies, 2008), and a cut/fill operation available in ArcGIS (Price, 2002). Water surface elevations were set at zero depth for each data collection event.

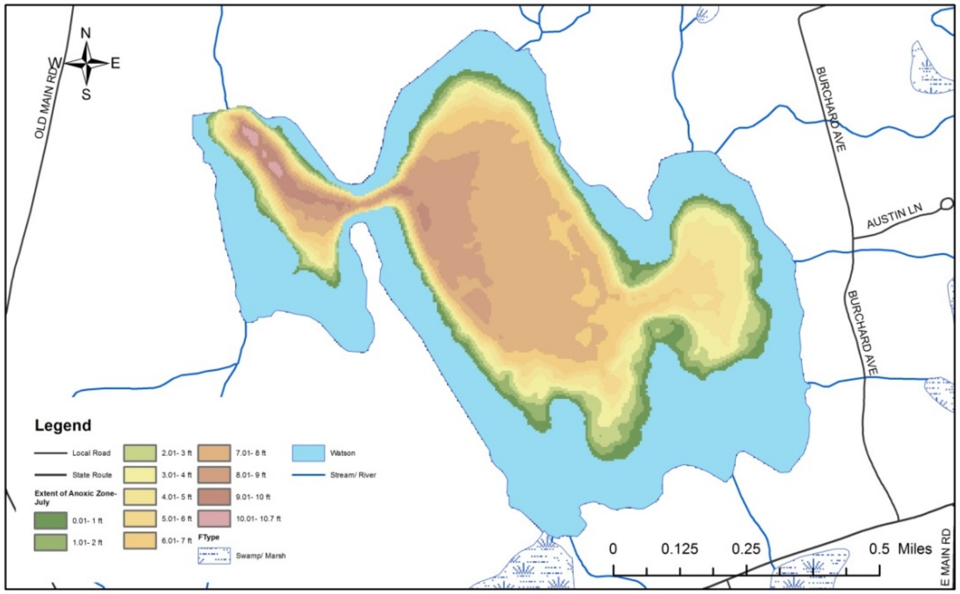
DO measurements within the water column of Watson Reservoir were taken on July 22, 2015 and August 26, 2015. DO measurements for St. Mary's Pond were taken on Aug 26, 2015 The DO measurements were taken at 1 foot intervals. Bathymetric contours were available at 0.5 foot intervals. Because the bathymetry for the Reservoir and Pond were available at a smaller interval than the DO measurements, the oxic/anoxic zone was set mid-way between the depth within the water column where DO measurements of less than 2 mg/L were seen. (For example, on July 22, 2015 a DO value of 0.64 mg/L was measured at 15 ft below the water surface and a D.O value of 3.03 mg/L was measured at 14 ft below the water surface; therefore the 0 depth for the anoxic layer was set at 14.5 feet below the water surface on July 22, 2015). Anoxic volumes calculated for Watson Reservoir ranged from 349.8 million gallons (MG) on July 22, 2015 to 492.6 million gallons on August 26, 2015. The extent and depths of the anoxic zone within Watson Reservoir can be seen in the accompanying figures. An anoxic layer was not observed in St. Mary's Pond, likely due to the presence of air diffusers and the shallow depth of the waterbody.

Anoxic Volume Calculations for Watson Reservoir Watershed

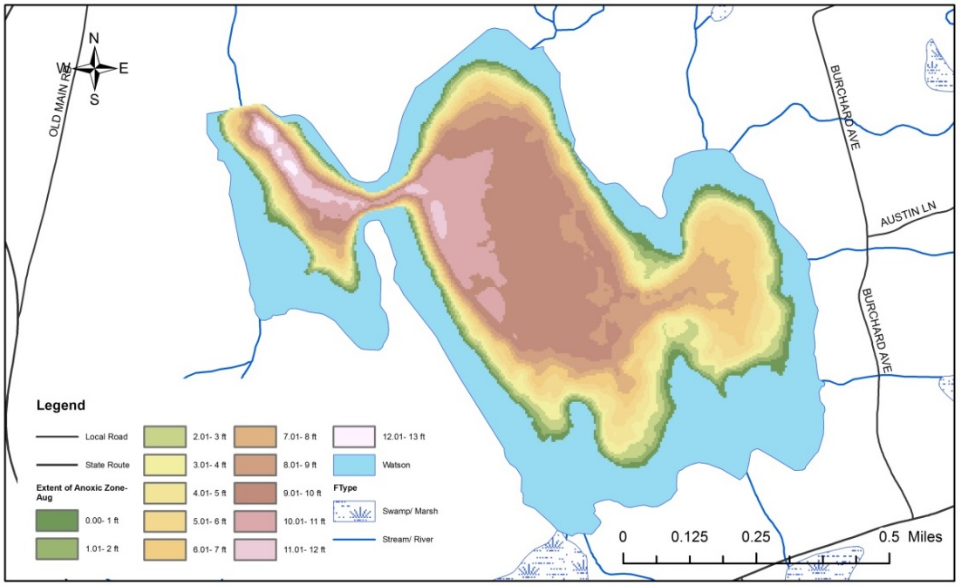
Watershed	Dissolved Oxygen Measurement Date	Volume (cubic feet)	Volume (Million Gallons)
Watson Reservoir	July 22, 2015 August 26, 2015	46,767,284 65,855,133	349.8 492.6

Apex Companies, L. (2008, October 23). Bathymetric Reservoir Survey- Nonquit Pond and Watson Reservoir.

Price, M. (2002, October-December). Deriving Volumes with ArcGIS Spatial Analyst. ArcUser. ESRI.



Extent of Anoxic Zone on July 22, 2015



Extent of Anoxic Zone on August 26, 2015

Technical Appendix D – Watershed Treatment Model (WTM)

Summary Description of the Watershed Treatment Model

The Watershed Treatment Model (WTM), developed by the Center for Watershed Protection, was used in both the Watson Reservoir and St. Mary's Pond Watersheds to estimate pollutant loads to the two water supply reservoirs. The WTM is a model that can be used to estimate the loading of various pollutants to a waterbody based on land use and other activities within a watershed. The basis of the WTM is a pollutant loading calculation developed by Schueler (1987) called the Simple Method. Based on user-specified input describing characteristics of the watershed, the WTM estimates total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), and fecal coliform bacteria (FC) loads from various land uses.

In addition to pollutants generated from land uses, the WTM estimates pollutant loads from other sources (secondary sources) that may be present, but are not necessarily associated with a particular land use. These secondary sources may include on-site sewage disposal systems (OSDS), sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), illicit connections, urban channel erosion, livestock, winter-time road sanding, and non-stormwater point sources.

In addition to primary and secondary loads, the WTM model also estimates reductions to pollutant loads based on management activities occurring within the watershed. These management practices may include turf management, pet waste education, erosion and sediment control at construction sites, street sweeping and catch basin cleanouts, existing BMPs, and riparian buffers.

The WTM is available at:
http://www.cwp.org/online-watershed-library/cat_view/65-tools/91-watershed-treatment-model

Sources and Model Assumptions

Parameter	Sources	Model Assumptions & Notes
Primary Sources		
Watershed Boundary	TMDL watershed delineation.	The Watershed Boundary for St. Mary's Pond and Watson Reservoir were taken from delineations previously defined for both watersheds and used as the outer boundary for the WTM load calculations.
Sub-basin and Watershed Treatment Area Delineations	Fuss and O'Neil, 2015- derived from U.S. Geological Survey Stream Stats and RIGIS LIDAR- 2 ft. elevation contours.	Sub-basin boundaries for Watson Reservoir were determined using a combination of The U.S. Geological Survey Stream Stats application and 2 ft. elevation contours available from the RIGIS LIDAR dataset. WTM areas for St. Mary's Pond were delineated from the 2 ft. elevation contours available from the RIGIS LIDAR dataset.
Land Cover and Land Use	RIGIS 2011 Land Cover and Land Use data set based on Spring Aerial Photography.	RIGIS land use classifications were simplified for input into WTM. Acreage for various classifications was determined in ArcGIS by intersecting the land use with a shape file of sub-basins/watershed treatment areas in each watershed.
	Photos & notes from field visit, November 2015	*Choices validated against photos, aerials, & known information about watershed (see land use table for grouping).*
EMCS	RI Storm water Manual; NSQD, 2005; Selected Regional EMCs; and WTM Default values.	EMCs values for residential, commercial, industrial, and undeveloped/rural land use categories were taken from the RI Storm water Manual. Agricultural EMC values for pasture/orchard, etc. and cultivated land were taken from selected regional values. Recreation/open space EMCs were taken from selected NSQD values. Other categories such as forest were given WTM default values.
	Aerial photos. Photos & notes from field visit	*Choices validated against photos, aerials, & known information about watershed*
Impervious %	Calculated from 2011 Land Cover and Land Use and Impervious Surfaces raster dataset available from RIGIS.	The impervious surface data set available from RIGIS as a statewide dataset representing impervious surfaces in both 2003-2004 and 2011. The percent impervious for land use classes in each watershed was determined by converting the Impervious raster dataset to a vector format and then intersecting this with the 2011 land use data. GRIDCODE = 0, pervious; GRIDCODE = 1, impervious.
Annual Rainfall	U.S. Climate Data Website- Tiverton, RI	This average annual rainfall amount was available from the following website: http://www.usclimatedata.com/climate/tiverton/rhode-island/united-states/usri0104

Parameter	Sources	Model Assumptions & Notes
Stream Length	U.S. Geological Survey Stream Stats	Stream lengths in the Watson Reservoir Watershed area were determined from the Stream Stats on-line application: http://water.usgs.gov/osw/streamstats/ From field reconnaissance it was determined that there were no perennial tributaries contributing flow to St. Mary's Pond, therefore stream length did not apply.
Soils Information	2014 Soils dataset from RIGIS, U.S. Geological Survey Water Table Maps and Groundwater Toolbox.	2014 Rhode Island Soil Survey Program soils delineated with name, type and feature attributes. Hydrologic Soils Group data were available in the soils data set, field HYDRO_GROU: A, B, C, D, and variable. An estimate of the depth to groundwater was made by referring to U.S. Geological Survey Water Table Maps and information from the U.S. Geological Survey Groundwater Toolbox. http://water.usgs.gov/ogw/gwtoolbox/ From these sources the depth to groundwater in Watson Reservoir was set at 3-5 ft. and the depth to groundwater in St. Mary's Pond Watershed was set to >5 ft.
Runoff Coefficients	Virginia Erosion & Sediment Control Handbook, 1980.	Runoff coefficients for Rural Land Uses were selected from a range of values listed in the Virginia Erosion & Sediment Control Handbook. Values for Cropland ranged from 0.15 to 0.4 and for Pasture/Orchard, etc. values ranged from 0.12 to 0.35.
Secondary Sources		
General Sewage Data	RIGIS Sites- E911 layer- 2014 and WTM defaults	The number of dwelling units per model area was determined by intersecting the Sites- E911 layer with the respective sub-basin/ WTM area shape file. The SITETYPE field designates whether a site is residential, commercial, outbuilding, etc. Residential = R1 and R3. Wastewater Use and Concentration information can be found in Table 4.2 pg. 4-3 in the WTM 2013 Documentation.
Nutrient Concentration in Stream Channels	Haith et al. 1992	A mid- range value of 0.15 was used for Soil P (%) and Soil TN (%). See figures 4.1 and 4.2 in the WTM 2013 Documentation. From figures it is seen that values for both TP and TN can range from 0.10 to 0.19 percent in Rhode Island.
On-Site Sewage Disposal (OSDS)	Personal Communication and 2014 Soils	By viewing the 2012 Sewer Lines and Sewered Areas GIS layers available from RIGIS it was determined that both St. Mary's and Watson Reservoir Watershed areas were 100% un-sewered. Soils for both areas were set to Clay/Mixed Soils. The default failure rate of 10% was assumed, System type was set to 100% conventional, with medium maintenance. Typical separation from groundwater was assumed to be 3-5 ft. in Watson Reservoir and >5 ft. in St. Mary's Pond Watershed. The OSDS density was set at less than 1 per acre in Watson Reservoir and varied from 1-2 per acre up to >2 per acre in WTM Area 3.

Parameter	**Sources**	**Model Assumptions & Notes**
SSOs, CSOs, Illicit Connections	2012 Sewer Lines and Sewered Areas available from RIGIS	Since there was neither sewer lines nor sewer areas in either watershed, the value for miles of sanitary sewer, # of CSOs/year, and fraction of population illicitly connected were all set to 0.
Urban Channel Erosion	NA to Non-urban watersheds.	Method 3 was selected as the method to estimate channel erosion which is based on typical estimates. The estimated value was set to 0, since both watersheds are not Urban in nature.
Livestock	NA	The WTM loading rates for Hobby Farms/Livestock animals were adapted from the Chesapeake Bay Program and are limited to animals that are confined. Since the animals in the watershed area modeled for the Newport Phosphorus Study were pastured animals it is assumed that the loads associated with these animals are reflected by the pasture loading rates (agricultural). See pg. 4-20 from the WTM 2013 Documentation.
Road sanding	Rhode Island Department of Administration, 2014.	An average application rate of salt state wide for the period 2005- 2013 was estimated at 516 lbs. /lane mile, assuming a 1:1 ratio of salt/road sand from all dates listed on the Rhode Island Department of Administration State Wide Planning Technical Paper (RI DOA, 2014, Figure 2). Looking at the specific gravity of salt vs. sand it was estimated that the sand application rate was 655 lbs/ land mile. This rate was multiplied by the lane miles per model area to determine the amount of road sand applied per sub-basin/WTM area. Road miles were determined by intersection the E911 Road layer with the shape file containing the respective sub-basins/watershed treatment areas for each watershed. The fraction of roads that are open is determined by dividing the amount of roadway that is open by the amount of road that drains to catch basins. Open sections do not have catch basins.
Existing Management Practices		
Turf Condition and Management Practices	Personal Communication	After internal communication between Fuss and O'Neil employees it was assumed that 5% of Lawns in each watershed were bare/compacted, 20% of homes were less than 10 years old, and 10% of lawn area was highly managed. Other- Commercial, Roadway, and Industrial land use categories were assumed to have Better management/ nutrient management compared with residential turf.
Pet Waste Education	Personal Communication	After internal communication between Fuss and O'Neil employees it was assumed that there was not a pet waste education program in place in either watershed.

Parameter	Sources	Model Assumptions & Notes
Street sweeping	Initial values from previous modeling efforts	It was assumed that the type of sweeper used to remove sand from road ways was a mechanical sweeper and that sweeping was done monthly- annually is more accurate, but not an available option in the WTM.
BMP Type	Personal Communication	Initial assumption for each watershed was that there are currently no structural BMP's actively maintained in either watershed.
Vegetative Buffers/Riparian Buffers	Personal Communication	Initial assumption for the each watershed was that vegetative buffers exist in areas that are currently forested. Since there are currently no restrictions on activities within the buffer the maintenance factor was set at 0.4.
Catch basin cleanouts	Initial values from previous modeling efforts.	Only a small area of Watson Reservoir has catch basins- a section of Watson Tributary 5. For St. Mary's Pond Watershed and this small area of Watson Reservoir Watershed it was assumed that catch basins are cleaned "as needed", semi-annual cleaning was assumed, Acreage captured by the respective catch basins was determined from the impervious coverage available from RIGIS.
Future Management Practices		
Residential Lawn Care Education	Personal Communication	For modeling reductions in nutrient loads it was assumed that 20% of the population was aware of the message (percentages in parenthesis is the fraction est. to implement change). The goals of the program included: Reduction of Fertilizer Use to Recommended Levels (50%), Switch to Non-Phosphorus Fertilizer (25%), Change to Organic Fertilizer (10%), Add Soil Amendments to Lawns (10%), Convert 25% of lawn to forest or native vegetation (10%), no fertilizer (10%).
Pet Waste Education	Personal Communication	For modeling reductions in nutrient loads it was assumed that 20% of the population was aware of the message. Number of dwelling units was taken from E911 layer. Fraction of households with dog (40%), Owners who walk their dogs (50%), Owners who clean up after dog (60%), and Fraction willing to change behavior (60%).
Street Sweeping	Personal Communication	It was assumed that the type of sweeper used to remove sand from road ways was a mechanical sweeper and that sweeping was done monthly- annually is more accurate, but not an available option in the WTM.
Vegetative Buffers/Riparian Buffers	Calculated from 2011 Land Cover and Land Use data layer and buffer of St. Mary's Pond, Watson Reservoir and tributary streams.	Proposed vegetative buffer areas were determined from an intersection of 100 and 200 foot buffers of hydrography layers in each watershed and forested land use from the RIGIS 2011 Land Cover and Land Use Layer. Areas that are currently forested were assumed to be existing buffers and areas with other land use classifications were estimated to be the proposed buffer areas. From a literature review of articles on nutrient reductions seen in buffers the following reductions for the riparian buffers were assumed: TN- 50%; TP- 40%; TSS- 75%; Bacteria 0%; and Runoff- 50%. The proposed buffer areas were given a maintenance value of 0.6-

Parameter	Sources	Model Assumptions & Notes
		ordinance specifies activities, but no enforcement or education.
Catch basin cleanouts	See Existing Management Practices.	The same assumptions for catch basin cleaning in the existing management practices section of the WTM were used for future management practices.
Septic System Education	Personal Communication	For modeling purposes it was assumed that there was a Septic System Education Program in place and that 20% of residents were aware of the message and 50% were willing to change their behavior.
Structural BMPs	Personal Communication	Siting of proposed structural BMPs were determined by Fuss and O'Neill employees. Drainage areas were calculated based on percent impervious layer. Road ways were assumed crested. The Design storm was 1.0 inches. Water Quality Volumes WQv's were bracketed at 25 and 100% to get a range of reduction values. Discount Factors included Design and Maintenance. The Design factor was set to 1.0- specific standards, not legally binding and the Maintenance Factor was set to 0.6- maintenance specified but poorly enforced.

Rhode Island Department of Administration, 2014. Statewide Planning Technical Paper #000. 'Road Salt/Sand Application in Rhode Island', Rhode Island Division of Planning, 18.p DRAFT.

Virginia Erosion and Sediment Control Handbook, 1980. Virginia Soil and Water Conservation Committee.

		Percent Impervious	
Land Use Category WTM Model	**2011 Land Use Classification RIGIS**	**Watson Reservoir**	**St. Mary's Pond**
Low Density Residential (<1 du/acre)	Low Density Residential (>2 acre lots)	16.2[1]	28.44[1]
	Medium Low Density Residential (1 to 2 acre lots)	NA	NA
Medium Density Residential (1-4 du/acre)	Medium Density Residential (1 to 1/4 acre lots)	23.9	25.55
High Density Residential (>4 du/acre)	Medium High Density Residential (1/4 to 1/8 acre lots)	--	NA
	High Density Residential (<1/8 acre lots)	--	32.96[2]
Rural	Transitional Areas (urban open)	21.0	--
	Idle Agriculture	2.5	--
	Vacant Land	0.0	0.00
	Power Lines (100' or more width)	--	0.00
Developed Recreation- include with Urban Open?	Developed Recreation	--	11.88
Commercial	Commercial (sale of products and services)	59.2	--
Agricultural	Pasture (agricultural not suitable for tillage)	1.9	2.47
	Cropland (tillable)	3.0	1.01
	Orchards, Groves, Nurseries	11.2	--
Institutional	Institutional (schools, hospitals, churches, etc.)	100.0	21.97
Forest	Deciduous Forest (>80% hardwood)	1.1	2.25
	Mixed Forest	1.1	0.00
	Brush land (shrub and brush areas, reforestation)	0.3	3.97
	Softwood Forest (>80% softwood)	0.0	--
Open Water	Water	0.0	0.0
Wetland	Wetland	1.1	0.0

[1] Low Density Residential % Impervious is weighted by the % Impervious acreage of LDR and MLDR land use classifications.

[2] High Density Residential % Impervious is weighted by the % Impervious acreage of MHDR and HDR land use classifications.
(--, means there is no land use type in the watershed; NA, means a separate % Impervious value was not entered into the WTM Model.)

Existing Modeled Land Use for Watson Reservoir

	Existing Modeled Land Use Composition (acres)													
			Rural				Agricultural							
Watershed	Low Density Residential	Medium Density Residential	Urban Open	Idle Agriculture	Vacant Land	Commercial	Pasture	Cropland	Orchards, etc.	Institutional	Forest[1]	Open Water	Wetland	Total Area
Watson Tributary A (Includes Overland Flow Ares 1 and 2)	0.57	0.0	0.0	9.16	0.0	0.0	4.93	1.42	0.0	2.44	209.66	0.26	0.00	228.44
Watson Tributary 5	2.68	14.06	0.00	<0.01	0.00	0.00	1.83	0.00	0.00	0.00	103.39	0.02	0.00	121.98
Watson Tributary B	24.28	6.08	0.00	11.50	0.00	0.00	2.31	6.73	0.00	0.00	39.73	0.00	0.00	90.63
Overland Flow Area 3	4.52	0.00	0.00	0.00	0.00	0.00	5.31	0.62	0.00	0.00	7.45	0.00	0.00	17.89
Watson Tributary 4	20.90	0.23	0.00	0.00	0.00	0.00	14.17	5.94	<0.01	0.00	84.31	0.76	0.00	126.31
Overland Flow Area 4	5.57	0.00	0.00	0.00	0.00	0.00	8.43	0.00	0.00	0.00	0.73	<0.01	0.00	14.73
Watson Tributary 3	11.25	7.96	1.42	1.91	0.00	0.00	4.54	6.93	5.95	0.00	56.30	0.66	0.00	96.92
Overland Flow Areas 5 & 6	5.32	3.69	0.00	0.00	0.00	0.00	4.87	1.28	0.00	0.00	38.08	<0.01	0.00	53.24
Watson Tributary 2	60.82	37.03	0.00	3.58	2.16	2.29	25.46	21.54	36.58	0.00	189.71	0.89	22.68	402.73
Watson Tributary 1	7.01	0.70	0.00	0.00	0.00	0.00	6.47	2.57	2.10	0.00	45.75	0.45	0.00	65.05
Watson Tributary 0	13.49	4.56	0.00	0.00	0.00	0.00	0.05	64.96	3.94	0.00	123.93	0.00	0.00	210.93
Watson Tributary C	17.22	13.90	0.00	0.00	0.00	0.00	79.66	99.81	6.61	0.00	78.06	0.57	26.52	322.36

	Existing Modeled Land Use Composition (acres)													
			Rural				Agricultural							
Watershed	**Low Density Residential**	**Medium Density Residential**	**Urban Open**	**Idle Agriculture**	**Vacant Land**	**Commercial**	**Pasture**	**Cropland**	**Orchards, etc.**	**Institutional**	**Forest[1]**	**Open Water**	**Wetland**	**Total Area**
Overland Flow Areas 7 and 8	6.75	0.00	0.00	0.00	0.00	0.00	54.00	59.90	0.00	0.65	44.19	<0.01	0.00	165.50
Watson Reservoir Total	180.38	88.20	1.42	26.14	2.16	2.29	212.04	271.70	55.18	3.10	974.99	3.59	49.21	1,916.73

[1] Forested Land includes Deciduous Forest (>80% hardwood), Mixed Forest, Brush land (shrub and brush areas, reforestation), and Softwood Forest (>80% softwood).

Existing Modeled Land Use for St. Mary's Pond

Watershed	Existing Modeled Land Use Composition (acres)															
				Rural						Agricultural						
	Low Density Residential	Medium Density Residential	High Density Residential	Urban Open	Idle Agriculture	Vacant Land	Power Lines	Developed Recreation	Commercial	Pasture	Cropland	Orchards, etc.	Institutional	Forest	Open Water	Wetland	Total Area
St. Mary's WTM Area 1	3.63	34.43	5.05	--	--	--	--	29.34	--	5.69	37.83	--	--	13.84	<0.01	1.31	131.12
St. Mary's WTM Area 2	--	26.18	51.22	--	--	4.85	--	0.22	--	0.20	4.68	--	1.45	38.89	0.67	1.71	130.05
St. Mary's WTM Area 3	--	--	1.88	--	--	--	--	--	--	--	21.11	--	--	27.63	<0.01	--	50.63
St. Mary's WTM Area 4	--	0.42	--	--	--	--	0.81	--	--	--	82.80	--	--	15.54	--	--	99.57
St. Mary's Pond Total	3.63	61.03	58.15	--	--	4.85	0.81	29.56	--	5.89	146.42	--	1.45	95.90	0.68	3.02	411.37

Modelled Pollutant Loads- Example Watershed- Watson Tributary 3

						Percent of Total Load to Surface Water				
	TN Lb/year	**TP** Lb/year	**TSS** Lb/year	**Fecal Coliform Billion/year**	**Runoff Volume** acre-ft	**TN** %	**TP** %	**TSS** %	**FC** %	**Runoff Depth** %
Watson Tributary 3										
Existing Load to Surface Water										
Urban Land- Land Use	304	55.55	2,190	1,498	35	20.99	38.05	1.50	42.69	26.52
Channel Erosion	--	--	--	--	--	--	--	--	--	--
Forest	310	25	12,393	1,487	19	21.41	17.12	8.50	42.38	14.39
Rural Land	806	62	130,998	483	79	55.66	41.78	89.83	13.76	59.85
OSDS	28	5	184	42	--	1.93	3.42	0.13	1.20	--
Open Water	--	--	--	--	--					
Total Storm Load	862	116	131,313	3,467	132	59.35	79.45	90.04	98.80	100.00
Total Non-Storm Load	586	31	14,523	42	--	40.47	20.55	9.96	1.20	--
Total Load to Surface Waters	**1,476**	**147**	**145,836**	**3,509**	**132**	100.00	100.00	100.00	100.00	100.00
Existing Loads to Groundwater										
Urban Land	3,860.1	178.2	--	0.00		92.31	96.17	--	0	
OSDS	321.7	7.1	--	0.00		7.69	3.83	--	0	
Total	4,181.8	185.3	--	0.00		100.00	100.00	--	0	

Additional Model Inputs

	Watson Reservoir	St. Mary's Pond
Road Sanding (lbs/yr)- Entire Watershed	4,522	1,869
% With storm drains	0.0%	TBD
% Without storm drains	100.0%	TBD
Total length of streams (miles)	8.13	0.00
Dwelling units	206	185[2]
Percentage of dwelling units un-sewered	100%	100%
Number of dwelling units with onsite septic within 100ft of water[1]	8	0
Soils (Percent)		
A	0.00	0.00
B	0.6	0.00
C	79.1	99.44
D	19.2	0.56
VARIABLE	1.1	0.00

[1] The number of dwelling units within 100 ft. of a waterway was determined by buffering Watson Reservoir and St. Mary's Pond by by 100 ft. For Watson Reservoir the tributaries draining to the reservoir were also buffered by 100 ft.

[2] Approximately 91 of the dwelling units in St. Mary's Pond Watershed are town homes.

Event Mean Concentrations and Export Coefficients

Developed Land Uses - Event Mean Concentrations (TN, TP, TSS in mg/L and Fecal Coliform in MPN/100ml)

Source	WTM Default				NSQD, 2005				RIDEM Stormwater Manual, 2010			
Pollutant	**TN**	**TP**	**TSS**	**FC**	**TN**	**TP**	**TSS**	**FC**	**TN**	**TP**	**TSS**	**FC**
Low Density Residential	2.1	0.31	49	20,000	2.1	0.31	49	7,000	2.1	0.3	100	7,000
Medium Density Residential	2.1	0.31	49	20,000	2.1	0.31	49	7,000	-	-	-	-
High Density Residential	2.1	0.31	49	20,000	2.1	0.31	49	7,000	-	-	-	-
Commercial	2.1	0.22	43	20,000	2.1	0.22	43	4,600	2.1	0.2	75	4,600*
Industrial	2.2	0.25	81	20,000	2.2	0.25	81	2,400	2.1	0.25	120	2,400*
Institutional	-	-	-	-	2.0	0.18	17	-	-	-	-	-
Recreation/Open Space	-	-	-	-	1.3	0.31	48.5	7,200	-	-	-	-

Source	Regional EMC or Other Source (as noted)				Selected				Comments
Pollutant	**TN**	**TP**	**TSS**	**FC**	**TN**	**TP**	**TSS**	**FC**	
Low Density Residential	3.18 (2)	0.27 (2)	34 (2)	2,950 (2)	3.18	0.27	34	2,950	Selected regional values
Medium Density Residential	3.5 (1)(2)	0.41 (1)(2)	49 (1)(2)	12,360 (1)(2)	3.50	0.41	49	12,360	Selected regional values
High Density Residential	3.81 (2)	0.64 (2)	102 (2)	16,901 (2)	3.81	0.64	102	16,901	Selected regional values
Commercial	1.85 (1)	0.15 (1)	44 (1)	9,306 (1)	1.85	0.15	44	9,306	Selected regional values
Industrial	4.0 (1)(2)	0.11 (1)(2)	42 (1)(2)	1,467 (1)(2)	4.00	0.11	42	1,467	Selected regional values

Source	**Regional EMC or Other Source (as noted)**				**Selected**				**Comments**
Institutional	-	-	-	-	2.0	0.18	17	9,306	Selected NSQD Values, FC assumes same as Commercial
Recreation/Open Space	-	-	-	-	1.3	0.31	48.5	7,200	Selected NSQD Values

Rural Land Uses - Export Coefficients (TN, TP, and TSS in lb/ac/yr and Fecal Coliform in billion/ac/yr)

Source	**WTM Default**				**Regional EMC or Other Source (as noted)**				**Selected**				**Comments**
Pollutant	**TN**	**TP**	**TSS**	**FC**	**TN**	**TP**	**TSS**	**FC**	**TN**	**TP**	**TSS**	**FC**	
Cropland	-	-	-	-	14.4 (3); 15.7 (4)	4.0 (3); 0.94 (4)	1997' (4)	-	12.1	0.94	1997	7	Selected TN as average of 2 regional sources; FC assumed same as Pasture/Orchard; Chose lower TP value since assumed less fertilization that typical agricultural crops
Pasture/Orchards, etc.	5.0	0.75	100	39	1.9 (2); 7.7 (3); 5.6 (4)	0.1 (2); 1.3 (3); 0.5 (4)	47 (2); 591 (4)	7 (2)	5.1	0.63	319	7	Selected the average of regional values
Forest	2.0	0.2	100	12	2.5 (2)	0.2 (2)	100 (2)	12 (2)	2.5	0.2	100	12	Selected regional TN value
Water/Wetland	-	-	-	-	0.4 (2)	0.03 (2)	2 (2)	0.4 (2)	0.4	0.03	2	0.4	Selected regional values

Notes:

TN = Total Nitrogen; TP = Total Phosphorus; TSS = Total Suspended Solids; FC = Fecal Coliform

Conversion equation used for Pasture/Orchard

NSQD (2005) does not provide rural land use data.

RIDEM Stormwater Manual (2010) has one category for Undeveloped/Rural, which lists values from the Merrimack River Watershed Assessment Study, (CDM, 2004) which are listed under the "Regional EMC or Other Source" column.

Sources:

Maestre & Pitt and Center for Watershed Protection (2005). The National Stormwater Quality Database, Version 1.1.

Caraco, D. and Center for Watershed Protection, Inc. (2013). Watershed Treatment Model (WTM) 2013 Documentation.

Rhode Island Department of Environmental Management and Coastal Resources Management Council (2010). Rhode Island Stormwater Design and Installation Standards Manual, December 2010 .

Regional EMC or Other Sources identified by number:

1. CDM (2004). Merrimack River Watershed Assessment Study - Screening Level Model.
2. BETA Group, Inc. (2006). Quality Assurance Project Plan. Development of a Watershed Based Plan for Massachusetts. Converted values presented in mg/L into lb/ac/yr assuming 0% impervious area for Forest and 2% impervious area, 46 inches of rain per year, for agricultural land uses.
3. Reckhow et al. (1980): "Modeling Phosphorus Loading and Lake Response under Uncertainty: A Manual and Compilation of Export Coefficients." From Lin, J. (2005) Review of Published Export Coefficient and Event Mean Concentration (EMC) Data. Converted values from kg/ha/yr to lb/ac/yr.
4. CH2M HILL (2001). PLOAD version 3.0, An ArcView GIS Tool to Calculate Nonpoint Sources of Pollution in Watershed and Stormwater Projects: User's Manual.

Technical Appendix E – WTM Existing Conditions Results

Existing Loads (Primary, Secondary, and Existing Management Practices) for Watson Reservoir Watershed

Subwatershed		Existing Load (lb/year)			Runoff Volume (acre-ft)
	Drainage Area (Acres)	TP	TN	TSS	
Watson Tributary 0	210.9	131	1,359	145,406	125.0
Watson Tributary 1	65.1	35	296	13,334	30.1
Watson Tributary 2	402.7	408	2,802	99,744	308.3
Watson Tributary 3	96.9	76	565	25,817	60.5
Watson Tributary 4	126.3	83	649	26,833	65.6
Watson Tributary 5	122.0	68	509	12,710	44.4
Watson Tributary A	228.4	57	655	28,747	57.5
Watson Tributary B	90.6	105	701	25,148	76.9
Watson Tributary C	322.4	257	2,409	241,800	271.2
Watson OF 3	17.9	20	135	4,224	15.1
Watson OF 4	14.7	18	116	3,234	16.2
Watson OF 5 and 6	53.2	34	257	8,896	25.6
Watson OF 7 and 8	165.5	114	1,209	141,863	136.6
Watson Reservoir Watershed Total	**1,916.7**	**1,405**	**11,662**	**777,754**	**1,233.0**

Existing Loads (Primary, Secondary, and Existing Management Practices) for St. Mary's Pond Watershed

Subwatershed		Existing Load (lb/year)			Runoff Volume (acre-ft)
	Drainage Area (Acres)	TP	TN	TSS	
WTM 1	118.6	239	1,562	90,050	163.1
WTM 2	142.6	398	2,002	43,926	206.1
WTM 3	50.6	33	363	45,561	30.4
WTM 4	99.6	63	431	10,094	95.0
St. Mary's Pond Watershed Total	**411.4**	**733**	**4,358**	**189,631**	**494.6**

Existing Yields (Primary, Secondary, and Existing Management Practices) for Watson Reservoir Watershed

Subwatershed		Existing Yield (lb/acre/year)		
	Drainage Area (Acres)	TP	TN	TSS
Watson Tributary 0	210.9	0.6	6.4	689.4
Watson Tributary 1	65.1	0.5	4.5	205.0
Watson Tributary 2	402.7	1.0	7.0	247.7
Watson Tributary 3	96.9	0.8	5.8	266.5
Watson Tributary 4	126.3	0.7	5.1	212.4
Watson Tributary 5	122.0	0.6	4.2	104.2
Watson Tributary A	228.4	0.2	2.9	125.8
Watson Tributary B	90.6	1.2	7.7	277.5
Watson Tributary C	322.4	0.8	7.5	750.1
Watson OF 3	17.9	1.1	7.6	236.0
Watson OF 4	14.7	1.3	7.9	219.4
Watson OF 5 and 6	53.2	0.6	4.8	167.1
Watson OF 7 and 8	165.5	0.7	7.3	857.1
Watson Reservoir Watershed Total	**1,916.7**	**0.7**	**6.1**	**405.8**

Existing Yields (Primary, Secondary, and Existing Management Practices) for St. Mary’s Pond Watershed

Subwatershed		Existing Load (lb/year)		
	Drainage Area (Acres)	TP	TN	TSS
WTM 1	118.6	2.0	13.2	759.3
WTM 2	142.6	2.8	14.0	308.1
WTM 3	50.6	0.6	7.2	900.0
WTM 4	99.6	0.6	4.3	101.4
St. Mary’s Pond Watershed Total	**411.4**	**1.8**	**10.6**	**461.0**

Reductions to Existing Loads from Future Management Options in the Watson Reservoir Watershed

	Load Reduction (lb/year)		
Future Management Practice	**TP**	**TN**	**TSS**
Buffers (100-ft)	90	560	6,275
Buffers (200-ft)	145	888	9,600
Nutrient Management (25%)(1)	102	1,152	156,273
Nutrient Management (75%)	306	3,455	468,820
Residential Education (2)	85	401	245
Street Sweeping	2	21	317
Structural BMPS (25/60)	76	410	2,749
Structural BMPS (100/60)	281	1,531	10,235

NOTE: Current Existing Load for the Watson Reservoir Watershed: TP- 1,405 lb/year; TN- 11,662 lb/year; TSS- 777,754 lb/year.

(1) Loads from Agricultural and Golf Courses were reduced by 25 and 75 percent to bracket potential Load reductions from potential future agricultural best management practices.

(2) Residential Education includes reductions from Lawn Care Education, Pet Waste Education, and Septic System Education.

Reductions to Existing Loads from Future Management Options in the St. Mary’s Pond Watershed

	Load Reduction (lb/year)		
Future Management Practice	**TP**	**TN**	**TSS**
Buffers (100-ft)	24	137	2,109
Buffers (200-ft)	65	361	5,550
Nutrient Management (25%)(1)	32	330	35,312
Nutrient Management (75%)	96	990	105,935
Residential Education (2)	50	241	319
Street Sweeping	5	40	3,766
Structural BMPS (25/60)	83	284	7,305
Structural BMPS (100/60)	317	1077	28,358

NOTE: Current Existing Load for the St Mary’s Pond Watershed: TP- 733 lb/year; TN- 4,358 lb/year; TSS- 189,631 lb/year.

(1) Loads from Agricultural and Golf Courses were reduced by 25 and 75 percent to bracket potential Load reductions from potential future agricultural best management practices.

(2) Residential Education includes reductions from Lawn Care Education, Pet Waste Education, and Septic System Education.

Technical Appendix G – Vegetative Buffer Conditions

Existing vegetative buffers around Watson Reservoir and St Mary's Pond were estimated by intersecting 100 and 200 foot buffers around each water body with existing forested land use/land cover (mixed forest and deciduous forest (>80% hardwood)). The existing forested area was available from the RIGIS 2011 Land Use/Land Cover dataset developed from spring 2011 orthophotography with a minimum mapping unit of 0.5 acres (Rhode Island Geographic Information system, 2015). The percent of existing vegetative buffer around each waterbody was calculated as the acreage of existing forested area divided by the acreage of the total buffer area from 0 to 100 feet and 0 to 200 feet..

Watershed	Vegetative Buffer Width	Percent Existing Buffer (Forested Area)
Watson Reservoir	100 foot	66.4
	200 foot	67.2
St Mary's Pond	100 foot	62.5
	200 foot	59.7

The WTM model requires a linear length in miles be entered into the model, which was measured for both the existing forested area and the new proposed vegetative buffer areas. This value was then multiplied by the buffer width to come up with a buffer area. From this data a treatability factor is estimated in the WTM which is based on the calculated buffer area and the impervious area values from the Primary Loads tab (land use) in the WTM. In general a higher percent impervious area within a subwatershed will result in a lower treatability factor.

Treatability Factors vary from subwatershed to subwatershed. In some instances the treatability factor associated with a 100 foot buffer is 100% (existing + proposed), in these instances changing the buffer width from 100 to 200 feet in width does not increase removal rates. However, on a watershed-wide basis an increased reduction of TP, TN, and TSS is seen as the buffer width increases from 100 to 200 feet in width.

Since the WTM does contain default removal rates for TP, TN, and TSS from vegetative buffers, a literature review was conducted to determine removal rates reported in the literature. A table of these values is presented below. Removal rates for modeling purposes were 40% for TP, 50% for TN, and 75% for TSS.

Literature Review of Nitrogen, Phosphorus, and TSS Reductions from Vegetative Buffers

Source	Total Phosphorus (TP) Reduction (Percent)	Total Nitrogen (TN) Reduction (Percent)	Total Suspended Solids (TSS) Reduction (Percent)
(Gitau, Veith, Gburek, & Jarrett, 2006)	40	--	--
(Merriman, Gitau, & Chaubey, 2009)	53	47	76
(Gitau., Veith, & Gburek, 2004)	38	--	--
(Lee, Isenhart, & Schultz, 2003) (1)	91.3	93.9	97.2
(Peterjohn & Correll, 1984)	80	89	--
(Osborne & Kovacic, 1993) (2)	83	98	--
(Lowrance, et al., 1995) (3)	77.2	80.1	97.4

Notes: (1) Removal efficiencies based on vegetative buffers containing switch grass and woody vegetation;
(2) Article noted that nutrients may be released from vegetative buffer strips during the dormant season;
(3) Removal efficiencies based on vegetative buffers that have a combination of grass and woody vegetation.

Sources:

Gitau, M. W., Veith, T. L., Gburek, W., & Jarrett, A. A. (2006, December). Watershed Level Best Management Practice Selection and Placement in the Town Brook Watershed, New York. Journal of the American Water Resources Association.

Gitau., M., Veith, T., & Gburek, W. (2004). Farm-Level Optimization of BMP Placement for Cost-Effective Pollution Reduction.

Lee, K., Isenhart, T., & Schultz, R. (2003). Sediment and Nutrient REmoval in an Established Multi-Species Riparian Buffer. Journal of Soil and Water Conservation. Vol. 58. No. 1.

Lowrance, R., Altier, J., Newbold, J., Schnabel, P., Groffman, P., Denver, J., et al. (1995). Water Quality Functions of Riparian Forest Buffer Systems in the Chesapeake Bay Watershed. U.S. Environmental Protection Agency, Washington, D.C. EPA 903-R-95-004/CBP/TRS 134/95.

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Peterjohn, W., & Correll, D. (1984, October). Nutrient Dynamic in an Agricultural Watershed: Observations on the Rold of A Riparian Forest. Ecology, Vol. 65, No. 5, pp. 1466-1475.

Rhode Island Geographic Information system. (2015, July). Planning and Cadastral Data. http://www.rigis.org/data/plan.

Reductions to Existing Loads in Watson Reservoir and St. Mary's Pond Watersheds from Individual Structural BMPs at 100% of Water Quality Volume (WQv).

Watershed **Structural BMP-ID**	**Load Reduction (lb/year)**		
	TP	**TN**	**TSS**
Watson Reservoir Watershed			
WR_O_A&B (1)	13	70	449
WR_1_A	2	9	48
WR_1_B	13	70	394
WR_2_A	32	179	1,319
WR_2_B	14	76	569
WR_2_C	52	279	1,991
WR_3_A	5	27	188
WR_4_A	48	273	1493
WR_4_B	14	81	460
WR_C_A	67	354	2,520
WR_OF5_A	15	79	550
St Mary's Pond Watershed			
SM_1_A	11	61	700
SM_1_B	66	195	5,901
SM_1_C	29	163	1,775
SM_2_A	77	234	7,194
SM_2_B	131	404	12,501

(1) WR_0_A and WR_0_B modeled as a single area.

Technical Appendix H – Calculation of BMP Costs

Planning-level costs associated with proposed structural best management practices (BMPs) in the Watson Reservoir and St. Mary's Pond Watersheds were estimated using data and methods in the 2011 report Costs of Stormwater Management Practices in Maryland Counties (King & Hagan, 2011), augmented with local BMP construction cost data where available. Sources of the costs provided in King and Hagan (2011) include national literature review or published articles and reports, previously developed stormwater cost databases and models, MS4 reports, interviews with local stormwater staff, contractors and others who work on stormwater projects, and applications of the Water Environment Research Foundation stormwater unit cost model. The estimates provided in King & Hagan (2011) are life cycle costs per impervious acre treated by a BMP, in 2011 dollars.

Life cycle costs were estimated for the proposed stormwater BMPs over a 20-year period including pre-construction costs (planning, permitting, and design), construction costs, and maintenance costs. The construction costs provided in King & Hagan (2011) were modified by adjusting the 2011 construction costs to 2016 costs based on the RS Means Construction Index (RSMeans, 2016). Inflation was estimated at 8.4% over the five-year period.

In King & Hagan (2011), pre-construction costs range from 10 to 40% of construction costs (King & Hagan, 2011). Based on professional judgement and knowledge of regional construction practices and cost, the pre-construction costs for Watson and St. Mary's Pond Watersheds were estimated at 20% of construction costs. In addition, initial BMP costs, including preconstruction and construction costs, were amortized over a 20-year period at 3% interest (i.e., annual bond payment required to finance the initial cost of the BMP) to estimate an annualized initial cost for each BMP.

BMP construction costs were estimated for Wet Vegetated Treatment Systems (WVTS), Filtering Practices (Sand, below ground), Bioretention (New-Suburban), and Bioswales (New). Inflation-adjusted 2016 construction costs were based on the values provided in King & Hagan (2011). The WVTS construction costs provided in King & Hagan (2011) were modified to reflect construction costs from a recently installed WVTS in Middletown, RI. (The Middletown, RI system treats a 72-acre drainage area with an estimated impervious cover of 40%. The total construction cost for this system was approximately $750,000. The cost per impervious acre treated was applied to the two potential WVTS structures identified for the St. Mary's Pond Watershed: SM_2_A and SM_2_B).

Stormwater BMP costs are highly site-specific and can vary based on differences in soil type, slope, and various landscape features, as well as land use characteristics. Other factors that may affect cost include project scale, project design features, zoning and permitting conditions (King & Hagan, 2011). The BMP costs presented in this study are preliminary, order-of-magnitude cost estimates that are appropriate for planning-level studies. These preliminary cost estimates should be refined during the design process.

Sources:

King, D., & Hagan, P. (2011, October 10). Costs of Stormwater Management Practices In Maryland Counties. Prepared for Maryland Department of the Environment Science Services Administration (MDESSA). University of Maryland Center for Environmental Science (UMCES).

RSMeans. (2016, January 1). Historical Cost Indexes. http://rsmeansonline.com/References/CCI/3-Historical%20Cost%20Indexes/1-Historical%20Cost%20Indexes.PDF.

Cost-effectiveness of Structural BMPs identified for Watson Reservoir and St. Mary's Pond Watersheds

Watershed Structural BMP-ID	Cost Effectiveness (1) ($/lb)		
	TP Removed	TN Removed	TSS Removed
Watson Reservoir Watershed			
WR_O_A&B (1)	$ 321.38	$ 59.68	$ 9.30
WR_1_A	$ 835.58	$ 185.68	$ 34.82
WR_1_B	$ 53.10	$ 9.86	$ 1.75
WR_2_A	$ 449.58	$ 80.37	$ 10.91
WR_2_B	$ 511.21	$ 94.17	$ 12.58
WR_2_C	$ 244.53	$ 45.57	$ 6.39
WR_3_A	$ 197.61	$ 36.59	$ 5.26
WR_4_A	$ 245.22	$ 43.12	$ 7.88
WR_4_B	$ 412.60	$ 71.31	$ 12.56
WR_C_A	$ 193.03	$ 36.53	$ 5.13
WR_OF5_A	$ 306.30	$ 58.16	$ 8.35
St Mary's Pond Watershed			
SM_1_A	$ 819.07	$ 147.70	$ 12.87
SM_1_B	$ 314.46	$ 106.43	$ 3.52
SM_1_C	$ 770.44	$ 137.07	$ 12.59
SM_2_A	$ 342.41	$ 112.67	$ 3.66
SM_2_B	$ 414.14	$ 134.29	$ 4.34

(1) Cost Effectiveness ($/lb) was estimated by dividing the Total Annual Cost by the reductions in (lb/year) of TP, TN, and TSS for each structural BMP in the Watson Reservoir and St. Mary's Pond Watersheds.

Planning-Level Cost Estimates for Proposed Stormwater Best Management Practices
St Mary's Pond and Watson Reservoir Watersheds

BMP Name	BMP Type	Impervious Area Treated (Acres)	Cost per Impervious Acre Treated				Cost				Total Cost (Over 20 Years)
			Total Initial Cost[1]	Initial Cost Annualized Over 20 Years[2]	Average Annual Maintenance Cost[3]	Total Annual Cost	Total Initial Cost[1]	Initial Cost Annualized Over 20 Years[2]	Average Annual Maintenance Cost[3]	Total Annual Cost	
St Mary's Pond Watershed											
SM_1_A	Linear Bioretention	2.48	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 96,868.80	$ 6,511.10	$ 2,498.61	$ 9,010	$ 180,194.35
SM_1_B	Tree Filters or Filtration Retrofits	3.94	$ 52,080	$ 3,501	$ 1,767	$ 5,268	$ 205,195.20	$ 13,792.34	$ 6,962.00	$ 20,754	$ 415,086.81
SM_1_C	Linear Bioretention	6.15	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 240,219.00	$ 16,146.49	$ 6,196.16	$ 22,343	$ 446,852.92
SM_2_A	Bioretention or WVTS[4]	9.01	$ 31,250	$ 2,101	$ 826	$ 2,926	$ 281,566.10	$ 18,925.66	$ 7,439.92	$ 26,366	$ 527,311.65
SM_2_B	Bioretention or WVTS[4]	18.54	$ 31,250	$ 2,101	$ 826	$ 2,926	$ 579,382.42	$ 38,943.60	$ 15,309.22	$ 54,253	$ 1,085,056.37
									Total:	**$ 132,725.10**	**$ 2,654,502.09**
Watson Reservoir Watershed											
WR_0_A	Linear Bioretention		$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ -	$ -	$ -	$ -	$ -
WR_0_B	Linear Bioretention	1.15	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 44,919.00	$ 3,019.26	$ 1,158.63	$ 4,178	$ 83,557.86
WR_1_A	Linear Bioretention	0.46	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 17,967.60	$ 1,207.70	$ 463.45	$ 1,671	$ 33,423.14
WR_1_B	Linear Bioretention	0.19	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 7,421.40	$ 498.83	$ 191.43	$ 690	$ 13,805.21
WR_2_A	Linear Bioretention	3.96	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 154,677.60	$ 10,396.76	$ 3,989.72	$ 14,386	$ 287,729.68
WR_2_B	Linear Bioretention	1.97	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 76,948.20	$ 5,172.13	$ 1,984.78	$ 7,157	$ 143,138.25
WR_2_C	Linear Bioretention	3.5	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 136,710.00	$ 9,189.06	$ 3,526.27	$ 12,715	$ 254,306.54
WR_3_A	Bioretention	0.2	$ 48,825	$ 3,282	$ 1,659	$ 4,940	$ 9,765.00	$ 656.36	$ 331.70	$ 988	$ 19,761.25
WR_4_A	Linear Bioretention	3.24	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 126,554.40	$ 8,506.44	$ 3,264.32	$ 11,771	$ 235,415.19
WR_4_B	Linear Bioretention	1.59	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 62,105.40	$ 4,174.46	$ 1,601.93	$ 5,776	$ 115,527.83
WR_C_A	Linear Bioretention	3.56	$ 39,060	$ 2,625	$ 1,008	$ 3,633	$ 139,053.60	$ 9,346.59	$ 3,586.72	$ 12,933	$ 258,666.08
WR_OF5_A	Bioretention	0.93	$ 48,825	$ 3,282	$ 1,659	$ 4,940	$ 45,407.25	$ 3,052.08	$ 1,542.41	$ 4,594	$ 91,889.80
									Total:	**$ 76,861.04**	**$ 1,537,220.84**

NOTES

Inflation Rate- based on the RSMeans Historical Cost Index. January 1, 2016. http://rsmeansonline.com/References/CCI/3-Historical%20Cost%20Indexes/1-Historical%20Cost%20Indexes.PDF

Preconstruction Costs- assumed to be 20% of initial construction costs

Cost estimtates- obtained from "Costs of Stormwater Management Practices In Maryland Counties" prepared for Maryland Department of the Environment by Dennis King and Patrick Hagan of the University of Maryland, Center for Environmental Science (UMCES), October 10, 2011.

WVTS cost estimates- based on a recent cost estimate of WVTS structure in Middletown, RI (72 Acre Drainage Area, 40% Impervious Area, $750,000 Construction Cost). Cost estimate was applied to St Mary's Pond WVTS structures SM_2_A and SM_2_B.

[1] Total initial cost includes pre-construction costs (design, planning, and permitting) and construction costs (capital, labor, material and overhead costs). Construction costs in 2011 dollars were converted to 2016 dollars using R.S. Means Construction Cost Indexes (equivalent to 1.085% increase).

[2] Initial BMP costs, including preconstruction and construction costs, are amortized over 20 years at 3% to arrive at annualized initial costs.

[3] Combined annual operating, implementation, and maintenance costs.

[4] Wet Vegetated Treatment System (WVTS) conservatively assumed for cost estimating purposes.

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NARRAGANSETT BAY ESTUARY PROGRAM

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