TOTAL MAXIMUM DAILY LOAD ANALYSIS FOR THE TEN MILE RIVER WATERSHED

UPPER TEN MILE RIVER, CENTRAL POND, TURNER RESERVOIR, LOWER TEN MILE RIVER, OMEGA POND

PAWTUCKET and EAST PROVIDENCE, RHODE ISLAND

Final Report
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Executive Summary

This report describes data collected by the Rhode Island Department of Environmental Management's Office of Water Resources to assess the quality of the Ten Mile River and its impoundments, and based upon these results, the findings of water quality impairment. The report identifies the pollutant levels considered acceptable to supporting recreational use and aquatic life. Pollutant reductions and abatement actions necessary to restore the river system's quality in support of these uses are described in detail.

RIDEM performed this work in accordance with its responsibilities under the federal Clean Water Act to assess the quality of the state's waters, and identify those waters that are not meeting water quality standards. On a bi-annual basis, DEM is required to report the findings of this assessment in the state's Integrated Water Quality Monitoring and Assessment Report. The list of impaired waters reported therein as Category 5 Waters identifies river, lake, and coastal waters not meeting standards and the reasons for impairments. Once a water body is identified as impaired, RIDEM is required to develop a Total Maximum Daily Load (TMDL). A TMDL is a planning document that establishes specific goals to meet water quality standards in waterbodies where water quality standards are not met. The TMDL identifies actual and potential sources of pollutants causing the water quality impairment, and determines the maximum amount of the pollutant that can be discharged to the waterbody and still meet Rhode Island's Surface Water Quality Standards. It includes both required and recommended implementation activities to abate pollutant sources and allow water quality goals to be met.

The Ten Mile River, Central Pond, Turner Reservoir, and Omega Pond do not meet state water quality standards for total phosphorus, dissolved oxygen, pathogens, and the following metals: aluminum, cadmium, lead, and iron. Pathogens such as enterococci and fecal coliform are a human health concern and can reduce recreational opportunities when levels exceed established criteria. Elevated levels of metals have adverse effects on aquatic life. Nutrient enriched conditions are often observed in the impoundments of the Ten Mile River. These include: excessive growth of rooted aquatic plants and algae, low levels of water clarity, depressed levels of dissolved oxygen in the bottom waters, and frequent cyanobacteria blooms. These conditions also affect the aquatic health of the Ten Mile River and are largely a result of elevated levels of phosphorus in the water.

The data used for assessing these waterbodies, as well as for developing the TMDLs included 9 sampling surveys conducted between 2007 and 2008 at 8 locations in the Ten Mile River. This sampling was conducted jointly with staff from the Massachusetts Department of Environmental Protection (MADEP) and US Environmental Protection Agency. Samples were collected for a suite of parameters including fecal coliform bacteria, nutrients, and dissolved and total metals. Additional nutrient sampling in all impoundments was conducted in 2009. Continuous measurements of dissolved oxygen were collected in 2007 and 2009 from stationary sondes located in Central Pond, Turner Reservoir, and Omega Pond. Flow data, for pollutant loading calculations, was obtained from two locations: 1) a USGS gauging station located just downstream of the Turner Reservoir and 2) at Central Avenue at the MA/RI state line.

As noted, this TMDL addresses multiple pollutants; depending upon the pollutant, different methodologies were used to evaluate pollutant source loadings, calculate allowable loads and the required pollutant reductions, and determine how those reductions get allocated among the different sources. The pathogen and metals TMDLs were developed using spreadsheet based methodologies while the phosphorus TMDL was developed using a combination of a phosphorus loading program developed by the U.S. Army Corps of Engineers and a land use based phosphorus export coefficient model.

The Ten Mile River is effluent dominated, meaning that a majority of the flow in the river during periods of no precipitation (termed baseflow) consists of treated wastewater discharged from two municipal publicly owned treatment works (POTWs) located in North Attleborough and Attleboro, Massachusetts. The watershed is also heavily urbanized; total coverage by impervious surfaces in the Massachusetts portion of the watershed is 20% and increases to over 40% in Rhode Island. Thus under rain and/or snowmelt events, urban runoff containing pathogens, metals, and phosphorus, flows largely untreated into the Ten Mile River – further degrading its water quality.

Other sources of pollutants to the Ten Mile River and its impoundments include: 1) nuisance populations of non-migratory geese and other waterfowl at specific locations in the watershed including parks, public access areas and golf courses, 2) contaminated sediments re-introduced to the water column via scour of streambed and streambank during high flows, 3) contaminated groundwater, 4) phosphorus released from sediments in impounded portions of the river, and 5) natural sources that include native wildlife, forests and other undeveloped land, and atmospheric deposition. These source categories may intermittently contribute pollutants to the river system, but are not easily quantified.

The focus of this TMDL's pollution abatement recommendations are the more quantifiable and controllable sources such as urban runoff, nuisance populations of waterfowl, and fertilizer and other chemical applications at golf courses. The TMDL recommends that implementation activities in the Rhode Island portion of the watershed focus on the largest and most controllable source of phosphorus, pathogens, and metals, which is stormwater runoff from urbanized land uses. The cities of Pawtucket and East Providence, and the Rhode Island Department of Transportation (RIDOT) will be required to amend their Stormwater Management Program Plans consistent with the requirements described in the implementation plan. Other implementation measures needed from municipalities and watershed residents include more aggressive and effective management of pet waste and control of nuisance waterfowl at specified locations in the watershed.

In addition to these recommended activities, it is critical that levels of phosphorus, pathogens, and metal entering from the Massachusetts' portion of the watershed are reduced if the downstream portion of the Ten Mile River is to meet water quality objectives. Towards that end, the TMDL establishes allowable pollutant loads at the northern MA/RI state line. RIDEM will continue work with US EPA and MADEP to implement water quality restoration actions including efforts to improve the quality of effluent discharged from the two wastewater treatment facilities.

The water quality restoration actions outlined in this TMDL complement the US Army Corps of Engineers' $4.8 million project to restore anadromous fish to the Ten Mile River by creating fish ladders at Omega Pond Dam, Hunt's Mill Dam and the dam at Turner Reservoir. With completion of all three fishways, alewives, blueback herring and American shad will be able to reach their freshwater spawning habitats in the Ten Mile River up to the golf Club Dam in Pawtucket. The Ten Mile River project is the largest fish run restoration project in Rhode Island. The three fish ladders will provide access to about 340 acres of spawning habitat, an acreage that can support more than 200,000 river herring and 25,000 American shad. Restoring fish passage to the Ten Mile River provides significant benefits to the freshwater and estuarine ecosystems and to the surrounding communities. Improving the quality of these waters is essential to the river's restoration.

1.0 Introduction

The State of Rhode Island assesses its water bodies for compliance with water quality standards criteria established for their designated uses as required by the Federal Clean Water Act (CWA). Assessed water bodies are placed into one of three categories, depending on water quality assessment results: supporting designated use, not supporting designated use, or not assessed. These water bodies are found on Rhode Island's 305(b) list as required by that section of the CWA that addresses the assessment process. This document is available on the Rhode Island Department of Environmental Management website.

A subset of the water bodies that do not meet designated uses are included under Category 5 of the 305(b) list, and are assigned to Rhode Island's 303(d) list, named after that section of the CWA. Water bodies included in the 303(d) list are required to have a Total Maximum Daily Load (TMDL) evaluation for the water quality constituent(s) in violation of the water quality criteria. The TMDL process establishes the allowable loading of pollutants or other quantifiable parameters for a water body based on the relationship between pollution sources and in-stream water quality conditions. This allows water quality based controls to be developed to reduce pollution and restore and maintain water quality.

The TMDL is often defined as the sum of loads allocated to point sources (i.e. waste load allocation, WLA), loads allocated to nonpoint sources, including natural background sources (i.e. load allocation, LA), and a Margin of Safety (MOS). The loadings are required to be expressed as mass per time, toxicity, or other appropriate measures (40 C.F.R. 130.2[I]). A TMDL is a tool for implementing state water quality standards in the affected waterbody. The TMDL establishes the allowable pollutant loading to a waterbody and provides a framework for identifying specific actions needed to reach water quality standards. The ultimate goal of the TMDL process is to reduce pollutant loadings to a waterbody in order to improve water quality to the point where state water quality standards are met.

One of the major components of a TMDL is to establish instream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. Instream numeric endpoints represent the water quality goals that are to be achieved by implementing the load or pollutant reductions specified in the TMDL. The endpoints allow for a comparison between current instream water quality conditions and those conditions that are expected to restore beneficial uses. The endpoints are usually based on either the narrative or numeric criteria available in state water quality standards.

This Total Maximum Daily Load (TMDL) plan addresses total phosphorus, pathogen and metals impairments to the Rhode Island portion of the Ten Mile River and metals, total phosphorus, and dissolved oxygen impairments to Central Pond, Turner Reservoir, and Omega Pond.

These waters are listed on Rhode Island's 2012 303(d) List of Impaired Waters and do not support the designated use that is associated with the enterococcus and fecal coliform bacteria criteria, which include primary and secondary contact recreational activities, and for the metals, total phosphorus, and dissolved oxygen impairments, the designated use of fish and wildlife habitat.

1.1 Study Area

The Ten Mile River is an urbanized and highly impounded river located in southeastern Massachusetts and northeastern Rhode Island. The 54 km^2 watershed is a tributary to the Seekonk River and ultimately Narragansett Bay. This TMDL addresses impairments in the Ten Mile River from the MA-RI state line to the confluence with the Seekonk River. It includes three major impoundments: Central Pond, Turner Reservoir, and Omega Pond. Waterbody segments are described in Table 1. The study area is presented in Figure 1.

Table 1. Waterbody Segment Descriptions in the Ten Mile River watershed.

Waterbody ID	Waterbody	Waterbody Size
RI0004009-01A	Ten Mile River from the RI/MA state line to the inlet of Central Pond, Pawtucket	3.61 miles
RI0004009L-01A	Central Pond north of Newman Avenue Dam, East Providence	130 acres
RI0004009L-01B	Turner Reservoir south of Newman Avenue Dam, East Providence	85.1 acres
RI0004009-01B	Ten Mile River from the outlet of Turner Reservoir to the inlet of Omega Pond, East Providence	3.15 miles
RI0004009L-03	Omega Pond, East Providence	33.2 acres

1.2 Pollutants of Concern

As stated earlier, this TMDL addresses impairments associated with the designated uses of primary and secondary contact recreation and fish and wildlife habitat. These impairments are: enterococci, fecal coliform bacteria, dissolved cadmium, dissolved lead, total aluminum, total iron, total phosphorus, and dissolved oxygen. Waterbody-specific impairments addressed in this TMDL are listed below in Table 2.

The lower Ten Mile River (segment RI0004009-01B) is also identified on the 2012 303d list as impaired for benthic-macroinvertebrate bioassessments. TMDL development for this impairment is scheduled for 2016; causes contributing to this aquatic life impairment may be associated with the pollutants of concern in this TMDL.

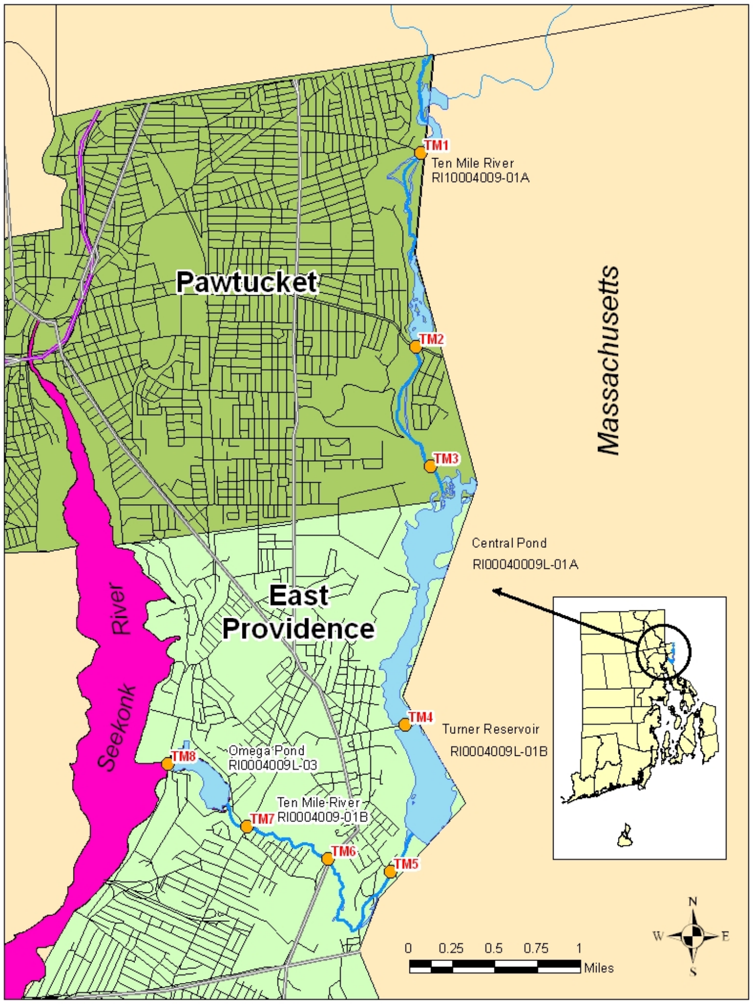

Figure 1. Applicable Waterbody Segments in the Ten Mile River, Rhode Island.

Slater Park Pond, located in Pawtucket, RI, is a 24 acre run-of-the-river impoundment of the Ten Mile River. According to the RIDEM dam database, the impoundment was created by the State of Rhode Island Metropolitan Park Commission in 1926 by transforming a large swampy area into a shallow impoundment. Recent staff surveys of the impoundment show it to have an average depth of approximately 2-3 feet. Water residence times of approximately 3 days and 0.3 days, respectively were calculated under the 7Q10 and mean annual flows of 12 cfs and 107 cfs.

Based on water residence time, Slater Park Pond would not meet the definition of a "lake" as defined in EPA's April 2000 Nutrient Criteria Technical Guidance Manual for Lakes and Reservoirs ("natural and artificial impoundments with a surface area greater than 10 acres and a mean water residence time of 14 or more days"). Although this definition is provided as guidance to states, the manual also states that other features of a waterbody should be taken into consideration. DEM staff note that this run of the river impoundment behaves more like a river than a lake (including excessive rooted aquatic plants but very low (avg ~ 3.0 ug/l) levels of chlorophyll a.

Based on EPA guidance and staff field verification, RIDEM is correcting the identification of the run-of-the river area known as Slater Park Pond, from a lake to a river waterbody type. As of the 2012 Integrated Report, this run-of-the river area is now incorporated into the Upper Ten Mile River WBID# RI0004009R-01A. This resulted in the addition of total phosphorus as an impairment to the Upper Ten Mile River. It has been determined that portions of the Upper Ten Mile River, namely the run-of-the river area historically referred to as Slater Park Pond, contain undesirable and/or nuisance aquatic algal growth – thus violating the state's narrative nutrient criteria for freshwater rivers.

In Massachusetts, the Ten Mile River and nearly all its tributaries are designated as Class B waters (fishable, swimmable). Only the Four Mile Brook and the upper reach of the Seven Mile River are designated as Class A "outstanding resource" waters (ORWs). The MA 2012 List of Integrated Waters is available at the following website: www.mass.gov/eea/docs/dep/water/resources/07v5/12list2.pdf. Pages 165-166 describe the 303(d) Listings for waters within the Massachusetts portion of the watershed. The entire length of the Ten Mile River is impacted by various impairments including: excess algal growth, fecal coliform, total phosphorus, turbidity, aquatic plants, chlordane, dissolved oxygen saturation, and organic enrichment (sewage) biological indicators.

Table 2. Waterbody Segment Identification, Water Use Classification, and 303(d) Impairments Addressed in this TMDL.

Waterbody	Waterbody Segment ID	Class	Impairments
Ten Mile River	RI0004009-01A	B1[1]	Aluminum, Cadmium, Iron, Lead, Enterocooccus, Fecal Coliform, Total Phosphorus[2]
Central Pond	RI0004009L-01A	B1[1]	Aluminum, Cadmium, Dissolved Oxygen, Total Phosphorus
Turner Reservoir	RI0004009L-01B	B	Aluminum, Cadmium, Dissolved Oxygen, Total Phosphorus
Ten Mile River	RI0004009-01B	B	Aluminum, Cadmium, Enterococcus
Omega Pond	RI0004009L-03	B	Aluminum, Cadmium, Dissolved Oxygen, Total Phosphorus, Fecal Coliform

[1]Classified as B1 due to potential impacts from Attleboro Water Pollution Control Facility, Attleboro, MA.
[2]Does not meet the narrative portion of total phosphorus criteria.

1.3 Priority Ranking

The 303(d) List identifies impaired waterbodies and a scheduled time frame for development of TMDLs. As such, it is used to help prioritize the State's water quality monitoring and restoration planning activities. Scheduling is not necessarily representative of the severity of water quality impacts, but rather reflects the priority given for TMDL development with consideration to shellfishing waters, drinking water supplies and other areas identified by the public as high priority areas. The TMDL schedule for all waterbody segments addressed in this report is 2012.

1.4 Applicable Water Quality Standards

A water quality standard defines the water quality goals of a surface waterbody, or portion thereof, by designating the use or uses of the water and by setting criteria necessary to protect those uses. Water quality standards are intended to protect public health, safety, and welfare, enhance the quality of water and serve the purposes of the federal Clean Water Act. The most recent iteration of the State's Water Quality Regulations was completed in 2012 and is the basis for setting water quality targets in this TMDL.

Water Use Classification and Designated Uses

Surface waters of the state are categorized according to the water use classifications of rule 8.B of Rhode Island's Water Quality Regulations (RIDEM 2012) based on public health, recreation, propagation and protection of fish and wildlife, and economic and social benefit. Each class is identified by the most sensitive, and therefore governing, water uses to be protected. Surface waters may be suitable for other beneficial uses, but are regulated to protect and enhance the designated uses. Class B and B1 waters are found within the Ten Mile River watershed (Table 1.2). These water quality classifications are described below and in Section 8.B(2) of Rhode Island's Water Quality Regulations.

Class B waters are designated for fish and wildlife habitat and primary and secondary contact recreational activities. They shall be suitable for compatible industrial purposes and cooling, hydropower, aquacultural uses, navigation, and irrigation and other industrial purposes. These waters shall have good aesthetic value.

Class B1 waters are designated for fish and wildlife habitat and primary and secondary contact recreational activities. They shall be suitable for compatible industrial purposes and cooling, hydropower, aquacultural uses, navigation, and irrigation and other industrial purposes. These waters shall have good aesthetic value. Primary contact recreational activities may be impacted due to pathogens from approved wastewater discharges however all Class B criteria must be met.

Numeric Water Quality Criteria

Numeric criteria for fecal coliform bacteria, enterococci, dissolved oxygen, and total phosphorus are taken from Table 1 of DEM's Water Quality Regulations (DEM 2012). Acute and chronic criteria for toxics, including metals, are taken from Appendix B Table 1 of the same regulations.

Fecal Coliform Bacteria and Enterococci

For class B and B1 waters fecal coliform bacteria concentrations are not to exceed a geometric mean value of 200 MPN/100ml and not more than 10% of the samples shall exceed a value of 400 MPN/100ml. These criteria are applied only when adequate enterococci data are not available. The criteria for enterococci in non-designated bathing beach waters is a geometric mean density not to exceed 54 colonies per 100ml. The above-criteria apply to all waterbody segments in the Ten Mile River.

Total Phosphorus

The following criteria for total phosphorus are taken from Table 1.8.D.(2) of RIDEM's Water Quality Regulations (RIDEM, 2012) and excerpted below.

10(a). Average Total phosphorus shall not exceed 0.025 mg/l in any lake, pond, kettlehole, or reservoir, and average Total P in tributaries at the point where they enter such bodies of water shall not cause exceedance of this phosphorus criteria, except as naturally occurs, unless the Director determines, on a site-specific basis, that a different value for phosphorus is necessary to prevent cultural eutrophication.

10(b). None [nutrients] in such concentration that would impair any usages specifically assigned to said Class, or cause undesirable or nuisance aquatic species associated with cultural eutrophication, nor cause exceedance of the criterion of 10(a) above in a downstream lake, pond, or reservoir. New discharges of wastes containing phosphates will not be permitted into or immediately upstream of lakes or ponds. Phosphates shall be removed from existing discharges to the extent that such removal is or may become technically and reasonably feasible.

The above criteria are applicable in Central Pond, Turner Reservoir, and Omega Pond. The upper Ten Mile River, from the MA/RI state line to the inlet of Central Pond and including Slater Park Pond, does not meet the narrative portion of the total phosphorus criteria. This is due to undesirable/nuisance aquatic species documented in Slater Park Pond that include significant amounts of variable watermilfoil (*Myriophyllum heterophyllum*) and curlyleaf pondweed (*Potamogeton Crispus*).

Dissolved Oxygen

Dissolved oxygen criteria for freshwaters are dependant on whether the waterbody is designated as a coldwater or warmwater fishery. Freshwater rivers and streams, and lakes and ponds are designated as coldwater, warmwater, or unassessed based upon the potential for the presence of brook trout by evaluating current and historical presence/absence information, habitat, water quality and physical characteristics data.

Class B and B1 waters in the Ten Mile River have been categorized as warm water fisheries. For Class B (warm water fish habitat), the dissolved oxygen content should not have less than 60% saturation, based on a daily average, and the instantaneous minimum dissolved oxygen concentration should not be less than 5mg/l, except as naturally occurs. The 7-day mean water column dissolved oxygen concentration should not be less than 6 mg/l.

Toxicants

Available data indicate that dissolved cadmium (Cd) and lead (Pb) and total aluminum (Al) and iron (Fe) violate applicable criteria and thus are the toxicants of concern in the Ten Mile River. The aquatic life criteria for dissolved cadmium and lead are based on the ambient hardness of the water body. Hardness is a measure of the concentration of cations (largely calcium and magnesium) in solution, with hardness usually measured as calcium carbonate ($CaCO_3$) equivalents in mg/l. An increase in hardness decreases the toxicity of metals, because calcium and magnesium cations compete with the metal ions for complexing sites, allowing fewer metal complexes to form and therefore resulting in a lower level of toxicity to organisms.

The chronic and acute criteria for dissolved cadmium and lead can be calculated using water hardness (in mg/l as $CaCO_3$) based on equations in Table 2-Appendix B of Rhode Island's Water Quality Regulations and shown below in Table 3. The toxicity of total aluminum and total iron are not hardness dependent and are also shown in Table 3.

Table 3. Applicable Freshwater Criteria Equations and Base e Exponential Values.

Parameter	*ACUTE (ug/l)* $CF \times e^{(m_a [\ln Hardness] + b_a)}$			*CHRONIC (ug/l)* $CF \times e^{(m_c [\ln Hardness] + b_c)}$		
	CF =	m_a =	b_a =	CF =	m_c =	b_c =
Dissolved Cadmium	@	1.0166	-3.924	@	0.7409	-4.719
Dissolved Lead	#	1.273	-1.46	#	1.273	-4.705
Total Aluminum	750			87		
Total Iron	No criteria			1000		

@ = Cadmium Conversion Factors: acute CF= 1.136672 – [(ln H) x 0.041838] chronic CF= 1.101672 – [(ln H) x 0.041838]
# = Lead Conversion Factors: acute and chronic CF= 1.46203 – [(ln H) x 0.145712]

The water quality standards for toxicants, including dissolved and total metals, set forth in Appendix B of the state of Rhode Island Department of Environmental Management Water Quality Regulations (DEM 2012) state that "to protect aquatic life, the one-hour average concentration of a pollutant should not exceed the acute criteria more than once every three years on the average. The four-day average concentration of a pollutant should not exceed the chronic criteria more than once every three years on the average. These aquatic life criteria shall be achieved in all waters, except mixing zones, regardless of the waters' classification. In addition, the acute and chronic aquatic life criteria for freshwaters shall not be exceeded at or above the lowest average 7 consecutive day low flow with an average recurrence frequency of once in 10 years (7Q10)".

Numeric Water Quality Targets

The numeric water quality targets for fecal coliform bacteria, enterococci, and total phosphorus are set at the water quality criteria for each applicable waterbody segment in the Ten Mile River. These targets are set to the water quality criteria necessary to restore the designated uses to the waterbody segments. For example, targets for fecal coliform and enteroccci are set to what is necessary to restore the designated uses of primary and secondary contact recreational activities. Targets for toxicants are set to what is necessary to restore the designated uses of fish and wildlife habitat. The numeric water quality targets used to set TMDL's for each parameter are explained in more detail in Sections 5-7.

Antidegradation Policy

Rhode Island's antidegradation policy requires that, at a minimum, the water quality necessary to support existing uses be maintained (see Rule 18, Tier 1 in the State of Rhode Island's Water Quality Regulations). If water quality for a particular parameter is of a higher level than necessary to support an existing use (i.e. bacterial levels are significantly below Class B standards), that improved level of quality should be maintained and protected (see Rule 18, Tier 2 in the State of Rhode Island's Water Quality Regulations). Because water quality criteria are violated in several locations, Tier 2 does not apply.

2.0 Background

2.1 Geographic Setting

The Ten Mile River watershed is located in southeastern Massachusetts and a small portion of northeastern Rhode Island (Figure 2). It is the smallest of the 27 major watersheds in Massachusetts with a total drainage area of approximately 54 square miles (140 km^2). Originating in Cargill Pond in Plainville, Mass, the stream flows generally southwest through North Attleborough, Attleboro, and Seekonk to Pawtucket and East Providence, Rhode Island where it turns northwest and flows for approximately 2.2 mi (3 km) prior to its discharge to the Seekonk River via Omega Pond.

The total length of the river is 22 miles (35.4 km), of which 15 miles (24 km) are in Massachusetts. The elevation of the mainstem drops from approximately 230 feet (70 m) above mean sea level at the source to approximately thirteen feet (4 m) prior to flowing over the Omega Pond Dam. Many dams were built along the Ten Mile River and for much of its length the river flows through various-sized impoundments.

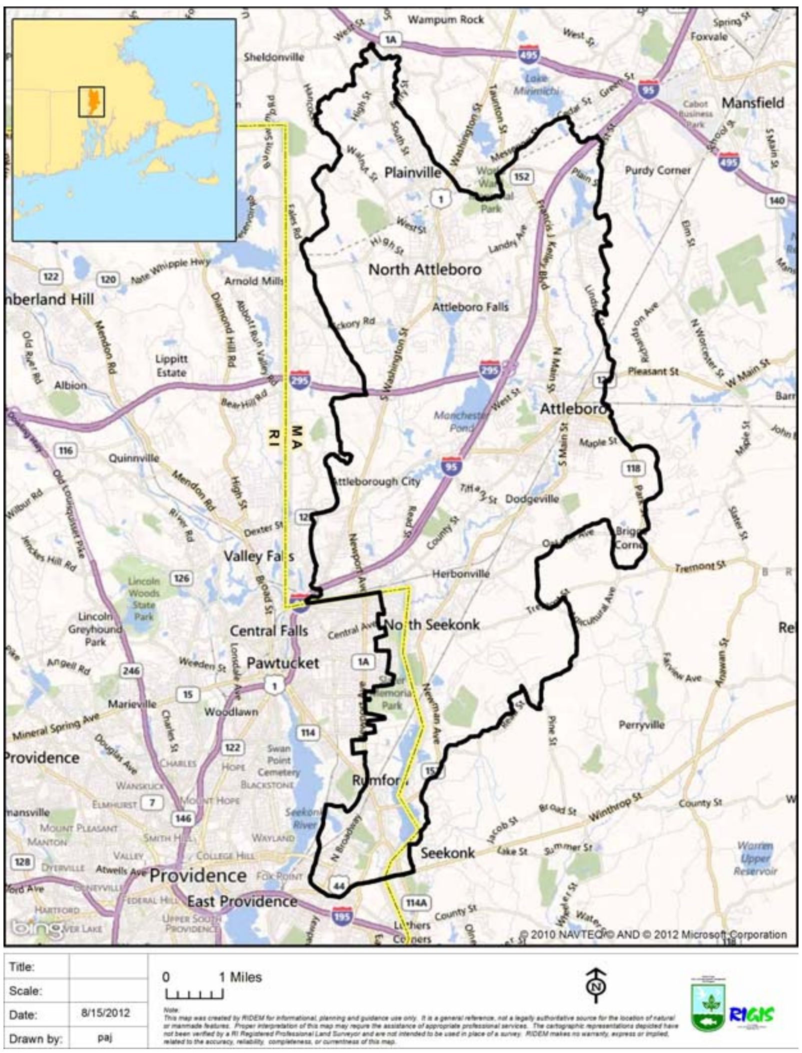

Figure 2. Ten Mile River watershed.

General land use in the basin is shown in Figure 3. Land use in the Massachusetts portion of the watershed is predominantly residential and forestland with moderate amounts of commercial/industrial uses; primarily in Attleboro. Within the Rhode Island portion, land use is primarily high density residential and commercial/industrial uses. The enitre Rhode Island portion of the watershed is sewered and the cities of East Providence and Pawtucket are designated and permitted as MS4's. A majority of Attleboro and North Attleborough are serviced by the two wastewater treatment facilities which discharge to the Ten Mile River. Both municipalities are also regulated as MS4's under EPA's Phase II Stormwater Program.

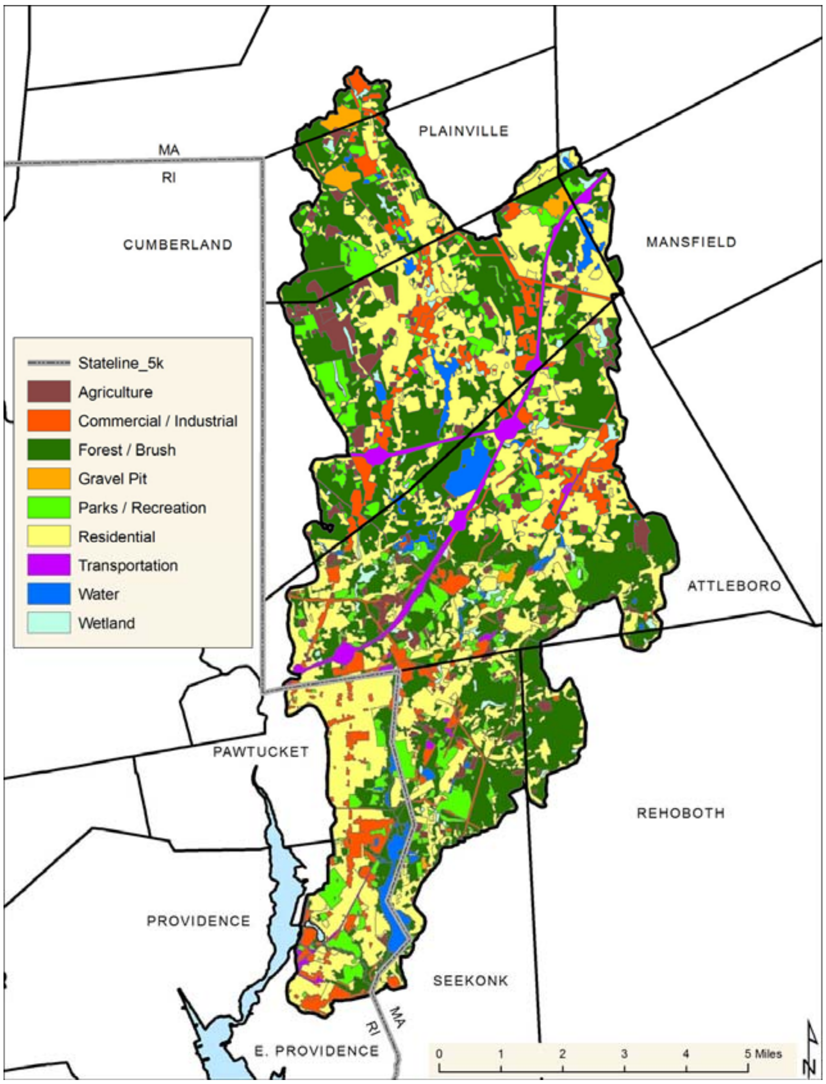

Figure 3. General Land Use in the Ten Mile River watershed.

2.2 Basin Hydrology

The Ten Mile River originates from Cargill Pond, located in the Town of Plainville, MA and flows generally south, through numerous impoundments, across the Massachusetts and Rhode Island border, before ultimately discharging to the Seekonk and Providence Rivers of Narragansett Bay. The Ten Mile River has two major tributaries, the Seven Mile River and the Bungay River. The Seven Mile River begins in North Attleborough, flows south through Attleboro and joins the Ten Mile River in Seekonk. The Bungay River originates at the outlet of Greenwood Lake and flows south to join the Ten Mile River in Attleboro.

Flow throughout the mainstem of the Ten Mile River is highly restricted, with various dams creating a total of 15 impoundments. These impoundments comprise almost half the length of the river. During periods of low and/or falling flows, wastewater discharge from the North Attleborough WWTF and the Attleboro WPCF can significantly alter the flow rate (by making up an increasing proportion of the total flow), water chemistry, and water quality of the Ten Mile River and its impoundments.

The US Geological Survey (USGS) operates a single gaging station (01109403) in the Ten Mile River (http://waterdata.usgs.gov/nwis/uv?01109403). The gage is located downstream of the Turner Reservoir at Pawtucket Avenue, East Providence, RI (same location as station TM6). The period of record is from October 1986 to the current year. The annual mean daily flow for the Ten Mile River at station 01109403, based on the period of record is 110 cfs and the calculated 7Q10 flow is approximately 13 cfs. Historical discharge, expressed as daily mean flow, is presented in Figure 4.

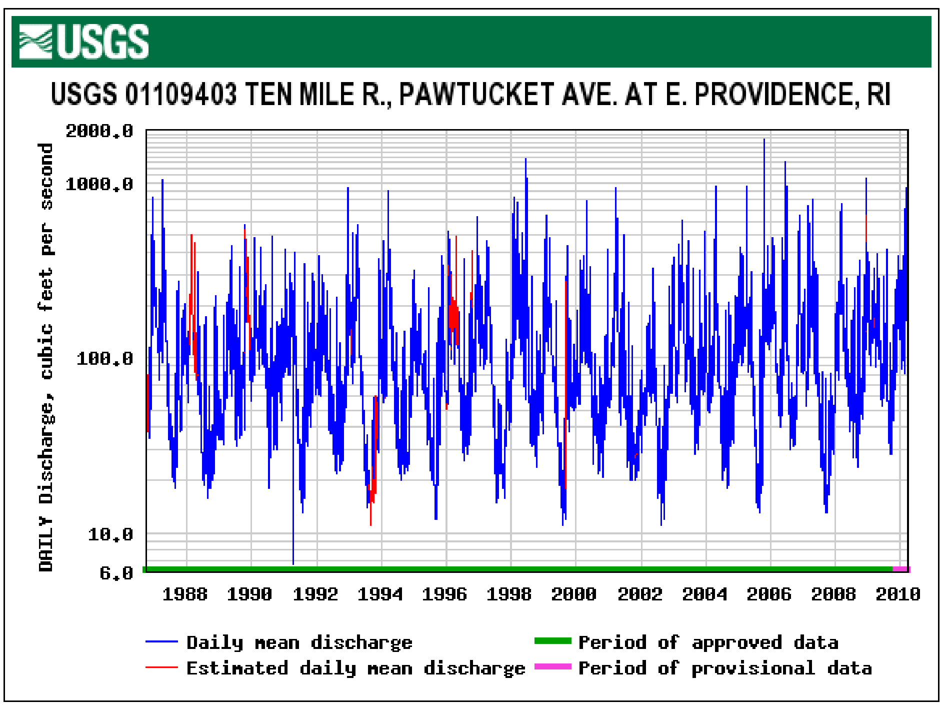

Figure 4. Historical discharge at USGS gage 01109403 on the Ten Mile River.

2.3 Wetland/Riparian Attributes

Areas of emergent wetland in the Ten Mile River occur within the fringing shorelines, as well as along the margins of the riverine corridor connecting them. In Turner Reservoir/Central Pond, an extensive area of emergent and scrub-shrub wetland is located at the inflow of Ten Mile River to the reservoir, where a vegetated delta has been created by sediment deposition. Additional wetlands also exist along the margins of the impoundment, particularly in several shallow coves. Also, several smaller water bodies that are hydraulically connected to the reservoir by small streams or inlets contain wetlands. Predominant wetland types include aquatic bed as well as lacustrine emergent, with major wetland vegetation species being cattail, yellow water lily, sedges, pickerelweed, and willow.

2.4 Fisheries Resources

The Ten-Mile River is designated as a warmwater fishery from its headwaters in Plainville Massachusetts, to the Rhode Island border by the Commonwealth of Massachusetts, Division of Fisheries and Wildlife. This warmwater designation applies throughout the entire portion of the river in Rhode Island. The designation of warmwater fishery in both states indicates that generally the water temperatures in the river are too warm to sustain year round populations of coldwater fish (i.e. trout, salmon).

Although the water temperature of the Ten Mile River is considered too warm to support naturally reproducing trout populations, some portions of the mainstem, and Bungay River in Massachusetts are stocked with trout in the spring by the Massachusetts Division of Fisheries and Wildlife in order to provide a put and take trout fishery. There are also some sections of the river where year round populations of trout have been sustained as indicated by the presence of natural reproduction. These include some of the areas upstream near the headwaters of the mainstem Ten Mile.

The numerous ponds and impoundments that are located along the course of the river provide fisheries habitat to many warmwater fish species. These include chain pickerel, redfin pickerel, largemouth bass, bluegill, yellow perch and white sucker. These impoundments can also raise water temperatures in the river, thereby perpetuating the warmwater fish habitat (to the exclusion of potential coldwater habitat). This occurs when the inflowing water is held, allowed to warm and then released downstream. Therefore, it is presumed that historical coldwater fish habitat has been changed to warmwater fish habitat by the construction of these dams and their resulting impoundments.

2.5 Fish Passage Projects

The Ten Mile River historically provided habitat for various species of anadromous fish. These included blueback herring and alewives (collectively referred to as river herring), American shad, and Atlantic salmon, as well as the catadromous American eel. However, during the last approximately 100 years, dams were built along the river to provide water power for various industrial purposes. These dams blocked the upstream migration of pre-spawning adults of anadromous fish to their historic spawning habitat and have resulted in their populations have been either reduced or eliminated from the rivers.

In 1999, the U.S. Army Corps of Engineers completed the Rhode Island Ecosystem Restoration Reconnaissance Report/Analysis, under Section 905(b) of the Water Resources Development Act of 1986 (WRDA 86). This authority provides for cost shared studies of degraded aquatic ecosystems in order to determine best methods of restoration and to implement habitat restoration projects. In this study, the Ten Mile River was identified as a river where anadromous fish could be restored by providing fish passage beyond and/or over the obstructing dams.

Three dams were identified as requiring fish passage to restore anadromous fish to the lower Ten Mile River. These are Omega Pond Dam, Hunts Mill Dam, and Turner Reservoir Dam. Omega Pond Dam is currently owned by the city of East Providence and is constructed of masonry and earth. It has a hydraulic height of 15 feet and forms Omega Pond, which covers approximately 33 acres. Hunts Mill Dam is owned by the city of East Providence, and is constructed of masonry and rockfill. It has a hydraulic height of 8.5 feet, and forms a small pond, Hunts Mill Pond, which, during higher flows, can extend to the base of Turner Reservoir Dam. Turner Reservoir Dam is owned by the city of East Providence, and is constructed of concrete and earth. The dam has a hydraulic height of 22 feet, and forms the 300-acre Turner Reservoir/Central Pond complex. These dams have historically blocked the upstream migration of native anadromous fish to their historical spawning and nursery habitat along the Ten Mile River and points upstream from Turner Reservoir.

Providing fish passage beyond these dams will open-up approximately three miles of riverine habitat below Turner Reservoir, as well as approximately 340 acres of lacustrine habitat in both Turner Reservoir and Omega Pond. In addition, approximately one (1) river mile of riverine spawning and nursery habitat for anadromous shad and blueback herring will become available in the areas upstream from Turner Reservoir/Central Pond along the Ten-Mile River. This would allow anadromous alewives, blueback herring, and American shad access to historical riverine and/or lacustrine spawning and nursery habitat from the mouth of the river to areas upstream from Turner Reservoir.

As of 2012, the fish passage projects at the Hunts Mill Dam and Turner Reservoir have been completed. The Omega Pond fish passage project is scheduled to be completed in 2014.

2.6 Recreational Values and Resource Protection

Along its course, the Ten Mile River and its impoundments provide significant recreational and cultural resources. Turner Reservoir/Central Pond is used heavily for recreation, including non-powered boating, canoeing, recreational fishing, as well as for hiking and bird-watching. The area surrounding Hunts Mill Pond provides parkland for picnicking and passive recreation. Also, the Museum of East Providence History is located at the historic John Hunt House on the original property of Hunts Mill. Omega Pond is also used for recreational fishing and non-power boating, as well as passive recreation. With sporadic portages, the mainstem of the river from the MA/RI state line to Omega Pond is fully accessible to canoes/kayaks.

The Ten Mile River Greenway extends approximately 2.5 miles from Armstice Boulevard, near the outlet of Slater Park Pond, along the mainstem of the river and along Central Pond before terminating at the Kimberly Ann Rock ball fields in East Providence In the future an extension may continue north of Armistice Boulevard another mile to the playing fields along Daggett Avenue in Ten Mile River Park. The Greenway receives heavy use and is an important recreational resource for the Cities of East Providence and Pawtucket.

The Ten Mile River Watershed Council was started in 2006 with a clean-up at Central Pond in East Providence. In January of 2007 the group Incorporated and registered as a nonprofit with the State of RI. They are based in East Providence, with a goal to protect and promote the Ten Mile River and its' watershed from East Providence, Rhode Island to Attleboro, Massachusetts and beyond. The Council wants to educate the public on the importance of keeping the water and the land surrounding it viable and healthy and working to improve the recreational opportunities in the watershed with water, biking and hiking trails. The group sponsors 4 to 5 clean-ups in the watershed a year and holds monthly paddles. The Council has supported the need and construction of the fish passage projects, as part of restoring a balanced ecosystem to the Ten Mile River.

2.7 Notable Water Quality Issues

Water quality problems in the Ten Mile River watershed date back at least to the early twentieth century. During the period of colonial settlement and industrialization, the river was used as a prime energy source for manufacturing industries which resulted in severe pollution in many parts of the river by the 1900's. Attleboro and North Attleborough comprise the urban core of the watershed that, at the turn of the century, supported a diversified mix of industries led by jewelry, plating and textiles.

Water quality in the river improved with the completion of two wastewater treatment plants- North Attleborough WWTF and the Attleboro WPCF. However, elevated levels of nutrients and metals in the water column and sediments continue to impact the river's biological communities and diminish its recreational potential.

Turner Reservoir was created as a drinking water supply for the city of East Providence. The dam at this site dates from about 1930. The water received basic treatment at the Hunts Mills Water Treatment Facility. Water pollution caused by industrial discharges and runoff into the Ten Mile River upstream of the Turner Reservoir, rendered the reservoir unsuitable for drinking water supply. In 1970, after years of planning and construction, East Providence connected to the Providence Water System which is supplied by the Scituate Reservoir.

Wastewater Treatment Facilities

Two wastewater treatment facilities, both located in Massachusetts, discharge directly to the Ten Mile River. The facilities are important in terms of water quality because the combined volume of treated wastewater makes of a majority of baseflow in the downstream portions of the river. The North Attleborough Wastewater Treatment Facility (WWTF) is located on Cedar Road in North Attleborough, Massachusetts. The facility collects and treats an average of 3.1 million gallon per day of industrial and domestic wastewater from the Town as well as the Town of Plainville. It has a permitted annual average capacity of 4.61 mgd. Treatment facilities at the plant include screening, aerated grit chambers, primary clarifiers, first-stage aeration tanks and clarifiers, second-stage aeration tanks and clarifiers, gravity sand filters, chlorine contact tanks, dechlorination facilities, and post aeration tanks. Sludge handling facilities include flotation thickeners and centrifuges.

The Attleboro Water Pollution Control Facility (WPCF) is located at 27 Pond Street North in Attleboro, Massachusetts. The Attleboro WPCF discharges to the Ten Mile River about 200 yards from the Rhode Island border. It has a permitted annual average capacity of 8.6 mgd and serves the City of Attleboro with some septage collected from portions of North Seekonk and Attleboro.

Historical Contamination

Manufacturing in the Ten Mile River watershed began in the late 1700's, and with it, the construction of dams, which provided waterpower for the numerous industries that developed along its corridor. With the completion of the Boston and Providence Railroad in the mid-1800's, a transportation link was established between the industries on the Ten Mile River, and other locations, allowing for increased production. The primary industries included jewelry and textiles however paper, primary metals and machinery were manufactured in various towns and cities within the watershed. In addition, the river was used for process water and as a conduit for wastewater disposal. As a result, the Ten Mile River began experiencing poor water quality by the mid-1900's.

Since the implementation of the Clean Water Act and Amendments of 1972 and 1977, which provided funding for construction of wastewater treatment plants, the river is significantly cleaner now than it was in the 1960's and 1970's. However, it is still impacted by the effects of development and the residual levels of various pollutants from the existing and past usage. More recently, the Ten Mile River has been the subject of comprehensive habitat and water quality restoration efforts, by various private, state, local and federal agencies. These include efforts to reduce point and non-point sources of pollution as well as anadromous fisheries restoration. During 1996 and 1997, Turner Reservoir was stocked with alewives and blueback herring by RIDEM. This resulted in successful spawning as indicated by the netting of juvenile river herring in the fall of those years. In addition, habitat studies conducted during that time indicated that the Ten Mile River could also support American shad.

Hazardous Waste Sites

In the Rhode Island portion of the Ten Mile River watershed there are approximately 52 Leaking Underground Storage Tanks (LUST), 36 solid waste investigations and/or site remediation facilities, and 172 Resource Conservation and Recovery Act (RCRA) sites. In the Massachusetts portion of the watershed there are approximately 318 RCRA sites. It was beyond the scope of this study to evaluate each of these sites with respect to the TMDL parameters.

EPA New England's Office of Site Remediation and Restoration (OSRR) administer the region's waste site cleanup and reuse programs. A review of the website used to locate hazardous waste sites in New England revealed the existence of several sites in Rhode Island and Massachusetts. Sites thought to have reasonable potential to contribute contaminants to the Ten Mile River or impoundments are briefly described in Section 4.0 of this report.

Urban Runoff

As areas become more developed, the amount of impervious cover increases, and natural filter systems are no longer in place to intercept runoff. This has serious implications for both water quality and flood control. Typical pollutants in runoff from impervious areas include pesticides, oil, metals, litter, fertilizers, sediment, salt, and bacteria. A growing body of scientific literature has shown that groundwater recharge, stream base flow, and water quality measurably change and can decrease as impervious cover increases. Studies have shown a direct relationship between the intensity of development, as indicated by the amount of impervious surface, and the degree of damage in a watershed (Center for Watershed Protection 2003).

The total coverage by impervious surfaces in the Massachusetts portion of the watershed is 20%. Impervious cover increases to approximately 42% in the Rhode Island portion. Water quality impacts have been observed at watershed impervious coverage of as low as 11 (CT DEP 2007, Maine DEP 2007). Because increases in impervious cover generally translate to increases in stormwater runoff and the percentage of impervious coverage in the watershed is significantly higher than literature values, it is reasonable to assume that stormwater runoff plays a major role in the overall water quality in the Ten Mile River.

Central Pond Cove Fish Kills

Several fish kills have been reported at a narrow cove, located in East Providence on the western side of Central Pond, to the east of Taylor Drive and an old railroad bed. The cove is approximately 1200 feet long and ranges in width from 20 to 170 feet. The site is located to the east of Narragansett Industrial Park. Residents and RIDEM staff have also reported several previous episodes of strong odors, variously described as sewerage-like, putrid or musty. RIDEM staff also observed the presence of iron floc and an oil-like sheen (possibly manganese oxide) encircling the shoreline of the cove. At various times, the surface water of the cove has taken on a milky, turbid or brown appearance.

In response to complaints, RIDEM's Office of Compliance and Inspection (OCI) staff inspected nearby properties in Narragansett Industrial Park, to identify any potential source of pollutants. Soil samples were taken and analyzed for various metals. The levels of all metals were below the Direct Exposure Criteria for residential properties. For details, see OCI files 01-058, 01-072, and 03-066. These files are available at DEM Offices in Providence, RI.

RIDEM Water Resources staff collected water samples from the cove on June 7, 2010. The samples were analyzed for dissolved copper, cadmium, lead, zinc, total iron, hardness and pH. The pH averaged 7.0. Except for iron, all metal concentrations were below both acute and chronic water quality criteria. Iron levels were as high 8180 mg/l in that portion of the cove to the west of the railroad bed. High iron levels in the cove may be related to iron floc and manganese oxide deposits along the shoreline. These deposits may occur naturally and are fairly common in groundwater discharge areas, such as springs and wetlands. The iron and manganese deposits may also be indicative of contaminated or acidified soil, although there is no evidence that this is the case.

At present, the cause of the fish kills, odors, and discolored surface water is not known. There is no evidence that pollutants, from the nearby Narragansett Industrial Park, play any role in the fish kills. There is no acute water quality criteria for iron, only chronic criteria, so it in unlikely that the high iron concentrations were the cause of the sudden die-offs. The remaining water column metal concentrations were well below acute as well as chronic water quality criteria.

It is possible that the fish kills were a natural occurrence. It is notable that both fish kills were reported in early spring after ice-out. Under some conditions, prolonged ice coverage can lead to low dissolved oxygen. In cold water, oxygen levels less than 2-3 ppm for an extended time will begin to kill fish. If levels drop to 1-2 ppm or lower throughout the cove, a complete fish kill may result.

3.0 Water Quality and Resource Impairments

The most recent water quality conditions in the Ten Mile River and impoundments were determined from analysis of data collected by RIDEM between 2007 and 2009 and from limited data collected by volunteers from the University of Rhode Island's Watershed Watch Program from 2008-2011. Available physical and chemical data were used to assess the overall water quality of surface waters within the watershed, provide quality data for 305(b)/303(d) assessment purposes, and develop TMDLs for applicable waterbody segments.

The bulk of the data used to support TMDL development was collected during nine (9) synoptic surveys at eight (8) stations within the RI-portion of the watershed in 2007-2008 (Figure 5) as well as the additional nutrient sampling in the impoundments in 2009. Samples were analyzed for fecal coliform bacteria, total phosphorus, ammonia, TKN, nitrate, nitrite, and a suite of dissolved and total metals. Ancillary data collection activities conducted in 2007 and 2009 included collection of continuous (diel) monitoring of dissolved oxygen, temperature, and specific conductance at surface and depth locations in the Turner Reservoir and Omega Pond and at a single surface location in Central Pond.

All data were collected according to a US EPA approved quality assurance project plan developed by RIDEM in 2007 (RIDEM, 2007) and available on-line at: http://www.dem.ri.gov/pubs/qapp/tenmile.pdf. A final data report, which includes all data (2007-2009), an evaluation of data quality, results, and a discussion of actual and potential pollution sources, is also available on-line at: http://www.dem.ri.gov/programs/benviron/water/quality/rest/pdfs/tendata.pdf

Enterococci data in the upper Ten Mile River was collected by University of Rhode Island's Watershed Watch Program. Watershed Watch is a statewide volunteer monitoring program that provides training, equipment, supplies, and analytical services. The program meets strict quality assurance and quality control guidelines in the field and in its state-certified laboratory, which allows its data to be used by RIDEM when assessing water quality conditions in monitored waters. Volunteers collected a total of eighteen water samples in the upper Ten Mile River just upstream of the inflow to Central Pond for enterococci analysis.

For the 2007-2008 data, ancillary information such as previous precipitation in the watershed and phase of hydrograph during each RIDEM survey was acquired. In addition, a flow duration curve was constructed using mean daily flows reported at the USGS station in the Ten Mile River. This information, summarized below in Table 4, was used to classify the hydrologic and meteorological conditions at the time of each survey. As shown in Table 4, four of the nine surveys of 2007 and 2008 were conducted under what could be considered a dry weather/baseflow influenced condition and five of the surveys were conducted under the influence of stormwater runoff.

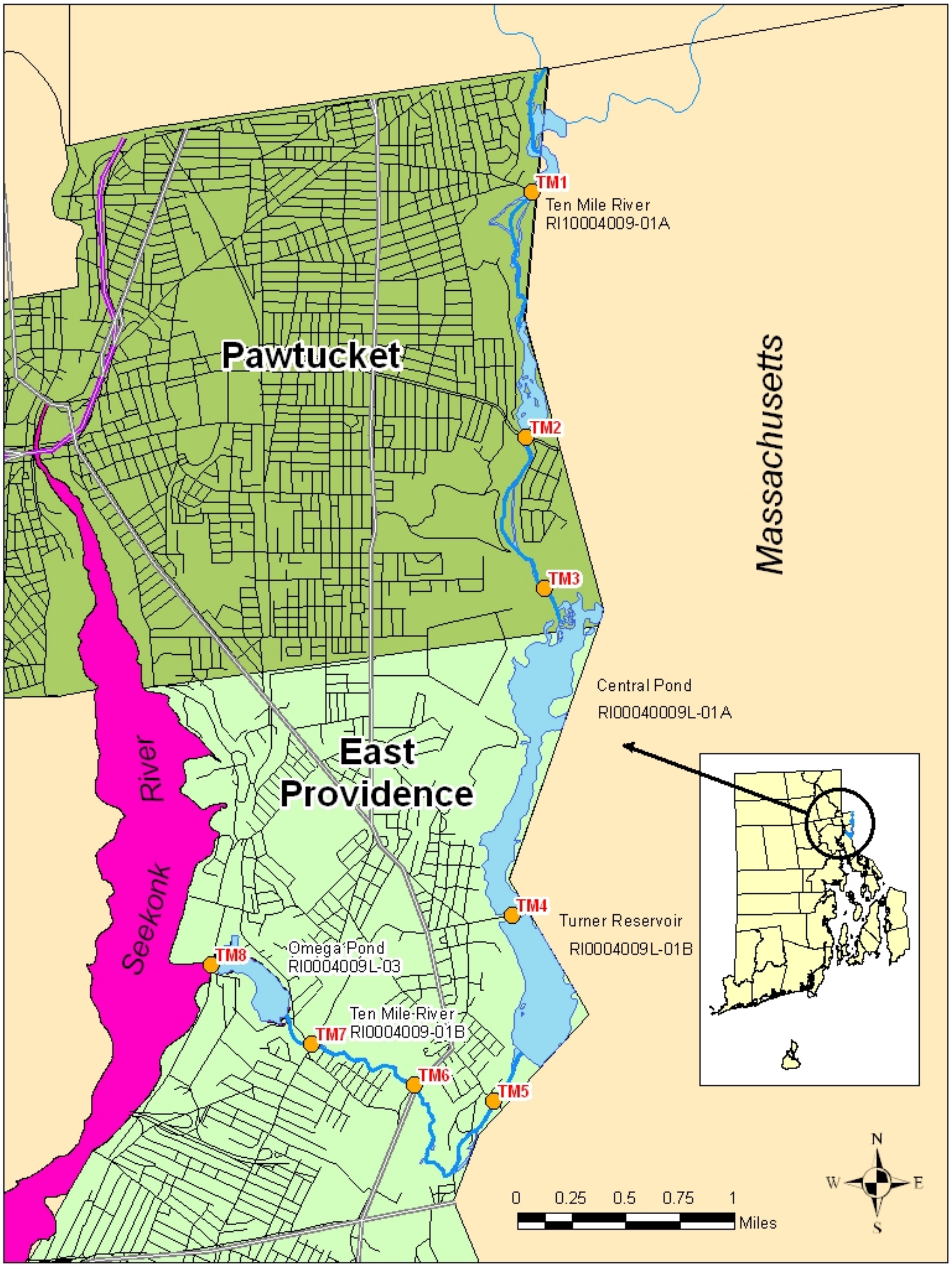

Figure 5. Ten Mile River Sampling Stations for the 2007 and 2008 surveys.

Table 4. Hydrographic and meteorological conditions for 2007-2008 surveys.

Survey Date	Hourly Flow at time of survey[1]	Phase of Hydrograph	Prior or Current Meteorological Condition	Flow[2]	Wet or Dry Weather Influenced[2,3]
5/22/2007	192	Receding limb of storm hydrograph	2.1 inches 6 days prior	High flows	Wet
6/19/2007	62	Slow recession not related to storm	0.11 inches 7 days prior	Mid-range	Dry
7/2/2007	39	Slow recession-baseflow	0.15 inches previous day	Mid-range	Dry
7/31/2007	88	Near peak, receding limb of storm hydrograph	1.51 inches previous day	Wet Weather Influenced	Wet
8/21/2007	20	Low-steady state	Trace precipitation past 10 days	Low-flows	Dry
9/4/2007	15	Low-steady state	Trace precipitation past 24 days	Low-flows	Dry
9/12/2007	84	Near peak, receding limb of storm hydrograph	2.11 inches 2 days prior	Wet Weather Influenced	Wet
3/6/2008	307	Rising	0.75 inches 2 days prior	High Flows	Wet
8/1/2008	60	Receding limb of storm hydrograph	0.9 inches 5 days prior	Mid-range	Wet

[1] Reported at USGS gaging station 01109403. Hourly value is an average of 15-minute data
[2] As determined by DEM staff
[3] Flow affected by regulations and diversions from upstream reservoirs.

3.1 Pathogens Summary

All pathogen data used to develop TMDL's are presented in Appendix A. Box plots of fecal coliform data obtained between 2007 and 2008 are displayed in Figure 6. Box plots include the mean (dashed line in box), median (solid line in box), the 25th-75th percentile range (solid boxes), and maximum and minimum values in dataset (error bars). Sample size (n) is 9 for each station. For a majority of surveys, the highest fecal coliform concentrations occurred upstream of Central Pond; at stations TM1, TM2, and TM3. The overall downward trend in fecal coliform concentrations from the MA/RI border to the Turner Reservoir is evident in Figure 6, as is the slight upward concentration trend from the outlet of the reservoir to the outlet of Omega Pond. Enterococci data for the upper Ten Mile River are available for variable years from a single URIWW station.

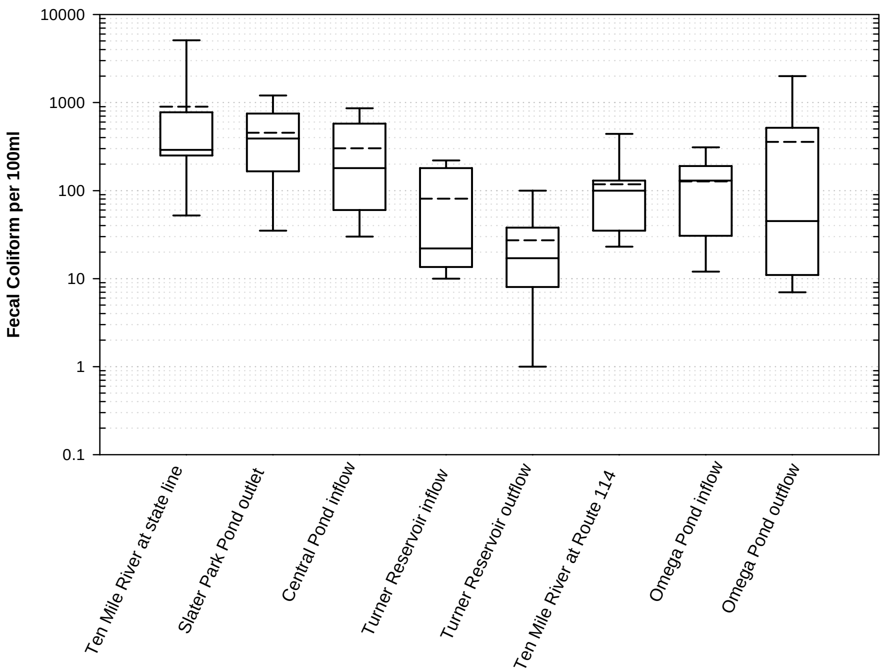

Figure 6. Fecal coliform bacteria concentrations in the Ten Mile River and impoundments.

Table 5 presents geometric mean and percentile statistics for the 2007-2008 pathogen data. These data were segregated by the weather/flow condition as defined in the final data report. All waterbody segments in the Ten Mile River exhibit elevated wet weather (high flow) influenced pathogen levels relative to those during dry weather and low flow.

These data clearly show that under both the dry and wet weather condition, the highest levels of fecal coliform bacteria occur at the Massachusetts-Rhode Island state line. Central Pond, Turner Reservoir, and the lower Ten Mile River all meet the current fecal coliform criteria for Class B waters and therefore are all fully supportive of the designated use of primary and secondary contact recreation. The upper Ten Mile River and Omega Pond fail to meet both the geometric mean and 90th percentile criteria for fecal coliform bacteria. The upper Ten Mile River also exceeds the Class B geometric mean enterococci criteria of 54 colonies/100ml.

For the majority of waterbody segments, the highest levels of pathogens were associated with wet weather-stormflow events. This was not unexpected given the large amounts of impervious surface cover in the Ten Mile River watershed. As shown in Table 5, the wet weather 90th percentile values for fecal coliform bacteria exceeded the respective water quality criteria most often for waterbodies on the 303(d) list for pathogens.

Table 5. Statistical analysis of 2007-2008 fecal coliform data in the Ten Mile River.

Waterbody Name	WQ Station(s)	Fecal Coliform[1] Statistics (fc/100ml) (2007-2008)					
		Geometric Mean	90th Percentile	DW Geometric Mean	WW Geometric Mean	DW 90th Percentile Value	WW 90th Percentile Value
MA/RI State Line	TM1	384	1980	284	489	304	3540
Upper Ten Mile River[a]	TM2	176	796	89	304	215	828
	TM3	303	864	320	290	627	1032
Central Pond	TM4	42	204	23	67	117	212
Turner Reservoir	TM5	13	100	23	8	46	68
Lower Ten Mile River	TM6	79	200	89	71	254	308
	TM7	82	254	100	67	147	286
Omega Pond[a]	TM8	66	1104	22	157	70	1552

[1] Class B fecal coliform criteria are as follows: A geometric mean value not exceeding 200 fc/100ml and a 90th percentile value not exceeding 400 fc/100ml.
[2] Class B enterococci criteria are as follows: A geometric mean value not exceeding 54 colonies/100ml.
[a] 2010 303(d) pathogen listing

Table 6 below presents the most recent (2008-2011) enterococci data collected in the upper Ten Mile River by URI Watershed Watch Volunteers. The sampling station is located where the mainstem of the river, the Ten Mile Greenway, and the railroad tracks intersect. The states' enterococci criterion is a geometric mean value of less than 54 MPN/100ml.

Table 6. Upper Ten Mile River enterococci data collected by URI Watershed Watch.

Sampling Date	Enterococci (MPN/100 ml)	Sampling Date	Enterococci (MPN/100 ml)
May 8, 2008	21	May 15, 2010	142
June 7, 2008	103	June 19, 2009	87
July 11, 2008	71	July 15, 2009	9678
August 16, 2008	2105	August 17, 2009	35
September 20, 2008	130	September 15, 2009	35
October 25, 2008	5	October 16, 2009	3654
Geometric Mean	**165**	**Geometric Mean**	**285**
May 2, 2009	60	May 21, 2011	183
June 13, 2009	4839	June 18, 2011	456
July 18, 2009	4839	July 22, 2011	108
August 16, 2009	8	August 17, 2011	307
September 14, 2009	68	September 17, 2011	89
October 17, 2009	26	October 15, 2011	378
Geometric Mean	165	Geometric Mean	213
4-YR Geometric Mean Value		**167**	

3.2 Total Phosphorus Summary

The criteria for total phosphorus, located in Table 1 of DEM's Water Quality Regulations (DEM 2012), states that "average total phosphorus shall not exceed 0.025 mg/l in any lake, pond, kettlehole, or reservoir, and average total phosphorus in tributaries at the point where they enter such bodies of water shall not cause exceedance of this phosphorus criteria." This numeric criterion applies to the following impoundments: Central Pond, Turner Reservoir, and Omega Pond. Total phosphorus data collected between 2007 and 2009 are presented below in Table 7. Survey median total phosphorus concentrations at the surface ranged from a minimum of 0.065 mg/l in the Turner Reservoir to a maximum of 0.079 mg/l in Omega Pond. The 3-year seasonal mean total phosphorus concentration for the upper Ten Mile River (segment) is 0.071 mg/l. These data confirm the total phosphorus impairments for these waterbodies as described on the 2012 303d List.

Table 7. Total Phosphorus Data collected from 2007-2009 in the Ten Mile River Impoundments[1].

Upper Ten Mile River[2]		Central Pond		Turner Reservoir			Omega Pond
Date	TP in mg/l	Date	TP in mg/l	Date	TP in mg/l	Date	TP in mg/l
22-May-07	0.052	22-May-07	0.046	22-May-07	0.048	22-May-07	0.048
19-Jun-07	0.062	19-Jun-07	0.071	19-Jun-07	0.050	19-Jun-07	0.057
2-Jul-07	0.070	2-Jul-07	0.041	2-Jul-07	0.050	2-Jul-07	0.040
31-Jul-07	0.093	31-Jul-07	0.078	31-Jul-07	0.064	31-Jul-07	0.092
21-Aug-07	0.077	21-Aug-07	0.115	21-Aug-07	0.110	21-Aug-07	0.131
4-Sep-07	0.065	4-Sep-07	0.048	4-Sep-07	0.050	4-Sep-07	0.061
12-Sep-07	0.067	12-Sep-07	0.054	12-Sep-07	0.053	1-Aug-08	0.063
1-Aug-08	0.052	1-Aug-08	0.077	1-Aug-08	0.058	3-Jun-09	0.050
22-May-07	0.047	3-Jun-09	0.070	3-Jun-09	0.050	3-Jun-09	0.210
22-May-07	0.056	30-Jun-09	0.090	3-Jun-09	0.060	30-Jun-09	0.070
19-Jun-07	0.052	29-Jul-09	0.110	30-Jun-09	0.060	30-Jun-09	0.340
2-Jul-07	0.089	20-Aug-09	0.070	30-Jun-09	0.110	29-Jul-09	0.090
31-Jul-07	0.070	17-Sep-09	0.070	29-Jul-09	0.090	29-Jul-09	0.110
21-Aug-07	0.037	8-Oct-09	0.060	29-Jul-09	0.130	20-Aug-09	0.080
4-Sep-07	0.083			20-Aug-09	0.080	20-Aug-09	0.140
12-Sep-07	0.047			20-Aug-09	0.130	17-Sep-09	0.070
1-Aug-08	0.047			17-Sep-09	0.060	17-Sep-09	0.060
3-Jun-09	0.080			17-Sep-09	0.060	8-Oct-09	0.100
30-Jun-09	0.100			8-Oct-09	0.090	8-Oct-09	0.110
29-Jul-09	0.120			8-Oct-09	0.100		
20-Aug-09	0.120						
17-Sep-09	0.060						
8-Oct-09	0.060						
Mean	0.071	Mean	0.071	Surface Mean	0.065	Surface Mean	0.073

[1]Shaded cells indicate sample was collected ~ 1m above the bottom.
[2]Upper Ten Mile River characterized from data collected at TMDL stations TM2 and TM3.

Algal blooms occur frequently in the lower three impoundments. Mean chlorophyll a concentrations in Central Pond, Turner Reservoir, and Omega Pond in 2009 were 15.0 ug/l, 23.0 ug/l, and 16.0 ug/l, respectively with maximum values of 35.0 ug/l, 41.0 ug/l, and 36.0 ug/l, respectively. Several long-time residents of the Central Pond-Turner Reservoir shoreline have stated that nearly every summer these waterbodies exhibit extensive algal blooms.

Cyanobacteria blooms also appear to be common in the Ten Mile River impoundments. Exposure to cyanobacteria and their toxins can pose risks to humans, pets, livestock and wildlife. Exposure may occur by ingestion, dermal contact, and aspiration or inhalation. Risks to people may occur when recreating in water in which a blue-green algae bloom is present, or from the use of drinking water that uses a surface water source in which a blue-green algae bloom is present.

Exposure to blue-green algae can cause rashes, skin and eye irritation, allergic reactions, gastrointestinal upset, and other effects. At high levels, exposure can result in serious illness or death. Depending on the particular cyanobacterium, and the amount to which one is exposed, blue-green algae have the potential to cause a variety of adverse health effects, including liver toxicity (e.g., Microcystis aeruginosa) and neurotoxicity (e.g., Anabaena circinalis). Microcystin toxins may also promote tumor growth.

Dated color photographs from the mid-1980's obtained from the RIDEM dam safety records show what are very likely cyanobacteria blooms in Central Pond and Turner Reservoir. Cyanobacteria blooms were documented in 2007 and again in 2009. The cyanobacteria bloom in 2007 was notable for its duration, intensity, and prevalence of wide-spread scums. Laboratory results from water samples collected in the Turner Reservoir in 2007 showed elevated levels of algal toxin, microcystin. These levels, exceeding 25,000 micrograms per liter, were significantly above guidelines set by the World Health Organization (WHO) for recreational contact (In 2007, DEM had no criteria for total cyanobacteria cell count or microcystin). At that time, comparison of sampling data was limited to WHO guidance. For recreational contact, the WHO recommends a series of guideline values associated with the probability of health effects at three levels.

Low probability of adverse health effects: 2-4µg per liter of microcystin. This guideline is based on protection against irritative and allergenic effects. Recreational contact with microcystin at or below this concentration is unlikely to pose a health risk to an average person. However, individual sensitivities to allergens vary greatly making it difficult to determine 'safe' concentrations.

Moderate probability of adverse health effects: 20 µg per liter of microcystin-LR. This guideline is based on protection against hepatotoxic effects due to accidental ingestion. It is based on the tolerable daily intake for an adult (60kg) accidentally ingesting 100mL of water while swimming. Risk increases for children (due to lower body weight and greater likelihood of accidental ingestion) and to individuals with compromised liver function.

High probability of adverse health effects: Scums can represent thousand-fold concentrations of microcystin. Accidental ingestion of small volumes could cause serious harm. Immediate action to avoid contact with visible scums is advised.

Joint health advisories were issued in 2007 by the Rhode Island and Massachusetts Departments of Health discouraging recreational contact with Central Pond, Turner Reservoir, the lower Ten Mile River, and Omega Pond. The bloom in 2009 was not as severe in terms of duration or intensity however a health advisory was again issued by both states.

3.3 Trophic State Classifications

The trophic condition of Central Pond and Turner Reservoir was initially assessed in 1972 as part of the National Eutrophication Survey conducted by the USEPA. The study determined that both waterbodies were highly eutrophic with phosphorus loadings 45 times that necessary to maintain eutrophic conditions (USEPA 1974). The USEPA study also involved the estimation of the annual total phosphorus loading to the Central Pond-Turner Reservoir complex via monthly water chemistry sampling and measurements of flow. The annual total phosphorus load to the reservoirs was estimated at 177,490 lbs. For comparison, the 2007-2009 estimated growing season total phosphorus load to Central Pond calculated for this TMDL (using the FLUX software, described in Section 7.0) is approximately 7,190 lbs.

Lakes are considered to undergo a process of "aging" which can be characterized by the trophic status as oligotrophic, mesotrophic, or eutrophic. Oligotrophic lakes are normally associated with deep lakes which have relatively high levels of dissolved oxygen throughout the year, bottom sediments typically contain small amounts of organic matter, chemical water quality is good, and aquatic populations are both productive and diverse. Mesotrophic lakes are characterized by intermediate levels of biological productivity and diversity, slightly reduced dissolved oxygen levels, and generally have adequate water quality to support designated uses. However, there is the recognition that these lakes are naturally or culturally moving towards a eutrophic state. Lakes which are classified as eutrophic typically exhibit high levels of organic matter, both suspended in the water column and in the upper portions of sediments. Biological productivity is high, often indicated by seasonal algae blooms and excessive plant growth. Dissolved oxygen concentrations are low, and may reach extreme levels during critical periods. In addition, water quality is often poor resulting in violations of various designated uses.

The Carlson Trophic State Index (TSI) (Carlson, 1977) was developed to estimate the algal production and determine the trophic state based upon chlorophyll pigments, secchi depth, and total phosphorus. The TSI is a logarithmic scale that ranges from approximately 0 to 100. The three index variables chlorophyll pigments (Chl), secchi depth (SD), and total phosphorus (TP) use regression equations to estimate the index value and algal production. Secchi depth refers to the depth at which a secchi disk can be seen and measures the clarity of the lake. These three index variables are interrelated and should produce the same index value for a given combination of variable values. The regression equations used to calculate the TSI are shown below.

$$\mathrm{TSI\ (SD)} = 60 - 14.41 \ln(\mathrm{SD})$$
$$\mathrm{TSI\ (Chl)} = 9.81 \ln(\mathrm{Chl}) + 30.6$$
$$\mathrm{TSI\ (TP)} = 14.42 \ln(\mathrm{TP}) + 4.15$$

Trophic state can be related to the trophic state index and water quality conditions as shown in Table 8. Recent trophic state calculations for Central Pond, Turner Reservoir, and Omega Pond were calculated using available data from RIDEM and the University of Rhode Island Watershed Watch Volunteers during various years. The results, summarized Table 9, clearly show that eutrophic conditions dominate in these impoundments.

Table 8. Trophic state, trophic state index and corresponding waterbody conditions[1].

TSI	Trophic State	Water Quality Condition(s)
<30	Oligotrophic	Clear water, high DO through the year in the entire hypolimnion
30-40	Oligo-Mesotrophic	Clear water, possible periods of limited hypolimnetic anoxia
40-50	Mesotrophic	Moderately clear water, increasing chance of hypolimnetic anoxia in summer
50-60	Meso-eutrophic (Meso-trophic to mildly eutrophic)	Decreased transparency, anoxic hyplimnion, macrophyte problems
60-70	Eutrophic	Blue-green algae dominance, scums possible, extensive macrophyte problems
70-80	Hypereutrophic	Heavy algal blooms possible throughout summer, dense macrophyte beds
>80	Hypereutrophic	Algal scums, summer fish kills, few macrophytes due to algal shading, rough fish dominance

[1]Based on Carlson's TSI Index (Carlson 1977), Vollenweider and Kerekes (1980), Thomann and Mueller (1987) and Lake Assessment Process and Methods of the Minnesota Pollution Control Agency.

Table 9. Trophic State Calculations for Ten Mile River Impoundments.

Central Pond			**Omega Pond**		
Year	**TSI**	**Trophic State**	**Year**	**TSI**	**Trophic State**
1972	TP (71)	Hypereutrophic	2007	TP (68)	Eutrophic
2007	TP (64)	Eutrophic	2009	TP (67)	Eutrophic
2009	TP (66)	Eutrophic		Chl (58)	Eutrophic
	Chl (57)	Meso-eutrophic			
Turner Reservoir[1]					
Year	**TSI**	**Trophic State**	**Year**	**TSI**	**Trophic State**
1972	TP (70)	Hypereutrophic	2007	Chl (63)	Eutrophic
2000	TP (74)	Hypereutrophic	2008	Chl (31)	Oligo-Mesotrophic
	Chl (54)	Meso-eutrophic	2009	TP (68)	Eutrophic
2001	TP (72)	Hypereutrophic		Chl (52)	Meso-eutrophic
	Chl (45)	Mesotrophic	2010	TP (67)	Eutrophic
2002	TP (74)	Hypereutrophic		Chl (53)	Meso-eutrophic
	Chl (55)	Meso-eutrophic			
2003	TP (72)	Hypereutrophic			
	Chl (61)	Eutrophic			

[1]Turner Reservoir exhibits elevated levels of dissolved color.

3.4 Dissolved oxygen monitoring in Central Pond and Turner Reservoir-2007

Continuous monitoring of dissolved oxygen, temperature, specific conductance, and chlorophyll a was conducted in Central Pond and the Turner Reservoir in the summer and fall of 2007. YSI 6600 meters were deployed at a single site in Central Pond and surface and depth stations at a single location in the Turner Reservoir (Figure 7). Sonde preparation, calibration (pre- and post-), deployment, and data QA/QC were conducted according to an EPA approved quality assurance plan:

http://www.dem.ri.gov/pubs/qapp/nbfsmn.pdf

The sonde in Central Pond was deployed in the lower portion of the reservoir in approximately 1.8 meters of water and 0.9 meters below the surface. The sonde in the Turner Reservoir was deployed in the lower and deepest portion of the reservoir in approximately 3.7 meters of water. The surface sonde was placed approximately 1.8 meters from the surface and the bottom sonde was placed approximately 1.8 meters off the bottom).

Dissolved oxygen (in percent saturation) and chlorophyll a data for all sondes are summarized in Figures 3.5-3.7. The station results are as follows using the freshwater warm water fish habitat criteria for dissolved oxygen:

Central Pond- no violations of dissolved oxygen criteria

Lower Turner Reservoir (surface water station)-
4 violations to the daily average (<60% saturation)
95 violations of the instantaneous values (<5 mg/L) using hourly data

Lower Turner Reservoir (bottom water column station)-
2 violations of the 7 day mean (<6 mg/L for a 7 day period)
8 violations of the daily average (<60% saturation)
217 violations of the instantaneous values (<5 mg/L) using hourly data

Both Central Pond and Turner Reservoir exhibited wide swings in dissolved oxygen as evidenced in Figures 8-10. Variation in dissolved oxygen concentration in lakes is complex, depending primarily on productivity, stability of the water column, pollutant inputs, and morphology. The dissolved oxygen concentration is typically not uniform in the vertical and horizontal directions and may have significant seasonal variations. In shallow lakes, photosynthesis during high light levels and low wind levels may result in dissolved oxygen concentrations in the range of 17-30 mg/L (170-300%). Warming of lakes during the spring and summer can produce gas supersaturation near the thermocline, and photosynthesis also increases the oxygen concentration above the thermocline.

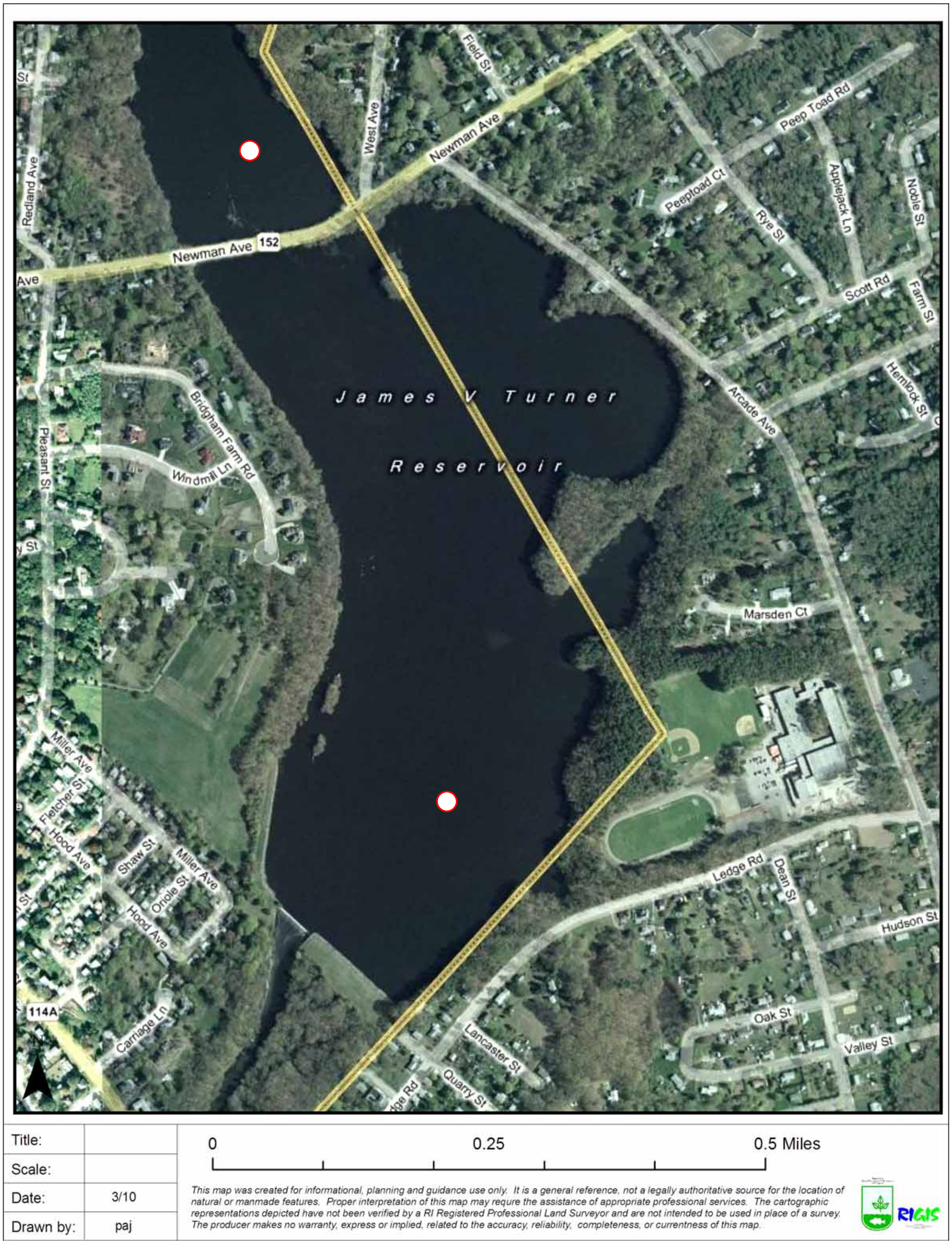

Figure 7. YSI 6600 Sonde Deployment Locations (2007).

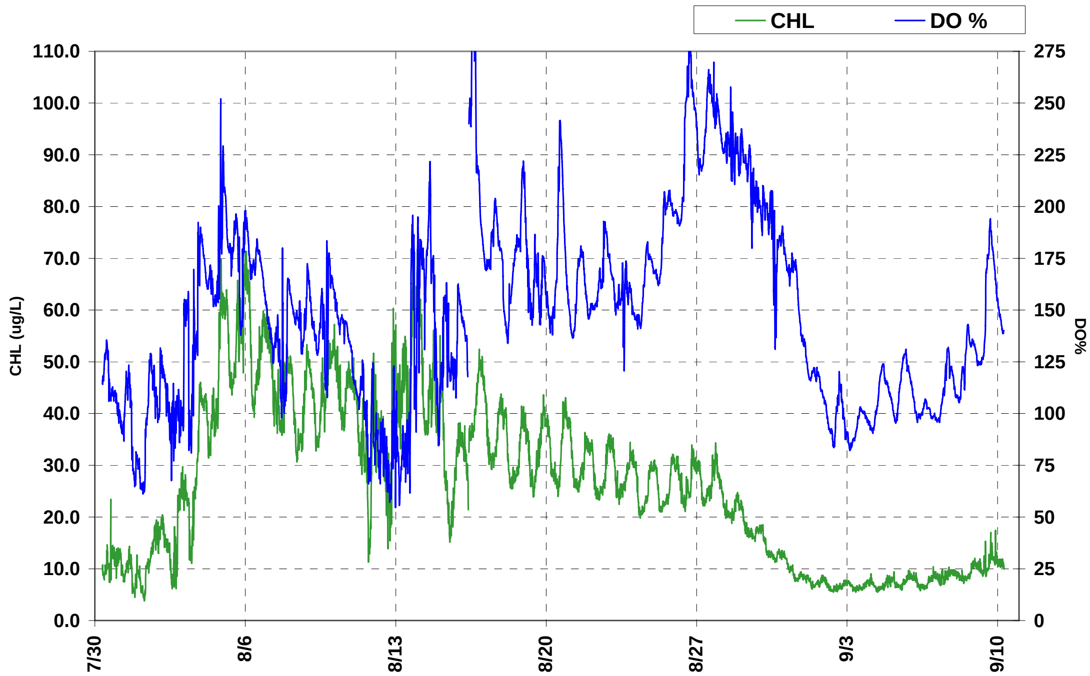

Figure 8. Chlorophyll a and Dissolved Oxygen in Central Pond.

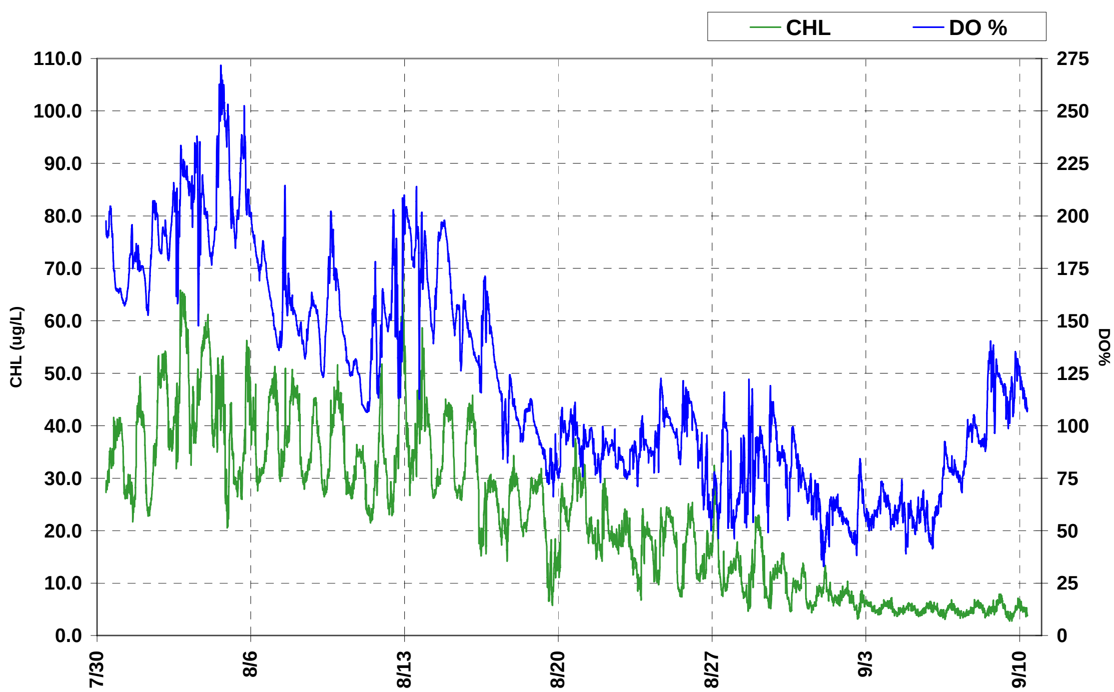

Figure 9. Chlorophyll a and Dissolved Oxygen in Turner Reservoir-surface.

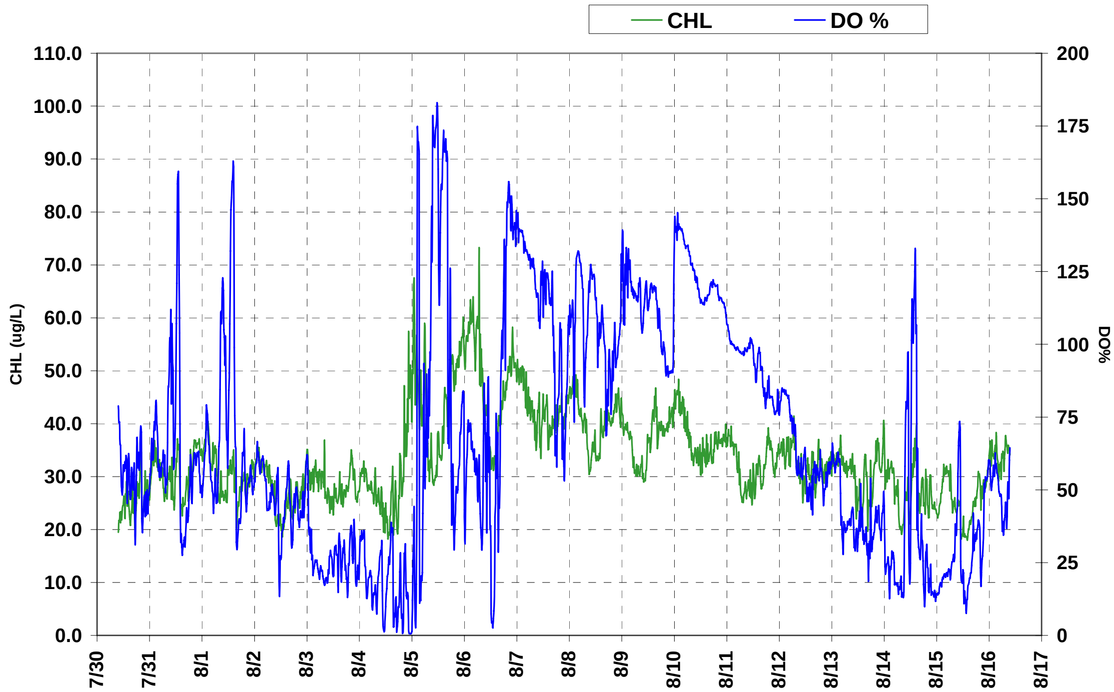

Figure 10. Chlorophyll a and Dissolved Oxygen in Turner Reservoir-bottom.

3.5 Dissolved oxygen monitoring in Omega Pond and Turner Reservoir-2009

Continuous measurements of dissolved oxygen, temperature, depth, specific conductance, and chlorophyll were collected in Turner Reservoir and Omega Pond from June through Sept 2009. These data were collected using YSI 6-series sondes, deployed at 'surface' and 'depth' locations in the water column in what was estimated to be the deepest part of each impoundment.

The approximate locations of both sondes are shown in Figure 11. At each location, a 'surface' sonde was deployed approximately 0.6-0.9 meters below the surface and a 'depth' sonde was deployed approximately 0.9 meters off the bottom. Total water column depths were approximately 3.5-4.0 meters in the Turner Reservoir and 3.5 meters in Omega Pond.

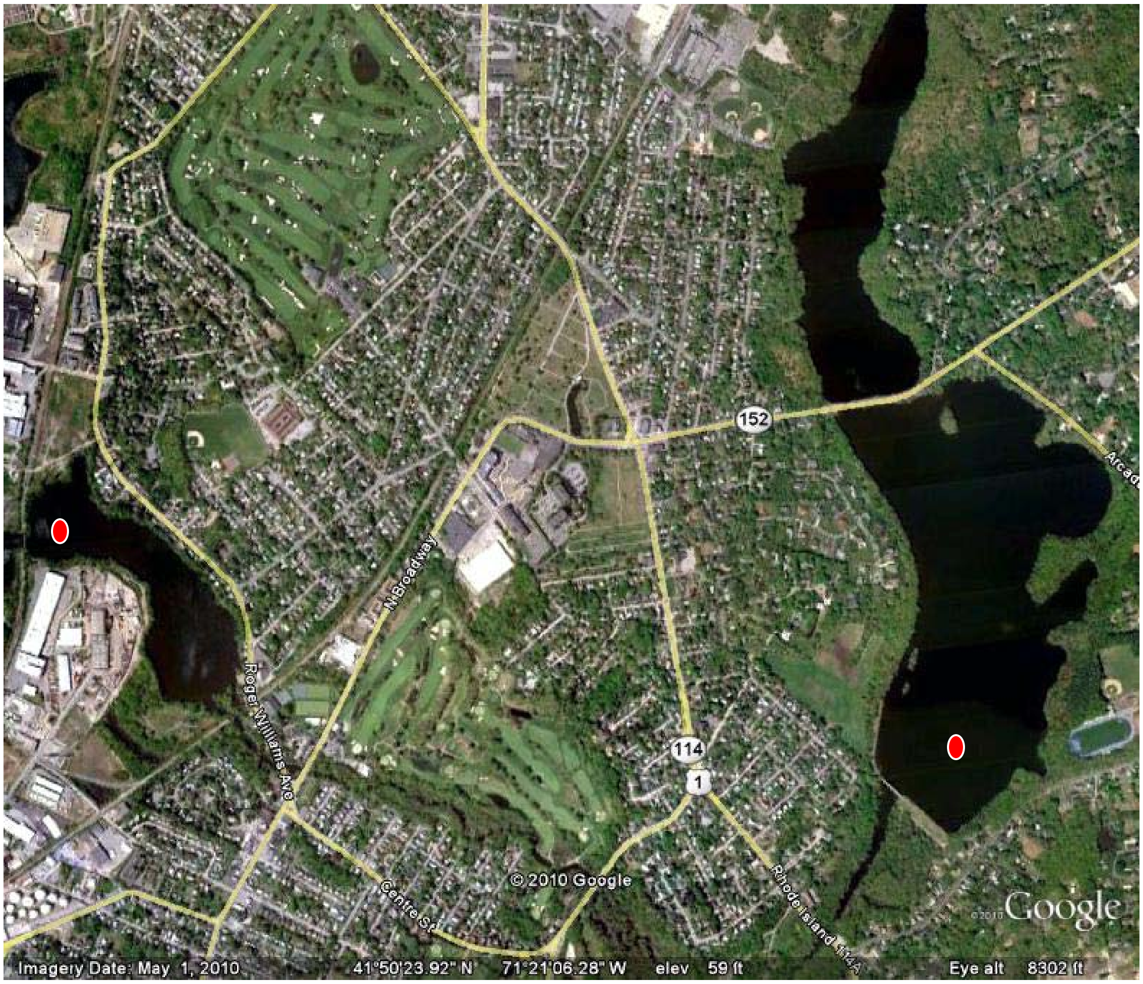

Figure 11. Approximate Location of YSI Sonde deployments.

The 2009 data have undergone QA-QC by DEM staff and have been flagged and/or edited where necessary. In general, the data reveal occasional hypoxic conditions at the surface and near anoxic conditions in the bottom waters. The hydrogen sulfide released from sulfur fixing bacteria in the sediments is believed to have affected the bottom sensors' accuracy in measuring dissolved oxygen conditions in the Turner Reservoir with measurements indicating more severe hypoxia/anoxia than possibly exist – as such these data have been flagged and edited from the dataset.

Vertical profiling data obtained with a YSI-85 handheld monitor frequently showed weak to moderate thermal stratification accompanied by near-anoxic conditions in the bottom 0.5 to 1.0 meters of both impoundments. Examination of precipitation and discharge data in conjunction with dissolved oxygen levels obtained from YSI 6-series sondes showed that moderate rainfall events and associated increases in flow flushed out the near-anoxic bottom water in both impoundments and mixed the water column such that dissolved oxygen levels became similar at surface and depth. After these types of events, the impoundments again showed re-establishment of thermal stratification and associated decreases in bottom water dissolved oxygen levels. The continuous dissolved oxygen data obtained in 2007 from the Turner Reservoir show similar near-anoxic conditions in the bottom waters of the Turner Reservoir, adding credibility to the 2009 'near-bottom' datasets.

Rhode Island's freshwater warm water fish habitat criteria for dissolved oxygen are given in Table 1. 8.D of the States' Water Quality Regulations: http://www.dem.ri.gov/pubs/regs/regs/water/h20q09.pdf). Both Turner Reservoir and Omega Pond are listed on the State's 2012 303(d) List of Impaired Waters for dissolved oxygen, based on the 2007 and 2009 datasets.

3.5 Internal Cycling of Phosphorus

Existing phosphorus data collected in both Omega Pond and Turner Reservoir strongly suggests the occurrence of phosphorus release from pond sediments. Several water column samples were taken at both Omega Pond and Turner Reservoir. Samples were taken at the deepest areas of the ponds, at 1 meter below the surface and 1 meter above the bottom. The ponds were sampled on six occasions, between June 3 and October 8, 2009 (Table 3.3). Samples were analyzed for total phosphorus. Both ponds have elevated phosphorus concentrations in bottom waters relative to surface concentrations. Specifically, for the entire sampling period, for Turner Reservoir, the mean surface total phosphorus concentration was 73 ug/l, while the mean bottom concentration was 97 ug/l. For Omega Pond, the difference between phosphorus concentrations at the surface and at depth is even more pronounced. For the same period, for Omega Pond, the mean surface concentration was 77 ug/l, while the mean depth concentration was 162 ug/l.

Dissolved oxygen and temperature data from Turner Reservoir and Omega Pond indicate that the ponds become intermittently stratified during the summer months. The difference between surface and bottom oxygen concentrations is more pronounced during periods of stratification. YSI 6600 sondes were installed in both Omega Pond and Turner Reservoir, at 1m below the surface and 1m above the bottom. The sondes collected continuous (15-min) measurements of temperature and dissolved oxygen, as well as other parameters. The probes were deployed on June 30 and removed on September 24, 2009. Both temperature and dissolved oxygen data indicated that there were 3-4 episodes of both stratification and anoxia in the bottom waters, in both ponds.

These periods of stratification were interrupted by storm events. The resulting high flows were sufficient to perturb the weakly stratified ponds, mixing the entire water column, and reoxygenating the bottom waters. There were 42 days of anoxia in the bottom waters of Turner Reservoir and 55 anoxic days in Omega Pond. Phosphorus samples were taken during two periods of stratification and anoxia, on June 30 and August 20, 2009. The mean surface phosphorus concentration in Turner Reservoir for these two days was 70 ug/l, while the mean bottom concentration was 120 ug/l. For the same period, for Omega Pond, the mean surface concentration was 75 ug/l, while the mean depth concentration was 240 ug/l.

3.6 Dissolved and Total Metals Summary

The Ten Mile River, Central Pond, Turner Reservoir, and Omega Pond have historically had aquatic life impairments for several metals including copper, cadmium, and lead. The 2008 303(d) listings were based on historic data collected by the Narragansett Bay Commission in 2000 and 2001. Given the historic industrial activity along the river and the documented groundwater and sediment contamination, the existence of two wastewater treatment facilities and several hazardous waste site cleanups (with metals present in groundwater), as well as the highly urbanized nature of the watershed, it was felt that a full suite of metals analysis should be included in the 2007 and 2008 monitoring program. All surface water samples sent to the EPA Region 1 Laboratory in Chelmsford, MA were analyzed for both the dissolved and total fractions of a suite of metals.

There were no acute criteria violations of any of the metals sampled during the 2007-2008 monitoring, however violations of the chronic criteria for several metals (Al, Cd, Pb, Fe) were numerous and widespread throughout the river and its impoundments; Violations of the chronic criteria for dissolved lead and total aluminum occurred under both baseflow conditions and wet weather-stormflow conditions. Violations of dissolved cadmium and total iron occurred solely under wet weather-stormflow conditions. The higher frequency of violations for all metals during the stormflow condition occurred because in nearly all cases, both the metal concentrations were higher and the hardness of the samples was lower. In general, both the median and maximum values of cadmium, lead, aluminum, and iron were highest at the MA/RI state line.

All dissolved and total metals data are presented in tabular form in Appendix B and C of the final data report:
http://www.dem.ri.gov/programs/benviron/water/quality/rest/pdfs/tendata.pdf

Figures 12 through 19 show plots of cadmium, lead, aluminum, and iron. All plots are segregated by weather and flow condition and present the median dissolved and particulate fraction, as well as the total metal calculated from each dataset. The median value was chosen to be the best indicator of each datasets ‘typical value’ since the sample size is small (n=5 wet weather, n=4 dry weather). For statistical analysis, values of non-detect (ND) were replaced with half of the detection limit. Scaling is maintained for both plots of each individual metal.

A general conclusion to be drawn from analysis of the metals data is that the wet-weather stormflow condition produces notably higher levels of metals than the dry weather baseflow condition. Distinct differences between dissolved and particulate metals concentrations also exist between the stormflow and baseflow condition. Table 10 displays median statistics calculated by pooling all station data and then segregating by weather/flow condition.

Cadmium
Dissolved and total cadmium data, segregated by weather and flow condition, are presented graphically in Figures 12 and 13. Both figures show scatter plots of dissolved, particulate, and total cadmium data in the downstream direction from the Massachusetts-Rhode Island state line to the outflow of Omega Pond in East Providence. Plotted points are calculated median values from the wet weather stormflow dataset (n=5) and the dry weather and baseflow dataset (n=4). The reported laboratory detection limit for dissolved Cd ranged from 0.2 to 0.1 ug/l.

The highest median dissolved and total cadmium concentrations calculated from the dry weather and low-baseflow condition dataset occur in the upper portions of the Ten Mile River and the outlet of Slater Park Pond. Median concentrations of cadmium in the entire system, in general, are quite low. Median dissolved cadmium concentrations remain consistent (~ 0.12 ug/l) in the upper portion of the river and Slater Park Pond and then drop to what is essentially non-detect (ND) for the remainder of the system. Median total cadmium concentrations show an increase between the state line to the outlet of Slater Park Pond, from 0.25 ug/l to 0.35 ug/l and then drop again to 0.22 ug/l in the mainstem of the river just upstream of the inlet of Central Pond. This is due to the increased fraction of particulate cadmium, rather than dissolved. Median total cadmium concentrations then remain fairly consistent through the remainder of the upper Ten Mile River and Slater Park Pond, approaching or just above the ND level.

The highest median cadmium concentrations calculated form the wet weather stormflow datasets occur at the MA-RI state line station. Median particulate cadmium concentrations in the upper Ten Mile and Slater Park Pond are notably higher under the wet weather condition, while median dissolved cadmium concentrations are similar in range to those found in the baseflow condition. Median dissolved cadmium concentrations drop to ND levels at the outflow of Central Pond. Median total cadmium concentrations drop from a peak of 0.35 ug/l at the state line to approximately 0.12 ug/l at the outflow of Omega Pond.

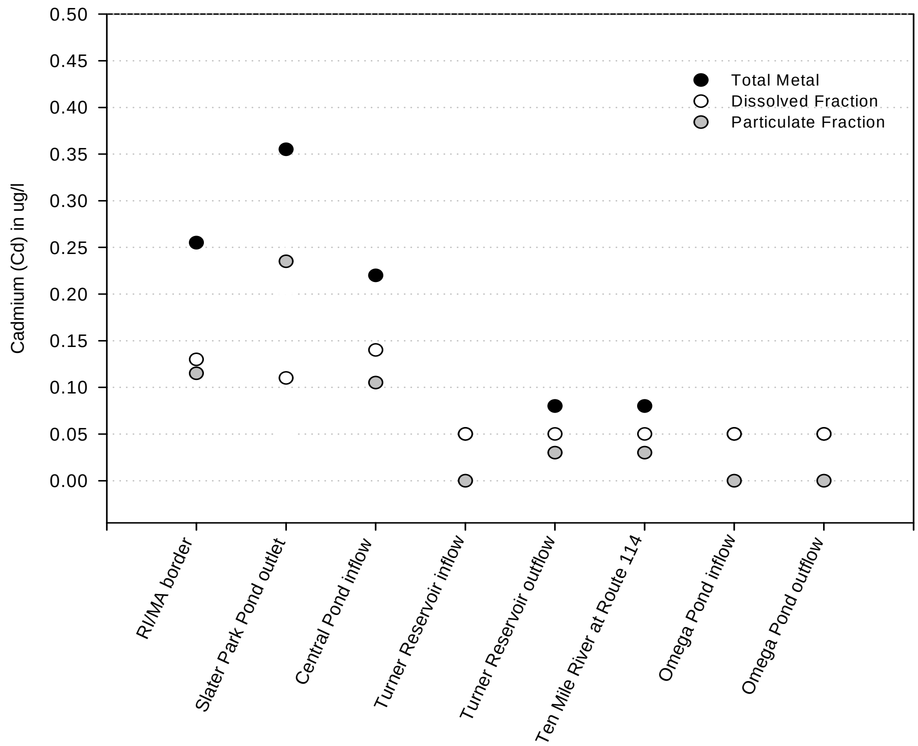

Figure 12. Median Cadmium Levels in the Ten Mile River: Baseflow.

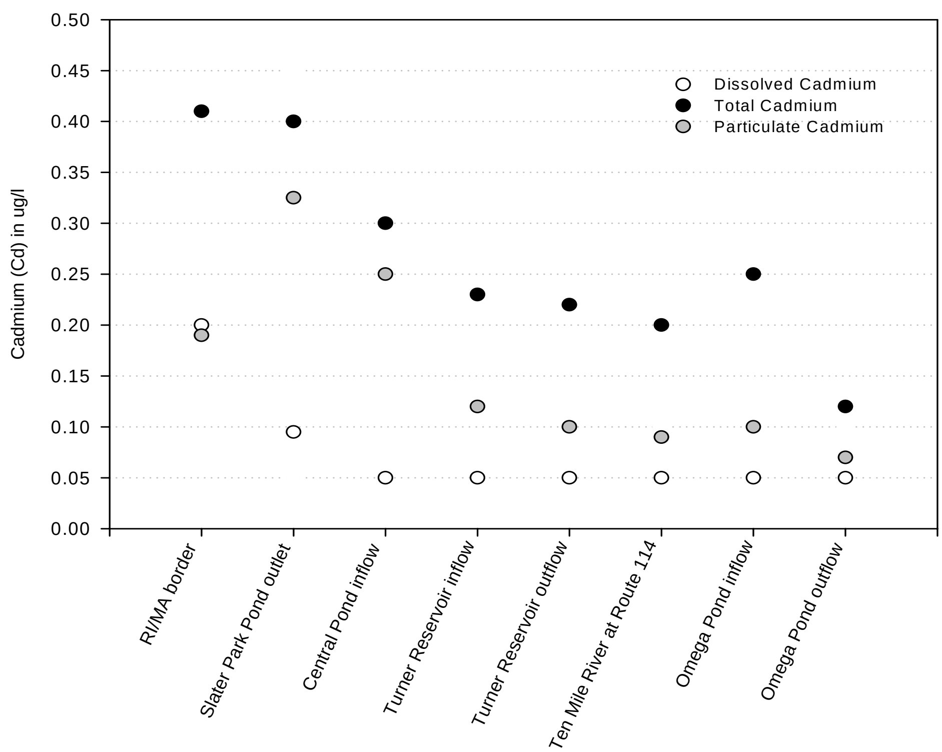

Figure 13. Median Cadmium Levels in the Ten Mile River: Stormflow.

In two of the five wet weather surveys, dissolved cadmium levels increased at the outflow of Central Pond. Dissolved cadmium levels at the Central Pond outflow during these two events were approximately two and six times higher than at the inflow (0.50 ug/l to 0.100 ug/l and 0.050 ug/l to 0.32 ug/l, respectively). The cause for these increases is thought to be related to stormwater runoff.

Lead

Lead data, segregated by weather and flow condition, are presented graphically in Figures 14 and 15. Both figures show scatter plots of dissolved, particulate, and total lead data in the downstream direction from the Massachusetts-Rhode Island state line to the outflow of Omega Pond in East Providence. Plotted points are calculated median values from the wet weather stormflow dataset (n=5) and the dry weather and low-baseflow dataset (n=4). For eight of the nine surveys, the laboratory detection limit for dissolved lead was reported as 0.2 ug/l. One of the nine surveys the reported laboratory detection limit increased to 0.5 ug/l

The majority of total lead in the Ten Mile River and impoundments under the dry weather- low and baseflow condition exists in the particulate form. Particulate lead accounted for approximately 53% to 90% of the total lead in the Ten Mile River and impoundments. Median values of dissolved lead were generally very low, less than 1.0 ug/l throughout the entire system with the highest median values (1.0 ug/l) occurring at the state line. Median dissolved lead levels showed a gradual decline in the downstream direction from the state line to the outlet of Omega Pond. Median values of total lead were also highest at the state line (4.0 ug/l) dropping to approximately 1.2 ug/l at the outlet of Omega Pond.

Similar to the dry weather low-baseflow condition, the highest wet weather-stormflow median values of particulate and dissolved lead occurs at the state line with a progressive decrease in concentration in the downstream direction. Median levels of particulate lead are similar to those in dry weather; the dissolved fraction is greater, and leads to larger levels of total lead. Median total lead concentrations, which drop from 6.0 ug/l at the state line to 1.3 ug/l at the Turner Reservoir outflow. Median total lead concentrations then show a slight increase from the outflow of the Turner Reservoir (1.3 ug/l) to the outflow of Omega Pond (2.0 ug/l).

Particulate lead accounts for roughly 50% to 70% of the total lead measured in the Ten Mile River from the state line to the inflow of Central Pond. Downstream of the Central Pond-Turner Reservoir complex more of the total lead is in particulate form (70%-85% range).

Median dissolved lead concentrations remain fairly low throughout the system with the highest median value (1.5 ug/l) at the state line. Concentrations then show a gradual decline in the downstream direction approaching non-detect values at the outlet of the Turner Reservoir.

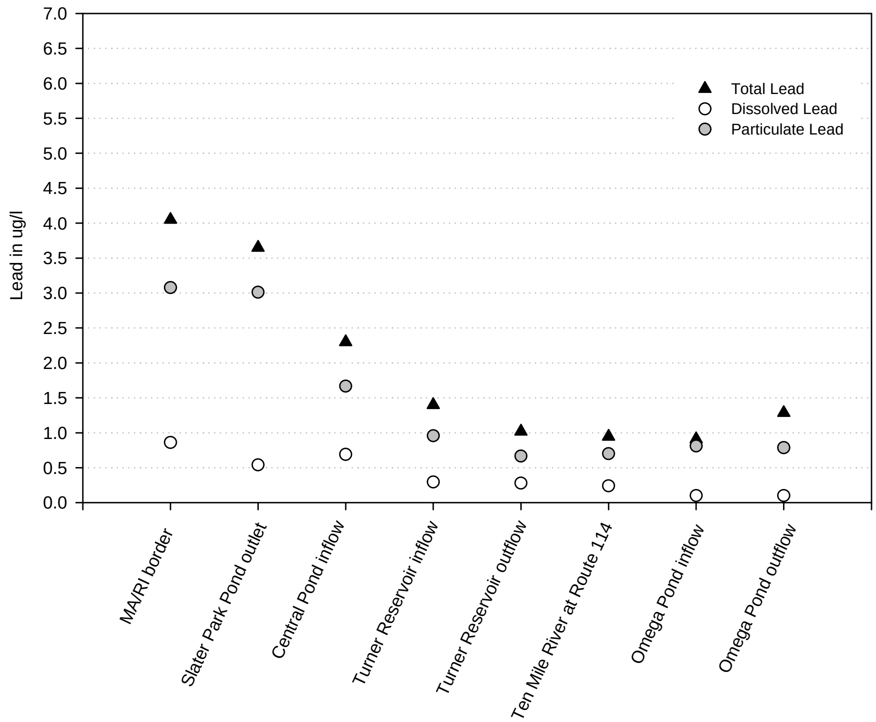

Figure 14. Median Lead Levels in the Ten Mile River: Baseflow.

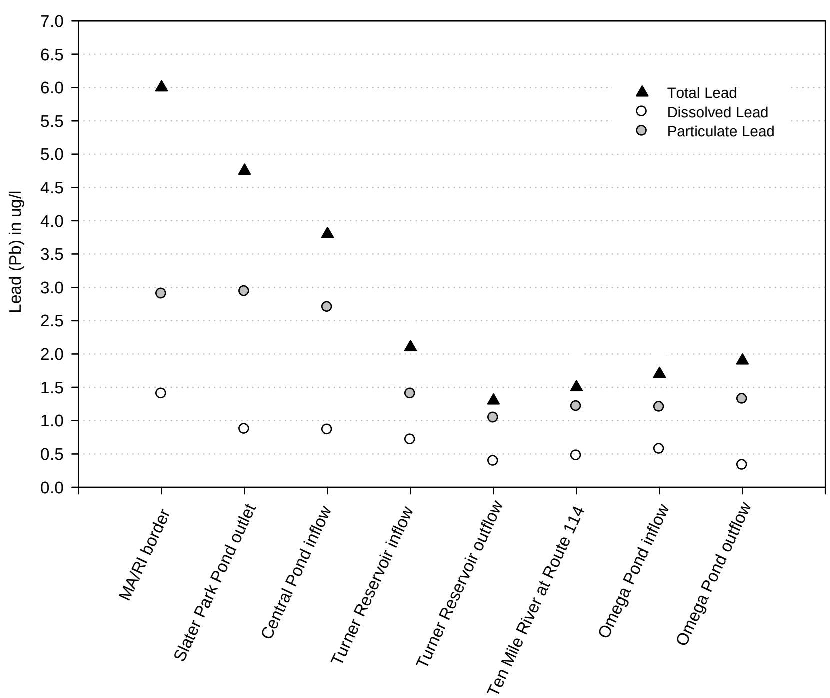

Figure 15. Median Lead Levels in the Ten Mile River: Stormflow.

Aluminum
Aluminum data, segregated by weather and flow condition, are presented graphically in Figures 16 and 17. Both figures show scatter plots of dissolved, particulate, and total aluminum data in the downstream direction from the Massachusetts-Rhode Island state line to the outflow of Omega Pond in East Providence. Plotted points are calculated median values from the wet weather stormflow dataset (n=5) and the dry weather and baseflow dataset (n=4). The reported laboratory detection limit for total Aluminum was 5.0 ug/l

Particulate aluminum makes up a large majority of the total aluminum within the entire Ten Mile River and impoundments. During dry weather-baseflow, median total and particulate aluminum concentrations are highest at the state line (85 ug/l and 75 ug/l, respectively) and the outlet of Slater Park Pond (95 ug/l and 90 ug/l, respectively). A slight increase in both the particulate and total concentration is noted between these stations, as is the significant drop between the outlet of Slater Park Pond and the inlet of Central Pond. Median total and particulate concentrations remain static (~42.0 ug/l and 35 ug/l) for the remainder of the Ten Mile and impoundments. Dissolved aluminum concentrations are highest at the state line (median-10.0 ug/l) and drop to approximately 5.0 ug/l, remaining at that level throughout the remainder of the system.

During wet weather-stormflow conditions, a majority of the aluminum in the Ten Mile River and impoundments is in the particulate form. Median dissolved aluminum concentrations are highest at the state line (21.0 ug/l) and are generally less than 15.0 ug/l throughout the remainder of the system. Median total aluminum concentrations were highest in the Ten Mile River from the state line extending to the inflow of Central Pond. Median total aluminum concentrations then decrease from approximately 120 ug/l at the Central Pond inflow to 60 ug/l at the Turner Reservoir outflow. From the outflow, median total aluminum values show a notable increase to ~88.0 ug/l at the Omega Pond outflow.

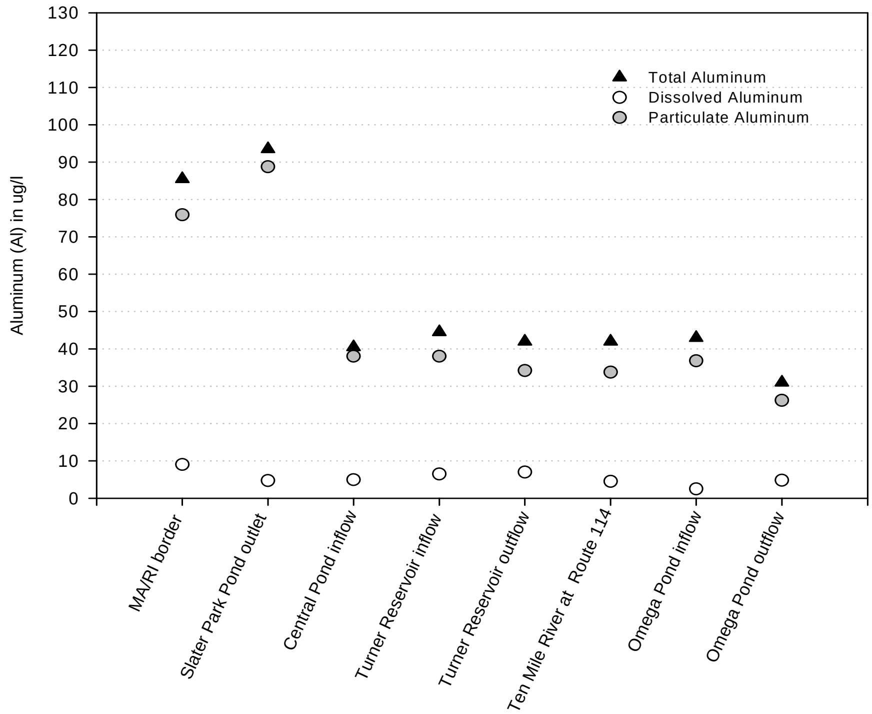

Figure 16. Median Aluminum Levels in the Ten Mile River: Baseflow.

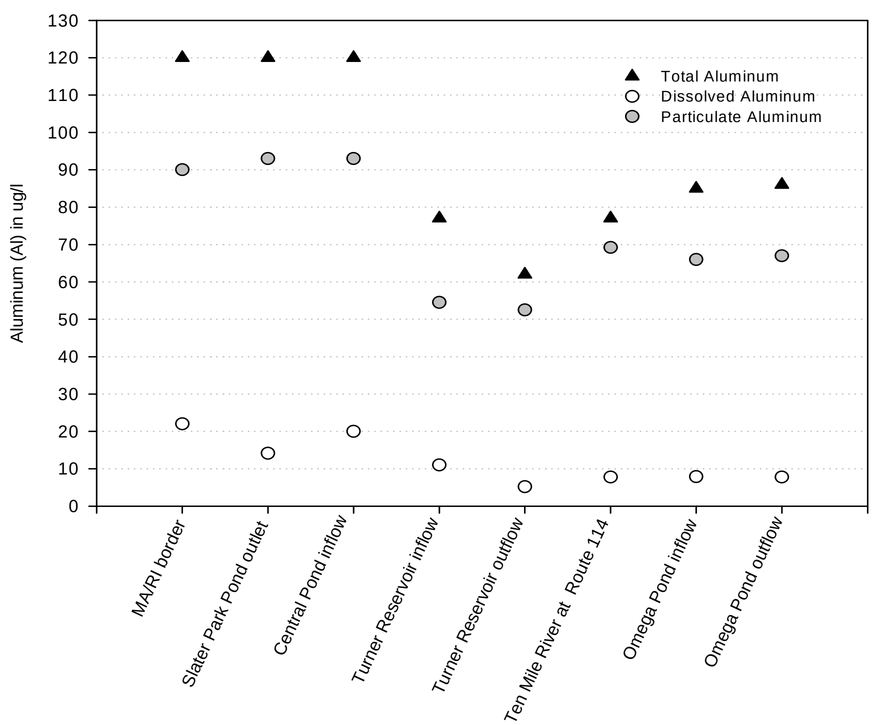

Figure 17. Median Aluminum Levels in the Ten Mile River: Stormflow.

Iron

Iron data, segregated by weather and flow condition, are presented graphically in Figures 18 and 19. Both figures show scatter plots of dissolved, particulate, and total iron data in the downstream direction from the Massachusetts-Rhode Island state line to the outflow of Omega Pond in East Providence. Plotted points are calculated median values from the wet weather stormflow dataset (n=5) and the dry weather and low-baseflow dataset (n=4). The reported laboratory detection limit for total Iron was 50.0 ug/l.

The highest dry weather-baseflow median concentrations of total and dissolved iron are at the state line (710 ug/l and 400 ug/l, respectively). A gradual decline in both total and dissolved median iron concentrations are noted from the state line to the inflow of the Turner Reservoir. Median levels of total and dissolved iron stabilize throughout the reservoir and the remainder of the Ten Mile (400 ug/l and 100 ug/l, respectively). Under dry weather baseflow conditions a larger proportion of total iron is in the particulate, rather than dissolved fraction.

The highest total and dissolved median iron concentrations under the wet weather stormflow condition are at the state line (1000 ug/l and 200 ug/l). A steep decline in total iron is noted from the state line to the Turner Reservoir inflow. From the inflow of the reservoir to the outflow of Omega Pond, median concentrations of total, particulate, and dissolved iron all remain static (500 ug/l, 300 ug/l, and 150 ug/l, respectively).

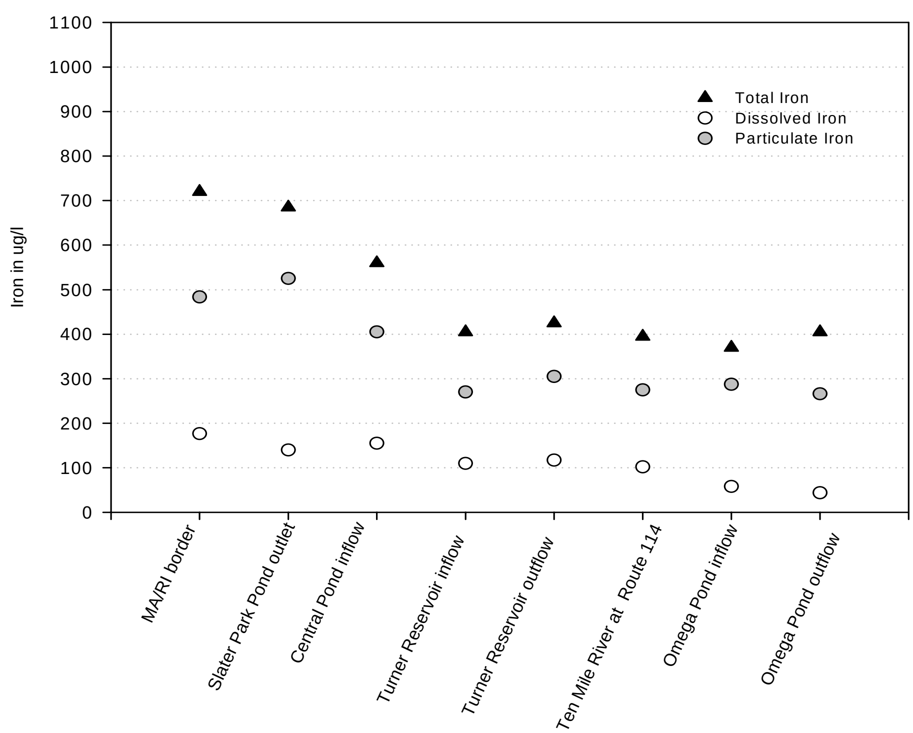

Figure 18. Median Iron Levels in the Ten Mile River: Baseflow.

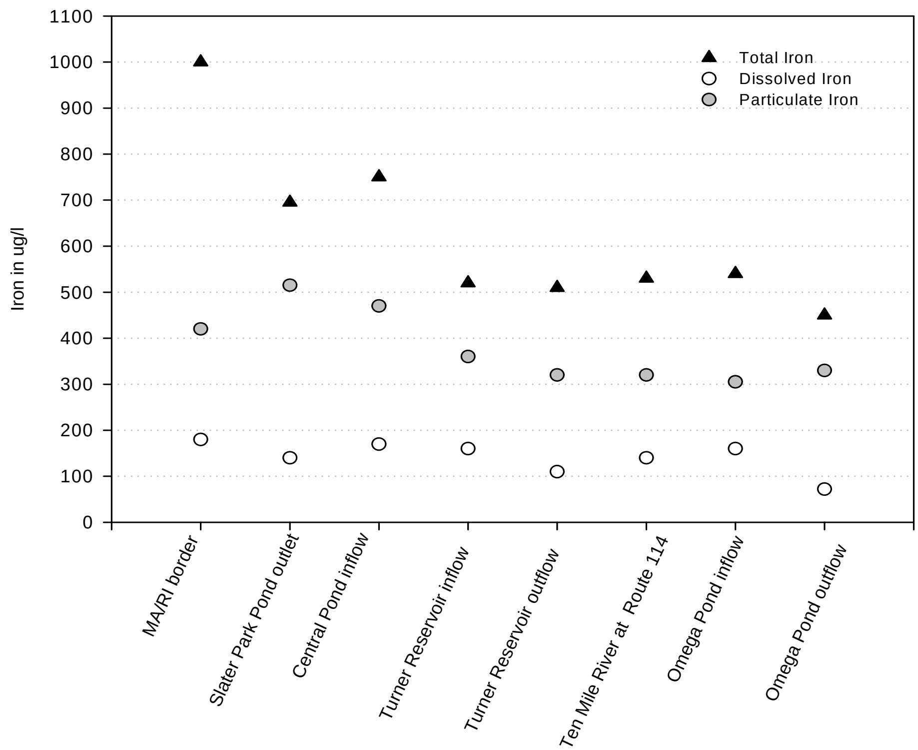

Figure 19. Median Iron Levels in the Ten Mile River: Stormflow.

With respect to the states' aquatic life criteria, there were no acute criteria violations of any of the metals sampled during the 2007-2008 monitoring. Violations of the chronic criteria for various metals were numerous and widespread throughout the six waterbody segments; Figure 20 provides a total count of chronic metals violations (Fe, Pb, Cd, Al), by flow and hydrologic condition, in all waterbody segments in the Ten Mile River.

Violations of the chronic criteria for dissolved lead and total aluminum occurred under both dry weather-steady state conditions and wet weather-stormflow conditions. Violations of dissolved cadmium and total iron occurred solely under wet weather-stormflow conditions. The higher frequency of violations for all metals during the stormflow condition occurred because in nearly all cases, both the metal concentrations were higher and the hardness of the samples was lower. In general, and as noted earlier, both the median and maximum values of cadmium, lead, aluminum, and iron were highest at the MA/RI state line (Table 10).

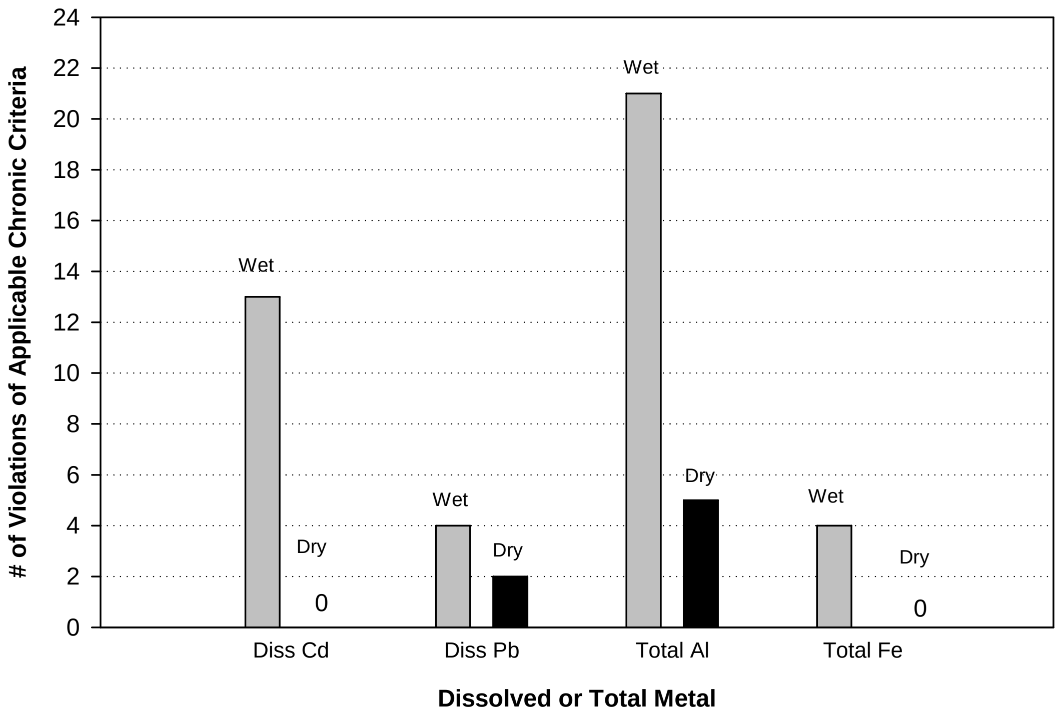

Figure 20. Total Count of Metals Criteria Violations in all Waterbody Segments in the Ten Mile River.

Table 10. Metals Summary in the Ten Mile River and Impoundments (2007-2008).

	Metal Concentration in ug/l (ppb)							
	Dissolved Cadmium		**Dissolved Lead**		**Total Aluminum**		**Total Iron**	
Location	Median	Maximum	Median	Maximum	Median	Maximum	Median	Maximum
MA/RI State Line	0.17	0.54	1.30	3.10	95	180	790	1100
Slater Park Pond	0.12	0.27	0.79	3.00	107	170	685	1200
Central Pond inlet	0.11	0.22	0.80	2.70	98	170	620	1100
Central Pond outlet	0.05	0.32	0.49	1.30	57	97	420	730
Turner Reservoir outlet	0.05	0.30	0.39	0.96	48	99	470	620
Ten Mile River	0.05	0.30	0.38	1.00	64	100	430	640
Omega Pond inlet	0.05	0.33	0.28	1.10	62	97	390	630
Omega Pond outlet	0.05	0.29	0.28	0.90	51	130	450	740

4.0 Pollutant Sources to the Ten Mile River

There are numerous sources of pathogens, nutrients, and metals that exist in the Ten Mile River watershed (Table 11). Given the highly urbanized nature of the watershed, as well as historic untreated discharges from over 30 metal fabrication/electroplating and jewelry industries and other legacy pollutants, it is believed that anthropogenic sources contribute a majority of the pollutants of concern. Many of the source categories presented in Table 11 and described in more detail in sections 4.1-4.12 are associated with one or more pollutants.

Table 11. General Source Categories and associated Pollutant(s) of Concern.

Source / Section	Pollutant of Concern		
	Pathogens	Phosphorus	Metals
Stormwater / 4.1	*	*	*
Wastewater Treatment Facilities / 4.2	*	*	*
Other Sanitary Sources / 4.3	*	*	
Other NPDES/RIPDES Permitted Discharges / 4.4		*	*
Waterfowl, Wildlife and Domestic Pets / 4.5	*	*	
Golf Courses / 4.6	*	*	*
Uncontrolled Disposal of Waste/Illegal Dumping / 4.7	*		*
Hazardous Waste Cleanup Sites / 4.8			*
Groundwater and Sediment Contamination / 4.9			*
Atmospheric Deposition / 4.10		*	*
Background-Natural Sources / 4.11		*	*
Internal Sources- Sediments / 4.12		*	*

Probably the most significant sources of pollutants to the Ten Mile River includes direct stormwater runoff from municipal separate storm systems (MS4s) in North Attleborough and Attleboro, Massachusetts and Pawtucket and East Providence, Rhode Island, and to a lesser extent, the Rhode Island Department of Transportation (RIDOT), and Massachusetts wastewater facilities located in North Attleborough and Attleboro. These sources are also the most controllable in the watershed.

Other potential sources to the Ten Mile River in both RI and MA include other sanitary sources, NPDES/RIPDES permitted discharges, uncontrolled disposal of waste and illegal dumping sites, atmospheric sources, contaminated groundwater and sediments, and non-point sources such as waterfowl, wildlife, and domestic animals.

4.1 Stormwater

Stormwater is a significant source of pollutants in the highly urbanized Ten Mile River watershed, where impervious land surfaces make up approximately 22% of the combined RI and MA portions of the watershed. The western portions of the watershed, encompassing both the cities of Pawtucket and East Providence are the most urbanized and contain large amounts of commercial, industrial, and high density residential development. Stormwater from privately owned property, such as parking lots, and commercial and industrial areas may be discharged into these municipal or state owned drainage systems or may be conveyed directly to the Ten Mile River via overland flow, stormwater pipes, or other conveyances.

A majority of the watershed is regulated under the Phase II Municipal Separate Stormwater Sewer System (MS4) Program. In Rhode Island, Pawtucket (RIR040024), East Providence (RIR040030), and the Rhode Island Department of Transportation (RIPDES permit RIR040036) have applied for coverage under the Rhode Island Phase II Stormwater General Permit (issued in 2003) and have prepared the required Phase II Stormwater Management Plans (SWMPP) In Massachusetts, the communities covered under the MS4 General Permit include Plainville, North Attleborough, Attleboro, and Seekonk, as well as the MASS Department of Transportation. The storm drain network in the watershed is extensive, and although outfall locations have largely been mapped only limited mapping of storm drain networks is available.

Fifty six identified outfalls drain high density residential, commercial, industrial, and transportation land uses, within the Rhode Island portion of the watershed (Figure 21). Of note are the large amounts of commercial/industrial land uses that drain to Central Pond, namely the Narragansett Industrial Park. It is unknown how many outfalls drain to the Massachusetts portion of the Ten Mile River watershed, however similar land uses dominate portions of Attleboro's urban core, as well as the upper portion of the river near the RI/MA state line. The Cities of East Providence, Pawtucket, and RIDOT confirm the existence of the following outfalls:

East Providence:
16 outfalls discharging to Central Pond ranging in size from 12-36"
7 outfalls ranging in size from15-24"
7 outfalls discharging to Omega Pond ranging in size from 12-36"
15 outfalls discharging to the Ten Mile River ranging in size from 12-42"

Pawtucket:
5 outfalls discharging to the Ten Mile River, including Slater Park Pond ,ranging in size from 12-36"

RIDOT:
Six outfalls, owned by RIDOT, discharging to the Ten Mile River and/or impoundments. These outfalls range in size from 8-36".

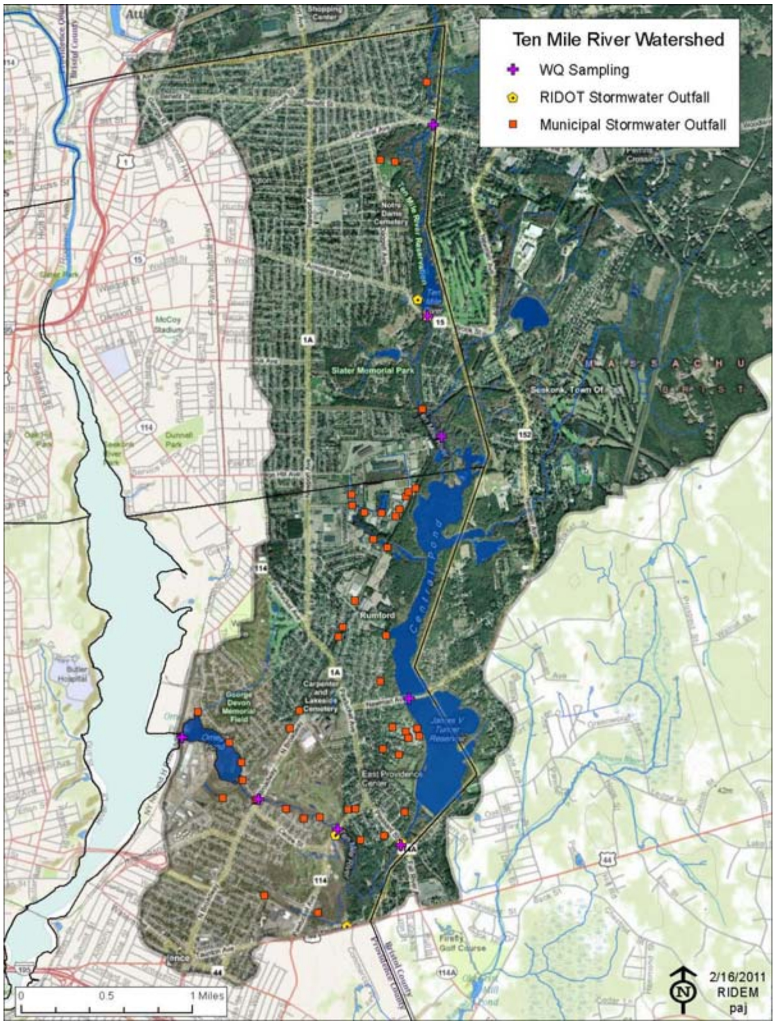

Figure 21. Schematic of municipal and RIDOT outfalls to Ten Mile River.

Pathogens

For the majority of waterbody segments, the highest levels of pathogens were associated with wet weather-stormflow events. This was not unexpected given the large amounts of impervious surface cover in the Ten Mile River watershed. As shown in Table 3.2, the wet weather 90th percentile values for fecal coliform bacteria exceeded the respective water quality criteria most often for waterbodies on the 303(d) list for pathogens.

Bacteria from a wide range of sources including pet waste and urban wildlife and waterfowl are washed untreated into runoff and discharged into surface waters through stormwater systems or by direct overland flow. Pet waste left on trails, sidewalks, streets, and grassy areas is often flushed into the nearest waterway or catch basin when it rains. Like human waste, animal waste can contain harmful bacteria and viruses that make water unfit for drinking, swimming, or irrigation. According to recent research, non-human waste represents a significant source of bacterial contamination in urban watersheds. Genetic studies by Alderiso et al. (1996) and Trial et al. (1993) both concluded that 95 percent of the fecal coliform found in urban stormwater was of non-human origin.

DNA fingerprinting techniques have clearly shown pet waste to be a major contributor of bacteria in urban and suburban watersheds. Dogs in particular are likely a major source of fecal coliform bacteria, given their population density and daily defecation rate. A study by Lim and Oliveri (1982) found that dog feces were the single greatest source contributing fecal coliform and fecal strep bacteria in highly urban Baltimore catchments.

Trial et al. (1993) reported that cats and dogs were the primary source of fecal coliform in urban sub watersheds in the Puget Sound Region. Bacterial source tracking studies in a watershed in the Seattle, Washington area found that nearly 20% of the bacteria isolates that could be matched with host animals were matched with dogs (Samadpour, M. and N. Checkowitz, 1998). A study conducted by the Washington State Department of Ecology determined that in an area with a population of approximately 100,000 individuals, dogs were found to generate approximately two and a half tons of feces per day, equating to nearly two million pounds per year.

Given that residential areas drain to the Ten Mile River and impoundments, pet waste is expected to be a significant source of bacteria carried in stormwater. MADEP estimates that there is approximately one dog per 10 people producing an estimated one-half pound of feces per dog per day (MADEP et. al., 2009). Using the 2000 census data, a population estimate of 35,000 was calculated for the RI portions of the watershed (East Providence and Pawtucket). This translates to an estimated 3,500 dogs in the watershed producing 1,750 pounds (over ¾ of a ton) of feces per day.

Phosphorus

Stormwater runoff can be a major source of total phosphorus in urban environments. Lee and Jones-Lee (1995) stated that urban stormwater runoff contains about 100 times the total concentrations of phosphorus that are typically derived from stormwater runoff from forested areas. In another study, mean total phosphorus concentrations in stormwater runoff in two urban southern Wisconsin watersheds were measured between 140 and 2370 ug/l (Waschbusch et al., 1999; Browman et al., 1979). Waschbusch et al. (1999) determined that lawns and streets were the largest sources of total phosphorus in the watersheds, with lawns contributing more than streets. The street fraction of the phosphorus load was associated with sediment, and to a lesser extent leaf litter.

Fertilizers are transported to nearby waterbodies via stormwater runoff. Johnson (2005) found that the predominant pathways through which pesticides, applied in urban areas, reach a waterbody were stormwater runoff, dry weather discharges from storm drains, and possibly direct discharges (i.e. dumping). In addition, it was believed that storm drains conveyed essentially all pesticides found in urban creeks. While difficult to quantify, pesticides are commonly used in residential, commercial, and industrial settings.

Pesticides and fertilizers can contain significant amounts of phosphorus. Much of the phosphorus lost from fertilized lawns and fields is adsorbed to soil particles. Erosion can entrain these particles, and they can be transported, via the stormwater system or by direct flow, into receiving waters. Accidental application of fertilizers and pesticides onto impermeable surfaces such as the edges of driveways and roadways can lead to direct transport into storm drain systems.

In one study of runoff from a residential area abutting Lauderdale Lakes, Wisconsin (Garn et al., 1996), researchers found that surface-water inflow from the small near shore drainage area accounted for only 4 percent of the water inflow to the lake, but represented 51 percent of the total annual phosphorus input from all sources. In another study (Garn, 2002) conducted in the same area, researchers sampled runoff from the lawns of lakeside homes. They found that the median concentration of dissolved phosphorus from regular-fertilizer sites (0.77 mg/L) was significantly greater than that from nonphosphorus-fertilizer sites (0.33 mg/L) and unfertilized lawn sites (0.38 mg/L). Dissolved phosphorus in runoff is important because it is readily available for plant growth.

Given the dominant land uses within the watershed it is probable that some unknown and unquantifiable fraction of phosphorus loading (via surface runoff) to the river comes from these sources.

Metals

Urban runoff is universally recognized as a major source of metals to receiving waters. Heavy metals are of particular interest in urban runoff due to their toxicity, ubiquitousness within the urban/industrialized landscape, and the fact that they cannot be chemically transformed or destroyed (Davis et al. 2001). The literature is replete with studies showing elevated levels of many metals, including cadmium, copper, lead, and zinc in urban runoff.

The final report of the U.S. EPA’s Nationwide Urban Runoff Program (NURP) found that metals such as copper, lead, and zinc were the most prevalent constituents found in urban runoff (U.S. EPA 1983). Stormwater outfalls discharging to the Ten Mile River were not sampled for metals, however TMDL-related data collection activities by RIDEM in the Woonasquatucket River, a watershed with similar land uses to the Ten Mile, have shown that stormwater outfalls draining high density residential, commercial, and industrial land uses, as well as state and local roadways can have very high levels of metals (Table 12).

Table 12. Wet weather stormwater outfall sampling locations and data summary[1].

Outfall	Predominant Catchment Land Use	Dissolved Cd (ug/l)	Dissolved Cu (ug/l)	Dissolved Pb (ug/l)	Dissolved Zn (ug/l)
S-1	Roadway, commercial, residential	Max 0.073 Mean 0.043	Max 5.80 Mean 2.97	Max 0.860 Mean 0.337	Max 45.00 Mean 26.97
S-2	Roadway, commercial	Max 0.139 Mean 0.073	Max 16.00 Mean 6.42	Max 2.32 Mean 0.993	Max 209.00 Mean 76.48
S-3	High density residential and commercial	Max 0.212 Mean 0.070	Max 24.00 Mean 10.82	Max 2.04 Mean 1.20	Max 287.00 Mean 76.27
S-41	Industrial, commercial	Max 0.207 Mean 0.130	Max 12.00 Mean 9.29	Max 2.94 Mean 2.56	Max 227.00 Mean 110.8
S-5	Roadway, commercial, industrial	Max 0.145 Mean 0.086	Max 9.60 Mean 6.96	Max 2.02 Mean 1.25	Max 124.00 Mean 83.20

[1] Taken from Table 4.2 of Woonasquatucket River Fecal Coliform and Dissolved Metals TMDL-2007.

The ultimate sources of metals in urban stormwater runoff are numerous and can be very difficult to trace. Metal fluxes depend on land use characteristics, specific materials and components (the urban infrastructure) residing within the catchment area, hydrometeorological effects, and others (Davis et al. 2001). In non-industrial-commercial areas, automobile/transportation activities have been shown to make up a large portion of metals found in stormwater runoff (Table 13): (http://www.nrdc.org/water/pollution/storm/chap2.asp). Other sources of metals in urban runoff may include metal roof runoff and pesticides and fertilizers.

Table 13. Sources of Heavy Metals from Transportation-Related Activities.

Source	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Gasoline	•			•				•	•
Exhaust							•	•	
Motor Oil & Grease		•			•		•	•	•
Antifreeze					•				•
Undercoating								•	•
Brake Linings				•	•		•	•	•
Rubber	•			•				•	•
Asphalt				•			•		•
Concrete				•			•		•
Diesel Oil	•								
Engine Wear					•	•	•	•	•

Source: Local Ordinances: A Users Guide, Terrene Institute and EPA, Region 5, 1995.

Pitt (1979) found that automobile tire wear was a major source of zinc in urban runoff and was mostly deposited on street surfaces and nearby adjacent areas. Exhaust particulates, fluid losses, drips, spills, and mechanical wear products can all contribute lead, cadmium, zinc, and copper to street surfaces.

In a recent study conducted in lower San Francisco Bay, California and sponsored by the Santa Clara Valley Nonpoint Source Program www.stormwatercenter.net/Library/Practice/6.pd) researchers examined the significance of various metal pathways into the Lower San Francisco Bay. Specifically, the comparative loading potential of five urban source areas was studied using a mass balance approach. The sources were atmospheric deposition, automotive leaks and tire wear, runoff from industrial and residential sites, and water supply. Cars and other vehicles were found to produce over 50% of the total load of copper, cadmium, and zinc. These loading estimates were generated without accounting for tailpipe emissions that produce further deposition of metals. Another major metal loading pathway was found to be the wear and tear of automobile tires. The authors of the study concluded that tire wear alone accounted for at least half of the total cadmium and zinc loads delivered to the Bay each year, while atmospheric deposition (discussed below) remained the primary loading pathway for lead. Specific sources of lead included diesel fueled vehicles.

Roof runoff can be a significant source of metals to stormwater, particularly in industrial and commercial areas. Roofing materials in many commercial and industrial buildings contain various amounts of copper, zinc, and aluminum. On metal roofs, rainwater can react with the roof surface and adsorb metals such as copper, zinc, and aluminum, especially where acid rain is prevalent (NC Cooperative Extension; http://www.bae.ncsu.edu/stormwater/PublicationFiles/RooftopRunoff2009.pdf).

Studies of roof runoff have shown that galvanized metal roofs are sources of zinc at concentrations two to twenty times greater than other urban source areas, and often produce runoff that exceeds acute toxicity for aquatic life (City of San Jose 2008). Materials, paints, and coatings associated with roofing are also suspected of being significant sources of copper and lead (City of San Jose; 2008; www.cityofpaloalto.org/civicax/filebank/documents/3719).

The presence of heavy metals in inorganic pesticides and fertilizers is well established. Many inorganic pesticides including herbicides, insecticides, fungicides, and rodenticides can contain various amounts of arsenic, mercury, lead, and copper. Fertilizers are known to contain metals such as arsenic, cadmium, nickel, lead, zinc, copper, aluminum, and iron.

The recycling of hazardous industrial wastes into fertilizers can introduce metals and chemicals into specific land uses in a watershed; namely farms, lawn and garden soils, and urban landscaping. A study conducted by the California Public Interest Research Group (CPIRG) Charitable Trust tested 29 fertilizers from 12 states for 22 different toxic metals (http://www.pirg.org/toxics/reports/wastelands/WasteLands.pdf). Concentrations of metals in each commercial fertilizer were compared to EPA's Land Disposal

Restriction standards, which are levels of concern that are limits for keeping hazardous substances from leaching from lined landfills or waste disposal sites. In all, the twenty fertilizers exceed levels of concern for nine toxic heavy metals. The most frequently exceeded levels of concern were for cadmium, chromium, lead, and vanadium.

4.2 State of Massachusetts Wastewater Treatment Facilities

Two wastewater treatment facilities, both located in Massachusetts, discharge directly to the Ten Mile River. The North Attleborough Wastewater Treatment Facility (WWTF) is located on Cedar Road in North Attleborough, Massachusetts. The Attleboro Water Pollution Control Facility (WPCF) is located at 27 Pond Street in Attleboro, Massachusetts.

The North Attleborough facility collects and treats an average of 3.1 million gallon per day of industrial and domestic wastewater from North Attleborough as well as the Town of Plainville. It has a permitted annual average capacity of 4.61 mgd. In January of 2007 a new NPDES Permit for North Attleborough was jointly issued by the US EPA and the MA DEP. The new permit contained reduced limits for nitrogen and several metals. The permit was modified in February of 2008, with lowered limits for phosphorus. The new limits imposed on North Attleborough's Wastewater Treatment Facility will require upgrades to the existing treatment facilities. The improvements were scheduled to be completed by June, 2013.

The Attleboro Water Pollution Control Facility (WPCF) is located at 27 Pond Street North in Attleboro, Massachusetts. The Attleboro WPCF discharges to the Ten Mile River a short distance (approximately 250 meters) from the Rhode Island border. The Seven Mile River discharges to the Ten Mile River just over the state line and likely has variable diluting effects on pollutant loadings from the MA portion of the Ten Mile River. The Attleboro WPCF has a permitted annual average capacity of 8.6 mgd and serves the City of Attleboro with some septage collected from portions of North Seekonk and Attleboro. In September of 2008 a new NPDES Permit for Attleboro was jointly issued by the US EPA and the MA DEP, the new permit contained reduced limits for phosphorus (seasonal), nitrogen, and various metals.

Pathogens

The permit limits for fecal coliform listed in the new permits, issued to the Attleboro facility in September of 2008, and North Attleborough in January of 2007, remain unchanged from the previous permits. The average monthly limit for both facilities is 200 fc/100 ml. The maximum daily limit is 400 fc/100 ml. The average monthly and maximum daily limits are both applicable for the entire year.

The average monthly fecal coliform concentrations for both facilities are well below the permit limits (Tables 14-15). For the 2009-2011 time-period, the monthly average discharge concentration, for the North Attleborough facility, ranged from 1- 43 fc/100 ml, with most values well under 10 fc/100 ml. For the Attleboro facility, the monthly average discharge concentration ranged from 1- 122 fc/100 ml, with a mean value of 18 fc/100 ml. Treated wastewater from these facilities is not considered a source of pathogens to the Ten Mile River.

Table 14. Monthly Fecal Coliform Data[1] for North Attleborough WWTF (2009-2011).

Mo/Yr	Avg Mo. Value (fc/100 ml)	Mo/Yr	Avg Mo. Value (fc/100 ml)	Mo/Yr	Avg Mo. Value (fc/100 ml)
1/2009	1	1/2010	3	1/2011	2
2/2009	2	2/2010	1	2/2011	7
3/2009	1	3/2010	43	3/2011	26
4/2009	4	4/2010	3	4/2011	6
5/2009	2	5/2010	1	5/2011	2
6/2009	1	6/2010	1	6/2011	2
7/2009	1	7/2010	9	7/2011	2
8/2009	1	8/2010	3	8/2011	2
9/2009	1	9/2010	---	9/2011	2
10/2009	3	10/2010	2	10/2011	7
11/2009	3	11/2010	2	11/2011	4
12/2009	4	12/2010	5	12/2011	2

[1]Sampled 3 times per week

Table 15. Monthly Fecal Coliform Data[1] for Attleboro WPCF (2009-2011).

Mo/Yr	Avg Mo. Value (fc/100 ml)	Mo/Yr	Avg Mo. Value (fc/100 ml)	Mo/Yr	Avg Mo. Value (fc/100 ml)
1/2009	19	1/2010	3	1/2011	7
2/2009	3	2/2010	2	2/2011	25
3/2009	10	3/2010	---	3/2011	25
4/2009	13	4/2010	2	4/2011	13
5/2009	10	5/2010	21	5/2011	12
6/2009	2	6/2010	13	6/2011	3
7/2009	7	7/2010	20	7/2011	6
8/2009	11	8/2010	19	8/2011	23
9/2009	10	9/2010	15	9/2011	68
10/2009	25	10/2010	32	10/2011	33
11/2009	20	11/2010	5	11/2011	13
12/2009	3	12/2010	3	12/2011	122

[1]Sampled 2 times per week

Phosphorus

The new permit, issued to the Attleboro facility in September of 2008 and the modified permit issued to North Attleborough facility in February of 2008, both include reduced limits for total phosphorus. Specifically, the average monthly limit for both permits was lowered to 0.1 mg/l during the critical growing period (April 1 through October 31). This was decreased from a limit of 1 mg/l for the same time period, for the previous permit.

The limit for total phosphorus, for the period of November 1 through March 31, remained unchanged (1 mg/l).

The North Attleborough facility violated the average monthly criteria, for the critical growing period (April 1 through October 31), seven times (Table 16) during the 2009-2011 time period. For the 2009-2011 time period, the monthly average total phosphorus concentration, for the critical growing period, for the North Attleborough facility, ranged from 0.01- 0.2 mg/l, with a mean value of 0.10 mg/l. The monthly average total phosphorus concentration, for the cold-weather period (November 1 through March 31), for the North Attleborough facility, ranged from 0.02-1 mg/l, with a mean value of 0.26 mg/l. There were no violations of the cold-weather average monthly criteria, for the North Attleborough facility.

Table 16. Monthly Average TP Data[1] for North Attleborough WWTF (2009-2011).

Mo/Yr	Avg Mo. Value (mg/l)	Month/Yr	Avg Mo. Value (mg/l)	Mo/Yr	Avg Mo. Value (mg/l)
1/2009	0.06	1/2010	0.02	1/2011	1
2/2009	0.08	2/2010	0.03	2/2011	0.41
3/2009	0.13	3/2010	0.81	3/2011	0.36
4/2009	0.17*	4/2010	0.08	4/2011	0.13*
5/2009	0.2*	5/2010	0.01	5/2011	0.14*
6/2009	0.1	6/2010	0.07	6/2011	0.05
7/2009	0.09	7/2010	0.08	7/2011	0.07
8/2009	0.1	8/2010	0.17*	8/2011	0.13*
9/2009	0.1	9/2010	0.01	9/2011	0.07
10/2009	0.06	10/2010	0.06	10/2011	0.2*
11/2009	0.1	11/2010	0.21	11/2011	0.04
12/2009	---	12/2010	0.34	12/2011	0.1

*Indicates violation of monthly average limit.
[1] Sampled 3 times per week

For the Attleboro facility, for the 2009-20011 time period, there were no violations of either the critical growing or cold-weather average monthly criteria (Table 17). With the exception of two months when no value was reported, the Attleboro facility consistently reported a monthly average value of 0.1 mg/l for each month of the critical growing period. The monthly average total phosphorus concentration, for the cold-weather period, ranged from 0.1- 0.6 mg/l, with a mean value of 0.29 mg/l.

Table 17. Monthly Average TP Data[1] for Attleboro WPCF (2009-2011).

Month/Yr	Avg Mo. Value (ug/l)	Month/Yr	Avg Mo. Value (ug/l)	Month/Yr	Avg Mo. Value (ug/l)
1/2009	0.5	1/2010	0.3	1/2011	0.4
2/2009	0.2	2/2010	0.4	2/2011	0.4
3/2009	0.1	3/2010	0.2	3/2011	0.1
4/2009	0.1	4/2010	0.1	4/2011	0.1
5/2009	0.1	5/2010	0.1	5/2011	0.1
6/2009	0.1	6/2010	0.1	6/2011	0.1
7/2009	0.1	7/2010	0.1	7/2011	0.1
8/2009	0.1	8/2010	---	8/2011	0.1
9/2009	0.1	9/2010	0.1	9/2011	0.1
10/2009	0.1	10/2010	0.1	10/2011	---
11/2009	0.2	11/2010	0.3	11/2011	0.1
12/2009	0.3	12/2010	0.6	12/2011	0.3

[1] Sampled 3 times per week

The 2008 NPDES permits issued by US Environmental Protection Agency specify design flows of 4.6 MGD (7.1 cfs) for the North Attleborough WWTF and 8.6 MGD (13.3 cfs) for the Attleboro WPCF. This results in a combined discharge of over 20 cfs. As the North Attleborough and Attleboro WWTFs approach their permitted discharges, the discharge from the combined facilities will make up a greater percentage of the river flow than currently exists, resulting in significantly less dilution of the treatment facilities' effluent.

Metals

The new permit, issued to the North Attleborough Facility in January of 2007, contained reduced limits for several metals including total aluminum and cadmium. Limits for total lead were unchanged from the 1999 permit. The 2008 permit limits for total metals are listed in Table 18.

Table 18. Metals Discharge Limitations for North Attleborough WWTF (2008).

Metal	Average Monthly	Maximum Daily	Sample Type[1]
Copper, Total (ug/l)	9.9	14.8	24-hr Composite
Lead, Total (ug/)	3.4	Report	24-hr Composite
Aluminum, Total (ug/l)	92	140	24-hr Composite
Zinc, Total (ug/l)	127	127	24-hr Composite
Cadmium, Total (ug/l)	0.3	2.2	24-hr Composite

[1] Sampled 1 time/month

The new NPDES Permit issued to Attleboro in September of 2008 also contained reduced limits for various metals (Table 19).

Table 19. Metals Discharge Limitations for Attleboro WPCF (2008).

Metal	Average Monthly	Maximum Daily	Sample Type[1]
Copper, Total (ug/l)	13	19.6	24-hr Composite
Lead, Total (ug/)	4.5	-	24-hr Composite
Aluminum, Total (ug/l)	122	950	24-hr Composite
Zinc, Total (ug/l)	-	-	24-hr Composite
Cadmium, Total (ug/l)	0.4	2.9	24-hr Composite

[1] Sampled 2 times/month

New NPDES permits were being developed for the Attleboro WPCF and North Attleborough WWTF during the 2006-2008 timeframe. There is evidence that during this time period both facilities were adjusting their dosages of aluminum and/or ferric salts to precipitate out total phosphorus in order to meet the new lower limits required in the 2008 permit. Table 20 presents total aluminum data for the Attleboro POTW during the 2007-2009 timeframe. Average permitted monthly limits for total aluminum changed from 210 ug/l in 1999 to 122 ug/l in 2008.

Based on this information and lack of other dry or wet weather sources of aluminum in the watershed, it appears that both facilities may have been the source of elevated total aluminum and iron observed in the Ten Mile River samples collected in 2007 and 2008. Effluent data from both facilities were obtained using EPA's Enforcement and Compliant History Online website tool: http://echo.epa.gov/?redirect=echo. Monthly average effluent data for total aluminum, cadmium, and lead were compared to appropriate limits and are summarized in Table 21. Another source of metals may be sediment resuspension during high flows. At present this source is unquantifiable.

Table 20. Table Monthly Average Total Aluminum Data for Attleboro WPCF (2008).

Month/Yr	Avg Mo. Value (ug/l)	Month/Yr	Avg Mo. Value (ug/l)	Month/Yr	Avg Mo. Value (ug/l)
1/2007	16	1/2008	19	1/2009	7
2/2007	15	2/2008	41	2/2009	-
3/2007	20	3/2008	-	3/2009	-
4/2007	325*	4/2008	15	4/2009	24
5/2007	47	5/2008	190*	5/2009	85
6/2007	66	6/2008	96	6/2009	79
7/2007	103	7/2008	190*	7/2009	47
8/2007	115	8/2008	125*	8/2009	99
8/2007	145	9/2008	121	9/2009	94
10/2007	205	10/2008	169*	10/2009	126*
11/2007	24	11/2008	45	11/2009	44
12/2007	-	12/2008	16	12/2009	34

* Indicates violation of monthly average limit.
- Average monthly limits for Al changed from 210 ug/l (1999 permit) to 122 ug/l (2008 permit).

Table 21. North Attleborough WWTF and Attleboro WPCF monthly average metals limits and violations (2007-present).

North Attleborough WWTF				
Parameter	**Monthly Average Limit (ug/l) 1999**	**1999 Permit Violations**	**Monthly Average Limit (ug/l) 2008**	**2008 Permit Violations**
Aluminum	140	1	92	7
Cadmium	None	-	0.3	0
Lead	3.4	0	3.4	0
Attleboro WPCF				
Parameter	**Monthly Average Limit (ug/l) 1999**	**1999 Permit Violations**	**Monthly Average Limit (ug/l) 2008**	**2008 Permit Violations**
Aluminum	210	2	122	2
Cadmium	9	0	0.4	0
Lead	60	0	4.5	0

4.3 Other Sanitary Sources

Pathogens

Sanitary sewer overflows are discharges of untreated wastewater from sewer systems. These overflows can be caused by clogged or cracked sewer pipes, by excess infiltration and inflow, by undersized sewer systems (piping and/or pumps), or by equipment failure. Such untreated wastewater can find its way to surface waters and cause bacteria violations. In addition to surface releases, cracked sewer pipes may contaminate groundwater and ultimately surface waters.

A query of DEM bypass event records shows that one bypass occurred in 2006 which discharged approximately 100 gallons of untreated sewage to the Ten Mile River at North Broadway Street in East Providence and a second one in 2013 where approximately 5,600 gallons of untreated sewage discharged to the river at Roger Williams Avenue. At present, it does not appear that this is a continuous or significant source of pathogens in the watershed. However, as the collection system ages, the frequency and severity of bypass or sanitary sewer overflows could also increase and become a more significant source. Also underground sanitary leaks, ultimately affecting surface waters, may go undetected

Illicit sewer connections into storm drains result in direct discharges of sewage via the storm drainage system outfalls. An illicit connection is an illegal connection between a sanitary sewer or septic system and a storm drain. It is not unexpected that illicit sewer connections would be found, particularly in the older developed portions of the watershed. A review of annual reports from East Providence and Pawtucket shows no evidence of illicit connections to outfalls draining to the Ten Mile River or impoundments. Nevertheless, oftentimes illicit connections can be transient in nature and may have occurred. Typically, these sources have short-term impacts on water quality since once they are discovered they are remediated fairly quickly. The routine IDDE work conducted by the MS4s as part of their Phase II requirements ideally ensures that this will be the case.

When properly designed, installed, and maintained, septic systems provide an effective and efficient means for treating wastewater. However, they are prone to failure with age, overuse, poor soil conditions, high water tables, or improper installation, repair, and/or maintenance. All of Pawtucket and East Providence are sewered, as is the majority of North Attleborough and Attleboro. However, Seekonk which shares the state line border with East Providence and makes up portions of the eastern shore of the Ten Mile River and its impoundments, is not sewered. Failed or non-conforming septic systems in Seekonk may contribute pathogens to the Ten Mile River. Wastes from failing septic systems enter surface waters either as direct overland flow or via groundwater. Wet weather events typically increase the rate of transport of pollutant loadings from failing septic systems to surface waters because of the wash-off effect from runoff and the increased rate of groundwater recharge.

Most of the homes in Seekonk located adjacent to the river or impoundments have significant buffers between them. The Town of Seekonk receives approximately 85 reports of failing or improperly functioning septic systems town-wide per year. Each of these reports is promptly investigated and any necessary repairs are made in a timely manner (personal communication, Beth Hallal, Seekonk Board of Health). Available information is inconclusive as to whether failing septic systems are a significant source of pathogens to the portion of the Ten Mile River addressed in this TMDL.

4.4 Other NPDES/RIPDES Permitted Discharges

A review of available information and databases found no other RIPDES permitted municipal wastewater discharges and no active Multi-Sector General Permit holders within the Rhode Island portion. There is however, one facility that has been issued an individual stormwater permit: Getty Terminals Corporation (RI0001651) located off North Broadway in East Providence. Sampling requirements under the permit do not include metals. A query and review of permitted discharges in Massachusetts, aside from the Attleboro and North Attleborough facilities and the North Attleboro National Fish Hatchery (NANFH), was beyond the scope of this TMDL. It is hoped that these sources will be examined in the future when MADEP develops TMDL's for the Massachusetts portion of the Ten Mile River watershed.

Phosphorus

The NANFH is located in North Attleborough, MA and was constructed in 1952. It raises Atlantic salmon for release in the Merrimack, Pawcatuck and Connecticut Rivers, as part of restoration efforts there. In addition to its main goal of raising Atlantic salmon the hatchery also provides numerous public outreach activities. Main supplies of eggs for the NANF Hatchery are the sea-run adult Atlantic salmon.

The NANFH is supplied by groundwater. Four wells pump 600 gallons/minute of water to the facility. The wells are located within the hatchery site and the locations are selected based on the quality of the water. In spite of the fact that North Attleboro and the surrounding areas were home to industrial and commercial facilities decades ago the groundwater is of high quality and requires no pre-treatment before use in fish culture. The only water treatment applied at the hatchery is chilling the water that is supplied to the incubation facility. Effluent water from the incubation facility, fry culture tanks and fish grow-out ponds/tanks is drained into a settling pond located at the northern tip of the site. Here the suspended solids in the effluents are allowed to settle. From this pond the effluent water is directed through two raceways into a stream, which is a tributary of the Bungay River.

NPDES permits are required, among others, for cold water fish facilities, including for trout and salmon, in ponds, raceways, or other structures that discharge at least 30 days per year. Facilities that produce less than 9,090 kg (or approximately 20,000 lbs) of aquatic animals per year or facilities which feed less than 2,272 kg (approximately 5,000 lbs.) of feed per month are not included (Mugg et al., 2003).

The NANFH produce about 9,000 kg of fish a year. For that reason, it is not required by Massachusetts NPDES rules to get discharge permits. Therefore, the facility discharges its effluents into the tributary of Bungay River without any restrictions by state discharge monitoring requirements. The management of the NANFH says that the state regulatory agency is satisfied with the quality of the discharges from their hatchery and that no complaints are reported by riparian owners or residents in the vicinity of the hatchery or by people living or working along the banks of the river to which the hatchery discharges its effluents (Hagos 2009).

Although it has not been shown that the North Attleboro fish hatchery is a significant source of phosphorus, the potential exists. Work done by RIDEM staff at the Lafayette Trout Hatchery, located in North Kingstown, Rhode Island, in conjunction with the Bellville Ponds TMDL, found based upon sampling conducted in June-July 2007 that the mean total phosphorus concentration at the raceway terminus was 0.102 mg//l. This mean phosphorus level was significantly higher than the mean concentration of the water supply source to the hatchery (well water) (0.055 mg/l).

4.5 Wildlife/Waterfowl/ Non-Migratory Waterfowl
A variety of both native and non-native wildlife such as ducks, migratory and non-migratory geese, mute swans, raccoons, fox, deer, muskrat, and rodents inhabit the open space lands, as well as urban and suburban lands, within the Ten Mile River watershed. These animals may contribute pathogens through stormwater runoff or direct deposition. Because of the great variety, complex distribution and dispersal patterns, and fluctuating populations of wildlife and waterfowl it can be difficult to assess their impact on water quality in the study area.

Low to moderate fecal coliform levels have been observed at sampling stations not thought to be impacted by human activities (including feeding of waterfowl). This suggests that native wildlife (the only other potential source) is not, in general, a significant source to the Ten Mile River. However, due to lack of data, wildlife contributions cannot be fully characterized at this point. The non-native wildlife source is also not readily controllable and therefore is not addressed in the Implementation Section of this TMDL.

It is likely, however, that localized degradation in water quality occurs in certain areas of the Ten Mile River where non-native wildlife densities are particularly high. Non-migratory geese and mute swans are frequently seen in various areas of the watershed. These geese are known as resident geese, since they do not migrate in the winter. The birds have adapted well to living in urban and suburban areas and their populations flourish with ample food sources - mainly green lawns - and a lack of predators. Unlike the wildlife source which is not readily controllable, cost-effective strategies exist that can reduce non-migratory geese and swan populations from utilizing specific areas and causing water quality problems.

Pathogens
Slater Memorial Park Pond, located in Pawtucket, RI is a small (approx 1.8 ha) pond that discharges to the Ten Mile River approximately 375 meters downstream of the Slater Park Pond outflow. The pond supports a relatively large population of resident ducks and geese. The presence of these waterfowl appear to be supported, in part, by the ideal park habitat (low cut grounds and easy access to the pond) and by frequent feeding, on the part of some park visitors. DEM staff note large quantities of goose droppings along the ponds vegetated shoreline. Park staffers have posted signage at numerous locations, discouraging feeding of waterfowl, however they report that these signs have been repeatedly vandalized and in some cases removed and thrown into the woods. It is highly

likely that wet weather events cause the pond's discharge to contribute to elevated pathogen loads to the Ten Mile River.

Portions of the lower Turner Reservoir, particularly the Bridgham Farm Conservation Area, consist of significant expanses of mowed grass, which appears to attract large populations of geese. TMDL staff have noted significant amounts of droppings along this shoreline that likely get washed into the reservoir during storm events. Smaller populations of geese and associated fecal material have also been noted along the western shore of the northern portion of Turner Reservoir, just south of Route 152 (Newman Ave) near the public launch site. Signage has been posted at this location to discourage illegal feeding, however it appears that illegal feeding of waterfowl continues at this public launch site.

The northern portion of Central Pond is a major molt location of mute swans. The molt occurs during the summer at which time swans regrow their flight feathers. During this time swans are flightless and congregate at locations capable of supporting their needs during this 1-2 month period. TMDL staff estimated well over 200 swans on several field visits during the early summer months. The overpopulation issue is exacerbated by the lack of any management from the abutting state, in this case MA.

During the study period, the lower portion of the upper Ten Mile River from the outflow of Slater Park Pond to the inflow of Central Pond was likely impacted by geese populations that frequently utilize the ideal habitat found at the Pawtucket Country Club, located in the City of Pawtucket. DEM staff have noted moderate to heavy amounts of fecal material deposited by geese in the parking lots and nearby shoreline areas. Fecal material from geese is visible on the shoreline of the pond as well as on the substrate of the shallow areas of the pond.

During a more recent visit in July 2013, no geese were observed and no fecal material was noted on the parking lot or adjacent shoreline. In fact, the golf course superintendent explained that beginning in 2010, they had experimented with various techniques to rid the course of the nuisance Canada Goose populations including use of dogs and allowing hunting on selected days in the fall/winter. These activities appear to have been quite successful in reducing the number of birds on the course and parking lot such that it no longer appears to be a significant source of pathogens.

Phosphorus

Animal waste also contains nutrients that have the potential to enrich surface water and thus contribute to the process of eutrophication. There has been a significant number of papers published examining how nutrients from both migratory and resident bird populations can effect water quality and speed the process of cultural eutrophication (Manny et al, 1994; Moore et al. 1998; Purcell, 1999; Portnoy, 1990; Kitchel et al., 1999, and Bland, 1996). Even in small numbers, larger waterfowl like geese are likely a significant source of phosphorus. However, studies have shown that the impact of excrement derived nutrient loadings to waterbodies from birds varies with: bird species, bird population density, feeding habits, dilution capacity of the waterbody, and time of year.

Hahn et al. (2008) reported that the annual phosphorus loading rate for mute swans is 0.2 kg/yr. Portnoy (1990) determined that approximately 42% of phosphorus loading in a Cape Cod pond was attributable to gulls. Migrating geese increased the total phosphorus loading rate in some wetland ponds at the Bosque del Apache National Wildlife Refuge in New Mexico by as much as 75% (Kitchel et al., 1999). Additionally, chlorophyll levels were found to increase in proportion to bird densities. Although the impoundments included in this study have small populations of waterfowl relative to typical wildlife refuges, most of the waterfowl is resident and not just present a few weeks a year.

As mentioned above, Slater Memorial Park Pond, located in Pawtucket, RI discharges to the Ten Mile River approximately 375 meters downstream of the Slater Park Pond outflow. This small pond is thought to be a source of phosphorus to Central Pond via the Ten Mile River (for the reasons stated above).

Central Pond is a significant molting area for mute swans. As many as 200 swans have been observed on Central Pond during the summer molt (RIDEM, 2006). The molt period for mute swans occurs from mid-July through late August. RIDEM division of Fish and Wildlife has conducted annual surveys of swans on Turner Reservoir (1993- 2012) and adjacent Central Pond (2002- 2012), during the months of August and September. The molting swan population for the period of record is approximately 226 birds. Assuming an annual loading rate of 0.2 kg/yr (Hahn et al., 2008), and an average population of approximately 200 birds, the swans produce approximately 40 kg of phosphorus during this molting season.

4.6 Golf Courses

Golf courses can be significant sources of pathogens, phosphorus, and metals to receiving waters. There are two golf courses in Rhode Island located, at least partially, within the Ten Mile River watershed. These include the Agawam Hunt Club Golf in East Providence and the Pawtucket Country Club, a portion of which is located in Pawtucket Rhode Island, with the majority being located in Seekonk Massachusetts. RIDEM staff observed direct surface hydrologic connections between both the Agawam Hunt Club and Pawtucket Country Club courses with the main trunk of the Ten Mile River system. There are also numerous golf courses in the Massachusetts portion of the watershed.

Pathogens

Golf courses provide excellent habitat for geese, including large expanses of turf and typically water features. Since there are numerous golf courses within the Ten Mile River watershed, especially in Massachusetts, and it is likely that many if not most of the golf courses have significant resident geese populations, it is reasonable to assume that golf courses may contribute to pathogen loads to the river and its impoundments.

Phosphorus

Golf courses are heavily fertilized and have drainage and irrigation systems designed to quickly move water through the soils and away from the course, and oftentimes to the nearest waterbody. Although golf course management practices have improved greatly in the last decade, they still appear to qualify as a stormwater hotspot, at least for total phosphorus and often for nitrate. Recent research by limnologists (Winter and Dillon, 2005) and the turf grass industry (Baris et al 2010) indicates that phosphorus and nitrate concentrations are elevated in streams that run through golf courses.

In one study (Kunimatsu, et al. 1999), researchers sampled water at two stations in a stream bisecting a golf course. One sampling station was located in a wooded area upstream of the golf course and the other was located downstream. The mean total phosphorus concentration downstream of the golf course (0.145 mg/l) was significantly higher than the mean phosphorus level in the up-gradient wooded area (0.0072 mg/l).

In another study (King et al, 2007) storm event samples were collected for 5 years from a golf course in Austin, Texas. Inflow and outflow samples were collected from a stream that transected the golf course. One hundred fifteen runoff-producing precipitation events were measured. The median PO4–P concentration at the outflow location (0.13 mg/l) was significantly greater than median concentration measured at the inflow location (0.10 mg/l). The median event load measured at the outflow (0.5 kg) was significantly greater than that measured at the inflow (0.2 kg). The annual PO4–P load resulting from storm event runoff was 0.51 $kg/ha^2/yr$. This amount represented approximately 6% of phosphorus applied over the contributing area for the same period.

Growing season total phosphorus loads from golf courses in the Ten Mile River watershed were estimated using various phosphorus export coefficients as described in Section 7.0 of this TMDL.

Metals

The extensive use of pesticides in golf course management raises concerns about its impact to water quality. As previously discussed, the presence of heavy metals in inorganic pesticides and fertilizers is well established. Many inorganic pesticides including herbicides, insecticides, fungicides, and rodenticides can contain various amounts of arsenic, mercury, lead, and copper. Recent studies have documented fairly significant surface runoff losses of pesticides applied.

Haith and Rossi (2003) used the TurfPQ model to simulate the runoff of 15 pesticides commonly applied to fairways and greens on golf courses in the northeastern USA. Mean annual pesticide runoff loads did not exceed 3% of annual applications for any pesticide or site, and most losses were substantially less than 1% of application.

A 3-yr field study (Ma et al., 1999) was conducted, measuring surface runoff of water and various commonly used pesticides from simulated golf course environments. Twelve plots were managed as a golf course fairway; appropriate amounts of pesticides were applied, as well as simulated rainfall. Measured pesticide runoff rates were considerably higher than those predicted by Haith and Rossi (1999) . The average annual runoff loss was 9.13, 15.41, and 10.82% of applied 2,4-D, dicamba, and mecoprop, respectively. Both mass and concentration of pesticide runoff decreased rapidly, with the first post-treatment event runoff averaging 74.5, 71.7, and 73.0% of the total runoff of 2,4-D, dicamba, and mecoprop, respectively. Given these measured runoff rates, it is reasonable to assume that without careful application, pesticides applied to golf courses have the potential to be a source of metals, however at present this is unquantifiable.

4.7 Uncontrolled Disposal of Wastes and Illegal Dumping

Metals

Metals contributions from automotive coolant dumping and oil dumping are possible in the Ten Mile River watershed. It was not uncommon during various site visits to find used motor oil and coolant containers and paper funnels in the mainstem, as well as parking lots, vacant lots, catch basins, and commercial areas located adjacent to the river in the lower and more urbanized portions of the watershed.

In the summer of 2008, RIDEM staff canoed the Ten Mile River from the state line to the inlet of Omega Pond, portaging where necessary. It was noted that various appliances, automotive debris including tires, shopping cars, bicycles, ladders, empty paint and herbicide containers, and other unidentified metal objects and containers existed within the mainstem and on the banks and portions of floodplain of the river. Although it cannot be quantified, it is certainly possible that metals leach from these objects and are released into the water column.

4.8 Hazardous Waste Cleanup Sites

There are numerous waste cleanup sites located within the Ten Mile River watershed. Waste cleanup sites include Superfund sites, federal facilities, brownfields, underground storage tank system releases, treatment, storage and disposal facility accidental releases, and oil spills. EPA New England's Office of Site Remediation and Restoration (OSRR) administers the region's waste site cleanup and reuse programs. The EPA provides a web site (http://www.epa.gov/region1/cleanup/index.html) to locate hazardous waste sites in New England, learn about EPA's cleanup programs, as well as to retrieve additional information regional cleanup efforts. A select list of cleanup sites are described in Appendix J. This is by no means a complete listing of all sites in the watershed that may contribute contaminants to groundwater.

Both RIDEM and MADEP have programs dedicated to various waste site cleanup areas. MADEP has a searchable database (http://public.dep.state.ma.us/SearchableSites2/Search.aspx) which is similar to the EPA website above. Many sites have not been investigated and still others have yet to be discovered. According to staff at RIDEM Office of Waste Management, it is reasonable to assume that all old industrial sites within the watershed have some form of groundwater contamination (Cynthia Gianfrancesco, RIDEM/Office of Waste Management, personal communication).

4.9 Groundwater and Sediment Contamination

Metals

Groundwater may be a natural and/or anthropogenic source of metals to the Ten Mile River. Subterranean flows may seep directly through the riverbed or surface at other points within the floodplain. Groundwater may contain naturally occurring dissolved metals concentrations, or enriched concentrations from overlying metals contaminated soils that contribute to exceedances of metals water quality criteria in the Ten Mile River. Groundwater discharges to storm drains or directly to the river provide an uninterrupted pathway for dissolved metals to the river. However, groundwater flows and their contribution to the Ten Mile River are poorly characterized.

Sediment release of toxic metals to the water column represents another likely source of contamination to the Ten Mile River-particularly in the impoundments which has received many years of contaminated discharges, including sediments, from various industrial and municipal discharges.

The fate of toxic metals in sediments depends on a combination of the physical, chemical, and biologic conditions. These conditions may vary dramatically, both spatially and temporally, in response to factors ranging from seasonal changes and storm events to human activities such as dredging or remediation efforts. In addition, the movement of contaminants, including pesticides, heavy metals, etc., is influenced by factors such as sorption, redox gradients, and pH, which in turn are greatly influenced by microbial communities and their activities (Ford et al. 2005). The bacterial community metabolism can affect valence states of metals via oxidation/reduction reactions, thereby altering the chemical speciation, fate, and the ultimate toxicity of the contaminant (Ford et al. 2005).

The effects of the movement of metal-enriched groundwater on metal loading in the river are unclear. A detailed study of the transport and fate of toxic metals from groundwater and sediment in the Ten Mile was beyond the scope of this project. Without more detailed groundwater and surface water investigations it remains speculative at best to assume on-site contamination results in a continuous metals load to the river or its impoundments. Remediation of contaminated groundwater and sediment are discussed further in the Implementation section of this report. In general, these projects are overseen by DEM's Office of Waste Management.

Mining, manufacturing, and the use of synthetic products (e.g. pesticides, paints, batteries, industrial waste, and land application of industrial or domestic sludge) can result in heavy metal contamination of urban and agricultural soils. Potentially contaminated soils may also occur at old landfill sites (particularly those that accepted industrial wastes) and industrial areas where chemicals may have been dumped on the ground, or in areas downwind from industrial sites. It may also occur in residential areas with poor housekeeping practices.

Resuspension of contaminated sediment-bound metals into the water column via streambank and/or streambed erosion due to high energy wet weather flows may be a possible mechanism whereby metals are introduced into the overlying water column.

These contaminated sediments can cause water quality problems by imparting acute or chronic toxicities to ambient surface waters.

Persistent contaminants associated with past and present cultural and natural influences enter aquatic systems and may be adsorbed onto or absorbed into sediments. These contaminated sediments may pose an ecotoxicological and human health risk if their contaminants are able to enter the aquatic food chain, or if people or organisms are otherwise exposed to them. Pathways of exposure include resuspension from disturbed sediments, chemical redox reactions due to anoxia, or streambank scour.

The origins of sediment contamination in the Ten Mile River can be generally divided between point and nonpoint sources of pollution. Point sources in the watershed include municipal sewage treatment plants, stormwater discharges, and both current and historic discharges from numerous industrial facilities. Nonpoint sources include dry and wet atmospheric deposition and unknown and/or unidentified discharges or leaks of metal containing substances, both intentional and unintentional.

Sediment transported downstream in the Ten Mile River during normal flow likely settles out behind each of the many dams along its course. During extremely high flows, some of the sediment can become suspended and carried further downstream, either to the terminal outflow at Omega Pond and to the Seekonk River, or to settle out behind one or more dams, including Slater Park, Turner, Hunts Mill, and Omega. The sediments that have accumulated behind many of the dams have been found to contain elevated levels of several metals including copper, zinc, and cadmium (in Central Pond and the Turner Reservoir); arsenic, cadmium, chromium, lead, nickel, zinc, and mercury (at Slater Park Pond), and copper, zinc, cadmium, and nickel (in Omega Pond).

Analysis of the in-stream metals data, collected in 2007 and 2008 (Table 3.4), shows that the wet-weather stormflow condition produces notably higher levels of particulate metals than the dry weather baseflow condition. The elevated levels of particulate metals, measured during the stormflow condition, are consistent for all of the metals sampled, including: cadmium, lead, copper, zinc, aluminum, and iron. The elevated levels of particulate metals may originate from stormwater or be the result of scouring and resuspension of sediment during periods of higher flows.

The historic industrial and municipal discharges upstream from the Turner Reservoir and other dams are believed to be the sources of the elevated metals concentrations in all of the sampled impoundments. A 1975 survey conducted by the (then) Massachusetts Water Resources Commission documented the presence of 39 industrial discharges to the Ten Mile River located variously in Plainville, North Attleborough, and Attleboro, MA. A vast majority of these discharges were from jewelry and metal finishing industries. Two municipal wastewater discharges (Attleboro and North Attleborough) were also included in the survey. It is unknown how many industrial and/or municipal discharges existed within the RI portions of the watershed during the 1975 survey.

The Army Corps of Engineers (ACOE) New England Office is presently working on a restoration Project in the Ten Mile River which is meant to restore anadromous fish migration to the lower Ten Mile River. The project's goals are to restore fish passage over the three most downstream dams on the Ten Mile River: Omega Pond Dam, Hunt's Mill Dam, and Turner Reservoir Dam. As part of this project, detailed environmental assessments were conducted that included sediment sampling at numerous locations in Central Pond, Turner Reservoir, Hunts Mill Pond, and Omega Pond.

The sediment samples that were collected in Central Pond and the Turner Reservoir during the summer/fall of 1999 (USACOE 2005) were found to have concentrations of metals above the severe biological effects levels established by the Ontario Ministry of the Environment (OME) for chromium, nickel, copper, zinc, cadmium, and lead. These reported sediment results are compared to sediment quality guidelines published by EPA in 2000 (Table 22) (EPA 2000).

Table 22. Concentrations of metals in sediments from Central Pond and Turner Reservoir from the USACOE[1] and Consensus-Based PEC concentrations[2].

	Metal concentration expressed as ug/l (mg/kg) dry weight							
Location	**Cr**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Hg**
Central Pond	407	564	1350	731	11.3	80.9	262	1.55
Turner Reservoir 1	350	1050	1400	678	6.54	71.9	176	1.68
Turner Reservoir 2	897	1750	2710	1500	13.5	157	401	3.33
Omega Pond 1	122	87	775	724	8.2	5.96	309	0.907
Omega Pond 2	273	124	753	1234	17.5	12.3	282	0.999
Omega Pond 3	369	343	1073	1221	17.3	22.5	501	1.473
Omega Pond 4	192	266	857	1321	14.7	14.7	514	1.172
Omega Pond 5	194	125	404	561	17.1	8.83	201	0.905
Omega Pond 6	100	61	295	296	4.38	3.84	107	0.734
Omega Pond 7	334	469	863	886	10.9	26.4	459	0.830
Hunts Mill 1	65	263	253	247	2.97	27.6	82	0.256
Hunts Mill 2	21	13	34.3	57	ND	0.5	24	0.050
Hunts Mill 3	65	162	213	213	ND	21.8	71	0.230
Consensus-Based Probable Effects Concentration (PEC)[2]	111	48.6	149	459	33	4.98	128	1.06

[1] Data taken from Table 2- USACOE Ten Mile River Feasibility Report 2005.
[2] EPA 2000. Prediction of sediment toxicity using consensus-based freshwater sediment quality guidelines. EPA 905/R-00/007. June 2000.

Probable effect concentrations (PEC's) are defined as the concentrations of metal above which harmful effects to sediment dwelling organisms are likely to be observed. It has been shown that an exceedance of a proposed sediment quality criterion does not necessarily mean that the chemical constituent of concern in the sediments is contributing dissolved forms of the constituent to the interstitial waters that are toxic-available to aquatic life associated with the sediments (Lee and Jones-Lee 1996). Nevertheless, comparison of the PEC value with those obtained from sampling provides an initial screening by indicating the potential for sediments to impart a toxic effect on the ambient surface waters. Indeed, Hellyer (2000) states that the chemical and physical characterization of river bed sediments is of interest as sediment quality is often a good indicator of aquatic system "health".

Sediments collected in Omega Pond and Hunts Mill Pond also had elevated concentrations of metals as well as other contaminants. Generally, for the specific metals that were sampled in all three locations (Turner Reservoir, Hunts Mill Pond and Omega Pond), the levels from both Omega Pond and Hunts Mill Pond were lower than those from the sediments in Turner Reservoir, with the exception of lead, which was higher in Omega Pond than in Turner Reservoir.

The ACOE study reported that levels of chromium, nickel, copper, zinc, and cadmium in the sediments of Omega Pond were generally one half of the concentration of the sediment in Turner Reservoir, but they were still above many of the levels where biological effects would occur in the life stages of sensitive aquatic organisms (i.e. Long and Morgan ER-L and ER-M as well as the Ontario Ministry of the Environment Levels for both the LEL and SEL). Lead levels in sediments from Omega Pond were generally higher than those from both Turner Reservoir and Hunts Mill Pond, with the highest concentration (from site 4) being 514 ppm, compared to the highest concentration of 401 ppm collected from Turner Reservoir. In contrast, the sediment lead levels in Hunts Mill Pond ranged between 71 ppm and 82 ppm.

In the absence of additional point or non-point sources of metal contamination downstream from Turner Reservoir, it could be assumed that the general reduction in sediment contaminant levels in both Hunts Mill and Omega Ponds could be due to the successive settling out of these materials behind the dams, with most of it settling in the Central Pond- Turner Reservoir complex, and the remaining settling out in the successive downstream areas. The fact that Hunts Mill Pond sediments generally contained the lowest levels of most of the contaminants could be due to it being the lowest dam and therefore providing the least amount of depth for sediment to collect. Most suspended sediments would therefore be carried over the dam and continue downstream to Omega Pond.

The ACOE study speculated that most of the contaminants in the sediments are the result of sources in the Ten Mile River upstream from the Central Pond-Turner Reservoir complex, however, the higher lead levels in Omega Pond may also be due to industrial discharges and urban runoff into Omega Pond.

In 1998 a reconnaissance was undertaken by EPA-New England (EPA-NE) and Massachusetts Department of Environmental Protection (MADEP) of the Ten Mile River watershed (Hellyer 2000). Seven discrete sediment sampling locations were identified as being representative of the past and current pollutant history of the river.

Sediment samples were collected from seven impoundments, including Slater Park Pond, and analyzed for a full suite of analytical parameters including inorganics (metals), volatile and semi-volatile organic compounds, chlorinated pesticides, polychlorinated biphenyls (PCBs), total organic carbon (TOC), grain size, acid volatile sulfides (AVS) and simultaneously extractable metals (SEM).

Chemistry analytical results revealed that sediments from all impoundments were highly contaminated with complex mixtures of inorganic chemicals (metals), volatile and semi-volatile organic compounds, chlorinated pesticides and PCBs. The study stated that, “Given the history of the river during and subsequent to the Industrial Revolution in New England, including jewelry, tannery, and electroplating works, such remnant contamination was not unexpected.” Of particular note were the extremely high levels of mercury found in all sediments.

Results were also screened using a new tool developed at EPA, the Sediment Ecotoxicological Screening Benchmark (SESB) tables. These SESB tables screen inorganics (primarily metals), chlorinated pesticides and polychlorinated biphenyls and volatile and semi-volatile organic hydrocarbons (SVOCs) relative to ecotoxicological screening benchmark values derived from the published scientific and technical literature. The results revealed contamination of potential ecotoxicological concern was observed at all sample locations. Results from one station, located near the outlet of Slater Park Pond, are presented in Figure 22.

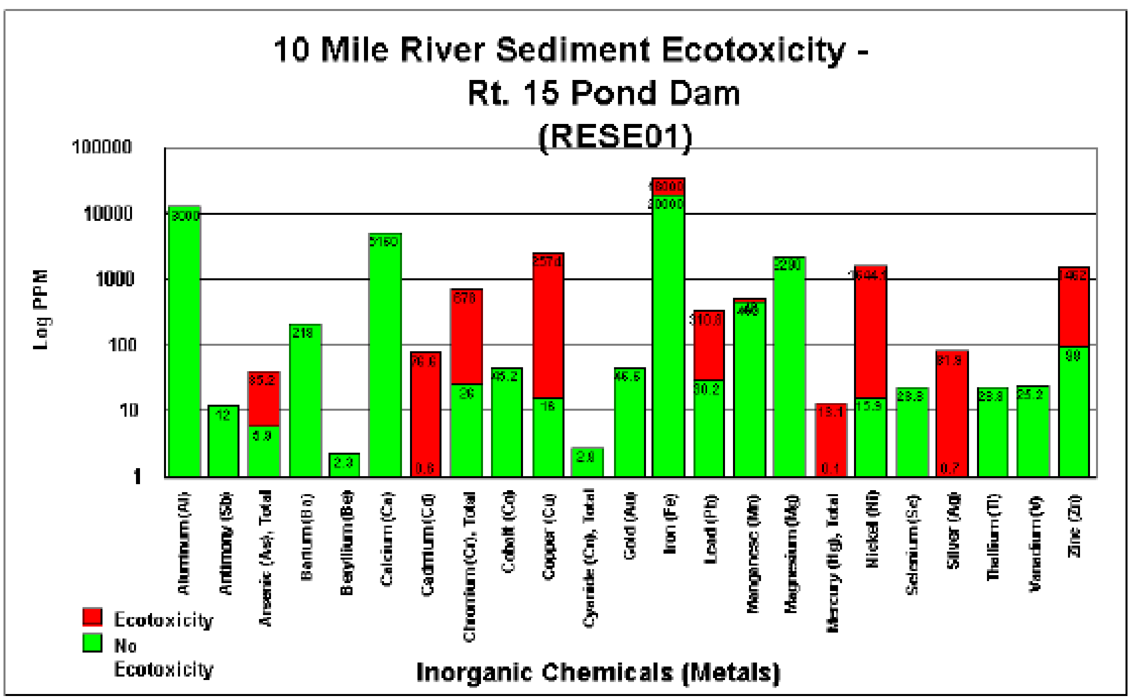

Figure 22. Slater Park Pond Sediment Ecotoxicity summary (USEPA 2000).

These analyses depict similarity and dissimilarity between sample sites based on observed contaminants. Biological tests of sediment samples were undertaken in which two freshwater invertebrate species (chironomids and amphipods) were exposed under controlled laboratory conditions. The amphipod test failed to meet test acceptability criteria with excessive mortality in the control animals. Thus these results could not be statistically analyzed and interpreted further. However, the chironomid test observed significant impairment of survival in three test site replicates: Dodgeville Pond Dam, Slater Park Pond Dam, and Wetherell Pond Dam. The authors state that the potential for adverse effects from these sediments could be underestimated since, for example, tests did not measure subchronic effects, such as reproduction and emergence.

The bioavailability and toxicity of metals in sediments is related to the geochemical speciation and chemical activity of the metals in the interstitial water of the sediment. Di Toro et al. (1992) conducted laboratory tests with marine and freshwater organisms to determine which factors controlled the toxicity of metals in sediments. Test results showed that the mortality of the animals was related to both the quantity of toxic heavy metals (Cu + Zn + Cd + Ni + Hg + Pb) and the acid volatile sulfide (AVS) released from acidified sediments. Metals extracted with the AVS are termed simultaneously extracted metals (SEM). If the SEM/AVS ratio was greater than 1 or 2, the sediments were toxic; if the ratio was below 1, the sediments were not toxic regardless of the total metal concentration. Di Toro et al. (1992) proposed that when the SEM/AVS ratio was less than 1, the toxic metals were all precipitated as insoluble metal sulfides and hence not biologically available. The high SEM/AVS ratio of 3.5 at the Slater Park Pond Pond Dam (RESE01) site led the author of the study to suggest that less sediment binding occurs at the Slater Park Pond site which results in greater bioavailability and higher toxicity of zinc, lead, copper, nickel, cadmium, arsenic, mercury and manganese.

The information presented above clearly indicates that there is widespread contamination throughout the sediments in the Ten Mile system and that, on some unquantifiable level, this contributes to the measured levels of metals in the water column under the dry weather baseflow and stormflow conditions. Contaminated sediments may be directly toxic to aquatic life (organisms found in the water column and in or near the sediment) or can be a source of contaminants for bioaccumulation (where a substance is taken up by an organism) in the food chain. To date no fish tissue data has been collected, however DEM strongly recommends fish tissue sampling for metals, organics, mercury, and other contaminants.

Wastewater disposal practices of certain types of businesses, such as automobile service stations, dry cleaners, electrical component or machine manufacturers, photo processors, and metal platers or fabricators are of particular concern because the waste they generate is likely to contain toxic chemicals, including metals. Other industrial sources of contamination include the cleaning of holding tanks or spraying equipment on the open ground, disposing of waste in septic systems or dry wells, and storing hazardous materials in uncovered areas or in areas that do not have pads with drains or catchment basins. Underground and above ground storage tanks holding petroleum products, acids, solvents and chemicals can develop leaks from corrosion, defects, improper installation, or mechanical failure of the pipes and fittings.

Improperly storing or disposing of household chemicals such as paints, synthetic detergents, solvents, oils, medicines, disinfectants, pool chemicals, pesticides, batteries, gasoline and diesel fuel can also lead to groundwater contamination. When stored in garages or basements with floor drains, spills and flooding may introduce such contaminants into the groundwater. When thrown in the household trash, the products may eventually be carried into the groundwater. Similarly, wastes dumped or buried in the ground can contaminate the soil and leach into the groundwater.

In the Rhode Island portion of the Ten Mile River watershed there are approximately 52 Leaking Underground Storage Tanks (LUST), 36 solid waste investigations and/or site remediation facilities, and 172 Resource Conservation and Recovery Act (RCRA) sites. In the Massachusetts portion of the watershed there are approximately 318 RCRA sites. It was beyond the scope of this study to evaluate each of these sites with respect to the TMDL parameters.

EPA New England's Office of Site Remediation and Restoration (OSRR) administers the region's waste site cleanup and reuse programs. A review of the website used to locate hazardous waste sites in New England revealed the existence of several sites in Rhode Island and Massachusetts. Sites thought to have reasonable potential to contribute contaminants to the Ten Mile River or impoundments were evaluated by RIDEM, however these could not be quantified to a satisfactory degree to include in this TMDL. These sites are described further in Appendix J.

Phosphorus

In the past, it was generally thought that phosphorus is typically adsorbed to soil particles and is not transported in groundwater. However, McCobb et al. (2003) demonstrated that phosphorus is transported in sewage-contaminated groundwater (McCobb et al., 2003). The amount of phosphorus that aquifer sediments can adsorb is related to the amount of iron oxides present, the pH, the total amount of phosphorus present, the amount of dissolved oxygen in water, and other ions in solution.

Although orthophosphate is soluble in water, it can bind or adsorb onto soil particles. The two types of minerals primarily responsible for orthophosphate adsorption in soils are clays and metal oxides, with fine-grained iron oxides responsible for most orthophosphate adsorption in the soil subsurface (Domagalski and Johnson, 2012). The amount of orthophosphate that can be adsorbed is limited by the amount of total surface area of the oxides or clays in a soil. When the sorption sites on the mineral surfaces become saturated with orthophosphate or other ions, any additional orthophosphate will remain in solution. Groundwater contamination may occur in areas of high phosphorus loading.

The ability of iron oxides to adsorb and retain phosphorus depends upon the presence of dissolved oxygen in the surrounding water and below-neutral pH (less than 7) (Domagalski and Johnson, 2012). In general, soils and aquifers lacking dissolved oxygen or having pH values greater than about 7 will tend to become saturated with orthophosphate more quickly than oxic or acidic soils and aquifers. In the absence of oxygen, iron oxides can dissolve and release adsorbed phosphorus back into the water, where concentrations of dissolved phosphorus increase. Even in an aquifer that has low amounts of dissolved oxygen, however, iron oxides do not necessarily dissolve, because this process is related to the presence of specific bacteria. Sandy or stony soils, with low clay and organic matter content also have a lesser capacity to adsorb phosphorus.

As part of the Mashapaug Pond TMDL (RIDEM, 2007), groundwater discharging to Mashapaug Pond, was sampled and analyzed for dissolved phosphorus as well as other constituents. The mean dissolved phosphorus concentration was 0.047 mg/l. Groundwater-derived phosphorus accounted for 7% of the total existing phosphorus load to Mashapaug Pond.

In support of the Bellville Ponds TMDL (RIDEM, 2010), well water at the Lafayette Trout Hatchery, located in North Kingstown, Rhode Island, was sampled 69 times between September 2006 and June 2009. Well water is the sole source of water used in hatchery operations. The mean and median total phosphorus concentration in the groundwater was 0.039 and 0.028 mg/l, respectively.

4.10 Atmospheric Deposition

Atmospheric deposition is the process by which airborne particles and gases are deposited to soils, vegetation, waters, and other surfaces, either through precipitation (wet deposition- rain, snow, clouds, and fog) or as a result of complex atmospheric processes such as settling, impaction, and adsorption; known as dry deposition. Pollutants in the atmosphere can be deposited on the watershed, washed off by rain, and become part of the stormwater runoff that reaches waterbodies.

Estimates of atmospheric deposition of trace metals and nutrients such as phosphorus, were developed by the combined efforts of the USEPA, the California Dept. of Environmental Protection, and the South Coast Air Quality Management District for point, mobile, and area sources from the Los Angeles metropolitan area: http://www.sccwrp.org/ResearchAreas/Contaminants/AtmosphericDeposition/TraceMetalsDeposition.aspx. These estimates revealed that the most significant source of metals to the atmosphere was resuspension of dust, often called ‘fugitive dust’, from roads by moving vehicles and from other paved and unpaved surfaces by wind. Construction dust was also found to be a source of metals to the atmosphere.

Phosphorus

Gibson et al. (1995) summarized a number of studies and found that wet atmospheric inputs of total phosphorus typically range from 0.05-0.40 kg/ha/yr and are not a significant source to most receiving waters. However, others have found that rainfall can contribute up to 25% of annual phosphorus inputs (Johnes et al., 1996) to freshwater waterbodies.

Ullman et al. (2005) reported that the atmospheric phosphorus load was approximately 3-5% of the total annual phosphorus load to Delaware's inland bays. Wet and dry deposition phosphorus loads were 0.012-0.019 kg/ha/yr and 0.026-0.054 kg/ha/yr, respectively. The atmospheric deposition rates for phosphorus were reported in the Long Island Sound Study (Hydro Qual, 1991) and the Chesapeake Bay Model Study (Cerco and Cole, 1993). The dry atmospheric deposition was 0.267 kg/ha/yr and the wet deposition concentration was 0.061 kg/ha/yr. The estimated phosphorus loading rate to Mashapaug Pond, located in Providence, Rhode Island, from atmospheric deposition is 25 kg/yr (RIDEM, 2007). The Reckhow Land Use Model (RLUM) was used to estimate phosphorus loadings from various land uses, including an atmospheric component, to waterbody segments in the Ten Mile River. This analysis is explained further in Section 7.0.

Metals

General Studies

Studies focusing on lead in the Los Angeles region (Sabin and Schiff 2007) showed that levels of lead present in resuspended dust far exceeded the supply from contemporary sources now that the main source of lead to the environment, leaded gasoline, has been reduced to near zero levels. Lead levels in the atmosphere and in newly deposited material appear to be supplied by resuspension of "old" lead present in soils and other surfaces.

The Michigan Department of Transportation (MDOT) conducted studies from 1995 through 1997 to evaluate the characteristics and significance of stormwater runoff quality from highways in Michigan (CH2MHILL 1998). As part of the study, concentrations of metals in rainfall were analyzed to assess the contribution that rainfall has on metals concentrations in highway runoff. Rainfall samples were collected at three sites and analyzed for dissolved and total lead, zinc, and copper. Results showed that rainfall provided a substantial source of dissolved and total metals concentrations in runoff during the study period- specifically on average, 41% of total recoverable metals in runoff originated from rainfall while 83% of the dissolved metals in runoff originated from rainfall. The study noted that the high fraction of dissolved metal originating from rainfall was particularly noteworthy because the dissolved fraction is the more bioavailable form and hence more toxic to aquatic life.

Elevated levels of metals in stormwater runoff may be derived from the leaching of metals from metals containing urban infrastructure. Due to the relatively acidic nature of rain in many urban areas, particularly in the northeast, metals in soils, on impervious surfaces, and within a variety of urban infrastructure have the potential to leach into the dissolved phase and enter surface waters. Rainfall pH levels in southern New England, including Rhode Island, measured by the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/) range between 4.5 and 4.7, which indicates that the precipitation is acidic. Previous research has suggested that lead and copper species leached from infrastructure after contact with acid rain are complexed by organic matter or partition to suspended solids, while cadmium and zinc remained primarily in solution (Morrison et al. 1990).

Rhode Island Ambient Air Quality Monitoring

Ambient air quality has been monitored at a network of stations in the State of Rhode Island since 1968. The monitoring network is operated and maintained by the Rhode Island Department of Environmental Management (RI DEM) Office of Air Resources (OAR) and by the Rhode Island Department of Health (RI HEALTH) Air Pollution Laboratory via an interagency contract agreement. The ambient air quality data collected are entered quarterly in the U.S. Environmental Protection Agency's (US EPA's) Air Quality System (AQS).

Rhode Island did not monitor for lead as a criteria pollutant during the years 1993-2010 because, after the removal of lead from gasoline, airborne lead concentrations in the State were substantially lower than the NAAQS for that pollutant. However, in October 2008, the US EPA's health-based NAAQS for lead was changed to 0.15 $\mu g/m^3$ as a rolling three-month average, as measured in Total Suspended Particulate (TSP), a level that is ten times more stringent than the standard it replaced. Since Rhode Island had not measured lead levels using the procedures specified in the NAAQS for many years, no data were available to definitively determine whether the ambient air in the State is in compliance with that standard. In 2011, Rhode Island began monitoring to determine whether lead levels in the State comply with the revised standard; those monitoring results are not yet available but will be presented in future years' Air Quality Data Summaries.

As part of the air toxics program, Rhode Island measures lead in PM_{10}, particles that are 10 micrometers or smaller, at the Urban League monitoring site in Providence. The highest 3-month average concentration of lead in PM_{10} measured at that site since 2007 is 0.005 $\mu g/m^3$, which is 3% of the new NAAQS. Therefore, TSP lead levels would have to be more than 30 times higher than the lead levels in PM_{10} for the Providence site to violate the NAAQS.

Rhode Island measured lead in both PM_{10} and TSP at the Urban League site during 2001 and 2002. During that period, 3-month average TSP lead levels were no more than twice as high as the PM_{10} lead levels. Therefore, it is unlikely that TSP lead levels at that site are now 30 times higher than the PM_{10} lead levels and would, therefore, exceed the new standard. Further, since there are no significant lead emissions sources in the State, it is unlikely that lead levels measured in other areas of the State would be substantially higher than at the Providence site.

Hi-volume PM_{10} samples are collected every sixth day at the Urban League NATTS site and analyzed for eight metals. Previously, that analysis was performed by the US EPA Region I laboratory but, since 2008, the metals analysis has been conducted by the Rhode Island Department of Health Laboratories. One of the metals, beryllium, is rarely detected at levels above the Minimum Detection Level. The remaining metals, antimony, arsenic, cadmium, chromium, lead, manganese and nickel, are frequently detected in the samples. The average concentrations of the detected metals in the Urban League PM_{10} samples for the years 2008-2012 (aside from arsenic) were all below the state's health benchmark values. The health benchmarks for arsenic, cadmium, lead and nickel correspond to a lifetime cancer risk of one in one million and the health benchmarks for antimony, chromium III and manganese, which are not carcinogens, were developed by the US EPA to protect against other health effects.

Based on the above information and the difficulty of relating metals concentrations in air to those measured in the Ten Mile, it does not appear that atmospheric sources of lead or cadmium constitute a significant source to the Ten Mile River. In addition, it would be exceedingly difficult to relate such sources to ambient concentrations in the water column. Nevertheless, it must be assumed that a small portion of the total load of any of lead or cadmium in the Ten Mile River has some atmospheric origin, however at present, this is unquantifiable.

4.11 Background-Natural Sources

Phosphorus

Phosphorus is the eleventh-most abundant mineral in the earth's crust and does not exist in a gaseous state. Natural inorganic phosphorus deposits occur primarily as phosphate in the mineral apatite. Apatite is found in igneous and metamorphic rocks, and sedimentary rocks. When released into the environment, phosphate will speciate as orthophosphate according to the pH of the surrounding soil. There are many sources of phosphorus in aquatic systems. Natural sources include native waterfowl waste, atmospheric deposition, weathering of geologic phosphate material, and plant decomposition.

The decay of plant material, including leaf litter, is an important natural source of phosphorus to many waterbodies, particularly impounded rivers, where the watershed size is much larger than lakes or ponds. Much of the released phosphorus is adsorbed to soil particles, but some may impact receiving waters, via leaching, conveyance by stormwater systems, or by direct deposition. A study conducted in Missouri (Stambaug et al, 2006) found that a typical Ozark forest drops about 2.1 tons of leaf litter per acre each year). Based on estimates of the phosphorus content of leaf litter, that corresponds to between 5.8 and 7 pounds of phosphorus per acre of forest annually.

Metals

Many metals occur naturally in the Earth's crust. They are therefore found naturally in soils and rocks with a subsequent range of natural background concentrations in soils, sediments, waters and organisms. Natural erosion and weathering of crustal materials take place over long periods of time and the amount of heavy metals released is generally small. It is difficult to estimate background levels of metals that exist in the Ten Mile River and impoundments. The river has a long history of contamination dating back to the Industrial Revolution and no metals data are available to evaluate a "natural condition" in the watershed. Nevertheless, it must be assumed that a small portion of the total load of any of the metals of concern in the Ten Mile River has natural origins, however at present, this is unquantifiable.

4.12 Internal Sources-Sediments
Phosphorus
Internal loading, the release of dissolved phosphorus from lake sediments, can play an important role in the phosphorus dynamics of lentic systems. Internal phosphorus loading originates from phosphorus accumulated in the lake sediments. The ultimate source of most of the sediment-bound phosphorus is external (e.g. wastewater or stormwater). Under certain conditions this sediment-bound phosphorus can be released into the water column, resulting in elevated phosphorus concentrations and algal blooms. In some cases, the majority of the phosphorus load to a waterbody can be due to internal loading.

The contribution of internal loading to the total phosphorus load of various waterbodies has been quantified in several studies. Keyes Associates et al. (1982) reported that the sediment was the major source of phosphorus to Gorton Pond, in Warwick, Rhode Island, contributing 54% of the phosphorus load. In 14 of 17 Washington lakes, where phosphorus budgets were available and internal loading was measurable, internal loading averaged 68% of the total phosphorus loading during the summer (Welch and Jacoby, 2001). Internal phosphorus loads accounted for between 56 and 66% of the total phosphorus load to Spring Lake in southwestern Michigan (Steinman and Rediske, 2003).

The phosphorus data for both Omega Pond and Turner Reservoir strongly suggests the occurrence of phosphorus release from pond sediments. Several water column samples were taken at both Omega Pond and Turner Reservoir. Samples were taken at the deepest areas of the ponds, at 1 meter below the surface and 1 meter above the bottom. The ponds were sampled on six occasions, between June 3 and October 8, 2009. Samples were analyzed for total phosphorus. Both ponds have elevated phosphorus concentrations in bottom waters relative to surface concentrations. Specifically, for the entire sampling period, for Turner Reservoir, the mean surface total phosphorus concentration was 73 ug/l, while the mean bottom concentration was 97 ug/l. For Omega Pond, the difference between phosphorus concentrations at the surface and at depth is even more pronounced. For the same period, for Omega Pond, the mean surface concentration was 77 ug/l, while the mean bottom concentration was 162 ug/l.

Dissolved oxygen and temperature data from Turner Reservoir and Omega Pond indicate that the ponds become intermittently stratified during the summer months. The difference between surface and bottom concentrations is more pronounced during periods of stratification. Probes were installed in both Omega Pond and Turner Reservoir, at 1m below the surface and 1m above the bottom. The probes took continuous measurements of temperature and dissolved oxygen, as well as other parameters. The probes were deployed on June 30 and removed on September 24, 2009. Both temperature and dissolved oxygen data indicated that there were 3-4 episodes of both stratification and anoxia in the bottom waters, in both ponds. These periods of stratification were interrupted by storm events. The resulting high flows were sufficient to perturb the weakly stratified ponds, mixing the entire water column, and reoxygenating the bottom waters. There were 42 days of anoxia in the bottom waters of Turner Reservoir and 55 anoxic days in Omega Pond. Phosphorus samples were taken during two periods of stratification and anoxia, on June 30 and August 20, 2009. The mean surface phosphorus concentration in Turner Reservoir for these two days was 70 ug/l, while the mean bottom concentration was 120 ug/l. For the same period, for Omega Pond, the mean surface concentration was 75 ug/l, while the mean bottom concentration was 240 ug/l.

Although the available data suggests the release of phosphorus from pond sediments is indicated in only Omega Pond and Turner Reservoir, internal cycling may also be occurring in the other impoundments of the Ten Mile River located in Massachusetts. In addition, phosphorus release from sediments of a waterbody does not necessarily constitute a phosphorus 'load' to that waterbody. Destratification occurs as a result of an increase in flow and a net transport of material (including phosphorus) downstream (i.e. over the spillway). It does not diffuse up-reservoir (against the gradient) and become available for algal growth.

5.0 Pathogen TMDL Analysis

5.1 Applicable Water Quality Criteria and Numeric Targets

Two applicable water quality criteria for pathogens apply in the Ten Mile River: 1) a geometric mean for **enterococci** less than 54 colonies/100ml, and 2) a geometric mean for **fecal coliform** of less than 200 MPN/100ml and a 90^{th} percentile value less than 400 MPN/100ml, <u>applied only when adequate enterococci data are not available.</u>

For this TMDL, the numeric water quality targets for all waterbody segments are set to either/both applicable water quality criteria described above. The exception is Omega Pond, which discharges directly to the tidal Seekonk River; a Class SB (saltwater) waterbody. In some areas, a waterbody segment with higher allowable limits of pathogens discharges to or is adjacent to a waterbody with more stringent criteria. In these places, the numeric water quality target must be the more strict criteria at the station nearest the boundary with the higher water quality standard.

The numeric water quality targets for Omega Pond must therefore meet the more stringent Class SB pathogen criteria, which are: an enterococci geometric mean less than 35 colonies/100ml and/or a fecal coliform geometric mean of less than 50 MPN and a 90^{th} percentile criteria less than 400 MPN.

5.2 Water Quality and Resource Impairments

Geometric mean and percentile statistics calculated from available pathogen data collected in 2007 and 2008 were used to determine initial compliance with the applicable pathogen criteria. This initial analysis (Tables 5 and 6) confirms the existing 303d pathogen listings for the upper Ten Mile River (RI0004009R-01A) and Omega Pond (RI0004009L-03). The impaired use is primary and secondary contact recreation, which primarily occurs during and after wet weather events

5.3 Seasonal Variation and Critical Condition Analysis/ Margin of Safety

Clean Water Act Section 303(d)(1)(C) requires that TMDLs “be established at a level necessary to implement the applicable water quality standards with seasonal variations…”. The Code of Federal Regulations (CFR) [40 CFR 130.7(c)(1)] states that determination of “TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters”. Seasonality and critical condition analysis were included in the TMDL and are described below.

Seasonal Variation

Seasonality addresses the need to insure year-round beneficial use support. Analysis of the existing data show that the highest levels of pathogens in the Ten Mile River are associated with wet weather events. Since wet weather events occur during all seasons, seasonality was not considered an issue. Additionally, Rhode Island’s water quality criteria for pathogens apply year round at all times. Because the numeric targets in this TMDL are equivalent to the applicable pathogen criteria, the TMDL’s for waterbody segments in the Ten Mile River are applicable at all times and are therefore protective of water quality under all seasons.

Critical Condition Analysis

Clean Water Act Section 303(d)(1)(C) states that determination of "TMDLs shall take into account critical conditions for streamflow, loading, and water quality parameters" [40 CFR 130.7(c)(1)]. The intent of this requirement is to ensure that water quality is protected during times when it may be most vulnerable to pollution. Critical conditions are important because they describe the condition(s) that cause a clear majority of violations of water quality standards and help in identifying the actions that may have to be undertaken to meet those standards.

As part of the critical condition analysis, available pathogen data were evaluated with respect to precipitation and streamflow response. Daily rainfall data for the watershed were obtained from the National Weather Service website: http://www.weather.gov/climate/index.php?wfo=box. Streamflow data were obtained from the US Geological Survey station located on the Ten Mile River: http://nwis.waterdata.usgs.gov/ri/nwis/uv?site_no=01109403

Hydrographs generated from either mean daily or hourly flow data were evaluated relative to prior rainfall over the watershed and the date and time of sample collection. This allowed for segregation of pathogen data into either a 'wet-weather/stormflow' condition or 'dry weather/baseflow' condition. Geometric mean and percentile statistics were then run on each dataset. Adequate enterococci data were not available for Central Pond, Turner Reservoir, Omega Pond, or the lower Ten Mile River. Table 23 displays geometric mean and 90th percentile statistics generated from this analysis as well as all pooled data.

For the majority of waterbody segments, the highest levels of pathogens were associated with wet weather-stormflow events. This was not unexpected given the large amounts of impervious surface cover in the Ten Mile River watershed. Research by Mallin et al. (2000) showed a strong correlation between runoff from impervious land cover in a coastal watershed and resulting deterioration of stream water quality. Mallin et al (2000) demonstrated that the most important anthropogenic factor associated with fecal coliform and e. coli abundance in coastal watersheds was percentage watershed impervious surface coverage. The study found that highly degraded water quality, as defined in the study by microbiological quality, occurred above 20% imperious surface threshold.

The majority of the watershed (31,238 acres- 12642 ha) is located in Massachusetts and total coverage by impervious surfaces in the MA portion is 20%, whereas 42% of the 3007 acres (1217 ha) of the watershed in the RI portion is impervious. Because increases in impervious cover generally translate to increases in stormwater runoff it is reasonable to assume that stormwater runoff plays a significant role in the sanitary quality in all waterbody segments of the Ten Mile River.

Table 23. Pathogen Statistics for Waterbody Segments within the Ten Mile River.

Waterbody Name / Location	WQ Station (s)	Fecal Coliform Statistics (fc/100ml)						Enterococci Statistics (colonies/ml)	
		Geometric Mean	90th Percentile	DW Geometric Mean	WW Geometric Mean	DW 90th Percentile Value	WW 90th Percentile Value	4-YR DW Geometric Mean	4-YR WW Geometric Mean
MA/RI State Line	TM1	384	1980	284	489	304	3540	na	na
Upper Ten Mile River[a]	TM2	176	796	89	304	215	828	na	na
	TM3	303	864	320	290	627	1032	72	552
Central Pond	TM4	42	204	23	67	117	212	na	na
Turner Reservoir	TM5	13	100	23	8	46	68	na	na
Lower Ten Mile River	TM6	79	200	89	71	254	308	na	na
	TM7	82	254	100	67	147	286		
Omega Pond[a]	TM8	66	1104	22	157	70	1552	na	na

[a] 303(d) pathogen listing segment for which a TMDL is developed (shaded)

As shown in Table 23, the wet weather 90th percentile values for fecal coliform bacteria exceeded the respective water quality criteria most often for waterbodies on the 303(d) list for pathogens. In addition, the upper Ten Mile River segment wet weather geometric mean value for enterococci were over nine times the dry weather geometric mean value.

For this TMDL, wet weather defines the critical condition. Data from this critical period were used to estimate the required percent reductions in pathogen concentrations in the Ten Mile River and Omega Pond. Percent reductions for fecal coliform bacteria were based on the difference between the calculated wet weather 90th percentile value and the primary contact/recreational use 90th percentile criteria. Enterococci reductions were based on the 4-year wet weather geometric mean value. A combination of pollution reductions based on wet weather bacteria loadings and identification and correction of other point and nonpoint loadings is expected to result in attainment of applicable water quality criteria during a majority of the time.

Margin of Safety

A margin of safety (MOS), designed to account for uncertainty in TMDL calculations, is a required element of a TMDL [40 CFR 130.33(b)7]. The MOS can be expressed explicitly as unallocated assimilative capacity, or can be incorporated implicitly in the TMDL through the use of conservative assumptions when calculating the allowable load (EPA 1991). The TMDL must contain a margin of safety (MOS) to account for uncertainty in the analysis.

Highly impounded and urbanized river systems such as the Ten Mile are difficult to assess given the variations in flow regime and the flushing and dilution characteristics of each impoundment; particularly with respect to stormflow conditions and multiple stormwater discharges. The sanitary quality of surface waters can be influenced to a large degree by meteorological conditions such as precipitation, solar radiation, and water/air temperature. Confounding factors also include the inherent variability associated with pathogen source 'generation' and 'transport' to surface waters.

A moderate level of uncertainty exists with respect to the sources of pathogens and their quantifiable effects on the sanitary quality of receiving waters in the watershed. Sources such as stormwater runoff and waterfowl can be specified with reasonable confidence since they contribute pathogens on a frequent basis, are relatively easy to identify, and oftentimes provide visual evidence of impact. Others sources such as failing onsite wastewater treatment systems, illicit discharges to stormdrains, and leaking sewer lines, may be more ephemeral and/or may occur without detection. In this TMDL, an explicit margin of safety equal to an additional <u>ten (10) percent of the calculated existing load</u> was assumed to conservatively account for possible uncertainties in the analysis such that:

FECAL COLIFORM ((90th Percentile Statistic X 0.10) + 90th Percentile Statistic) = 'existing' concentration

ENTEROCOCCI ((Geometric Mean Statistic X 0.10) + Geometric Mean Statistic) = 'existing' concentration

5.5 Establishing the Allowable Loading (TMDL)

While TMDL allocations are often expressed on a mass-loading basis (e.g. kilograms per day), EPA recommends establishing concentration-based TMDLs for pollutants that are not readily controllable on a mass basis (USEPA, 2001). Since the mass per day or total number of indicator organisms per day is not significant with respect to public health risk and protection of beneficial uses, concentration, the number of organisms in a given volume of water, is a more technically relevant criterion for assessing the relative impact of pollution sources, the sanitary quality of the waterbody, and the public health risk.

In this TMDL, the allowable load or loading capacity for each waterbody is expressed as a concentration set equal to the applicable water quality standard. Concentration is considered to apply daily because daily values are used to calculate the geometric means and percent variability. The allowable daily load is the criterion concentration multiplied by the flow in the receiving water. For the purposes of implementation and the reasons expressed below, the concentration and percent reduction pathogen TMDL targets are used.

Expressing bacteria TMDL reductions in terms of concentration provides a direct link between existing water quality and the numeric water quality criteria.
Using concentration to set TMDL reductions is more relevant and consistent with water quality standards, which apply for a range of flow and environmental conditions.

Expressing bacteria TMDL reductions as daily loads can be more confusing to the public and can be more difficult to interpret since they are dependent on flow conditions.

The waters of the state are assigned to an assessment unit (AU), which refers to a waterbody or waterbody segment. Each assessment unit has been assigned an identifying number, referred to as a waterbody ID number. In some cases the entire waterbody is considered as one AU, which is generally the case for lakes in the state. In other cases, the waterbody is segmented into several AUs. Water quality data collected within an AU is considered to be representative of the entire AU unless and until more recent data or information indicate otherwise.

Of the five (5) waterbody AU's in the Ten Mile River watershed, two (2) are on the states' 2012 303 (d) list for pathogens. Table 24 lists the sampling stations which were used to characterize the sanitary conditions in each of these waterbody segments, as well as at the state line. Figure 1 provides additional geographic information on waterbody segment locations and compliments Table 24. Station TM1, located at the MA/RI state line, was used to assess the pathogen load, expressed as a concentration, in the Ten Mile River at the state line.

Table 24. Stations Used to Develop pathogen TMDLs in the Ten Mile River.

Waterbody ID	Waterbody Segment Name	2010 303(d) Pathogen Listing	Station (s) Used to Determine Existing Condition	Total number of pathogen samples used for analysis
-	Ten Mile River at State Line	Fecal Coliform	TM1	5
RI0004009R-01A	Upper Ten Mile River	Fecal Coliform, Enterococcus	TM2, TM3 (fc) URI WW station[1] (ent)	10 11
RI0004009L-03	Omega Pond	Fecal Coliform	TM8	5

fc= fecal coliform, ent= enterococci
[1]Station location same as RIDEM TM3.

5.6 Required Reductions

Both the allowable and existing loads for this TMDL are expressed as a concentration. Allowable concentrations are set equal to the percentile portion of the applicable state water quality standard for fecal coliform bacteria (400 fc/100ml) and/or the geometric mean standard for enterococci (54 MPN).

For purposes of determining the required reductions, the observed pathogen concentration is derived from statistical analysis of wet weather pathogen data. In the upper Ten Mile River, data from two stations are used to characterize the existing fecal coliform concentration. In this case, the observed concentration is the largest of the two stations' individual 90th percentile values. Enterococci data for the upper Ten Mile River are available from a single URIWW station from 2008-2011. As such, the wet weather geometric mean statistic is calculated from this single station dataset (n=11). Data from a single station each, characterize the existing sanitary conditions in Omega Pond. Existing concentrations incorporate a 10% MOS as described in Section 5.3.

Pathogen reductions were then calculated from the difference between the observed and target concentration values at each relevant station. In the case of fecal coliform bacteria, it is expected that if the specified reductions to the 90th percentile values take place, the geometric mean values will also be met. Table 25 presents waterbody segment geometric mean and 90th percentile statistics for fecal coliform bacteria and enterococci. The required reductions needed to meet the TMDLs are also shown in Table 5.3. All pathogen data are presented in Appendix A, Tables 1 and 2.

Final waterbody segment reductions for fecal coliform range from 65% in the Upper Ten Mile River to 77% in Omega Pond. A 93% reduction in enterococci concentration is required in the Upper Ten Mile River. A 90% reduction in the existing fecal coliform concentration is required at the MA/RI state line.

Table 25. Ten Mile River Pathogen TMDL Reductions.

Waterbody Name	Representative WQ Station(s)	Fecal Coliform[1] Statistics (fc/100ml)			Enterococci[2] Statistics (colonies/ml)		
		WW 90th Percentile Value[a]	90th Percentile Criteria	Required Reduction[2]	WW Geometric Mean[a]	Geometric Mean Criteria	Required Reduction
MA/RI State Line	TM1	3894	400	90%	na	54	na
Upper Ten Mile River[1]	TM2	911	400	56%	na	54	na
	TM3	1135	400	65%	552	54	93%
Omega Pond[a]	TM8	1707	400	77%	na	54	na

[a] Statistics calculated from wet weather-stormflow dataset and include a 10% MOS.
[1]2012 303(d) listing is for fecal coliform and enterococci.
[2]Final segment reduction in shaded cell.

State Line Reduction

To ensure that the upper reaches of the Ten Mile River in Rhode Island meet applicable water quality criteria, this TMDL sets a fecal coliform reduction target of 90% at the MA/RI state line. Though applicable criteria are exceeded during dry weather, as described previously, wet weather conditions represent the critical condition upon which the reduction target is based. Thus at the state line, the most prevalent source of pathogens from the Massachusetts portion of the watershed, is likely stormwater runoff from impervious areas of Attleboro and North Attleborough. Clearly these sources impact the sanitary quality of the Ten Mile River in Rhode Island, inclusive of the impoundments. Other sources such as illicit connections or sanitary sewer leaks may occur as well. As shown in Table 23, the highest wet weather geometric mean and 90th percentile values for fecal coliform in the watershed exist at the MA/RI state line.

MADEP intends to develop pathogen TMDLs for the Ten Mile River watershed at some point in the future. MADEP's current approach to setting LA's and WLA's for pathogen sources will likely apply with the future Ten Mile River TMDLs (Rick Dunn, personal communication) such that pathogen sources such as (illicit discharges to storm drains and leaking sanitary sewers) would receive a WLA of zero (0). As a source, stormwater runoff would receive a WLA equivalent to applicable water quality criteria.

For the Ten Mile River segment from the North Attleborough WWTP discharge to the MA/RI state line the fecal coliform criteria adopted by the state of Massachusetts is as follows: *a geometric mean ≤ 200 colonies/100 ml, no more than 10% of samples above 400 colonies/100 ml*. Accordingly, this will be the projected stormwater WLA for this segment of the Ten Mile River when the TMDL is developed. These WLA are expected to provide adequate protection of RI's fecal coliform criteria for the upper segment of the Ten Mile River at the state line. The most recent (2008) NPDES permit limits for the Attleboro WPCF and North Attleborough WWTF are presented in Table 26. These limits apply year round and insure that applicable in-stream pathogen criteria are met.

Table 26. NPDES Permit Limits for fecal coliform at applicable MA facilities.

Facility	Permitted Discharge in MGD	Monthly Average	Daily Maximum	Sampling Frequency
North Attleboro WWTF	4.6	200 CFU/100ml	400 CFU/100ml	3/week
Attleboro WPCF	8.6	200 CFU/100ml	400 CFU/100ml	2/week

5.7 Load and Wasteload Allocations

EPA guidance requires that load allocations be assigned to either point (waste load) or nonpoint (load) sources. As is the case for most bacteria impairments, insufficient data exist to accurately differentiate between point and nonpoint sources of bacteria. In addition, there is no meaningful method to determine specific bacterial loading from multiple stormwater systems with hundreds of outfalls distributed through a combined bi-state watershed area of nearly 140 square kilometers. It has been clearly documented in the literature that waterbodies located within highly urbanized watersheds suffer from poor sanitary quality due to impacts from urban runoff.

As recommended by EPA Region 1, all bacteria source reductions for this TMDL are combined into the waste load allocation. However, in implementing this TMDL, both point and nonpoint controls in RI and MA will be necessary to meet the TMDL plan's water quality targets. As a source, stormwater runoff will receive 100% of the waste load allocation. It is difficult to determine the scale of reductions specifically necessary for regulated stormwater discharges such that water quality criteria will be met during wet weather. However, the WLA given to stormwater for these municipalities will require that the Phase II mandated six minimum measures be fully implemented and following an adaptive management approach, that structural best management practices be constructed to treat priority stormwater discharges such that bacteria loads are reduced to the maximum extent feasible.

Sources of fecal coliform bacteria such as failing septic systems that flow (via groundwater seeps and/or overland flow) into storm drains, illegal connections to storm drains, and leaking sanitary sewer lines will receive a waste load allocation of zero (0) since they are prohibited. Although waterfowl such as resident geese and mute swans are considered a likely source of pathogens to specific waterbody segments in the Ten Mile River-particularly in the vicinity of Slater Park Pond, it is exceedingly difficult to quantify these sources such that appropriate load allocations may be assigned. Although no load allocation is assigned, implementation activities must focus on abating this source to the maximum extent practicable using best available technologies. These are described further in the implementation section of this report.

Although there is little evidence that illicit connections, failing septic systems and/or sanitary sewer leaks have caused the observed pathogen elevations during wet weather, it is probable that they exist, have existed in the past, and may occur in the future. Therefore priority must be given to eliminating illicit connections and ensuring adequate sanitary waste disposal as a first step, where relevant. Implementation activities addressing these prohibited sources are currently incorporated into municipalities' Phase II Stormwater Programs.

The wasteload allocations given to stormwater for the cities of Pawtucket and East Providence will require that the Phase II mandated six minimum measures be fully implemented and following an adaptive management approach, that structural best management practices be constructed to treat priority stormwater discharges such that pathogen loads are reduced to the maximum extent feasible. This TMDL will require amendments to the Rhode Island municipalities' SWMPP. These amendments are described in detail in the Implementation Section of this TMDL.

Concentration-based bacteria TMDLs set the WLA and LA equal to the ambient water quality criterion and compliance is measured at ambient stations representative of conditions throughout the water body. Consequently, this TMDL approach represents a very conservative TMDL target-setting. There is a high level of confidence that the TMDLs established are consistent with water quality standards, and the entire loading capacity can be allocated among sources.

Wasteload allocations for the Upper Ten Mile River and Omega Pond are presented below.

Upper Ten Mile River (Segment RI0004009R-01A)

The required fecal coliform concentration reduction for the upper Ten Mile River segment is 65% and the required enterococci concentration reduction is 93%. For this segment of the river, the most significant source of pathogens, aside from sources originating upstream in the MA portion of the watershed and quantified at the state line, is stormwater runoff from contributing watershed areas in the City of Pawtucket, RI and the town of Seekonk, MA. The City of Pawtucket owns 5 outfalls that discharge to the upper Ten Mile River and the Town of Seekonk owns 18 outfalls that discharge to the river. In addition, a RIDOT owned outfall discharges to southwestern side of Slater Park Pond just above the spillway. All stormwater sources in RI will receive 100% of the wasteload allocation. Other possible sources present during both wet and dry weather may include (and have historically included) illicit discharges to stormdrains and leaking sanitary sewer lines. These sources will receive a wasteload allocation of zero (0).

There is little evidence that the upper segment of the Ten Mile River from the state line to the inlet of Slater Park Pond is impacted by resident waterfowl such as geese, as the existing riverine habitat does not appear to be ideal. The lower portion of the upper Ten Mile River from the outflow of Slater Park Pond to the inflow of Central Pond is, however, likely impacted by resident geese populations that frequently utilize the ideal habitat found at the Pawtucket Country Club and adjacent Slater Park Pond. DEM staff have noted moderate to heavy amounts of fecal material deposited by geese in the parking lot of the golf course and on the green areas. Much of this area drains directly to the pond. During the TMDL study, fecal material from geese is visible on the shoreline of the pond as well as on the substrate of the shallow areas of the pond. Since data collection activities began, the course has implemented various goose managment strategies that has resulted in a significant reduction in courses goose population. On a recent site visit, DEM observed no goose fecal material anywhere along the shoreline or in the parking lot of the course.

Another area frequented by resident geese and ducks is the pond within Slater Memorial Park, located within the City of Pawtucket. The pond is known to harbor significant populations of resident geese, swans, and ducks and it appears that feeding by park visitors does occur along the western side of the pond. The pond is hydraulically connected to the Ten Mile River via a small stream. Although this source category will not receive a load allocation, the TMDL will recommend measures that can be taken by the park staff to discourage or remove resident geese and other waterfowl from this location.

Omega Pond (Segment RI0004009L-03)

The required fecal coliform concentration reduction for Omega Pond is 77%. Aside from upstream sources, discussed above, the most prevalent source of pathogens to the pond is direct stormwater runoff discharges from the contributing watershed in the City of East Providence. The City of East Providence reports that 7 outfalls discharge to Omega Pond. RIDOT owns two outfalls that discharge to the lower Ten Mile River: which in turn discharges to Omega Pond. Any stormwater sources to this segment will receive 100% of the wasteload allocation. A wasteload allocation of zero (0) is set for illicit discharges to stormdrains and/or leaking sanitary sewer lines. There is little evidence that waterfowl or other nonpoint sources of pathogens exert any appreciable influence on the sanitary quality of Omega Pond. There is some evidence of an illicit connection(s) to the outfall draining just above Omega Pond at the railroad tracks. This TMDL will require additional investigation by the City of East Providence to confirm or refute the existence of this source.

The lower Ten Mile River is bisected, just upstream of Omega Pond, by the Agawam Hunt Club, a golf course located in East Providence. A site visit of the course by DEM staff revealed significant numbers of geese on and near the fairways and greens. In some areas, fecal material was observed adjacent to waterways leading to the Ten Mile River. Since data collection activities began, the course has implemented various goose managment strategies that has resulted in a significant reduction in courses goose population. On a recent site visit, DEM observed no goose fecal material anywhere along the shoreline or in the parking lot of the course.

5.8 Reasonable Assurance

EPA guidance calls for reasonable assurance when a TMDL is developed for waters impaired by both point and nonpoint sources. If a point source is given a less stringent wasteload (i.e. point source) allocation based on an assumption that nonpoint source load reductions will occur, there must be reasonable assurance that the nonpoint source reductions will occur before the TMDL can be approved. EPA uses this information to determine whether the load and wasteload allocations will achieve water quality standards. In this case, reasonable assurance is ***not*** required because point sources are ***not*** given less stringent wasteload allocations. As mentioned previously in Section 5.7 and as recommended by EPA Region 1, all bacteria sources are combined into the wasteload (i.e. point source) allocation.

6.0 Metals TMDL Analysis

6.1 Existing Metals Impairments

Rhode Island's final 2012 303(d) list identifies five waterbody segments within the Ten Mile River watershed as not supporting the designated use of fish and wildlife habitat. The impairments contributing to the loss of this designated use are dissolved cadmium (Cd) and lead (Pb), and total aluminum (Al) and total iron (Fe). Total phosphorus and dissolved oxygen also impair this designated use and are discussed separately in section 7.0.

Section 3.0 of this report presents an analysis of the relevant metals data collected by RIDEM staff in 2007 and 2008. In summary, violations of the chronic criteria for various metals were numerous and widespread throughout the mainstem and impoundments during the nine surveys; Table 27 displays the total count of chronic criteria violations of total aluminum and iron and dissolved lead and cadmium. These statistics are inclusive of all five waterbody segments in the Ten Mile River. There were no acute criteria violations of any of the metals sampled during the 2007-2008 monitoring period.

Table 27. Total[1] Violations of the Chronic Metals Criteria in all Waterbody Segments in Ten Mile River, RI.

Dissolved or Total Metal				
Flow/Weather Condition	**Cadmium**	**Lead**	**Aluminum**	**Iron**
Stormflow-wet weather	13	4	21	4
Base/low flow-dry weather	0	2	5	0

[1]Combined sample size for all stations is 72.

Violations of the chronic criteria for dissolved lead and total aluminum occurred under both dry weather-baseflow conditions and wet weather-stormflow conditions. Violations of dissolved cadmium and total iron occurred solely under wet weather-stormflow conditions. The higher frequency of violations for all metals during the stormflow condition occurred because in nearly all cases, both the metal concentrations were higher and the hardness of the water samples (and thus the criteria) was lower. In general, both the median and maximum values of cadmium, lead, aluminum, and iron were highest at the MA/RI state line (Table 28).

6.2 Critical Conditions and Seasonal Variation

Clean Water Act (CWA) and regulations require that TMDLs be established with consideration of critical conditions and seasonal variations, and that they describe the method chosen for including seasonal variations. Seasonality and critical condition analysis were included in the TMDL and are described below.

Table 28. 2007-2008 Metals Summary in the Ten Mile River and Impoundments.

	Metal Concentration in ug/l (ppb)							
	Dissolved Cadmium		Dissolved Lead		Total Aluminum		Total Iron	
General Location (Sampling Station)	**Median**	**Maximum**	**Median**	**Maximum**	**Median**	**Maximum**	**Median**	**Maximum**
MA/RI State Line (TM1)	0.17	0.54	1.30	3.10	95	180	790	1100
Slater Park Pond outlet (TM2)	0.12	0.27	0.79	3.00	107	170	685	1200
Central Pond inlet (TM3)	0.11	0.22	0.80	2.70	98	170	620	1100
Central Pond outlet (TM4)	0.05	0.32	0.49	1.30	57	97	420	730
Turner Reservoir outlet (TM5)	0.05	0.30	0.39	0.96	48	99	470	620
Ten Mile River (TM6)	0.05	0.30	0.38	1.00	64	100	430	640
Omega Pond inlet (TM7)	0.05	0.33	0.28	1.10	62	97	390	630
Omega Pond outlet (TM8)	0.05	0.29	0.28	0.90	51	130	450	740

Critical Conditions

The Clean Water Act, Section 303(d)(1)(C) requires that TMDLs "be established at a level necessary to implement the applicable water quality standards with seasonal variations". EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality is protected during times when it is most vulnerable. Critical conditions are important because they describe the single or multiple factors that cause violations of water quality standards. Furthermore, Rhode Island Water Quality Regulations (RIDEM 2010) state the acute and chronic aquatic life criteria for freshwaters shall not be exceeded at or above the 7Q10 flow. The range of flows surveyed included a low flow condition that closely approximates the calculated 7Q10 flow for each segment.

The critical flow/weather conditions for these TMDLs occur when the ratio of effluent or contaminated stormwater to stream flow is the greatest. These are found under both baseflow and wet weather-stormflow conditions. Both conditions were examined based on analysis of the data and knowledge of both existing and historic sources.

The critical condition for aquatic life protection most applicable to point source loadings such as wastewater treatment facility discharges usually involve periods of low or baseflow because the volumes associated with the point sources generally do not decrease with decreased streamflow. In other words, the assimilative capacity of the waterbody decreases with decreasing flow and increasing or constant point source load. As a result, the highest ambient pollutant concentrations associated with specific point source loads are generally expected under baseflow conditions. Under baseflows, the Ten Mile River can be characterized as 'effluent-dominated', meaning that a majority of the flow in the river is comprised of treated effluent from both the North Attleborough WWTF and the Attleboro WPCF. The lower the baseflow in the river, the more pronounced this effect becomes and the more various water quality parameters in the river are affected by the treated effluent.

Stormflow-wet weather conditions in the river are heavily influenced by the watershed's urban character, as increases in impervious cover translate to increases in both the volume of flow and quantity of pollutants in stormwater runoff. The total coverage by impervious surfaces in the Ten Mile River watershed is 20% in Massachusetts and 42% in Rhode Island. Existing data show that elevated levels of metals occur during the wet weather stormflow condition. This is the period when metals are introduced into the water column via stormwater inflows and scour of contaminated streambank and streambed sediments. As shown in Tables 10 and 28, the wet weather storm-flow condition results in the highest metal concentrations and most frequent chronic criteria violations of those metals.

Seasonality

Seasonality addresses the need to insure year round beneficial use support. The largest sources of metals include treated wastewater and stormwater, both of which occur year-round. The data used to develop the metals TMDLs were collected under a wide range of flow conditions, including base flow and stormflow. Surveys were conducted primarily during the spring and summer but these conditions can occur during any season.

Violations of the aquatic life criteria were found to occur under both conditions but with greater frequency under the wet weather stormflow condition. Since both the baseflow and wet weather condition can occur during any season and all data were used in the analysis, seasonality was thought to be adequately incorporated in this TMDL analysis. Additionally, Rhode Island's water quality criteria for aquatic life criteria apply year-round at all times. Because the numeric targets in this TMDL are equivalent to the applicable criteria, the TMDLs are applicable at all times and are therefore protective of water quality under all seasons.

6.3 Margin of Safety

A moderate amount of uncertainty exists with respect to individual and/or categorical sources of metals in the Ten Mile River and their relative contributions (loads) to the levels of total and dissolved metals measured in the water column. Unquantifiable sources include contributions from stormwater runoff, groundwater and contaminated streambed or streambank sediments. Effluent metals data exist for both wastewater treatment facilities, however it is reported as monthly averages which makes it difficult to relate to the measured levels in the water column on any given sample day.

Contaminated groundwater may be a source of metals to the Ten Mile River. Groundwater discharges to storm drains or directly to the river may introduce metals from contaminated sites to the river. There are several Resource Conservation and Recovery Act (RCRA) facilities in both Massachusetts and Rhode Island that are within the surface water and/or groundwater drainage of the Ten Mile River. Analytical results of groundwater samples collected from many of these sites have indicated the presence of various metals including aluminum, cadmium, zinc, lead, and copper. In addition, wetland and waterway testing of various sites has also shown elevated levels of various metals. In many cases, the hydraulic connection from the site to the river or impoundment is only inferred, making the determination of impact speculative at best. Overall, these specific contaminated sites and their potential groundwater contributions of metals to the Ten Mile River and impoundments are poorly characterized. Natural attenuation of lead and cadmium from these sites may occur however without comprehensive groundwater monitoring loading rates are unquantifiable.

The release of metals from sediments to the water column via re-suspension, sloughing and/or desorption represents another potential source of contamination to the Ten Mile River-particularly in the Rhode Island segment which has received years of contaminated discharges from the numerous jewelry and plating industries in Attleboro, North Attleboro, and Plainville. The fate of toxic metals in sediments underlying surface waters and impoundments of the Ten Mile River depends on a combination of physical, chemical, and biological processes. These conditions may vary dramatically, both spatially and temporally, in response to factors ranging from seasonal changes and storm events to human activities such as dredging or remediation efforts. In addition, the movement of metals is influenced by factors such as sorption, redox gradients, and pH, which in turn are greatly influenced by microbial communities and their activities (Ford et al. 2005). The bacterial community metabolism can affect valence states of metals via oxidation/reduction reactions, thereby altering the chemical speciation, fate, and the ultimate toxicity of the contaminant (Ford et al. 2005).

Levels of metals in the water column have been found to vary on a diurnal and seasonal basis due to: 1) sorption of metals to the surfaces of streambed material, 2) cycles of formation and dissolution of minerals containing metals, 3) uptake of metals by growing aquatic plants (particularly extensive algal blooms), 4) changes in the geochemical conditions within the streambed, and 5) diurnal variation in streamflow (Nimick et al 2003). Diurnal variation in levels of metals can also be due to diurnal variations in point source inputs.

A margin of safety (MOS), designed to account for uncertainty in TMDL calculations, is a required element of a TMDL [40 CFR 130.33(b)7]. The MOS can be expressed explicitly as unallocated assimilative capacity, or can be incorporated implicitly in the TMDL through the use of conservative assumptions when calculating the allowable load (EPA 1991). The TMDL must contain a margin of safety (MOS) to account for uncertainty in the analysis.

The MOS for this TMDL is explicit and was calculated by taking 10 percent of the total loading capacity as generated from the equations in Table 1.3 (for dissolved Cd and Pb) using the sampled hardness concentration. This 10 percent amount is essentially reserved: it is not available for a wasteload or load allocation and therefore makes the allocations smaller and thus, more protective. For example, if the calculated loading capacity for total aluminum on a particular survey date is 100 lb/day, then 10% or 10 lbs would be allocated to the MOS. Therefore, the wasteload and load allocation would have to equal 90 lbs/day (100 lb minus 10 lbs). The 10% MOS is only applied to the allowable load when actual violations of a metals criteria occurs.

6.4 Technical Analysis-Overall Approach

As stated earlier, of the nine surveys completed during 2007 and 2008, five were carried out in a wet weather stormflow condition and four were under a baseflow condition. Of the four baseflow surveys, one was completed very near the 7Q10 condition. The metals data collected in the mainstem and impoundments were thought to be adequately representative of these weather/hydrologic conditions. Because the aquatic life criteria are required to be met under all flow conditions, data from all nine surveys were used to evaluate the range of existing and allowable daily loads.

The technical approach used to develop the load-based TMDLs consisted of: 1) estimating the flow regime at various locations in Ten Mile River for each of nine (9) surveys, 2) determining applicable metals criteria under the varying flow conditions, 3) where applicable, utilizing these criteria to determine the loading capacities, during each survey, 4) calculating metals loads under each of the nine surveys, and 5) comparing these loads to the allowable loads and determining necessary load reductions. Differing percent reductions were obtained from different survey analysis and therefore a range of reductions for each individual toxicant are presented. This TMDL sets allowable loads for dissolved lead and cadmium and total iron and aluminum to the Ten Mile River at the MA/RI state line applicable under the critical 7Q10 condition as well as higher flow conditions. The technical analysis is detailed in the following sections.

Geographical Framework for TMDL Analysis

Figure 5 displays the location of 2007-2008 data collection stations used to develop this TMDL relative to the waterbody segments of concern. Existing and allowable daily loads were calculated for each of the eight stations in the RI portion of the watershed. Table 29 provides additional information and accompanies Figure 5. Outflow metal concentration and discharge were used to estimate loadings to each waterbody.

Station TM1 was sited to characterize metals concentrations in the Ten Mile River at the Massachusetts-Rhode Island state line. The upper segment of the Ten Mile River (RI0004009R-01A) begins at the RI/MA state line and ends approximately 3.1 miles (5.0 km) downstream at the inflow to Central Pond. Two sampling stations (TM2-TM3) were used to evaluate metals concentrations in the upper Ten Mile River segment.

Central Pond (RI0004009L-01A) and Turner Reservoir (RI0004009L-01B) are two hydraulically connected impoundments separated by State Route 152. The Central Pond-

Turner Reservoir complex has a combined surface area of approximately 215 acres (87 ha). Central Pond discharges to Turner Reservoir via a box culvert, under the road, approximately 20 feet (6.1 m) wide. Average depths, based on recent bathymetric survey data, in Central Pond and the Turner Reservoir are 4 feet (1.2 m) and 7.5 feet (2.3 m), respectively. The calculated residence time for the combined Central-Turner impoundment under the 7Q10 flow is approximately 50 days. Metals data collected at stations TM4 and TM5 were used to evaluate metals concentrations in Central Pond and Turner Reservoir, respectively.

The lower segment of the Ten Mile River (RI0004009R-01B) begins at the outflow of the Turner Reservoir and ends at the inflow to Omega Pond. The total length of this lower segment is approximately 3.2 miles (5.2 km). Metals data collected from stations TM6 and TM7 were used to evaluate the lower Ten Mile River segment. Omega Pond (RI0004009L-03) has a surface area of approximately 30 acres (12 ha) and an average depth of nearly 9 feet (2.7 m). The residence time under the 7Q10 flow is approximately 10 days. Omega Pond discharges to the left (east) bank of the Seekonk River approximately 0.75 miles (1.2 km) south of the Henderson Bridge. Sampling station TM8 was used to evaluate metals concentrations in Omega Pond.

Table 29. Sample Stations Used to Determine Existing and Allowable Metals Loads in the Ten Mile River.

Waterbody ID	Waterbody Segment Name	Station (s) Used to Determine Existing and Allowable Loads
-	Ten Mile River at MA/RI State Line	TM1
RI0004009R-01A	Upper Ten Mile River	TM2 / TM3
RI0004009L-01A	Central Pond	TM4
RI0004009L-01B	Turner Reservoir	TM5
RI0004009R-01A	Lower Ten Mile River	TM6 / TM7
RI0004009L-03	Omega Pond	TM8

Representativeness of dataset used to generate TMDLs

The TMDLs that address the dissolved and total metals impairments in the Ten Mile River were developed using the most recent water quality data available: nine (9) synoptic water quality surveys carried out during 2007 and 2008. Total and dissolved metals data were collected at eight (8) stations throughout the mainstem and impoundments during seven (7) surveys in 2007 and two (2) surveys in 2008.

A Flow Duration Curve (FDC) (Figure 23) was generated for the Ten Mile River using mean daily flows obtained from USGS station 01109403 located at Pawtucket Avenue in East Providence. The FDC represents the relationship between the magnitude and frequency of streamflow and provides an estimate of the percentage of time a given streamflow is equaled or exceeded. Mean daily flows for the period 1986 to 2009 were used to generate this curve. Mean daily flows on individual sampling dates are plotted on the curve as white boxes. The 7Q10 flow of 13 cfs at the USGS station was estimated using EPA's DFLOW software, which is available for download at: http://water.epa.gov/scitech/datait/models/dflow/index.cfm

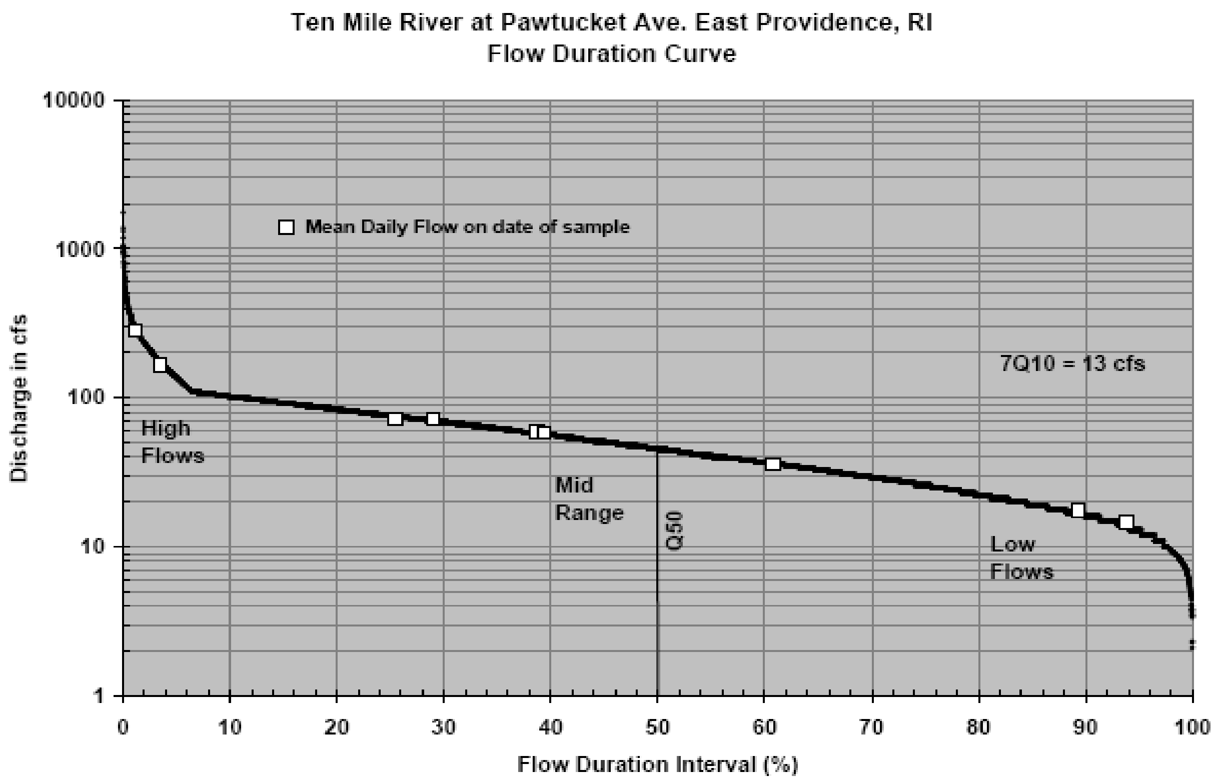

Figure 23. Flow duration curve for USGS Station 01109403 in the Ten Mile River.

Table 30 summarizes the hydrographic and meteorological conditions that existed prior to and during each of the nine surveys. As shown in Table 30, four of the nine surveys were conducted under what could be considered a baseflow/dry weather condition and the remaining five surveys were conducted under the influence of wet weather stormflows. Flows during the 9/4/2007 survey were very similar to the 7Q10 flow calculated from available USGS data. Mean daily flow on this date, as reported at the USGS gauging station, was 15 cfs. This is only 2 cfs above the calculated 7Q10 flow of 13 cfs. Accordingly, data collected from this survey were used as a best-estimation of the 7Q10 condition in the Ten Mile River and impoundments.

Table 30. Hydrographic and meteorological conditions for 2007-2008 surveys.

Survey Date	Hourly Flow at time of survey[1]	Phase of Hydrograph[2]	Prior or Current Meteorological Condition)	Comparison to Flow Duration Curve	Wet or Dry Weather Influenced[3]
5/22/2007	192	Receeding limb of storm hydrograph	2.1 inches 6 days prior	High flows	Wet
6/19/2007	62	Slow recession-baseflow	0.11 inches 7 days prior	Mid-range	Dry
7/2/2007	39	Slow recession-baseflow	0.15 inches previous day	Mid-range	Dry
7/31/2007	88	Near peak, rising limb of storm hydrograph	1.51 inches previous day	Wet Weather Influenced	Wet
8/21/2007	20	Baseflow	Trace precipitation past 10 days	Low-flows	Dry
9/4/2007	15	Baseflow	Trace precipitation past 24 days	Low-flows Near 7Q10	Dry
9/12/2007	84	Near peak, rising limb of storm hydrograph	2.11 inches 2 days prior	Wet Weather Influenced	Wet
3/6/2008	307	Rising	0.75 inches 2 days prior	High Flows	Wet
8/1/2008	60	Receeding limb of storm hydrograph	0.9 inches 5 days prior	Mid-range	Wet

[1] USGS gaging station 01109403
[2] As determined by DEM staff

Flow Balance Calculations

Prior to calculating allowable and existing loads, the flow regime throughout the watershed during each survey was estimated. The drainage area ratio method (Ries and Friesz, 2000) was used which relies upon mean daily flow information from a USGS gaging station within the watershed to calculate mean daily flows for all stations on each survey date. The drainage-area ratio method assumes that the streamflow at an ungaged site is the same per unit area as that at a nearby, hydrologically similar streamgaging station used as an index. The index station used for this analysis was USGS station 01109403, ideally located in the Ten Mile River at Pawtucket Ave in East Providence, RI. This station is located at the same geographical location as the 2007-2008 RIDEM water quality station TM6. The drainage at this station is 52.0 mi^2 (134.7 km^2) and the period of record is from October 1986-present.

Drainage areas for the remaining 7 ungaged sites (Stations TM1-TM5, TM7 and TM8) were determined from GIS analysis. Mean daily flows at TM6 for each survey date were acquired from the USGS website. These mean daily values were divided by the drainage area to determine streamflows per unit area at the index station. Combined WWTF flows were accounted for in this analysis. This ratio was then multiplied by the drainage area at the remaining ungaged sites to obtain estimated mean daily statistics.

This method is most commonly applied when the index gaging station is on the same stream as the ungaged site because the accuracy of the method depends on the proximity of the two, on similarities in drainage area, and on other physical and climatic characteristics of their drainage basins. The analysis is presented in Appendix D. Table 31 displays the estimated mean daily flows used to calculate allowable and existing daily loads for this TMDL analysis.

Table 31. Estimated flow statistics in the Ten Mile River (2007-2008 surveys).

Waterbody Segment/Location		Estimated Discharge[a] (as mean daily flow) in cfs				
	Station(s)	**7Q10**	**5/22/2007[2]**	**6/19/2007[1]**	**7/2/2007[1]**	**7/31/2007[2]**
MA/RI State Line	TM1	12	156	49	32	71
Upper Ten Mile River	TM2	12	159	50	32	72
	TM3	13	169	53	34	76
Central Pond	TM4	13	186	57	36	83
Turner Reservoir	TM5	13	188	57	37	84
Lower Ten Mile River	TM6	13	190	58	37	85
	TM7	13	193	59	37	86
Omega Pond	TM8	13	195	59	38	87
Waterbody Segment		**Estimated Discharge[a] (as mean daily flow) in cfs**				
	Station(s)	**8/21/2007[1]**	**9/4/2007[1]**	**9/12/2007[2]**	**3/6/2007[2]**	**8/1/2007[2]**
MA/RI State Line	TM1	18	14	65	243	49
Upper Ten Mile River	TM2	18	14	66	247	49
	TM3	18	15	70	264	52
Central Pond	TM4	19	15	76	290	57
Turner Reservoir	TM5	19	15	77	292	57
Lower Ten Mile River	TM6	19	15	78	296	58
	TM7	19	15	79	301	59
Omega Pond	TM8	19	15	80	304	59

[a] Rounded to nearest one.
[1] Low- baseflow sample event.
[2] Wet weather stormflow sample event.

6.5 Hardness Analysis

Rhode Island criteria for acute and chronic concentrations of dissolved cadmium and lead are based on ambient hardness of the waterbody (Table 3). Hardness is a measurement of the amount of minerals found in water and is usually reported as an equivalent quantity of calcium carbonate ($CaCO_3$). Freshwater aquatic life criteria for certain metals are expressed as a function of hardness because hardness and/or water quality characteristics that are usually correlated with hardness can affect the toxicities of these metals.

Increasing hardness has the effect of decreasing the toxicity of certain metals to aquatic life. Therefore, as hardness increases, the permissible metal criterion also increases. The converse is also true. Figure 24 displays the typical range of hardness observed in the Ten Mile River and the corresponding chronic criteria for dissolved lead and cadmium. For the range of observed hardness in the Ten Mile River (from 42-116 mg/l $CaCO_3$) the criteria for dissolved lead increases three-fold while the criteria for dissolved cadmium increases by a factor of two.

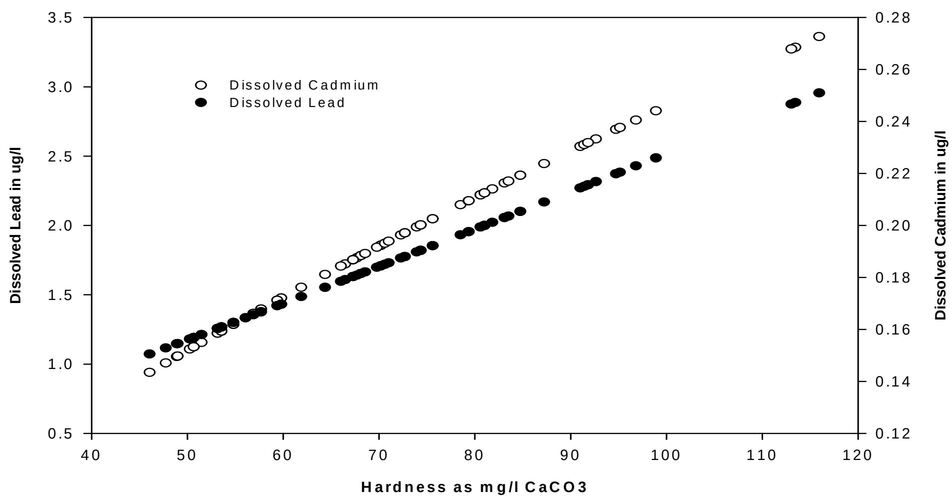

Figure 24. Chronic criteria for dissolved lead and cadmium as a function of hardness in the Ten Mile River.

Hardness data in the Ten Mile River and impoundments were analyzed for any notable and/or significant trends with respect to flow and/or weather condition as well as any changes in the downstream direction. This analysis resulted in several observations:

- A notable trend of decreasing hardness with increasing flow was observed under the base-low flow condition while no trend existed between hardness and flow under the wet weather stormflow condition.

- Notable differences exist between mean dry and wet weather hardness values at all stations in the Ten Mile River and impoundments. Under the baseflow or low flow condition, hardness generally decreases downstream of all impoundments.

Increases are generally observed in the mainstem of the river, possibly indicating groundwater inflows.

- Significant decreases in hardness are evident between the inflow and outflow of the Central Pond-Turner Reservoir complex. Lesser decreases in hardness are noted between the inflow and outflow of Omega Pond.

- During wet weather stormflow, and aside from a single survey, only slight differences in hardness are seen in the downstream direction, likely due to decreases in residence time in the impoundments.

6.6 Determination of Appropriate Chronic Criteria

Determining appropriate aquatic life criteria for dissolved cadmium and lead under the range of observed survey flows was critical in determining the allowable loads used to develop these TMDLs. Hardness values are needed to do this. As described above, significant differences in hardness trends and statistics exist between baseflow and stormflow conditions; as well as downstream of impoundments during low and baseflow conditions. For this reason, the calculated hardness value at each station, for each survey was used to determine the appropriate aquatic life criteria for dissolved cadmium and lead for all surveys used to develop this TMDL.

The equations provided in Table 1.3 (and Table 2-Appendix B of Rhode Island's Water Quality Regulations 2010) were used in combination with the ambient hardness values to calculate the appropriate chronic criteria for dissolved cadmium and lead for each waterbody segment for each survey. The resulting range of dissolved lead and cadmium criteria are displayed below in Table 32. The chronic criteria for total aluminum and total iron are independent of hardness and are therefore the same for all surveys (87 ug/l and 1000 ug/l, respectively).

Table 32. Range of Water Quality Criteria for Waterbody Segments in the Ten Mile River Watershed.

MA/RI State Line	Upper Ten Mile River RI0004009R-01A	Central Pond RI0004009L-01	Turner Reservoir RI0004009L-02	Lower Ten Mile River RI0004009R-01B	Omega Pond RI0004009L-03	Statistic
Dissolved Cadmium Chronic Criteria (ug/l)						
0.15	0.15	0.15	0.15	0.15	0.16	**Min**
0.27	0.27	0.23	0.22	0.24	0.23	**Max**
Dissolved Lead Chronic Criteria (ug/l)						
1.15	1.07	1.12	1.15	1.19	1.26	**Min**
2.95	2.89	2.29	2.10	2.37	2.31	**Max**

6.7 Calculation of the Range of Allowable Daily Loads

Allowable daily loads were calculated at each sampling location for each of the nine surveys using the calculated flow values and metals criteria, and results are displayed in Appendix E. The **range** of allowable daily loads for all metals for all surveys is provided below in Tables 33 and 34. The values in Tables 33 and 34 are essentially the TMDLs, expressed in lbs/day. A ten percent margin of safety was subtracted from the allowable daily load, except in cases where no metals violation occurred.

Table 33. Range of Allowable Metals Loads in the Ten Mile River Watershed Under Baseflow-Dry Weather Condition.

Metal	MA-RI State Line	Upper Ten Mile River	Central Pond	Turner Reservoir	Lower Ten Mile River	Omega Pond
		RI0004009R-01A	RI0004009L-01A	RI0004009L-01B	RI0004009R-01B	RI0004009L-03
Cadmium (lbs/day)	0.02 - 0.05	0.02 - 0.06	0.02 - 0.05	0.02 - 0.05	0.02 - 0.06	0.02 - 0.05
Lead (lbs/day)	0.22 - 0.43	0.22 - 0.53	0.18 - 0.44	0.17 - 0.36	0.17 - 0.47	0.19 - 0.45
Aluminum (lbs/day)	7 - 21	6 - 26	7 - 25	7 - 27	7 - 28	7 - 28
Iron (lbs/day)	75 - 264	75 - 286	81 - 307	81 – 307	81 - 318	81 - 318

Table 34. Range of Allowable Metals Loads in the Ten Mile River Watershed Under the Stormflow-Wet Weather Condition.

Metal	MA-RI State Line	Upper Ten Mile River	Central Pond	Turner Reservoir	Lower Ten Mile River	Omega Pond
		RI0004009R-01A	RI0004009L-01A	RI0004009L-01B	RI0004009R-01B	RI0004009L-03
Cadmium (lbs/day)	0.04 – 0.20	0.05 - 0.28	0.05 - 0.23	0.05 – 0.23	0.05 - 0.25	0.05 - 0.25
Lead (lbs/day)	0.38 - 1.50	0.41 - 1.53	0.39 - 2.03	0.36 - 2.05	0.37 - 2.23	0.40 – 2.26
Aluminum (lbs/day)	21 - 103	21 - 119	27 - 136	27 - 137	27 - 141	28 - 143
Iron (lbs/day)	238 - 1310	238 - 1423	307 - 1563	307 - 1547	313 - 1622	318 - 1639

During 7Q10 low flow conditions, the combined load from the North Attleboro WWTF and Attleboro WPCF constitute the largest source of metals to the Ten Mile River. No point source discharges exist in the Rhode Island portion of the watershed. Therefore, allowable loads under the 7Q10 condition were calculated for all metals at the MA/RI state line only. The estimated 7Q10 hardness value at the state line was used to calculate the appropriate criteria for dissolved cadmium and lead. This hardness value was taken from the value obtained during Survey #6, where flows were nearly as low as the calculated 7Q10 (at USGS gage). Chronic criteria were multiplied by the estimated 7Q10 flow at the state line and a conversion factor to get allowable loads. These are presented in below in Table 35.

Table 35. Allowable Daily Loads at the MA/RI State Line Under the 7Q10 Condition.

Metal	7Q10 Hardness (mg/l $CaCO_3$)	Applicable Criteria (ug/l)	Est. 7Q10 Flow	Conversion Factor	Allowable Daily Load (lbs/day)
Cadmium	116	0.273	12 cfs	5.39	0.02
Lead		2.95			0.19
Aluminum		87			5.6
Iron		1000			64.7

6.8 Range of Observed/Existing Loads

Using the same flow data and the observed metal concentrations, observed loads were calculated for each waterbody segment for each survey (also provided in Appendix E). The **range** of observed daily metals loads from the 2007-2008 sampling period are shown below in Tables 36 and 37.

Table 36. Range of Observed Metals Loads in the Ten Mile River Watershed Under Baseflow-Dry Weather Conditions.

Metal	MA-RI State Line	Upper Ten Mile River	Central Pond	Turner Reservoir	Lower Ten Mile River	Omega Pond
		RI0004009R-01A	RI0004009L-01A	RI0004009L-01B	RI0004009R-01B	RI0004009L-03
Cadmium (lbs/day)	0.01-0.03	0.004 -0.05	0.004 – 0.02	0.004 – 0.02	0.004 – 0.02	0.004 – 0.02
Lead (lbs/day)	0.02 – 0.66	0.02 – 0.57	0.01 – 0.40	0.01 – 0.29	0.01 – 0.31	0.01 – 0.29
Aluminum (lbs/day)	6 - 25	3 - 23	4 - 10	3 - 11	3 - 14	3 - 10
Iron (lbs/day)	40 - 243	30 - 226	27 - 190	23 - 190	21 - 184	25 - 169

Table 37. Range of Observed Metals Loads in the Ten Mile River Watershed Under Stormflow-Wet Weather Conditions.

Metal	MA-RI State Line	Upper Ten Mile River	Central Pond	Turner Reservoir	Lower Ten Mile River	Omega Pond
		RI0004009R-01A	RI0004009L-01A	RI0004009L-01B	RI0004009R-01B	RI0004009L-03
Cadmium (lbs/day)	0.04 – 0.19	0.03 – 0.11	0.02 – 0.50	0.02 – 0.47	0.02 – 0.54	0.02 – 0.48
Lead (lbs/day)	0.49 – 0.98	0.24 – 1.08	0.04 – 1.11	0.05 – 1.12	0.05 – 1.14	0.05 – 1.13
Aluminum (lbs/day)	26 - 124	27 - 171	18 - 120	17 - 121	20 - 123	16 - 118
Iron (lbs/day)	291 - 656	229 - 683	179 - 662	104 - 628	142 - 655	143 - 631

6.9 Range of Required Metals Load Reductions

The observed loads were compared against the allowable loads to determine the actual load reductions (in lbs/day) necessary to meet criteria under that flow/hardness condition. The actual load reductions were calculated for each sampling event and at each sampling location. Upstream reductions necessary to meet allowable loads were accounted for when calculating the next downstream segment reduction. Tables showing the data and calculations for the load reductions are included in Appendix F of this TMDL. Tables 38 and 39 show the range of required reductions to meet the wasteload allocations for each waterbody segment addressed in the TMDL under both the baseflow-dry weather condition and the stormflow-wet weather condition.

Table 38. Range of Required Daily Load Reductions Under the Dry Weather-Baseflow Condition.

	Toxicant (lbs/day)			
Waterbody	**Dissolved Cadmium**	**Dissolved Lead**	**Total Aluminum**	**Total Iron**
Ten Mile River at State Line	None Required	0.23 lbs	1.0 – 4.0 lbs	None Required
Upper Ten Mile River	None Required	None Required	2.0 – 3.0 lbs	None Required
Central Pond			None Required	
Turner Reservoir				
Lower Ten Mile River				
Omega Pond				

Table 39. Range of Required Daily Load Reductions Under the Wet Weather-Storm Flow Condition.

<table>
<tr><th></th><th colspan="4">Toxicant</th></tr>
<tr><th>Waterbody</th><th>Dissolved Cadmium</th><th>Dissolved Lead</th><th>Total Aluminum</th><th>Total Iron</th></tr>
<tr><td>Ten Mile River at State Line</td><td>0.02 – 0.13 lbs</td><td>0.08 – 0.44 lbs</td><td>5.0 -39.0 lbs</td><td>53.0 – 77.0 lbs</td></tr>
<tr><td>Upper Ten Mile River</td><td>None Required</td><td rowspan="5">None Required</td><td>2.0 – 35.0 lbs</td><td>26.0 lbs</td></tr>
<tr><td>Central Pond</td><td>0.27 lbs</td><td rowspan="4">None Required</td><td rowspan="4">None Required</td></tr>
<tr><td>Turner Reservoir</td><td>None Required</td></tr>
<tr><td>Lower Ten Mile River</td><td>0.03 – 0.08 lbs</td></tr>
<tr><td>Omega Pond</td><td>None Required</td></tr>
</table>

Required Reductions in the Ten Mile River at MA/RI State Line

The range of required reductions of metals in the Ten Mile River at the state line are presented below in Table 40. The data collected in support of the TMDL provide evidence of sources of metals in the Massachusetts' portion of the watershed which impact water quality in the Rhode Island portion of the river. Establishing metals specific allowable loads at the state line, such that water quality standards are achieved will have obvious benefit to the Rhode Island portions of the Ten Mile River and its impoundments.

Table 40. Range of Required Metals Load Reductions in the Ten Mile River at the MA/RI state line.

Ten Mile River at State Line		
Parameter	**Dry Weather Reductions**	**Wet Weather Reductions**
Dissolved Cd	None	0.02 – 0.13 lbs/day
Dissolved Pb	0.23 lbs/day	0.08 – 0.44 lbs/day
Total Al	1.0 – 4.0 lbs/day	5.0 – 39.0 lbs/day
Total Fe	None Required	53.0 – 77.0 lbs/day

6.10 Load and Wasteload Allocations

A TMDL is the combination of a wasteload allocation (WLA) that allocates allowable loadings for point sources (stormwater and non-stormwater), a load allocation (LA) that allocates allowable loadings for nonpoint sources and background sources, and a Margin of Safety (MOS). This TMDL sets percent reductions in metals loads at the MA/RI state line, however no WLA's or LA's are set for sources of metals originating in the Massachusetts portion of the watershed.

Nonpoint sources of cadmium, lead, aluminum, and iron to the Ten Mile River include air deposition, re-suspension of contaminated sediments and/or streambed/bank sloughing, contaminated groundwater, and natural background sources. As described in the source section of this TMDL, two studies have documented elevated levels of metals and organics in the sediments of impoundments in the Ten Mile River – however the extent to which these sediments contribute to elevated water column concentrations of metals is not known.

In addition, insufficient data are available to differentiate between nonpoint sources of metals and the numerous stormwater point source discharges regulated under the NPDES/RIPDES permitting programs. Furthermore, it is exceedingly difficult to control and/or mitigate nonpoint sources.

This TMDL considers discharges from MS4 areas as one of the primary sources of metals contamination in the Rhode Island portion of the Ten Mile River watershed. The literature is replete with studies reporting elevated levels of metals in stormwater runoff and it has been clearly documented that surface waters located within highly urbanized watersheds suffer from degraded water quality due to impacts from this runoff. In addition, stormwater runoff is the most controllable of the identified sources of metals in the Ten Mile River.

The wasteload allocations given to stormwater for the cities of Pawtucket (RIPDES Permit # RIR040030) and East Providence (RIR040024) and the Rhode Island Department of Transportation (RIDOT) (RIR040036) will require that the Phase II mandated six minimum measures be fully implemented and following an adaptive management approach, that structural best management practices be constructed to treat priority stormwater discharges such that metal load reductions sufficient to meet allowable metals loads are achieved.

There are no multi-sector general permit (MSGP) holders in the Rhode Island portion of the Ten Mile River watershed. Getty Terminals Corporation, located in East Providence, was issued a RIPDES permit (RIPDES # RI0001651) in 2010. The permit authorizes Getty Terminals to discharge to a swale/ephemeral channel which in-turn discharges to the Ten Mile River just upstream of Omega Pond. The discharges consist of treated stormwater runoff and hydraulic/hydrostatic test water however there are no monitoring requirements for dissolved lead or cadmium or total aluminum or iron.

At the state line, the largest wet weather sources of cadmium, lead, aluminum, and iron are thought to be stormwater runoff from impervious areas in Attleboro and North Attleborough. It is also believed that a portion of the increased metals concentrations observed in the river during higher flow conditions is a resuspension of previously "deposited" metals. Section 4.0 thoroughly documents the actual and potential sources of metals believed to exist in the Ten Mile River. The largest dry weather sources of dissolved lead, total aluminum, and total iron likely originated from wastewater discharges from the Attleboro WPCF and the North Attleborough WWTF.

As the North Attleboro and Attleboro WWTFs approach their permitted discharges, the discharge from the combined facilities will make up a greater percentage of the river flow, and dilution of the WWTF's effluent will become much less significant. It is noted that the combined permitted discharge from the North Attleboro and Attleboro WWTFs of 20 cfs is much higher than the estimated 7Q10 at the state boundary (12 cfs) based upon the historic record.

Both Attleboro and North Attleborough's current permit limits for cadmium, lead, and aluminum were effective as of 2008. No iron criteria apply to either facility. A more recent (2010-present) review of discharge data from these facilities shows few violations of their respective 2008 permit limits. However, applying the permitted discharge limits for total aluminum and dissolved lead and cadmium from the combined facilities, the calculated concentrations of these metals at the RI/MA state boundary will cause exceedances of the chronic criteria. This will need to be considered when both the facilities permits are up for re-issuance.

6.11 Required Reductions to meet Wasteload Allocations by Waterbody Segment

Wasteload allocations by waterbody segment are presented in this section. As stated earlier, only a range of reductions are required at the state line; no WLA or LA are set. The calculation of required reductions by waterbody segment take into account any upstream reductions necessary to meet allowable loads in determining the next downstream segment reduction. For example, if the allowable metals loads are met at the MA/RI state line then any additional and controllable metals loading to the upper Ten Mile River is theoretically derived from its sub-catchment.

Mitigation activities required/recommended to reduce stormwater contributions of metals to the river are described further in the Implementation Section of this TMDL.

Upper Ten Mile River (RI0004009R-01A)

The range of required metals reductions to meet the wasteload allocations in the upper Ten Mile River is presented in Table 41. Under dry weather conditions, only reductions in aluminum are necessary, and in wet weather, both aluminum and iron reductions are necessary. No dry weather point sources of aluminum have been identified in this segment. Wet weather sources of aluminum and iron likely include discharges from MS4s in both MA and RI. These sources are impossible to separate, given the lack of data.

A total of five (5) outfalls owned by the City of Pawtucket, and two (2) outfalls owned by RIDOT discharge to this segment. These outfalls will receive 100% of the WLA. Other possible sources include illicit discharges to storm drains or other illegal sources. These sources receive a wasteload allocation of zero (0) since they are prohibited.

Table 41. Range of Required Metals Load Reductions in the Upper Ten Mile River.

Upper Ten Mile River (RI0004009R-01A)		
Parameter	**Dry Weather Reductions**	**Wet Weather Reductions (WLA)**
Dissolved Cd	None	None
Dissolved Pb		None
Total Al	2.0 – 3.0 lbs/day	2.0 – 35.0 lbs/day
Total Fe	None	26.0 lbs/day

Central Pond (RI0004009L-01A)

The range of required metals reductions in Central Pond to meet the wasteload allocations is presented in Table 42. With upstream reductions in place, no additional reductions in metals are required from the Central Pond sub-watershed under the baseflow condition. Wet weather sources of metals to Central Pond likely originate from impervious areas of East Providence. Of particular importance are the outfalls draining the Narragansett Industrial Park which in-turn discharges via a small pond directly to the western shore of upper Central Pond. All stormwater outfalls discharging to this segment will receive 100% of the wasteload allocation. Sources such as illicit discharges to storm drains and illegal sources will receive a wasteload allocation of zero (0) since they are prohibited.

Table 42. Range of Required Metals Load Reductions in Central Pond.

Central Pond (RI0004009L-01A)		
Parameter	**Dry Weather Reductions**	**Wet Weather Reductions (WLA)**
Dissolved Cadmium	None Required	0.27 lbs/day
Dissolved Lead		None Required
Total Aluminum		
Total Iron		

Turner Reservoir (RI0004009L-01B)

With upstream reductions in place, no additional reductions in metals are required from the Turner Reservoir sub-watershed under the baseflow or stormflow condition. No direct stormwater discharges are known to exist to the Turner Reservoir and no other point sources are known to impact the pond.

Lower Ten Mile River (RI0004009R-01B)

With upstream reductions in place, no additional reductions in metals are required in the lower Ten Mile River under the baseflow condition. This segment requires metals reductions in wet weather only (Table 43). Wet weather sources of metals to the lower portion of the Ten Mile River originate from impervious areas of East Providence. Approximately ten (10) outfalls owned by the City of East Providence and three (3) outfalls owned by RIDOT discharge to this waterbody segment. All stormwater outfalls discharging to this segment will receive 100% of the wasteload allocation. Other possible sources include illicit discharges to storm drains or other illegal sources. These sources receive a wasteload allocation of zero (0) since they are prohibited.

Table 43. Required Metals Reductions in the Lower Ten Mile River.

Lower Ten Mile River (RI0004009R-01B)		
Parameter	**Dry Weather Reductions**	**Wet Weather Reductions**
Dissolved Cd	None	0.03 – 0.08 lbs/day
Dissolved Pb		None
Total Al		
Total Fe		

Omega Pond (RI0004009L-03)
With upstream reductions in place, no additional reductions in metals are required in Omega Pond under either the baseflow or stormflow condition. Wet weather sources of metals to Omega Pond originate primarily from impervious areas of East Providence. It is unclear how many outfalls, owned by the City of East Providence, discharge directly to Omega Pond. No RIDOT owned outfalls to Omega Pond have been identified.

6.12 Reasonable Assurance

USEPA guidance requires that in waters "impaired by both point and non-point sources, where a point source is given a less stringent wasteload allocation based on an assumption that non-point source load reductions will occur, reasonable assurance must be provided for the TMDL to be approvable" (USEPA 2001). This TMDL ***does not*** include less stringent WLAs for point sources based on anticipation of LA reductions from non-point sources, and therefore, a reasonable assurance demonstration is not required. Successful reduction in non-point sources depends on the willingness and motivation of stakeholders to get involved and the availability of private, federal, state, and local funds.

7.0 Total Phosphorus TMDL Analysis

7.1 Applicable Water Quality Criteria and Numeric Target(s)

Total Phosphorus

The following criteria for nutrients, which include total phosphorus and nitrogen, excerpted from Table 1 8.D.(2). Class-Specific Criteria - Fresh Waters of RIDEM's Water Quality Regulations (RIDEM, 2010), apply to Central Pond, Turner Reservoir, and Omega Pond:

10(a). Average Total phosphorus shall not exceed 0.025 mg/l in any lake, pond, kettle hole, or reservoir, and average Total P in tributaries at the point where they enter such bodies of water shall not cause exceedance of this phosphorus criteria, except as naturally occurs, unless the Director determines, on a site-specific basis, that a different value for phosphorus is necessary to prevent cultural eutrophication.

10(b). None [nutrients] in such concentration that would impair any usages specifically assigned to said Class, or cause undesirable or nuisance aquatic species associated with cultural eutrophication, nor cause exceedance of the criterion of 10(a) above in a downstream lake, pond, or reservoir. New discharges of wastes containing phosphates will not be permitted into or immediately upstream of lakes or ponds. Phosphates shall be removed from existing discharges to the extent that such removal is or may become technically and reasonably feasible.

Criterion 10(b) states that nutrient concentrations in a waterbody (and hence loadings to the water body) shall not cause undesirable aquatic species (e.g. cyanobacteria) associated with cultural eutrophication. This narrative standard is designed to prevent the occurrence of excessive algal and macrophyte growth (either native or invasive species), cyanobacteria blooms, and low dissolved oxygen conditions that currently occur in these impoundments.

The upper segment of the Ten Mile River (RI0004009R-01A), from the MA/RI state line, including Slater Park Pond, to the inlet of Central Pond is on the 2012 303(d) list as being impaired for total phosphorus. This listing is based on field observations in Slater Park Pond of excessive amounts of both invasive and native aquatic plants and nuisance algae. DEM currently has no total phosphorus criteria that apply to rivers and streams. The USEPA Publication 440/5-86-001 titled 'Quality Criteria for Water' (otherwise known as the EPA Gold Book) contains the following guidance regarding acceptable total phosphorus limits in flowing waters:

"To prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphates as phosphorus (P) should not exceed 50 ug/l in any stream at the point where it enters any lake or reservoir, nor 25 ug/l within the lake or reservoir. A desired goal for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments is 100 ug/l total phosphorus."

The guidance further states:

"There are two basic needs in establishing a phosphorus criterion for flowing waters: one is to control the development of plant nuisances within the flowing water and, in turn, to control and prevent animal pests that may become associated with such plants; the other is to protect the downstream receiving waterway, **regardless of proximity in linear distance**."

EPA has also released recommended ecoregional nutrient criteria, established as part of an effort to reduce problems associated with excess nutrients in water bodies in specific areas of the country. The published criteria represent conditions in waters in that ecoregion that are minimally impacted by human activities, and thus free from cultural eutrophication. The Ten Mile River watershed is located within Ecoregion XIV, Eastern Coastal Plains. The recommended total phosphorus criterion for this ecoregion, found in Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Rivers and Streams in Ecoregion XIV (2000), is 0.024 mg/l.

As a point of comparison to the above numerical criteria for flowing waters, the 2-year seasonal mean total phosphorus concentration for the upper Ten Mile River (segment) is 0.071 mg/l. At the point of inflow to Central Pond, the mean total phosphorus concentration, based on 5 years of combined URIWW and RIDEM data, is 0.078 mg/l.

Based on calculated 2007-2008 seasonal mean phosphorus levels, there appears to be little uptake or attenuation within the Ten Mile River from the MA/RI state line to the inflow of Central Pond. Mean total phosphorus concentrations from the 2007-2008 sampling season are shown below in Table 44.

Table 44. Mean Growing Season Total Phosphorus Concentrations in the Upper Ten Mile River.

Location	2007-2008 Mean Total Phosphorus (mg/l)
Ten Mile River at MA/RI State Line	0.068
Outlet of Slater Park Pond	0.067
Inflow to Central Pond	0.060

Under baseflow conditions (including 7Q10) there are no significant sources of phosphorus to the upper Ten Mile River, other than two wastewater treatment facility discharges located in Massachusetts. A small ephemeral stream drains Slater Memorial Park Pond and confluences with the Ten Mile River just upstream of the inflow to Central Pond. Field investigations conducted by RIDEM staff confirm that it does not flow into the mainstem during the mid to late summer time period. Coles Brook, located in Massachusetts discharges to Central Pond only during higher flows and is also dry for much of the mid and late summer time period. The Seven Mile River discharges to the Ten Mile River just upstream of the MA/RI border. No low flow point sources exist to the Seven Mile River. Low flow phosphorus concentrations in the Seven Mile River are less than 0.025 mg/l and relative to the loadings from treated wastewater are believed to be minor.

Based on this information, and in order to be protective of the 0.025 mg/l numeric criteria applicable in Central Pond and prevent the ongoing cultural eutrophication resulting from the current phosphorus loadings, this TMDL sets a numeric phosphorus target of 0.025 mg/l for the upper Ten Mile River (WBID #RI0004009R-01A). This numeric target applies to the entire segment of the river from the state line to the inflow of Central Pond.

Dissolved Oxygen and Algal Biomass

All of the Ten Mile River, including Central Pond, Turner Reservoir, and Omega Pond are classified as warm water fish habitat in the Rhode Island Water Quality Regulations (RIDEM 2010). The following standards apply for dissolved oxygen:

Dissolved oxygen content of not less than 60% saturation, based on a daily average, and an instantaneous minimum dissolved oxygen concentration of at least 5.0 mg/l. The 7-day mean water column dissolved oxygen concentration shall not be less than 6 mg/l.

Total phosphorus is typically the limiting nutrient to algal growth in the freshwater environment. For purposes of this TMDL, the total phosphorus target will also be used as a surrogate for excess algal growth/chlorophyll-a, and low dissolved oxygen, as these impairments, documented in Rhode Island's 303 (d) List largely result from excess phosphorus loadings.

The primary goal of this Total Phosphorus TMDL is to address the water quality impairments associated with excess phosphorus loadings including increased algal growth/chlorophyll a, frequent cyanobacteria blooms, and low dissolved oxygen. Reducing phosphorus is the most effective way to reduce algal abundance, because the growth of algae in freshwater environments is typically constrained by the availability of phosphorus. With algal abundance under control, the variability in dissolved oxygen levels (high daytime values, low nighttime values, and depressed oxygen levels following bloom crashes) will be reduced.

For the reasons described above, dissolved oxygen and chlorophyll-a (algae) targets are not set explicitly in the TMDL. RIDEM believes that these impairments will be addressed by reducing growing season phosphorus loadings to levels that would result in the consistent achievement of the 0.025 mg/l criteria (expressed as a mean).

7.2 Water Quality and Resource Impairments

Cultural Eutrophication

Under undisturbed natural conditions, phosphorus concentrations are very low in most aquatic ecosystems. Excessive nutrient levels can result in increases in algae and other primary producers, which may prevent both lentic (relating to still waters: lakes, ponds, impoundments, swamps) and lotic (relating to flowing waters) waters from meeting their designated uses. Typically, elevated levels of nutrients such as phosphorus will cause excessive algal and/or plant growth. Phosphorus and other nutrients (*i.e.*, nitrogen) promote the growth of nuisance levels of algae, such as phytoplankton (free floating algae) and periphyton (attached algae), filamentous algae such as moss and pond scum, and rooted aquatic plants, referred to generally as macrophytes.

Through respiration and the decomposition of dead plant matter, excessive algal and plant growth can reduce in-stream dissolved oxygen concentrations to levels that can negatively impact aquatic life. During the day, water column oxygen levels increase as primary producers (*e.g.*, algae, plants) photosynthesize providing oxygen to the water as a by-product of photosynthesis. At night, however, when photosynthesis ceases but respiration continues, dissolved oxygen concentrations decline. Furthermore, as algae and plants die, they are decomposed by bacteria that consume oxygen, and large populations of decomposers can consume large amounts of dissolved oxygen. Many aquatic insects, fish, and other organisms become stressed and may even die if dissolved oxygen levels drop below certain threshold levels.

Decomposing plant matter can also be unsightly and produce strong odors, negatively impacting both recreational uses and aesthetic value. When the nutrient-laden plant detritus settles to the bottom of impoundments and more quiescent areas of stream beds, additional ecosystem impacts may occur. In addition to physically altering the benthic environment and aquatic habitat, organic materials in the sediments can become available for future uptake, further perpetuating and potentially intensifying the eutrophic cycle. Excessive plant growth can eventually result in a loss of diversity and other changes in the aquatic plant, invertebrate, and fish community structure and habitat.

When phytoplankton biomass increases during eutrophication, there are coincident changes in taxonomic structure. Most notable is the increase in relative biomass of cyanobacteria with eutrophication (Havens 2005). In general, the potential for cyanobacteria dominance rises rapidly as total phosphorus concentrations increase from 0.03 mg/l to 0.10 mg/l (Dowling et al. 2001); however the response pattern in any given system also depends on other factors such as mean depth, mixing regime, flushing rate, and water temperature.

Central Pond, Turner Reservoir, and Omega Pond all exhibit cultural eutrophication as evidenced by low hypolimnetic dissolved oxygen levels (Turner Reservoir and Omega Pond), excessive macrophyte growth, elevated levels of phytoplankton growth (as evidenced by chlorophyll a concentrations), and frequent cyanobacteria blooms that have required recreational contact advisory postings by state public health departments in both Massachusetts and Rhode Island. These eutrophic conditions are primarily a result of the elevated levels of phosphorus in the water column from external sources such as wastewater treatment facility discharges and stormwater runoff.

As documented in Section 3.0, recent data collected between 2007 and 2009 (Table 7) reveal that mean total phosphorus concentrations in all three impoundments are well above the 0.025 mg/l criteria established by RIDEM. The mean total phosphorus concentrations for the 2-year survey in Central Pond, Turner Reservoir, and Omega Pond were fairly consistent (0.071 mg/l, 0.065 mg/l, and 0.079 mg/l, respectively). The 2-year growing season mean total phosphorus concentration for the upper Ten Mile River is 0.071 mg/l. These data confirm the total phosphorus impairments for these waterbodies as specified on the 2012 303d List.

Continuous measurements of dissolved oxygen were obtained in Central Pond in 2007 and in the Turner Reservoir and Omega Pond in 2007 and 2009, and are presented in Figures 8-10. No violations of the dissolved oxygen criteria were recorded in Central Pond. Numerous violations of both the instantaneous and 7-day mean dissolved oxygen criteria were found in Turner Reservoir and Omega Pond during both 2007 and 2009 deployments. Vertical profiles of dissolved oxygen at various locations in Turner Reservoir and Omega Pond show hypoxic conditions in the hypolimnion during stratification. As such, both Turner Reservoir and Omega Pond are listed on the State's 303(d) List of Impaired Waters for dissolved oxygen.

Algal blooms occur frequently in the lower three impoundments. Mean chlorophyll-a concentrations in Central Pond, Turner Reservoir, and Omega Pond in 2009 were 15 ug/l, 23 ug/l, and 16 ug/l, respectively with maximum values of 35 ug/l, 41 ug/l, and 36 ug/l. Several long-time residents of the Central Pond-Turner Reservoir shoreline have stated that nearly every summer these waterbodies exhibit extensive algal blooms. In 2007, 2010, and 2011, cyanobacteria blooms occurred that necessitated the issuance of health advisories restricting recreational activities on all or portions of Central Pond, Turner Reservoir, the lower Ten Mile River, and Omega Pond.

7.3 Critical Conditions and Seasonal Variation

Clean Water Act Section 303(d)(1)(C) requires that TMDLs "be established at a level necessary to implement the applicable water quality standards with seasonal variations…". The Code of Federal Regulations (CFR) [40 CFR 130.7(c)(1)] states that determination of "TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters".

As described in greater detail below, critical conditions for phosphorus loadings to the impoundments occur during the growing season, which, in this TMDL, is defined as the time period between April 1 and October 31. This is the period of time when the frequency and occurrence of nuisance algal blooms (including cyanobacteria), low dissolved oxygen, and extensive macrophyte growth are usually greatest.

The TMDL also sets an allowable total phosphorus load to the Ten Mile River at the MA/RI state line applicable under the critical 7Q10 condition. This is when, relative to phosphorus loadings from both North Attleborough WWTF and Attleboro WPCF, dilution is at a minimum, residence times in the impoundments are longest, and the chance for thermal stratification and associated depletions of dissolved oxygen in the hypolimnion are greatest.

7.4 Margin of Safety

A margin of safety (MOS), designed to account for uncertainty in TMDL calculations, is a required element of a TMDL [40 CFR 130.33(b)7]. The MOS can be expressed explicitly as unallocated assimilative capacity, or can be incorporated implicitly in the TMDL through the use of conservative assumptions when calculating the allowable load (EPA 1991). This TMDL incorporates an implicit margin of safety using the following conservative assumptions:

- No attenuation of phosphorus is assumed in the downstream direction.

- TMDL calculations are based on total phosphorus and assume that all the total phosphorus from point and nonpoint sources is available for algal growth. Dissolved phosphorus as a portion of the total, is generally more available for algal growth. Therefore, the use of total phosphorus is conservative.

- The assimilative capacity of the sediments in each reservoir was not included in the load assessment. Therefore, meeting the TMDL endpoints is not dependent on the sediments acting as a sink in the future.

7.5 TMDL Analysis Overview

Total phosphorus loadings to the upper Ten Mile River and the downstream impoundments are evaluated in this TMDL under the growing season, which is defined as April 1-Oct 31. In addition, the TMDL sets an allowable phosphorus load to the Ten Mile River at the state line under the 7Q10 condition.

Although 7Q10 conditions may or may not occur in any given year, clearly the summer-fall growing season conditions (meteorological, pollutant loading, and flow) occur every year and thus high levels of phosphorus loading have the ability, over time, to result in significant and cumulative changes (and losses) to the diversity of aquatic plant, invertebrate, and fish community structure and habitat. It thus represents a chronic and continuous degradation within the system.

The growing season TMDL analysis establishes allowable phosphorus loads, and assigns a wasteload and load allocation respectively for point and non-point sources within the RI portion of the watershed. The TMDL establishes allowable phosphorus loads for the Massachusetts portion of the watershed (both at the northern state line and along the border) for the growing season analysis and at the northern state line for the 7Q10 analysis, however they are not assigned a load or wasteload allocation.

7.6 7Q10 Allowable Phosphorus Load Estimation

The 7Q10 flow, defined as the seven-day, consecutive low flow with a ten year return frequency (the lowest stream flow for seven consecutive days that would be expected to

occur once in ten years) is a flow statistic commonly used in water quality and pollutant loading evaluations. Low flow conditions typically occur during periods of dry weather when the flow in the stream or river consists primarily of groundwater.
In theory, the 7Q10 flow condition may result in a more stressful environmental condition in the Ten Mile River impoundments than during the entirety of the growing season. Under the 7Q10 flow condition, dilution of phosphorus loadings from the two wastewater treatment facilities is at a minimum and water residence time at a maximum. Increased residence time enhances the ability of phytoplankton to uptake phosphorus, increases water temperature, and may also increase the chance of thermal stratification.

These factors, in combination with ideal meteorlogical conditions, result in increased algal and/or cyanobacteria growth. The death and decay of these elevated levels of algae and/or cyanobacteria cause an increase in bacterial decomposition in the bottom portion of the water column which can cause dissolved oxygen levels to decrease; resulting in fish/invertebrate death. Blooms of algae or cyanobacteria can interfere with recreational use and in the case of potentially toxigenic cyanobacteria blooms, can result in complete loss of this use.

Appendix B of the State Water Quality Regulations (RIDEM 2010) contains language regarding the hydrologic condition at which water quality criteria must be applied. For flowing waters this is the 7Q10 flow. The calculated 7Q10 flow in the Ten Mile River at the United States Geological Survey (USGS) gage 01109403 based upon 26 years of record (1986-2012) is approximately 13 cfs.

The combined mean growing season discharge (for years 2007-2009) from the North Attleborough WWTF and Attleboro WPCF was calculated to be 11.2 cfs. This means that, under the 7Q10 condition, approximately 86% of flow in the river consists of treated effluent from these two sources, making it clearly an ‘effluent dominated’ system.   The Attleboro and North Attleborough Treatment facilities in Massachusetts are the only permitted point source discharges into the Ten Mile River system having discharge limits for phosphorus (the North Attleborough National Fish Hatchery does have discharge limitations, however they do not include total phosphorus).

The 2008 NPDES permits issued by US Environmental Protection Agency specify design flows of 4.6 MGD (7.1 cfs) for the North Attleborough WWTF and 8.6 MGD (13.3 cfs) for the Attleboro WPCF. This results in a combined discharge of over 20 cfs. As the North Attleborough and Attleboro WWTFs approach their permitted discharges, the discharge from the combined facilities will make up a greater percentage of the river flow than currently exists, resulting in significantly less dilution of the treatment facilities’ effluent.

Because there are no significant sources of phosphorus in the Rhode Island portion of the watershed under 7Q10 condition, it is anticipated that if the numeric criterion of 0.025 mg/l is met in the Ten Mile River at the state line, it will also be met in the downstream impoundments. The allowable total phosphorus load for the Ten Mile River under 7Q10 conditions is calculated as the product of the estimated 7Q10 flow at the state line (12 cfs), the applicable numeric criteria of 0.025 mg/l, and a conversion factor of 5.39. **The resulting allowable load is 1.6 lbs/day.**

It is expected that total phosphorus load to the Ten Mile River at the permitted discharge limits and design flows from the combined facilities will greatly exceed the allowable load state line load of 1.6 lbs/day calculated in this TMDL. It will also result in exceedances of the total phosphorus target of 0.025 mg/l set for the upper Ten Mile River, Central Pond, Turner Reservoir, and Omega Pond. Clearly, it will be important to consider these downstream impacts when both the North Attleborough WWTF and Attleboro WPCF permits are up for re-issuance.

7.7 Growing Season Analysis

Aside from the 7Q10 condition, critical conditions for phosphorus loading also occur throughout the growing season when the occurrence and frequency of nuisance algal blooms and associated low hypolimnetic dissolved oxygen concentrations are usually greatest. The growing season spans the months during which water quality is the most likely to suffer from excessive phosphorus loadings that lead to nuisance levels of phytoplankton and macrophyte growth, low dissolved oxygen levels, and cyanobacteria blooms. This period of time also includes the months where flushing is at a minimum which allows for the accumulation of phosphorus in the impoundments where it can be utilized for algal growth. Public demand for recreational use of the river and its impoundments is also at its highest during these months, and unfortunately can be negatively impacted by cyanobacteria blooms and nuisance plant growth. The growing season analysis is meant to evaluate phosphorus loadings from all sources, including point, non-point, and natural background.

The existing growing season total phosphorus load to each reservoir was calculated using the U.S. Army Corps of Engineers FLUX software (Walker 1999) from data collected during the 2007-2009 timeframe. The FLUX software allows estimation of tributary mass loadings from sample concentration data and continuous (e.g., daily) flow records. Average growing season phosphorus loads from the treatment facilities and the fish hatchery were calculated using available flow and concentration data available from the EPA databases. The allowable total phosphorus load (lbs/day) to each reservoir was calculated as the product of the growing season average outflow (cfs) from each reservoir by the total phosphorus criteria of 0.025 mg/l, and a conversion factor of 5.39.

The required phosphorus reductions for each impoundment were calculated from the existing and allowable load estimates. The Reckhow Land Use model (Reckhow et al. 1980) will be used to determine the relative importance of the individual phosphorus sources in the watershed. The Reckhow Land Use Model is a lumped parameter model that estimates mass loads of phosphorus from agricultural, forest, and urban land uses. It also estimates phosphorus loads from septic systems and atmospheric deposition. Estimated average (2007-2009) growing season loads from the NPDES permitted sources were added to the model. The model results were used to help apportion the load between states, and to differentiate between point (WLA) and nonpoint (LA) sources of phosphorus as well as to guide implementation efforts.

The required phosphorus reductions for Central Pond were calculated from the existing and allowable load estimates. Central Pond is the first in a series of hydraulically connected impoundments in the Ten Mile River, followed by the Turner Reservoir and Omega Pond. Because of the interconnected nature of the impoundments, and the fact that there is little distance between them, calculation of the required reductions needed for Turner Reservoir and Omega Pond account for the expected upstream phosphorus reductions to the upper Ten Mile River and Central Pond. A detailed explanation of how total phosphorus reductions are calculated is provided in Section 7.9.

The FLUX software was developed by Dr. Walker using USACE reservoir data sets specifically for reservoir eutrophication applications. FLUX is an interactive program designed for use in estimating the loadings of nutrients or other water quality constituents and is offered as a companion to the BATHTUB model (Walker 1999). The estimates can be used in formulating reservoir nutrient balances over annual or seasonal averaging periods. Data requirements include (a) grab sample nutrient concentrations, (b) corresponding flow measurements (either instantaneous or daily mean values), and (c) a complete flow record (mean daily flows) for the period of interest.

Total phosphorus data from each impoundment were acquired during the growing seasons (April 1- Oct 30) between 2007 and 2009. All data for the Upper Ten Mile River, Turner Reservoir, and Omega Pond were collected by RIDEM. Central Pond data are a combination of RIDEM and URI Watershed Watch Data. The total phosphorus data used in the FLUX program to estimate the growing season loads to the upper Ten Mile River and each impoundment are presented below in Table 45.

Table 45. Total Phosphorus Data Used for FLUX Software Growing Season Load Estimates.

Upper Ten Mile River		Central Pond		Turner Reservoir		Omega Pond		Statistic
Date	***TP in mg/l***	***Date***	***TP in mg/l***	***Date***	***TP in mg/l***	***Date***	***TP in mg/l***	
5/22/07	0.047	5/22/07	0.046	5/22/07	0.048	5/22/07	0.048	
6/19/07	0.056	6/19/07	0.071	6/19/07	0.050	6/19/07	0.057	
7/2/07	0.052	7/2/07	0.041	7/2/07	0.050	7/2/07	0.040	
7/31/07	0.089	7/31/07	0.078	7/31/07	0.064	7/31/07	0.092	
8/21/07	0.070	8/21/07	0.115	8/21/07	0.110	8/21/07	0.131	
9/4/07	0.037	9/4/07	0.048	9/4/07	0.050	9/4/07	0.061	
9/12/07	0.083	9/12/07	0.054	9/12/07	0.053	9/12/07	No data	
6/7/08	0.106	8/1/08	0.077	8/1/08	0.058	8/1/08	0.063	
7/11/08	0.081	6/3/09	0.070	6/3/09	0.060	6/3/09	0.050	
8/1/08	0.047	6/30/09	0.090	6/30/09	0.060	6/30/09	0.070	
8/16/08	0.108	7/29/09	0.110	7/29/09	0.090	7/29/09	0.090	
9/20/08	0.100	8/20/09	0.070	8/20/09	0.080	8/20/09	0.08	
10/25/08	0.065	9/17/09	0.070	9/17/09	0.060	9/17/09	0.07	
5/2/09	0.030	10/8/09	0.060	10/8/09	0.090	10/8/09	0.1	
6/13/09	0.066							
7/18/09	0.093							
8/16/09	0.065							
9/14/09	0.101							
10/17/09	0.085							
	19		**14**		**14**		**13**	**n**
	0.073		**0.071**		**0.065**		**0.073**	**mean**
	0.108		**0.115**		**0.110**		**0.131**	**max**
	0.024		**0.022**		**0.019**		**0.025**	**st. dev**

In order to run the FLUX program, sampling day flows (n=13-19) and mean daily flows for the 2007-2009 growing season period (n=642) for each reservoir were estimated. The drainage area ratio method (Ries and Friesz, 2000) was used in conjunction with mean daily flow information from a USGS gaging station within the watershed to calculate mean daily flows for each impoundment for each survey date as well as the growing season period. The drainage-area ratio method assumes that the streamflow at an ungaged site is the same per unit area as that at a nearby, hydrologically similar stream gaging station used as an index.

The combined flows from the wastewater treatment facilities are accounted for in this analysis. The index station used for this analysis was USGS station 01109403 located in the Ten Mile River at Pawtucket Avenue in East Providence, RI and approximately 1.5 km downstream from the Turner Reservoir. This analysis is presented in Appendix D. Plots of mean daily flow at USGS gaging station 01109403 for the 3-year growing season period are shown in Figure 25. Yearly growing season mean daily flows range from 87% to 114% of the period of record (26-yr) average growing season mean of 91 cfs.

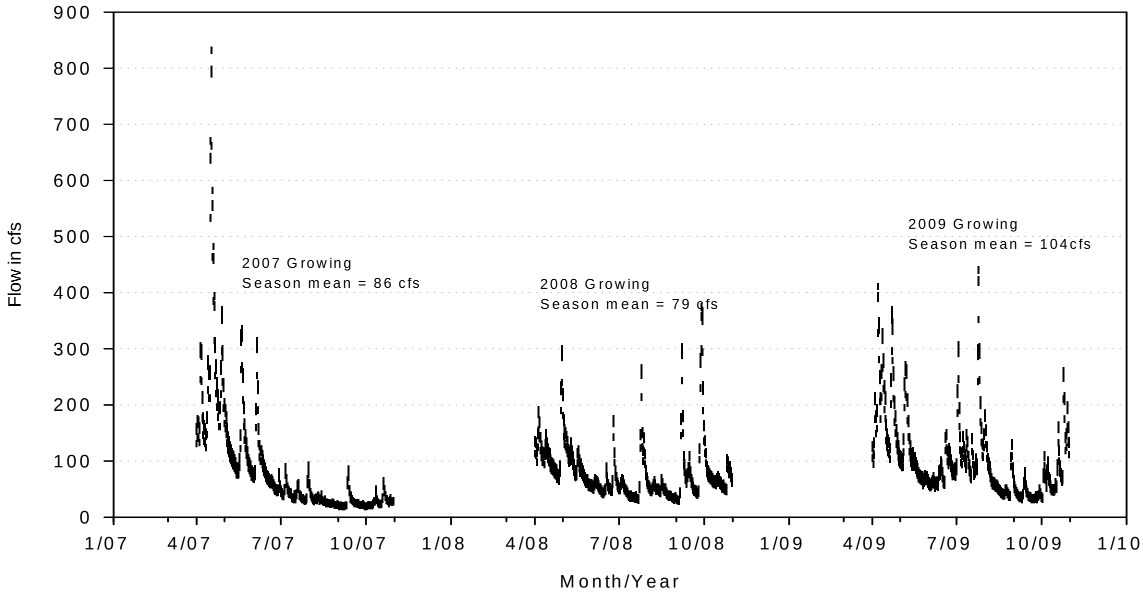

Figure 25. Growing Season Mean Daily Flows in the Ten Mile River at the USGS gage 01109403 .

Selection of Loading Calculation Method

Several choices are available within the FLUX program for calculating loads; including direct load averaging (Method 1), ratio estimates (Methods 2 and 3), and regression methods (Methods 4-6). Loading estimates are generally chosen based upon minimum bias and minimum variance. Uncertainty in each loading estimate is reflected by the coefficient of variation (CV) estimate reported for each calculation method. A description of the six methods is provided in Appendix G, along with the estimation algorithms used.

Method applicability depends on the flow/concentration dynamics and the sampling program design (Walker 1999). The data used to develop the phosphorus TMDLs were collected under a wide range of hydrologic conditions, including baseflow, near 7Q10 condition, and stormflows resulting from wet weather events. Surveys were conducted primarily during the spring and summer and thus are reflective of the growing season dynamics in these reservoirs. Of the available methods, Walker (1999) states that method 2 performs best when flow and concentration are unrelated or weakly related. A plot of total phosphorus and flow (Figure 26) for the Upper Ten Mile River and the three impoundments generally confirms this type of relationship and provides additional justification for use of load estimation Method 2.

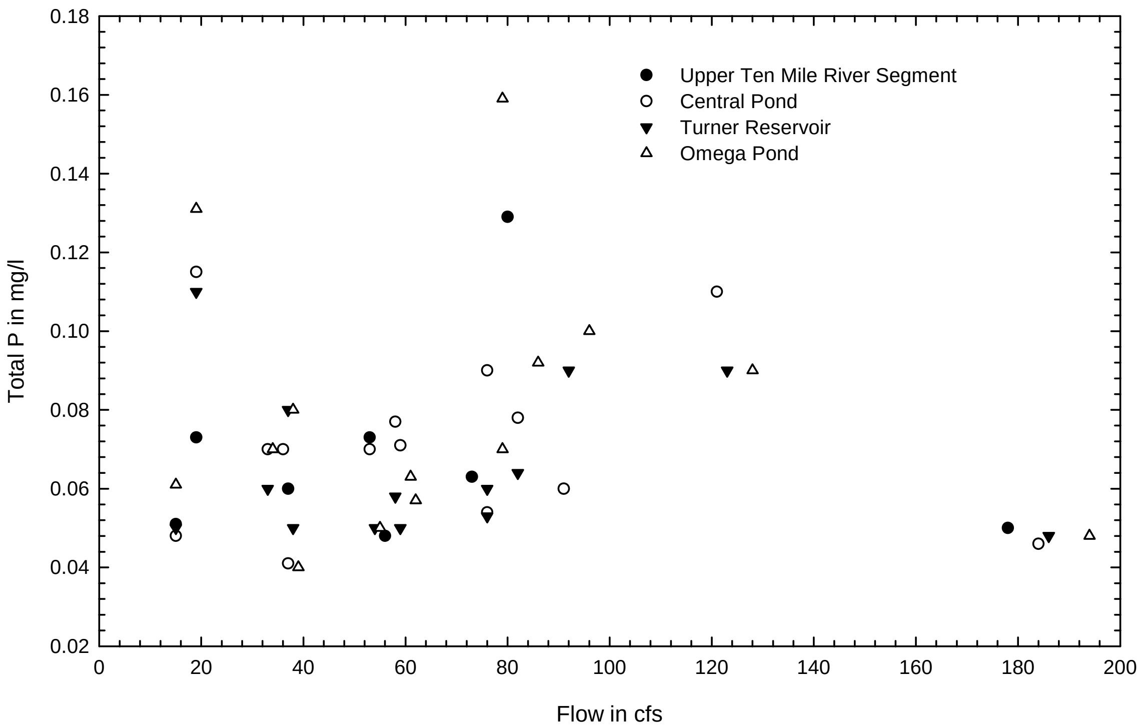

Figure 26. Relationship between total phosphorus concentration and outflow in three impoundments.

Method 2, which bases loading estimates on the flow-weighted average concentration times the mean flow over the averaging period, provides the lowest CV values, near 0.1, for nearly all impoundments. The CV equals the standard error of the mean loading divided by the mean loading and reflects sampling error in the flow-weighted mean concentration. In practice CV values <0.1 are adequate for mass-balance modeling and CV values between 0.1 and 0.2 are adequate for general modeling purposes (Walker 1999). Appendix H displays the flow and total phosphorus load summaries for each impoundment, as well as plots of observed loads versus FLUX predicted loads for each survey date. Method 2 provided the most robust estimates of total phosphorus loading to the Upper Ten Mile River and each downstream reservoir.

Loading Results

Average (2007-2009) growing season total phosphorus load estimates generated by the FLUX program for the Upper Ten Mile River segment and each impoundment are displayed below in Table 46. Flow and load summary output files are presented in Appendix H.

Table 46. FLUX Growing Season Total Phosphorus Loading Estimates for Upper Ten Mile River and Impoundments.

Waterbody Name	Growing Season average mean daily flow (cfs)[1]	Average Growing Season Load (lbs)	Average Growing Season[2] Load (lbs/day)	Coefficient of Variation (CV)
Upper Ten Mile River	81.0	6,859	32.1	0.0919
Central Pond	88.4	7,196	33.6	0.1219
Turner Reservoir	89.2	6,611	30.9	0.0982
Omega Pond	92.5	7,599	35.5	0.1154

[1]Derived from the FLUX program (n=642)
[2]Growing Season defined as April 1-Oct 31 (~214 days) and period of record 2007-2009

7.8 Calculation of Allowable Growing Season Total Phosphorus Loads

The total maximum daily loads (TMDLs), expressed as allowable growing season total phosphorus load to each impoundment, (Table 47) were calculated as the product of the growing season mean daily outflow (in cfs), the target total phosphorus concentration of 0.25 mg/l, and a unit conversion factor of 5.39. Section 7.5 details the derivation of mean daily flow records for each impoundment. The growing season mean daily outflow for Upper Ten Mile River and each impoundment is simply the average of the 2007-2009 April 1st - October 31st mean daily flows (see Sec 7.5). A comparison of existing and allowable growing season phosphorus loads for the Upper Ten Mile River segment and each of the three impoundments (Tables 46 and 47) shows that existing loads are approximately three (3) times the allowable loads.

Table 47. Allowable Growing Season Total Phosphorus Loads for Waterbodies in the Ten Mile River.

Waterbody	Waterbody ID	Growing Season Mean Daily Outflow in cfs	Target TP Concentration in mg/l	Allowable Growing Season TP Load in lbs	Allowable Growing Season Load lbs/day
Upper Ten Mile River	RI0004009R-01A	81.0	0.025	2338	10.9
Central Pond	RI0004009L-01A	88.4	0.025	2554	11.9
Turner Reservoir	RI0004009L-01B	89.2	0.025	2579	12.1
Omega Pond	RI0004009L-03	92.5	0.025	2677	12.5

7.9 Required Reductions and Load/Wasteload Allocations

The Reckhow Land Use Model- Overview and Justification for Use

Calculations of required phosphorus reductions were based on existing and allowable loads as well as natural background loads. The natural background load, derived with the Reckhow Land Use Model (RLUM), is calculated as the sum of estimated total phosphorus loads generated from forested lands within the watershed and atmospheric deposition to surface waters within the watershed of the upper Ten Mile River segment and each impoundment. Since phosphorus loads from these sources are expected to remain relatively static with time, they were subtracted out from both the existing and allowable load to each reservoir.

Because the impoundments are hydraulically connected, the phosphorus reductions required for each impoundment are 'carried through' downstream, starting with the Upper Ten Mile River, such that the expected reductions of phosphorus to each upstream segment/impoundment were accounted for in the next downstream impoundment. It was assumed that if the required phosphorus reductions to the Upper Ten Mile River segment were achieved (from sources in both MA and RI) then the total phosphorus concentration at the inlet of Central Pond would meet the 0.025 mg/l criteria. The 'expected' growing season load to Central Pond is then calculated as the sum of the allowable load to the Upper Ten Mile River and the sub-watershed load to Central Pond. The same logic applies to allowable and existing load calculations for Turner Reservoir and Omega Pond.

The RLUM was used as a secondary estimate of the growing season total phosphorus load to the upper Ten Mile River and downstream reservoirs, however the primary purpose of the model is to help to apportion the allowable growing season phosphorus load to various source categories (i.e. WLA and LA). As will be discussed in greater detail later in this section, the merit of the RLUM was based on how closely the results matched those of the FLUX model (Table 53), results of which was based on actual data. The mean relative percent difference between the two loading estimate methodologies for the three impoundments was very low: under 4%. As such, the RLUM was used with assurance when evaluating source categories of phosphorus (including percentages of total loads), required phosphorus reductions, and allocations of allowable loads.

Description of the RLUM

The RLUM is a "lumped parameter" model, which means that significant portions of the watershed are treated as a single unit, in this case a single land use type. The manual (Reckhow et al. 1980) provides additional detail including model development and export coefficient derivation. The total phosphorus load from the watershed is the sum of nonpoint sources and point sources of phosphorus. The total phosphorus load (*W*) from the watershed is calculated as:

$W = (EC_{ag} \text{ x } A_{ag}) + (EC_f \text{ x } A_f) + (EC_u \text{ x } A_u) + (EC_a \text{ x } A_s) + \text{Septic} + \text{PSI}$

$\text{Septic} = EC_s \text{ x (\# people x \# houses x \# years) x } (1\text{-}SR)$

Where:
W = total mass load of phosphorus (kg/yr)
EC_{ag} = export coefficient for agricultural land (kg/ha/yr)
EC_f = export coefficient for forest land (kg/ha/yr)
EC_u = export coefficient for urban land (kg/ha/yr)
EC_a = export coefficient for atmospheric input (kg/ha/yr)
EC_s = export coefficient for septic systems (kg/capita/yr)
A_{ag} = area of agricultural land (ha)
A_f = area of forest land (ha)
A_s = area of lake surface (ha)
A_u = area of urban land (ha)
PSI = point source input (kg/yr)
Septic = septic system input (kg/yr)
SR = soil retention coefficient

Model Setup

For this application of the RLUM, the point source input (PSI) is the combined load from the NPDES permitted sources: North Attleborough WWTF, Attleboro WPCF, and the North Attleborough National Fish Hatchery. The estimated 2007-2009 growing season phosphorus loads from these NPDES permitted sources are presented in Appendix I. Urban Land corresponds to impervious surface and stormwater runoff from permitted municipal separate stormwater discharges (MS4s). Forest land and atmospheric deposition make up the natural background component of the growing season phosphorus loads.

Phosphorus loads from septic systems were not calculated because: 1) properly sited and functioning septic systems were not considered sources of phosphorus 2) a majority of Attleboro and North Attleborough are serviced by sewers, 3) East Providence and Pawtucket are sewered, and 4) in any areas that may be unsewered, there are few residential dwellings that are within 200 feet of the shoreline of any of the impoundments or mainstem of the Ten Mile River.

Delineation of each impoundment's watershed was accomplished with ArcGIS software. Land use classifications within each sub-basin were obtained for both the Massachusetts and Rhode Island portions and were then grouped into four (4) categories: forest, urban, agriculture/open space, and water. In some cases, groupings were based on best professional judgment and review of the specific land use category via aerial photos. These groupings are shown in Table 48. Golf courses were delineated using GIS and added to the Reckhow Land Use Model equation as:

A_{gc} = area of golf course (ha)
EC_{gc} = export coefficient for golf course (kg/ha/yr)

Table 48. Grouping of Existing Land Use Categories into Reckhow Land Use Model Categories.

Massachusetts		Rhode Island	
Land Use Classification	**Reckhow Model Land Use Category**	**Land Use Classification**	**Reckhow Model Land Use Category**
forest	forest	barren	forest
freshwater wetland	forest	commercial	urban
golf course	golf course[1]	developed recreation	urban
gravel pit	forest	forest	forest
high density residential	urban	high density residential	urban
med density residential	urban	low density residential	urban
low density residential	urban	med density residential	urban
industrial	urban	industrial	urban
commercial	urban	waste disposal	urban
pasture	agriculture	utility row	forest
transportation	urban	transportation	urban
utility row	forest	freshwater wetland	forest
waste disposal	urban	golf course[1]	golf course
barren land	forest	pasture	agriculture
developed recreation	agriculture	crop	agriculture
crop	agriculture	woody shrub	forest
cranberry bog	agriculture	recreational	agriculture
woody shrub	forest		

[1]Category Added to RLUM equation.

The estimation of phosphorus loads in the RLUM relies on export coefficients that vary according to land use. The use of export coefficients for estimating phosphorus loads is based on the knowledge that, for a given climatological regime, specific types of land uses (e.g. agricultural, urban, or forest) will yield or export characteristic quantities of phosphorus to a downstream waterbody over an annual cycle. Export coefficients represent the average annual loads from a particular type of land use, and includes the phosphorus load delivered during both baseflow and storm events.

The actual phosphorus load to the three impoundments varies from year to year and is dependent on many factors, including precipitation patterns and loads from the treatment facilities. Measuring watershed-specific export coefficients typically requires specialized monitoring programs and intensive sampling over many years to adequately capture the phosphorus load from both baseflow and storm events, and subsequently estimate an average annual load.

Because of this, users often rely on export coefficients available from the scientific literature. These coefficients can vary significantly both on national and regional scales. For this application of the RLUM, the export coefficients chosen (Table 49) were derived from development and calibration of the New England Sparrow Model (Moore et al. 2004).

Table 49. Total Phosphorus Export Coefficients used in the Reckhow Model Application.

Category	Units	Export Coefficient
Developed Urban and Suburban	kg/ha/yr	0.389
Forested Land	kg/ha/yr	0.134
Agricultural Land	kg/ha/yr	1.08
Atmospheric to surface water	kg/ha/yr	0.25
Golf Courses	kg/ha/yr	Refer to Table 50

The U.S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency (USEPA) and the New England Interstate Water Pollution Control Commission (NEWIPCC), have developed a water-quality model, called SPARROW (Spatially Referenced Regressions on Watershed Attributes), to assist in regional total maximum daily load (TMDL) and nutrient-criteria activities in New England. The export coefficients derived from SPARROW model development (http://pubs.usgs.gov/sir/2004/5012/) were thought to be sufficiently representative of physical processes of phosphorus generation, delivery, and transport in the Ten Mile River watershed.

The atmosphere contributes phosphorus and phosphorus-containing material to terrestrial and aquatic ecosystems by wet or dry deposition. Phosphorus in the atmosphere can be derived from a number of sources including natural sources such as pollen, soil (from wind erosion) and forest fires, as well as anthropogenic sources such as fertilizer application and oil and coal combustion. Phosphorus can also be released into the atmosphere in vapor form from various materials (sewage sludge, landfills) by microbial reductions processes (Brunner and Bachofen 2000). The atmospheric to surface water export coefficient of 0.25 kg/ha/yr was chosen based on literature review completed by Rast and Lee (1983) and compares well with recent values derived from Minnesota watersheds (http://www.pca.state.mn.us/index.php/view-document.html?gid=3981)

Eight golf courses exist within the Ten Mile River watershed; three of which are either located in close proximity and/or have a direct hydrologic connection to the river or an impoundment, with the remaining five located in the upper portions of the watershed. Portions of the Pawtucket Country Club, located off Armstice Blvd in Pawtucket drain to Slater Park Pond. The Ledgemont Country Club, located in Seekonk, MA drains to Coles Brook which discharges to Central Pond. The Agawam Hunt Club, located in East Providence is bisected by the mainstem of the Ten Mile River between the outflow of the Tuner Reservoir and in the inflow of Omega Pond.

Site visits, review of aerial topography, and best profession judgment confirmed that different phosphorus export coefficients should apply to different golf courses in the Ten Mile River watershed (Table 50). Export coefficient values were obtained for low, mean, and high impact levels and were taken directly from literature review and various work conducted by F.B Environmental for development of Maine Lake TMDL’s (David Halliwell personal communication, March 21, 2013). Golf course managers from Agawam Hunt Club and the Pawtucket Country Club provided DEM staff with total phosphorus amounts applied annually to each course for the years 2007-1012. Phosphorus export coefficients for these courses were chosen with this information taken into consideration.

Table 50. Ten Mile River Golf Course Phosphorus Coefficient Exports used in RLUM Application.

Golf Course	Size in ha	Phosphorus Export Coefficient (kg/ha/yr)	Notes
All other (n=5) MA Golf Courses	135	1.55	All other golf courses in upper Ten Mile River watershed.
Pawtucket Country Club	26	3.10	No direct stream drainage, pond and parking lot drain directly to Slater Park Pond.
Ledgemont Country Club	53	3.10	Course is directly drained by Coles Brook, which appears to be an intermittent stream
Agawam Hunt Club	52	1.55	Course is bi-sected by mainstem Ten Mile River. Surface and sub-surface drainage directly to river.

The RLUM was used to evaluate phosphorus loads from the Upper Ten Mile River segment and/or impoundments total watershed area as well as the sub-catchment areas of Central Pond, Turner Reservoir and Omega Pond. Total and sub-catchment watersheds statistics are displayed in Table 51 and the catchments are shown graphically in Figure 27.

Table 51. Watershed and sub-watershed contributing areas used in the Reckhow Model Application.

River Segment/ Impoundment	Total Contributing Area (km^2)	Sub-catchment Contributing Area(km^2)
Upper Ten Mile River	118.9	-
Central Pond	131.6	12.7
Turner Reservoir	132.9	1.3
Omega Pond	138.6	5.7

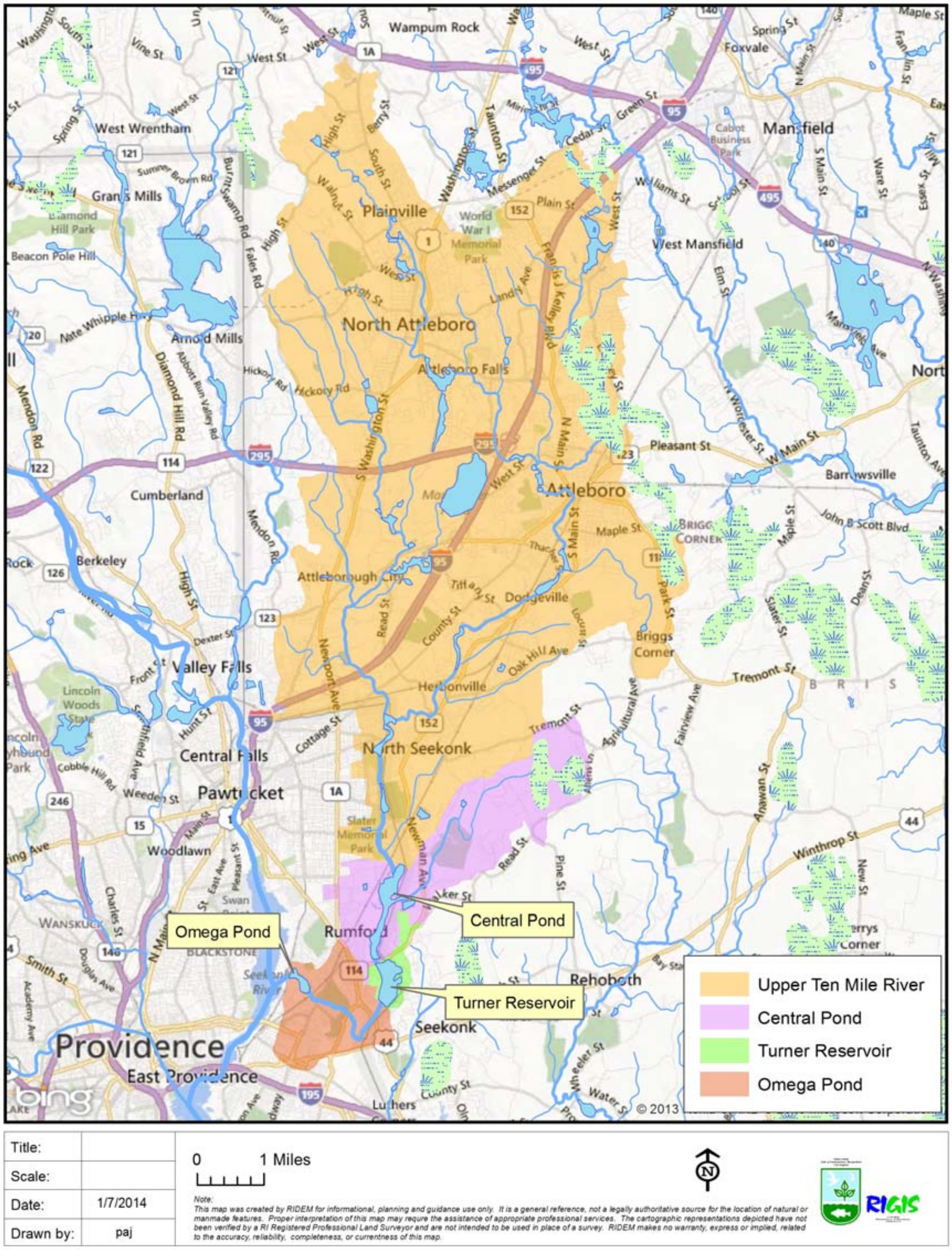

Figure 27. Catchment areas for Upper Ten Mile River segment Central Pond[1], Turner Reservoir[1], and Omega Pond[1].

[1]Sub-catchment area

Calculations of relative percent difference (RPD)[1] between the RLUM and the FLUX software results (Table 52) lend credibility to the use of the RLUM for purposes of calculating the required phosphorus reductions and allocating the growing season total phosphorus loads. The model was run for the entire watershed of each waterbody segment and again for the sub-watersheds of Central Pond, Turner Reservoir and Omega Pond. This analysis aided in segregating the upstream and sub-catchment growing season phosphorus loads.

[1] RPD = (ABS (V1-V2)/ (V1+V2)/2) X 100
Where ABS = absolute value, V1= RLUM result, V2= FLUX result

Table 52. Relative Percent Differences Between FLUX and RLUM predictions of total phosphorus loads.

River Segment/ Impoundment	Total Contributing Area (km^2)	RLUM predicted TP load (lbs/GS)	FLUX predicted TP load (lbs/GS)	Relative Percent Difference
Upper Ten Mile River[1].	118.9	6719	6859	2.1
Central Pond	131.6	7026	7196	2.4
Turner Reservoir	132.9	7072	6611	6.7
Omega Pond	138.6	7393	7599	2.8
Average Relative Percent Difference				**3.5**

[1] At inflow to Central Pond.

Upper Ten Mile River

Results from the RLUM application to the Upper Ten Mile River are shown in columns 4 and 5 of Table 53. The total land area draining to Upper Ten Mile River is 11,893 ha, or approximately 119 km^2. The estimated growing season total phosphorus load to the Upper Ten Mile River segment derived using the RLUM is 6719 lbs. The natural background phosphorus load, comprised of forest land and direct atmospheric deposition, contributes approximately 17% of the total growing season phosphorus load. The two largest sources of phosphorus to Upper Ten Mile River are urban land uses in Massachusetts and NPDES permitted discharges, also located in Massachusetts.

The 2007-2009 growing season total phosphorus load to the Upper Ten Mile River predicted by the FLUX software is 6859 lbs. The relative percent difference between loads predicted by FLUX and the RLUM was minimal, at 2.1%. Since the FLUX load is derived from actual data collected in the Upper Ten Mile River, it was thought to provide the best estimate of the average total phosphorus load during the 2007-2009 growing seasons. The RLUM was used to apportion the FLUX-predicted growing season phosphorus load between sources. To do this, the RLUM-derived percentages of the growing season load attributable to each source category were multiplied by the FLUX predicted load of 6859 lbs. Results of these calculations are shown in the last column of Table 53. These are the estimated 2007-2009 growing season total phosphorus loads delivered to the Upper Ten Mile River from each source category.

Table 53. RLUM Results and Adjusted FLUX estimated TP Loads to Upper Ten Mile River.

UPPER TEN MILE RIVER Land Use Category	Size (ha)	Export Coefficient kg/ha-yr / (lbs/ha-yr)	RLUM TP Load lbs/GS	% of Total RLUM TP load	FLUX Predicted TP load (lbs/GS)	Adjusted TP Load lbs/GS
Urban (Mass)	5065	0.389 / 0.856	2542	37.8%	6859	2595
Urban (RI)	180		91	1.3%		92
Agriculture (Mass)	53	1.08 / 2.38	73	1%		75
Agriculture (RI)	-			-		-
Golf Courses (MA)	135	1.55 / 3.41	541	8.0%		552
Pawtucket CC	26	3.10 / 6.82	104	1.5%		106
NPDES Sources			2200[2]	32.7%		2246
Direct Deposition	380[1]	0.25 / 0.55	123	1.8%		125
Forest (Total)	6053	0.134 / 0.295	1046	15.6%		1068
Total	**11892**		**6719 lbs**	**100%**		**6859 lbs**

[1] Combined surface area of impoundments in the watershed.
[2] See Appendix I.

Table 54 presents the existing and allowable loads to the Upper Ten Mile River, as well as the required load reductions and final allocations of the allowable growing season total phosphorus load to each source category. An 80% reduction in the growing season total phosphorus load is required at the state boundary. The 80% reduction also applies to each source category in the Rhode Island portion of the watershed.

Table 54. Existing and Allocated Growing Season TP Loads: Upper Ten Mile River.

Existing Growing Season Total Phosphorus Load	6859 lbs
Natural Background (Forest + Atmospheric) Load (125 lbs + 1068 lbs)	1193 lbs
Anthropogenic Growing Season Load (6859 lbs – 1193 lbs)	5666 lbs
Allowable Growing Season Load	2338 lbs
Allowable Load minus Natural Background Load (2338 lbs – 1193 lbs)	1145 lbs
Required Reduction from Anthropogenic Sources (5666 lbs – 1145 lbs)	4521 lbs
Expressed as a Percent	80%
Growing Season Total Phosphorus Load From Anthropogenic Sources in MA	**5648 lbs**
Growing Season Total Phosphorus Load From Anthropogenic Sources in RI	**92 lbs**
An 80% reduction in growing season phosphorus load is required at the MA/RI State Boundary	
Phosphorus Load Allocations Between Source Categories in Rhode Island	

Land Use Category	**Estimated GS Load (lbs)**	**Allowable Load (lbs)**	**WLA**	**LA**
Urban	92	19	100%	
Pawtucket CC	105	22		100%
Direct Deposition	125	125		Natural Background
Forest (Total)	1068	1068		Natural Background

Central Pond

It is expected that if the growing season total phosphorus reductions required to meet the allowable load to the upper Ten Mile River are realized, it will result in the attainment of the 0.025 mg/l total phosphorus criteria at the point of inflow (and adjacent boundary waters) to Central Pond during the growing season. Any additional phosphorus loading to Central Pond would theoretically be derived from its sub-watershed (see Figure 27). The RLUM was used to estimate this sub-catchment load and aid in allocating an allowable load from each source category.

Results from the RLUM application to the Central Pond sub-watershed are shown below in Table 55. The contributing sub-watershed is small (1265 ha- inclusive of the surface area of the reservoir) and contributes approximately 578 lbs of total phosphorus during the growing season. The largest source, expressed as a percent of the total load, is derived from the Ledgemont Country Club (37%). Urban land uses in MA and RI account for 20% and 16%, respectively, of the total load. The adjusted RLUM sub-catchment loads are presented in the final column of Table 55 and add up to the 337 lbs predicted by the FLUX software.

Table 55. RLUM Results and Adjusted FLUX estimated TP Loads to Central Pond Sub-Watershed.

Land Use Category	Size (ha)	Export Coefficient (kg/ha/yr)/(lbs/ha-yr)	RLUM TP Load lbs/GS	% of Total RLUM TP load	FLUX Predicted Sub-catchment Load (lbs/GS)[1]	Adjusted TP Load (lbs/GS)
Urban (Mass)	231	0.389	116	20%	337[1]	68
Urban (RI)	182	0.389	92	16%		53
Agriculture (Mass)	8	1.080	11	2%		7
Agriculture (RI)	0	1.080				
Forest (Total)	726	0.134	126	22%		73
Ledgemont CC	53	3.10	212	37%		124
Central Pond Surface Area (Direct Deposition)	65	0.250	21	4%		12
Total	**1265**		**578**			**337**

[1]Calculated as the difference between FLUX predicted watershed load to Upper Ten Mile River and Central Pond (7196 lbs – 6859 lbs)

The allowable sub-catchment growing season total phosphorus load of 216 lbs to Central Pond is calculated as the difference between the allowable loads to Central Pond and the upper Ten Mile River (Table 47 column 5). A 48% reduction is required from all source categories in the sub-watershed to meet this sub-catchment allowable load, however load and wasteload allocations are set for sources generated in Rhode Island only (Table 56).

Table 56. Existing and Allocated Growing Season TP Loads: Central Pond sub-watershed.

<table>
<tr><td colspan="4">Existing TP load to Central Pond predicted with FLUX software</td><td>7196 lbs</td></tr>
<tr><td colspan="4">Existing TP load to Upper Ten Mile River predicted with FLUX software</td><td>6859 lbs</td></tr>
<tr><td colspan="4">Difference (7196 lbs – 6859 lbs)</td><td>337 lbs</td></tr>
<tr><td colspan="4">RLUM predicted sub-catchment TP load</td><td>578 lbs</td></tr>
<tr><td colspan="4">Final Estimated TP growing season sub-catchment load to Central Pond</td><td>337 lbs</td></tr>
<tr><td colspan="4">Natural Background Estimate (Atmospheric- 12 lbs + Forestland- 73 lbs)</td><td>86 lbs</td></tr>
<tr><td colspan="4">Anthropogenic Sub-catchment TP Load (337 lbs – 86 lbs)</td><td>251 lbs</td></tr>
<tr><td colspan="4">Allowable Sub-catchment TP load (Table 47 column 5)- (2554 lbs – 2338 lbs)</td><td>216 lbs</td></tr>
<tr><td colspan="4">Allowable TP load with natural background subtracted out (216 lbs – 86 lbs)</td><td>130 lbs</td></tr>
<tr><td colspan="4">Required sub-catchment load reduction (251 lbs – 130 lbs)</td><td>121 lbs</td></tr>
<tr><td colspan="4">Expressed as a percent</td><td>48%</td></tr>
<tr><td colspan="5">A 48% reduction is required between all anthropogenic source categories</td></tr>
<tr><td>Land Use Category</td><td>Estimated GS TP Load (lbs)</td><td>Allowable GS TP Load (lbs)</td><td>WLA</td><td>LA</td></tr>
<tr><td>Urban (MA)</td><td>68</td><td>35</td><td colspan="2" rowspan="3">48% reduction from MA sources</td></tr>
<tr><td>Agriculture (MA)</td><td>7</td><td>3</td></tr>
<tr><td>Ledgemont CC (MA)</td><td>124</td><td>64</td></tr>
<tr><td>Urban (RI)</td><td>53</td><td>28</td><td>100%</td><td></td></tr>
<tr><td>Direct Deposition</td><td>12</td><td>12</td><td colspan="2"></td></tr>
<tr><td>Forestland</td><td>73</td><td>73</td><td></td><td></td></tr>
<tr><td>TOTALS</td><td>337</td><td></td><td></td><td></td></tr>
</table>

Turner Reservoir

It is expected that if the growing season total phosphorus reductions required to meet the allowable load to Central Pond are realized, it will result in the attainment of the 0.025 mg/l total phosphorus criteria at the point of inflow (and adjacent boundary waters) to Turner Reservoir during the growing season. Any additional phosphorus loading to the reservoir would theoretically be derived from its sub-watershed (see Figure 27). The RLUM was used to estimate this sub-catchment load and aid in allocating an allowable load from each source category.

Results from the RLUM application to the Turner Reservoir sub-watershed are shown below in Table 57. The contributing sub-watershed is approximately 133 ha- inclusive of the surface area of the reservoir) and the RLUM predicts a delivery of approximately 46 lbs of total phosphorus during the growing season. The largest source, expressed as a percent of the total load, is derived from urban sources in MA (38%). Urban land uses in RI account for 13% of the total load. The FLUX software predicts an average loss of 585 lbs of phosphorus during the 3-year growing season period. This may be due to internal mechanisms such as settling, however thus far the difference between the two predicted sub-catchment phosphorus loads is unaccounted for and the RLUM estimate will not be adjusted to match the FLUX estimate.

Table 57. RLUM Results and FLUX estimated TP Loads to Turner Reservoir Sub-Watershed.

Land Use Category	Size (ha)	Export Coefficient (kg/ha/yr)/(lbs/ha-yr)	RLUM TP Load lbs/GS	% of Total RLUM TP load	FLUX Predicted Sub-Catchment Load (lbs/GS)[1]
Urban (Mass)	34	0.389	17	38%	-585[1]
Urban (RI)	12	0.389	6	13%	
Forest (Total)	39	0.134	7	15%	
Turner Reservoir Surface Area (Direct Deposition)	48	0.250	16	34%	
Total	**133**		46		

[1]Calculated as the difference between FLUX predicted watershed load to Central Pond and Turner Reservoir (6611 lbs –7196 lbs)

The allowable sub-catchment growing season phosphorus load to the Turner Reservoir is 25 lbs. This is calculated as the difference between allowable loads to Turner Reservoir and Central Pond as specified in Table 47 column 5. Although the FLUX software shows a loss of total phosphorus loading to this sub-catchment, there are anthropogenic sources of phosphorus to the reservoir, namely urban land uses in RI and MA. As such, the RLUM load of 46 lbs must be reduced to meet the allowable load of 25 lbs. This will require a 46% reduction from urban land uses in both RI and MA. Application of the 46% reduction to the 6 lbs estimated to come from RI urban land use and the 17 lbs estimated to come from MA urban land uses amounts to an allowable load of approximately 3 lbs and 9 lbs, respectively. In RI, 100% of this will come from a WLA.

Omega Pond

If the allowable growing season total phosphorus loads to Central Pond and Turner Reservoir are met then any additional and controllable phosphorus loading to Omega Pond is theoretically derived from its sub-watershed (see Figure 27). The RLUM was used to estimate this sub-catchment load and aid in allocating an allowable load from each source category.

Results from the RLUM application to the Omega Pond sub-watershed are shown below in Table 58. The RLUM estimated that the 564 ha sub-watershed contributes approximately 327 lbs of phosphorus to the pond during the growing season. The two largest sources of phosphorus generated within the sub-catchment, expressed as a percent of the total load, are urban land uses in Rhode Island (57%) and the Agawam Hunt Club, located in East Providence (32%). The predicted growing season total phosphorus load from natural background is approximately 7% of the total.

Table 58. Reckhow Land Use Model Results for Omega Pond sub-watershed.

Land Use Category	Size (ha)	SPARROW Model Export Coefficient[1] (kg/ha/yr)	RLUM TP Load lbs/GS	% of Total RLUM TP Load	FLUX Predicted Sub-Catchment Load (lbs/GS)
Urban (Mass)	33	0.389	17	5%	
Urban (RI)	370	0.389	186	57%	
Agawam Hunt Club	52	1.55	103	32%	
Forest (Total)	94	0.134	16	5%	
Omega Pond Surface Area (Direct Deposition)	15	0.250	5	2%	988 lbs[1]
Total	**564**		**327**		

[1] Calculated as the difference between FLUX predicted watershed load to Turner Reservoir and Pond (7599 lbs –6611 lbs)

The difference of 661 lbs (988 lbs – 327 lbs) may have been generated from recycling of phosphorus from the pond sediments at various times within the 2007-2009 sampling period, however it is not accounted for, or allocated, in this TMDL. If future studies indicate that internal loading constitutes a significant source of phosphorus to Omega Pond it will have to be taken into consideration with respect to phosphorus control measures. As such, the RLUM predicted sub-catchment load of 327 lbs will be used as a best estimate of existing growing season load. It is important to note that the load allocation for the Agawam Hunt Club has been achieved (Section 7.10) and therefore emphasis should be placed on the remaining controllable load (203 lbs) which is comprised entirely of stormwater runoff from urbanized areas in the sub-catchment.

The natural background load of 21 lbs will be subtracted from both the existing load of 327 lbs as well as the allowable load of 98 lbs. Thus, the required reduction of 75% was calculated from the following: (307 lbs – 77 lbs)/307 lbs X 100%. Existing and allocated growing season loads to the Omega Pond sub-watershed are described in detail in Table 59 below.

Table 59. Existing and Allocated Growing Season TP Loads: Omega Pond sub-watershed.

FLUX Existing Growing Season TP Load to Omega Pond				7599 lbs
FLUX Existing Growing Season TP Load to Turner Reservoir				6611 lbs
Sub-catchment difference (7597 lbs – 6611 lbs)				988 lbs
RLUM Predicted sub-watershed growing season TP load to Omega Pond				327 lbs
Unaccounted and Unallocated Difference (988 lbs – 327 lbs)				661 lbs
RLUM Predicted sub-watershed growing season TP load to Omega Pond				327 lbs
Allowable load to Omega Pond – Allowable load to Turner Reservoir (2677 lbs – 2579 lbs)				98 lbs
Natural Background Load (Direct Deposition + Forest Land Use)				21 lbs
Allowable Load to Omega Pond with Natural Background Removed (98 lbs – 21 lbs)				**77 lbs**
Estimated anthropogenic sub-catchment load (327 lbs – 21 lbs)				**306 lbs**
Required TP reduction expressed as a percent (306 lbs – 77 lbs)/306 lbs X 100				75%
A 75% reduction is applied equally between source categories of phosphorus				
Land Use Category	**Estimated GS Sub-catchment Load (lbs)**	**Allowable Load (lbs)**	**WLA**	**LA**
Urban (Mass)	17	4	75% reduction from MA sources	
Urban (RI)	186	46	100%	
Agawam Hunt Club	103	26		100%
Direct Deposition	5	5	Natural Background	
Forest (Total)	16	16	Natural Background	
TOTALS	**327**	**98**		

Internal Cycling of Phosphorus

Both Omega Pond and the Turner Reservoir, due to their relatively shallow depth and, in the case of the Turner Reservoir, exposure to wind-induced mixing, tend to fluctuate between weakly stratified and non-stratified conditions during the growing season. Water column dissolved oxygen data collected during periods of weak stratification show that hypoxic (< 3.0 mg/l) conditions can exist in the bottom waters of both impoundments.

Water column samples collected in 2009 from ‘surface’ and ‘depth’ locations in Turner Reservoir and Omega Pond were analyzed for various constituents, including total phosphorus. These data (Table 60) show elevated levels of total phosphorus in the bottom waters at various times in Turner Reservoir and Omega Pond relative to those in the surface. These data suggest that phosphorus is released from the sediments and accumulates in the lowest portions of the water column. Phosphorus from sediments may be re-suspended by wind in Central Pond but this would be extremely difficult to quantify.

Table 60. Surface and Depth Water Column Total Phosphorus Concentration Data.

		Sampling Date					
Waterbody	**Sampling Location**	**6.03.09**	**6.30.09**	**7.29.09**	**8.20.09**	**9.17.09**	**10.08.09**
Turner Reservoir	~ 2 ft below surface	0.060	0.060	0.090	0.080	0.060	0.090
	~ 2 ft off bottom	0.050	0.110	0.130	0.130	0.060	0.100
Omega Pond	~ 2 ft below surface	0.050	0.070	0.090	0.080	0.070	0.100
	~ 2 ft off bottom	0.210	0.034	0.110	0.140	0.060	0.110

De-stratification occurs as a result of either increased inflow (i.e.stormflow from precipitation events) or wind mixing. Increased inflows from precipitation events reduce the residence time as water in the reservoir is replaced. However, the extent to which the ‘released’ phosphorus constitutes a quantifiable (and consistent) growing season “load” to these reservoirs is unknown for the following reasons:

- Accurate estimates of the area of hypoxic bottom water and subsequent phosphorus release and buildup are not available for these impoundments.
- Phosphorus release is likely highly variable on both seasonal and temporal scales.
- The primary mechanism for de-stratification is the volume and timing of inflow (i.e. flushing) which, during the growing season, is related to precipitation events and resulting stormflow. These cannot be predicted with certainty.
- De-stratification occurs at the same time down-gradient movement of water becomes enough to transport the released phosphorus out of the system. The released phosphorus may get transported down-gradient and out of the system.

The focus of this TMDL’s implementation section is the control of identified external sources of phosphorus discharged to these lakes. However, it must be understood that even if external loading is significantly reduced, little improvement may be seen in water quality for decades, because of continued internal loading. Even after wastewater treatment was installed reducing 80% of the external load to Shagawa Lake in Minneapolis, Minnesota, modeling indicates that it would take 80 years to achieve a 90% reduction in summer lake phosphorus, due to internal cycling (Chapra and Canale, RP.1991). Søndergaard et al. (1993) estimated that, even after an 80–90% reduction in external phosphorus loading to a shallow hypereutrophic Danish Lake, phosphorus would continue to be released from the sediment for approximately 20 years. One year after the drastic reduction in external phosphorus loading in 1982, net internal phosphorus loading was 8 $g/m^2/y$. This rate decreased slowly to 2 $g/m^2/y$ in 1990, 15 years after the reduction in external phosphorus loading. Therefore for the Turner Reservoir and Omega Pond, the more immediate achievement of water quality improvements may also entail use of in-lake management techniques to control the internal cycling of phosphorus.

Methods to control internal phosphorus recycling are discussed in more detail in the Implementation section of this TMDL.

7.10 Reasonable Assurance

When a TMDL is developed for waters impaired by point sources only, the issuance of a National Pollutant Discharge Elimination System (NPDES) permit(s) provides the reasonable assurance that the wasteload allocations contained in the TMDL will be achieved. This is because 40 C.F.R. 122.44(d)(1)(vii)(B) requires that effluent limits in permits be consistent with "the assumptions and requirements of any available wasteload allocation" in an approved TMDL.

When a TMDL is developed for waters impaired by both point and nonpoint sources, and the WLA is based on an assumption that nonpoint source load reductions will occur, EPA's 1991 TMDL Guidance states that the TMDL should provide reasonable assurances that nonpoint source control measures will achieve expected load reductions in order for the TMDL to be approvable. This information is necessary for EPA to determine that the TMDL, including the load and wasteload allocations, has been established at a level necessary to implement water quality standards.

Reasonable assurance is required in this TMDL because total phosphorus load allocations (LA's) are set for two golf courses located in Rhode Island. The following rationale provides reasonable assurance that the load allocations (LA) assigned to these courses have been met.

In June of 2013, RIDEM staff met with the course managers at the Pawtucket Country Club and the Agawam Hunt Club. Both course managers were aware of the various water quality issues within the Ten Mile River and have made it a priority to ensure that the golf courses are maintained such that environmental/water quality impacts to the river are minimized. The golf course managers for Pawtucket Country Club and Agawam Hunt Club provided DEM with the seasonal amounts of total phosphorus applied to their courses. In addition, the course managers provided, in detail, the following general fertilizer application procedures and other pollution reduction measures which are presently conducted by both course managers:

- Established turf on older golf courses such as Agawam Hunt Club and Pawtucket Country Club require little additional phosphorus containing fertilizer. Nitrogen is the most important nutrient for established courses.

- Fertilizer is applied judiciously by trained professionals to maximize uptake by turf and minimize loss via runoff.

- Phosphorus containing fertilizers are expensive and the less that is applied, the more money that is saved.

- Aggressive goose management techniques have been pursued with high success.

Table 61 summarizes the phosphorus application information provided by course managers from the Agawam Hunt Club and the Pawtucket Country Club.

Table 61. Ten Mile River Golf Course Phosphorus Coefficient Exports used in RLUM Application.

		Total Phosphorus applied to entire course (lbs)						% Reduction of TP applied from 2007-2009 to 2012
Golf Course	**Size in ha**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	
Pawtucket Country Club	26	394	251	186		135	78	72%
Agawam Hunt Club	52	-	150	150	50	50	50	67%

Pawtucket Country Club- Pawtucket, RI

An 80% reduction in total phosphorus load was required for all anthropogenic sources (both point and non-point) to the upper Ten Mile River watershed. This reduction applies to the estimated growing season phosphorus load from the Pawtucket Country Club. The 2007-2009 mean total phosphorus applied on the course was 277 lbs (Table 62). Alternatively, the RLUM model predicted a total phosphorus load of 106 lbs.

The country club manager stated that approximately 78 lbs of total phosphorus was applied to the course in 2012 (Table 62). This represents a 72% reduction (in terms of the total applied) from the 2007-2009 mean application of 277 lbs. It was conservatively assumed that a small percentage (less than 20%) of what is applied to the course actually ends up in the waterway. Accordingly, 20% of the current application rate of 78 lbs (16 lbs) is well below the allowable load of 21 lbs.

Agawam Hunt Club- East Providence, RI

A 75% reduction in total phosphorus load to the Omega Pond sub-watershed was required for all anthropogenic sources, both point and non-point. This reduction applies to the estimated phosphorus load from the Agawam Club. The 2007-2009 mean total phosphorus applied on the course was 150 lbs (Table 62). Alternatively, the RLUM model predicted a total phosphorus load of 103 lbs.

Approximately 50 lbs of total phosphorus were applied to the course in 2012 (and in 2010 and 2011), which represents a 67% reduction from the 2007-2009 mean of 150 lbs. Assuming that a very small percentage (less than 20%) of what is applied to the course ends up in the waterway then 20% of 50 lbs is approximately 10 lbs, which is well below the allowable load of 26 lbs.

It is clear from the data provided by the course managers that there have been significant reductions in phosphorus application in the 5 years since data had been collected for this TMDL. The course owners indicated that their goal was to keep annual phosphorus application totals static and near or below the 2012 application amounts.

8.0 TMDL Implementation

This section describes both required and recommended best management practices (BMP's) that will need to be implemented in order to meet the water quality targets established in Sections 5-7 of this TMDL. This section also provides additional resources for municipalities and other individuals regarding many different pollution abatement strategies and programs.

Given the complexities of the water pollution problems to be addressed in the Ten Mile River system, an adaptive management approach to meeting water quality objectives would be advantageous. An adaptive approach involves exploring alternative ways to meet management objectives, predicting the outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of management actions, and then using the results to update knowledge and adjust management actions as appropriate. At the center of this approach is the inherent recognition of a feedback loop of monitoring, evaluation, and management adjustments that focuses specifically on learning about the impacts of management actions that are implemented and their contribution toward the goal of restoring water quality in impaired waters.

The adaptive management approach is particularly applicable to management decisions affecting nutrient and metals sources in the Ten Mile River watershed. Essential to effective management of these sources is an understanding of the Ten Mile River system's ecological response to nutrients and metals discharges. The approach must recognize the TMDL's findings that the critical condition for nutrients occurs under low flow (7Q10) during which the river is WWTF effluent dominated and retention period in the river's impoundments is longest, and for metals occurs under high wet weather flows. Implementation of an adaptive management approach does not preclude the need for more comprehensive stormwater abatement measures in both Rhode Island and Massachussets.

As described previously, at the time that sampling was conducted in 2007-2009, the Attleboro and North Attleborough wastewater treatment facilities in Massachusetts were upgrading their treatment processes in an effort to meet the more stringent metals and nutrient limits set by their revised NPDES permits. These process changes resulted in elevated levels of total aluminum and total iron discharged from the plants. Since that time the necessary upgrades to meet the more stringent nutrient and metal limits have largely been completed. RIDEM proposes to coordinate with MADEP in conducting follow-up monitoring at the state line sampling location to assess current nutrient and metals concentrations.

Since there are no wastewater treatment facilities in RI that impact this watershed, implementation activities in the Rhode Island portion of the watershed should focus on the largest and most controllable source of phosphorus, pathogens, and metals, which is stormwater runoff from urbanized land uses. The cities of Pawtucket and East Providence, and the Rhode Island Department of Transportation (RIDOT) will be required to amend their Stormwater Management Program Plans consistent with the requirements described in the following sections of this implementation plan. Other implementation measures include more aggressive and effective management of pet waste and control of nuisance waterfowl at specified locations in the watershed. In Massachusetts stormwater is regulated through both federal and state programs. Those programs include, but are not limited to, the federal and state Phase I and Phase II NPDES stormwater program, and, at the state level, the Wetlands Protection Act (MGL Chapter 130, Section 40), the state water quality standards, and the Massachusetts Clean Water Act, Ground Water Quality Standards, the River Protection Act and the Surface Water Discharge Permitting Program.

Fertilizer application rates and other nutrient reduction measures practiced by the golf courses have been documented and provide reasonable assurance that the two golf courses located in Rhode Island have met their total phosphorus load allocations. It is important that these implementation activities be continued.

Other sources of nutrients and metals to the Ten Mile River are thought to exist with a reasonable amount of certainty. However, as discussed in Section 4.0, measurement and/or quantification of such sources is speculative at best and as such, control would be extremely difficult. As specified previously, these sources include atmospheric deposition, waste cleanup sites and groundwater/sediment contamination (legacy pollutants), uncontrolled disposal of waste and illegal dumping, and background/natural sources.

Estimates of atmospheric deposition of phosphorus and metals to the Ten Mile River are not thought to be significant. Continued efforts by regional and national groups to reduce atmospheric pollution will result in additional local benefits within the watershed over the long term. Lastly, natural or background sources, such as naturally-occurring phosphorus or metals, that may leach out of soil or bedrock and non-stormwater related pathogen contributions from native wildlife are not likely significant or controllable and are therefore not further discussed. Future sampling efforts should consider monitoring to establish background concentrations of naturally-occurring phosphorus and metals.

Rhode Island’s programs to support reduction of pollutants are described below and are organized by type of pollutant source. The sections below provide descriptions of various mitigation measures, required modifications to MS4 permits, relevant state and federal regulations, and useful web links to information resources for stormwater, wastewater management, golf courses, and waterfowl, wildlife, and domestic pets, as well as other sources. Relevant links to Massachusetts requirements and resources are also provided.

8.1 Stormwater Management

In 2007, Rhode Island adopted the Smart Development for a Cleaner Bay Act (General Laws Chapter 45-61.2), requiring RIDEM and the Coastal Resources Management Council (CRMC) to update the Rhode Island Stormwater Design and Installations Manual. The revised manual, adopted January 2011, provides twelve minimum standards addressing LID site planning and design strategies, groundwater recharge, water quality, redevelopment projects, pollution prevention, illicit discharges, and stormwater management system operation and maintenance, among other concerns. This revised manual provides appropriate guidance for stormwater management on new development and redevelopment projects and, most importantly, incorporates LID as the "industry standard" for all sites, representing a fundamental shift in how development projects are planned and designed. The revised stormwater manual is available on-line at: http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm

A companion manual on LID site planning and design has also been prepared by RIDEM to provide Rhode Island-specific guidance regarding the site planning, design, and development strategies that communities should adopt to encourage low impact development. This manual is also available on-line at the above link. Rhode Island joins a growing number of states and localities including the Puget Sound area (http://www.psat.wa.gov/Programs/LID.htm) that rely heavily on LID techniques to protect and restore their waters.

RIDEM recommends that a combination of structural and non-structural BMP's be used to manage stormwater runoff in the Ten Mile River watershed. Structural Best Management Practices (BMPs) are engineered constructed systems that can be designed to provide water quality and/or water quantity control benefits. Structural BMPs are used to address both existing watershed impairments and the impacts of new development. The Rhode Island Stormwater Design and Installation Standards Manual (December 2010) contains detailed specifications for the design of these BMPs that can be used to meet water quality objectives. Common structural BMPs include the following:

Infiltration systems: designed to capture stormwater runoff, retain it, and encourage infiltration into the ground;

Detention systems: designed to temporarily store runoff and release it at a gradual and controlled rate (considered acceptable for flood control only);

Retention systems: designed to capture a volume of runoff and retain that volume until it is displaced in part or whole by the next runoff event (considered acceptable for flood control only);

Wet vegetated treatment systems: designed to provide both water quality and water quantity control; and

Filtration systems: designed to remove particulate pollutants found in stormwater runoff through the use of media such as sand, gravel or peat.

Non-structural BMPs are a broad group of practices designed to prevent pollution through maintenance and management measures. They are typically related to the improvement of operational techniques or the performance of necessary stewardship tasks that are of an ongoing nature. These include institutional and pollution-prevention practices designed to control pollutants at their source and to prevent pollutants from entering stormwater runoff. Non-structural measures can be very effective at controlling pollution generation at the source, thereby reducing the need for costly "end-of-pipe" treatment by structural BMPs. Examples of non-structural BMPs include maintenance practices to help reduce pollutant contributions from various land uses and human operations, such as street sweeping, road and ditch maintenance, or specifications regarding how and when to apply fertilizers and pesticides.

Structural and non-structural BMPs are often used together. Effective pollution management is best achieved from a management systems approach, as opposed to an approach that focuses on individual practices. Some individual practices may not be very effective alone, but in combination with others, may be more successful in preventing water pollution.

As noted above, in Massachusetts, stormwater is regulated through both federal and state programs. Those programs include, but are not limited to, the federal and state Phase I and Phase II NPDES stormwater program, and, at the state level, the Wetlands Protection Act MGL Chapter 130, Section 40), the state water quality standards, and the Massachusetts Clean Water Act, Ground Water Quality Standards, the River Protection Act and the Surface Water Discharge Permitting Program.

The Massachusetts Stormwater Handbook, last revised in 2008, contains detailed specifications for the design of the structural and non-structural BMPs that are required for developments subject to the MA Wetlands Protection Act. The Handbook addresses LID site planning and design strategies, groundwater recharge, water quality, redevelopment projects, pollution prevention, illicit discharges, and stormwater management system operation and maintenance, among other concerns. It provides appropriate guidance for stormwater management on new development and redevelopment projects and requires that LID be considered for every project. The MA Stormwater Handbook is available on-line at:
http://www.mass.gov/eea/agencies/massdep/water/regulations/massachusetts-stormwater-handbook.html

8.1.1 RIPDES and MassDEP Phase II Stormwater Management Programs **SWMPPs**
Stormwater runoff is most often carried to waterways by publicly owned drainage networks. Historically, these storm drain networks were designed to carry stormwater away from developed land as quickly as possible to prevent flooding with little to no treatment of pollutants. In 1999, the USEPA finalized its Stormwater Phase II rule, which required the operators of small municipal separate storm sewer systems (MS4s) to obtain permits and to implement a stormwater management program as a means to control polluted discharges. In Rhode Island, the RIDEM RIPDES Program administers the Phase II program using a General Permit that was established in 2003 (RIDEM, 2003a). Rhode Island municipalities, the Rhode Island Department of Transportation

(RIDOT), and Federal, State, and Quasi-State agencies serving more 1000 people per day are regulated under the Phase II program. The regulated municipalities, located within the Rhode Island portion of the Ten Mile River watershed, include both Pawtucket and East Providence. In Massachusetts the Phase II MS4 program is administered under a 2003 General Permit co-issued by EPA New England and MassDEP, with EPA exercising lead administration responsibilities.

The Phase II Program requires MS4 operators to develop a stormwater management program that is based on six minimum measures. Operators develop Stormwater Management Program Plans (SWMPPs) that detail how their stormwater management programs comply with the Phase II regulations. SWMPPs describe BMPs for the six minimum measures, including measurable goals and schedules. The implementation schedules include interim milestones, frequency of activities, and result reporting. Plans also include any additional requirements that are mandated for stormwater that discharges to impaired waters.

The six minimum measures are listed below.

• A public education and outreach program to inform the public about the impacts of stormwater on surface water bodies;

• A public involvement/participation program;

• An illicit discharge detection and elimination program;

• A construction site stormwater runoff control program for sites disturbing 1 or more acres;

• A post construction stormwater runoff control program for new development and redevelopment sites disturbing 1 or more acres; and

• A municipal pollution prevention/good housekeeping operation and maintenance program.

In general, municipalities and RIDOT were automatically designated as part of the Phase II program if they were located either completely or partially within census-designated urbanized or densely populated areas. Densely populated areas have a population density greater than 1000 people per square mile and a total population greater than 10,000 people. Both communities in the Rhode Island portion of the watershed (Pawtucket and East Providence), are designated as Phase II municipalities, and require Phase II permits. In addition to RIDOT, non-municipal MS4 operators include federal, state, and quasi-state facilities serving an average daily population equal to or greater than 1,000 people. Accordingly the cities of Pawtucket and East Providence and RIDOT have submitted the required Stormwater Management Program Plans (SWMPPs).

In Massachusetts, all 8 communities in the Ten Mile River Watershed are covered by Phase II requirements noted above (Wrentham, Plainville, Foxborough, North Attleborough, Mansfield, Attleboro, Seekonk and Rehoboth). Operators of regulated MS4s are required to implement each of the six minimum control measures. Those six measures are outlined above. In addition, each permittee must determine if a TMDL has been developed and approved for any water body into which an MS4 discharges. If a TMDL has been approved then the permittee must comply with the TMDL including the application of BMPs or other performance requirements. The permittees must report annually on all control measures currently being implemented or planned to be implemented to control pollutants of concern identified in TMDLs. Finally, the MassDEP has the authority to issue an individual permit to achieve water quality objectives. Links to the MA Phase II permit and other stormwater control guidance can be found at
http://www.mass.gov/eea/agencies/massdep/water/wastewater/stormwater.html#8

The MassDEP Wetlands regulations (310 CMR 10.00) directs issuing authorities to enforce the MassDEP Stormwater Standards , place conditions on the quantity and quality of point source discharges, and to control erosion and sedimentation. The Stormwater Standards apply to new and redevelopment projects where there may be an alteration to a wetland resource area or within 100 feet of a wetland resource (buffer zone). The Standards require the application of structural and/or non-structural BMPs to control suspended solids, which have associated co-benefits for nutrient and metals removal. A stormwater handbook was developed to promote consistent interpretation of the Stormwater Management Policy and Performance Standards: Volume 1: Stormwater Policy Handbook and Volume 2: Stormwater Technical Handbook can be found along with the Stormwater Policy at
http://www.mass.gov/dep/water/laws/swmpolv1.pdf.

Water quality and flow monitoring programs in the Ten Mile River should be continued in order to assess progress towards and success of obtaining the TMDL's water quality goals. This monitoring is necessary to determine whether water quality goals are met through the implementation of the activities. Instream monitoring programs should be designed to capture spatial, seasonal and climatic variability. In the Ten Mile River, periodic biological surveys should be conducted to determine the impacts of contaminants reduction on biomass in critical reaches.

8.1.2 Required SWMPP Amendments to TMDL Provisions

In Rhode Island, Part IV.D of the Phase II General Permit requires MS4 operators to address TMDL provisions in their SWMPP if the approved TMDL identifies stormwater discharges that directly or indirectly contain the pollutant(s) of concern (Part II.C3). Operators must comply with Phase II TMDL requirements if they contribute stormwater to priority outfalls via system interconnections, even if they do not own the outfall. Operators are legally responsible for pollutants transported via their drainage systems including, for example, bacteria sources from wildlife that enter MS4 drainage systems. Operators must identify amendments needed to their current SWMPP to comply with TMDL requirements. Operators must also address any previously non-regulated areas that are brought into the Phase II program as part of a TMDL, and are encouraged to apply their requirements town-wide. To avoid confusion and to better track progress, the SWMPP amendments should be addressed in a separate TMDL Implementation Plan (TMDL IP). Upon approval of a TMDL, the cities of Pawtucket and East Providence, and RIDOT should make revisions in their TMDL IP. The 2003 RIPDES General Permit requires that the revisions (i.e. TMDL IP) be submitted within one hundred and eighty (180) days of the date of written notice from RIDEM that the TMDL has been approved, as described in more detail below (RIDEM, 2003a).

It is common for state-owned and municipal-owned storm drains to interconnect. RIDEM encourages cooperation between MS4 operators when developing and implementing the six minimum measures and in conducting feasibility analyses and determining suitable locations for the construction of BMPs. Communities affected by the Phase II program are encouraged to cooperate on any portion of, or an entire minimum measure when developing and implementing their stormwater programs. An important first step in implementing this TMDL will be to confirm the ownership of the priority outfalls identified in section 6.1 and to determine interconnections within these drainage systems to the priority outfalls.

8.1.3 TMDL Implementation Plan (IP) Requirements

The TMDL Implementation Plan (TMDL IP) must address all parts of the watershed that discharge to the impaired water and all impacts identified in the TMDL, including those areas that are brought into the Phase II program as part of a TMDL. The TMDL IP must describe the six minimum measures and other additional controls that are or will be implemented to address the TMDL pollutants of concern. MS4 operators must provide measurable goals for the development and/or implementation of the amendments to the six minimum measures and as relevant, for additional structural and non-structural BMPs that will be necessary to address the stormwater impacts identified in this TMDL.

TMDL IP requirements must include an implementation schedule, which must contain all major milestone deadlines, including start and finish calendar dates, estimated costs, proposed or actual funding sources, and anticipated improvement(s) to water quality. These requirements apply to any operators of MS4s contributing stormwater to specifically identified outfalls, regardless of outfall ownership.

The TMDL IP must specifically address the following requirements that are described in Part IV.D of the RIPDES Stormwater General Permit (RIDEM, 2003b).

• Determine the land areas contributing to the discharges identified in the TMDL using sub-watershed boundaries, as determined from USGS topographic maps, stormwater sewer maps, or other appropriate means;

• Address all contributing areas and the impacts identified by the Department;

• Assess the six minimum control measure BMPs and additional controls currently being implemented or that will be implemented to address the TMDL provisions and pollutants of concern and describe the rationale for the selection of controls including the location of the discharge(s), receiving waters, water quality classification, shellfish growing waters, and other relevant information;

• Identify and provide tabular description of the discharges identified in the TMDL including:
o Location of discharge (latitude/longitude and street or other landmark);
o Size and type of conveyance (e.g. 15" diameter concrete pipe);
o Existing discharge data (flow data and water quality monitoring data);
o Impairment of concern and any suspected sources(s);
o Interconnections with other MS4s within the system;
o TMDL provisions specific to the discharge;
o Any additional outfall/drainage specific BMP(s) that have or will be implemented to address TMDL provisions; and
o Schedule for construction of structural BMPs including those for which a Scope of Work is to be prepared, as described below.

This TMDL has determined that the six minimum measures alone are insufficient to restore water quality and that structural BMPs are necessary. The TMDL IP must describe the tasks necessary to design and construct BMPs that reduce the pollutants of concern and stormwater volumes to the maximum extent feasible. The TMDL IP must describe the process and the rationale that will be used to prioritize outfalls/drainage systems, select structural BMPs (or low impact development (LID) retrofits) and measurable goals to ensure that the TMDL provisions will be met. In a phased approach, operators must identify any additional outfalls not identified in the TMDL that contribute the greatest pollutant load and prioritize these for BMP construction. Referred to as a Scope of Work in the current permit, this structural BMP component of the TMDL IP must also include a schedule and cost estimates for the completion of the following tasks:

o Prioritization of outfalls/drainage systems where BMPs are necessary. If not specified in TMDL, priority can be assessed using relative contribution of the pollutant(s) of concern, percent effective impervious area, or estimated pollutant loads based upon drainage area, pipe size, land use, etc. A targeted approach to construct stormwater retrofit BMPs at state and locally owned stormwater outfalls is recommended;

o Delineation of the drainage or catchment area;

o Determination of interconnections within the system and the approximate percentage of contributing area served by each operator's drainage system, as well as a description of efforts to cooperate with owners of the interconnected system;

o Completion of catchment area feasibility analyses to determine drainage flow patterns (surface runoff and pipe connectivity), groundwater recharge potentials(s), upland and end-of pipe locations suitable for siting BMPs throughout the catchment area, appropriate structural BMPs that address the pollutant of concern, any environmental (severe slopes, soils, infiltration rates, depth to groundwater, wetlands or other sensitive resources, bedrock) and other siting (e.g. utilities, water supply wells, etc.) constraints, permitting requirements or restrictions, potential costs, preliminary and final engineering requirements;

o Design and construction of structural BMPs; and

o Identification and assessment of all remaining discharges, not identified in the TMDL, owned by the operator, contributing to the impaired waters addressed by the TMDL, taking into consideration the factors addressed above.

In summary, the SWMPPs must be revised to describe the six minimum measures and other additional controls that are or will be implemented to address the TMDL pollutants of concern. The operators must provide measurable goals for the development and/or implementation of the six minimum measures and additional structural and non-structural BMPs that will be necessary to address provisions for the control of storm water identified in this TMDL including an implementation schedule, which includes all major milestone deadlines including the start and finish calendar dates, the estimated costs and proposed or actual funding sources, and the anticipated improvement(s) to water quality. If no structural BMPs are recommended, the operator must evaluate whether the six minimum measures alone (including any revisions to ordinances) are sufficient to meet the TMDL's specified pollutant reduction targets.

8.1.4 Modifications to Six Minimum Measures

As described previously, Pawtucket and East Providence, and RIDOT must assess the six minimum control measure BMPs for compliance with the TMDL provisions and provide measurable goals for any needed amendments. The TMDL IP must include a description of selection of controls including the location of the discharge(s), receiving waters, water quality classification, and other relevant information (General Permit Part IV.D.3.c). The following sections outline activities that should or must be implemented and/or considered when modifying six minimum measures.

Public Education/Public Involvement

The public education program must focus on both water quality and water quantity concerns associated with stormwater discharges within the watershed. Public education material should target the particular audience being addressed, while public involvement programs should actively involve the community in addressing stormwater concerns.

The targeted educational campaign should include activities that residents can take to minimize water quality and water quantity impacts. For instance, measures that can reduce bacteria contamination include eliminating any wastewater or other illicit connections to the storm drain network, proper disposal of pet waste, proper storage and disposal of garbage, and eliminating waterfowl feeding. Proper methods of fertilizer and pesticide application should also be included.

Reducing runoff volume can be accomplished by grading the site to minimize runoff and to promote stormwater attenuation and infiltration, creating rain gardens, and reducing paved areas such as driveways. Driveways can be made of porous materials such as crushed shells, stone, or porous pavement. Buffer strips and swales that add filtering capacity through vegetation can also slow runoff. Waterfront properties as well as those adjacent to hydrologically connected streams and wetland areas should establish and maintain natural buffers, planted with native plants, shrubs and/or trees to minimize impacts of development and restore valuable habitat.

Other audiences include commercial, industrial, and institutional property owners, land developers, and landscapers. In addition to the activities discussed above for residential land use, educational programs for these audiences could discuss BMPs that should be used when redeveloping or re-paving a site to minimize runoff and promote infiltration. Measures such as minimizing road widths, installing porous pavement, infiltrating catch basins, breaking up large tracts/areas of impervious surfaces, sloping surfaces towards vegetated areas, and incorporating buffer strips and swales should be used where possible. The RI Stormwater Design and Installation Standards Manual (RIDEM and CRMC, 2010) discussed previously provides detailed guidance on LID techniques.

The University of Rhode Island Cooperative Extension's Stormwater Phase II Public Outreach and Education Project provides participating municipalities with education and outreach programs that can be used to address TMDL public education recommendations. This project is funded by RIDOT and has many partners, including RIDEM. More information may be found on the URI website (http://www.ristormwatersolutions.org/).

Illicit Discharge Detection and Elimination

Illicit discharges are any discharge to a separate storm drainage system that is not composed entirely of stormwater with some exceptions. On-site Wastewater Treatment Systems (OWTS) or sewer line connections to a storm drain result in the discharge of untreated sewage to a waterbody and are considered illicit discharges. Routine illicit discharge detection and elimination (IDDE) work conducted by the municipalities, including sampling storm drains in dry weather can reveal illicit discharges.

It is not unexpected that illicit sewer connections may be found in storm drainage systems serving the older developed portions of the Ten Mile River watershed. Any outfall with sampling results greater than 2400 MPN/100ml for pathogens, and/or those with elevated metal or phosphorus values and exhibiting a steady flow should be prioritized for further investigation to eliminate any illicit discharges.

The New England Interstate Water Pollution Control Commission developed a publication entitled Illicit Discharge Detection and Elimination Manual, A Handbook for Municipalities available at: http://www.neiwpcc.org/iddemanual.asp. This guidance includes an implementation protocol that satisfies the Illicit Discharge Detection and Elimination requirement of the NPDES program in MA.

The detection and elimination of illicit discharges to the Ten Mile River is a high priority for US-EPA and MassDEP and is an explicit requirement of the MA Stormwater Standards. Tracking down episodic illicit discharges to storm drainage systems can be a challenging endeavor that requires repeated water quality monitoring, aggressive source tracking techniques, and committed local resources.

Construction/Post Construction

MS4 operators are required to establish post construction stormwater runoff control programs for new land development and redevelopment at sites disturbing one or more acres (RIDEM, 2008). Untreated stormwater runoff contains high bacteria, phosphorus and metals loads, which may contribute significantly to the water quality problems. Land development and re-development projects must utilize best management practices the Ten Mile River and its impoundments are to be successfully restored. Consistent with the revised RI Stormwater Design and Installation Manual (RIDEM and CRMC, 2010), local ordinances meant to comply with the post construction minimum measures (General Permit Part IV.B.5.a.2.) must require that applicable development and re-development projects use LID techniques as the primary method of stormwater control to the maximum extent practicable and maintain groundwater recharge to pre-development levels.

As mentioned previously, examples of acceptable reduction measures include reducing impervious surfaces, sloping impervious surfaces to drain towards vegetated areas, using porous pavement, and installing infiltration catch basins where feasible. Other reduction measures to consider are the establishment of buffer zones, vegetated drainage ways, cluster zoning or low impact development, transfer of development rights, and overlay districts for sensitive areas. The revised RI Stormwater Design and Installation Standards Manual (RIDEM and CRMC, 2010) contains detailed information on use of low impact development (LID) techniques. To ensure consistency with the goals and recommendations of the TMDL, the TMDL IP must also address any revisions to local ordinances that are needed to ensure that:

• New land development projects employ stormwater controls to prevent any net increase in pathogens, phosphorus, and metals to the impaired waterbodies in the Ten Mile River Watershed, specifically:

o Upper Ten Mile River (RI0004009R-01A) - Pathogens, Aluminum, Cadmium, Iron, Lead, Phosphorus
o Central Pond (RI0004009L-01A) - Phosphorus, Aluminum, Cadmium
o Turner Reservoir (RI0004009L-01B) - Phosphorus, Aluminum, Cadmium
o Lower Ten Mile River (RI0004009R-01B) – Aluminum, Cadmium
o Omega Pond (RI0004009L-03) – Pathogens, Phosphorus, Aluminum, Cadmium

• Redevelopment projects employ stormwater controls to reduce pathogens, phosphorus and metal pollution to the impaired waterbodies in the Ten Mile River Watershed (as detailed above) to the maximum extent feasible.

In addition, Pawtucket and East Providence should also consider expanding ordinances to include projects that disturb less than one acre. At a minimum, the TMDL IP must assess the impacts of imposing these requirements on lower threshold developments. The TMDL IP should also assess and evaluate various enforceable mechanisms that ensure long-term maintenance of BMPs.

In Massachusetts MS4 operators are required to establish post construction stormwater runoff control programs and adopt local bylaws regulating new land development and redevelopment at sites disturbing one or more acres. Land development and re-development projects must utilize these best management practices as part of the effort to ensure that the Ten Mile River and its impoundments are successfully restored. EPA's has proposed expanding the use of the MA Stormwater Standards to all MS4 regulated areas in Massachusetts.

Good Housekeeping/Pollution Prevention
The RIDEM Storm Water General Permit (see Part IV.B.6.a.2 and Part IV.B.6.b.1) extends storm water volume reduction requirements to operator-owned facilities and infrastructure, as does the MS4 Genenral Permit in Massachusetts. In addition, any new municipal construction project or retrofit should incorporate BMPs that reduce storm water and promote infiltration.

The TMDL Implementation Plan should provide a list of municipally owned properties and any BMPs located within the Ten Mile River watershed that may have been implemented to date, and/or where opportunities exist for future implementation. As part of their Good Housekeeping/Pollution Prevention requirements, MS4 operators must identify the potential sources of pollution, including specifically the TMDL pollutants of concern, which may reasonably be expected to affect the quality of stormwater discharges from their facilities; and describe and ensure implementation of practices, which the permittee will use to reduce pollutants in stormwater discharges from the facility. The SWPPP must address all areas of the facility and describe existing and/or proposed BMPs that will be used and at minimum must include the following:

• Frequent sweeping of roads, parking lots and other impervious areas;
• Effective management (storage and disposal) of solid waste and trash;
• Regular inspection and cleaning of catch basins and other stormwater BMPs; and
• Other pollution prevention and stormwater BMPs as appropriate.

Structural BMP Requirements in Rhode Island
As described previously, this TMDL finds that the six minimum measures alone are insufficient. to restore water quality and that structural BMPs are needed. MS4 owners must identify priority outfalls as discussed above in section 8.1.3. As described in detail in section 8.1.3, an Implementation Plan must be completed that details the tasks necessary to design and construct BMPs that reduce the pollutants of concern and stormwater volumes to the maximum extent feasible. As noted previously, TMDL provisions apply to any MS4 operators contributing stormwater to identified outfalls regardless of outfall ownership. The BMP study should include all the components of Part IV.D.4 (RIDEM, 2003b) that were previously described in the TMDL IP section. It must evaluate the feasibility of distributing infiltration or equivalent BMPs throughout the drainage area of the priority outfalls as an alternative to end of pipe technologies since the amount of land available for BMP construction is limited.

8.3 MS4 Operator Specific Stormwater Measures

City of Pawtucket

The City of Pawtucket is authorized to discharge stormwater under the RIPDES Phase II Stormwater General Permit (Permit RIR040024) to the following waterbody segments: Central Pond (RI0004009L-01A) and Ten Mile River (upper) (RI0004009R-01A). Upon notification by RIDEM of the US Environmental Protection Agency's approval of this TMDL, Pawtucket will have 180 days to amend their SWMPP consistent with Part IV.D of the General Permit and these specific TMDL requirements.

The City has identified five (5) outfalls which discharge to the upper Ten Mile River ranging in size from 12-36". In addition to the modifications to the six minimum measures described above in Section 8.1.5, the City must also assess and prioritize drainage systems for the design and construction of BMPs that reduce both the pollutants of concern and stormwater volumes to the *maximum extent feasible* as detailed in Section 8.1.3. Priority should be given to those outfalls greater than 24-inches in diameter and identified below in Table 62.

Table 62. City of Pawtucket Priority Outfalls.

Outfall ID	**Direct Discharge to**	**LAT**	**LONG**	**Pipe Diameter (inches)**	**Receiving Waterbody**
028	River	41.8663	-71.3414	36	Ten Mile River
039	Stream	41.8871	-71.3445	36 and 24	Ten Mile River nr Dagget Avenue
041	River	41.8938	-71.3409	24	Ten Mile River
042	Pond	41.8755	-71.3420	36	Slater Park Pond-Ten Mile River

A reasonable first step is for the City of Pawtucket to coordinate with RIDOT to confirm outfall ownership and system interconnections. The City must also assess and prioritize the drainage systems listed above, as well identify any previously unidentified drainage systems wholly or partially owned by the city that drain to the Ten Mile River or its impoundments. The city must design and construct BMPs, within priority catchments that reduce the pollutants of concern and stormwater volumes to the *maximum extent feasible.* The City of Pawtucket should begin this assessment process by reviewing available information for outfalls, as well as any other monitoring data collected by the city or others. Attention must be given to whether the data was collected under dry or wet weather conditions and thus whether priority ought to be given to illicit discharge detection and elimination, or construction of BMPs to reduce wet weather pollutant loads.

City of East Providence
The City of East Providence is authorized to discharge stormwater under the RIPDES Phase II Stormwater General Permit (Permit RIR040030) listed above to the following waterbody segments: Central Pond (RI0004009L-01A), Turner Reservoir (RI0004009L-01B), Ten Mile River (lower) (RI0004009R-01B), and Omega Pond (RI0004009L-03). Upon notification by RIDEM of the US Environmental Protection Agency's approval of this TMDL, East Providence will have 180 days to amend their SWMPP consistent with Part IV.D of the General Permit and these specific TMDL requirements.

The City has identified 45 outfalls that drain to the Ten Mile River or its impoundents. In addition to the modifications to the six minimum measures described above in Section 8.1.5, the City must also assess and prioritize drainage systems for the design and construction of BMPs that reduce both the pollutants of concern and stormwater volumes to the *maximum extent feasible* as detailed in Section 8.1.3 above. Priority should be given to those outfalls that are greater than 24-inches in diameter as identified in Table 63.

Table 60. City of East Providence Priority Outfalls.

Outfall ID	LONG	LAT	Direct Discharge to	Pipe Diameter (in)	Receiving Waterbody
CP-6	-71-20-40.2	41-51-26.1	Stream	36	Central Pond
CP-14	-71-20-44.2	41-50-50.1	Wetland	24	Central Pond
TR-5	-71-20-31.6	41-50-21.9	Swale	24	Turner Reservoir
OM-1	-71-21-50.76	41-50-00.9	Pond	36	Omega Pond
OM-2	-71-22-00.7	41-50-27.1	Pond	36	Omega Pond
TM-7	-71-20-59.9	41-49-57.5	River	42	Lower Ten Mile River

A reasonable first step is for East Providence to coordinate with RIDOT to confirm outfall ownership and system interconnections. East Providence must also assess and prioritize the drainage systems listed above, as well identify any previously unidentified drainage systems wholly or partially owned by the city that drain to the Ten Mile River or its impoundments. The city must design and construct BMPs, within priority catchments that reduce the pollutants of concern and stormwater volumes to the *maximum extent feasible.* East Providence should begin this assessment process by reviewing available information for outfalls, as well as any other monitoring data collected by the city or others. Attention must be given to whether the data was collected under dry or wet weather conditions and thus whether priority ought to be given to illicit discharge detection and elimination, or construction of BMPs to reduce wet weather pollutant loads.

RIDOT

RIDOT is authorized to discharge stormwater under the RIPDES Phase II Stormwater General Permit (RIPDES Permit RIR040036) to the following waterbody segments: Ten Mile River (upper) (RI0004009R-01A) and Ten Mile River (lower) (RI0004009R-01B). Upon notification by RIDEM of the US Environmental Protection Agency's approval of this TMDL, RIDOT will have 180 days to amend their SWMPP consistent with Part IV.D of the General Permit.

RIDOT, has identified six (6) outfalls that discharge to the Ten Mile River and/or impoundments ranging in size from 8-36". In addition to the modifications to the six minimum measures described above in Section 8.1.5, RIDOT must also assess and prioritize drainage systems for the design and construction of BMPs that reduce both the pollutants of concern and stormwater volumes to the *maximum extent feasible* as detailed in Section 8.1.3 above. Priority should be given to those outfalls that are greater than 24-inches in diameter as identified below in Table 64.

Table 61. RIDOT Priority Outfalls.

Outfall ID	State Road	Direct Discharge to	Pipe Diameter (in)	Receiving Waterbody
TENM002	Pleasant Street	River	30	Ten Mile River
TENM005	Armistice Blvd	River	30	Ten Mile River
TENM006	Armistice Blvd	Pond	36	Slater Park Pond

A reasonable first step is for RIDOT to coordinate with the cities of East Providence and Pawtucket to confirm outfall ownership and system interconnections. RIDOT must also assess and prioritize the drainage systems listed above, as well identify any previously unidentified drainage systems wholly or partially owned by the city that drain to the Ten Mile River or its impoundments. The city must design and construct BMPs, within priority catchments that reduce the pollutants of concern and stormwater volumes to the *maximum extent feasible.* RIDOT should begin this assessment process by reviewing available information for outfalls, as well as any other monitoring data collected by the city or others. Attention must be given to whether the data was collected under dry or wet weather conditions and thus whether priority ought to be given to illicit discharge detection and elimination, or construction of BMPs to reduce wet weather pollutant loads.

Stormwater from Industrial Activities
Although no facilities have applied for coverage under the Multi-Sector General Permit (MSGP) in the Rhode Island portion of the Ten Mile River watershed, the following requirements would apply to any future MSGP holders in the Rhode Island portion of the watershed.

Facilities that discharge "stormwater associated with industrial activity" are regulated under the statewide general RIPDES permit prescribed in Chapter 46-12, 42-17.1 and 42-35 of the General Laws of the State of Rhode Island. As mentioned previously, stormwater is a significant source contributing to the pathogen, phosphorus, metals and related impairments in the Ten Mile River system. Stormwater from industrial activities may be discharged to these waters directly or via MS4s and may contain pollutant concentrations that contribute to the impairments.

Part I.B.3.k of the RIPDES Multi-Sector General Permit (MSGP) described below is applicable to future permitees:

New Discharges to Water Quality Impaired Waters. If the permittee is a new discharger the permittee is not eligible for coverage under this permit to discharge to an"impaired water", as defined in Appendix A unless the permittee:

1. prevents all exposure to stormwater of the pollutant(s) for which the waterbody is impaired, and retains documentation of procedures taken to prevent exposure onsite with the Storm Water Management Plan (SWMP); or

2. documents that the pollutant(s) for which the waterbody is impaired is not present at the site or is not present at levels above natural background, and retains documentation of this finding with the SWMP; or

3. at the time of submitting the NOI, provides to the RIPDES Program data to support a showing that the discharge is not expected to cause or contribute to an exceedance of a water quality standard, and retain such data onsite with the SWMP. To do this, the permittee must provide data and other technical information to the Department sufficient to demonstrate:

i. For discharges to waters without an EPA approved or established TMDL or other water quality determination made by the Department, that the discharge of the pollutant for which the water is impaired will meet in-stream water quality criteria at the point of discharge to the waterbody; or

ii. For discharges to waters with an EPA approved or established TMDL or waters with other water quality determination made by the Department, that there are sufficient remaining wasteload allocations in an EPA approved or established TMDL or other water quality determination to allow the facility's discharge and that existing dischargers to the waterbody are subject to compliance schedules designed to bring the waterbody into attainment with water quality standards.

The permittee is eligible under Part I.B.3.k.3 if the permittee documents that the discharge will not contribute to the existing impairment, in which case the permittee must maintain such documentation onsite with the SWMP and submit with the NOI a copy of the document. EPA's MSGP applies in areas of the country where EPA remains the NPDES permitting authority and has made the permit available for coverage, which includes Massachusetts.

Stormwater - Available Resources

Rhode Island Stormwater Design and Installation Standards Guidance Manual 2010 – This manual provides assistance to property owners, developers, engineers, consultants, contractors, municipal staff and others in planning, designing and implementing effective stormwater best management practices for the development and redevelopment of properties in Rhode Island.

The Stormwater Manual is available online at:
http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm

Rhode Island Low Impact Development (LID) Site Planning and Design Guidance for Communities - This document provides guidance to communities regarding the site planning, design, and development strategies that communities should adopt to encourage low impact development.
http://www.dem.ri.gov/programs/bpoladm/suswshed/pdfs/lidplan.pdf

Low Impact Development Checklist

This checklist was compiled by RIDEM to allow communities to quickly determine what specific LID site planning and design techniques they have adopted or may need to adopt to more effectively encourage LID practices for new development and redevelopment. The checklist for the cities of Pawtucket and East Providence. is shown in Appendix K.

RIDEM RIPDES Stormwater Page – This webpage provides information about Stormwater Phase I and Phase II programs as well as useful links to factsheets for Phase II permits, information on BMPs, and RIPDES regulations.

http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/stwater/index.htm

Rhode Island Stormwater Solutions Page- RI Stormwater Solutions is a statewide effort spearheaded by the University of Rhode Island with collaboration other state agencies to develop materials that towns, cities, and institutions across the state could use to meet their Phase II Stormwater Program requirements.

http://web.uri.edu/riss/

NPDES Phase II Fact Sheets **–** The USEPA publishes a series of fact sheets regarding NPDES Stormwater Phase II final rules.
http://cfpub.epa.gov/npdes/stormwater/swfinal.cfm

National Menu of Stormwater BMPs **–** The National Menu of BMPs for Stormwater Phase II was first released in October 2000. An updated version of this original webpage, including the addition of new fact sheets and the revision of existing fact sheets, is available through the USEPA website.
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/

University of New Hampshire Stormwater Center **–** The UNH Stormwater Center runs a facility that provides controlled testing of stormwater management designs and devices. Currently the Center is acting as a unique technical resource for stormwater practitioners by studying a range of issues for specific stormwater management strategies including design, water quality and quantity, cost, maintenance, and operations. The field research facility serves as a site for testing stormwater treatment processes, for technology demonstrations, and for conducting workshops. The testing results and technology demonstrations are meant to assist resource managers in planning, designing, and implementing effective stormwater management strategies. Detailed descriptions of multiple stormwater BMPs are available through their website and their annual reports.
http://www.unh.edu/unhsc/

Massachusetts Nonpoint Source Management Manual **-** was created and designed for use by municipal officials and residents in Massachusetts to promote understanding and implementation of the many different options for prevention and control of nonpoint source pollution. http://projects.geosyntec.com/NPSManual/

Massachusetts Watershed-Based Plan (WBP) **–** The purpose or objective of the WBP is to organize information about Massachusetts's watersheds, and present it in a format that will enhance the development and implementation of projects that will restore water quality and beneficial uses in the Commonwealth. The WBP follows EPA's recommended format and is presented consistent with Massachusetts's twenty-seven major planning basins.

http://www.mass.gov/eea/agencies/massdep/water/watersheds/nonpoint-source-pollution.html#3

Massachusetts Stormwater Technology Evaluation Project (MASTEP) **–** clearing house for evaluation of stormwater BMPs http://www.mastep.net/

Guidelines to Address Pathogen Pollution - Mitigation Measures to Address Pathogen Pollution in Surface Waters: A TMDL Implementation Guidance Manual for Massachusetts

http://www.mass.gov/eea/agencies/massdep/water/watersheds/total-maximum-daily-loads-tmdls.html

8.2 Massachusetts Wastewater Treatment Facilities

As stated earlier, two wastewater treatment facilities, both located in Massachusetts, discharge directly to the Ten Mile River. The North Attleborough Wastewater Treatment Facility collects and treats an average of 3.1 million gallon per day of industrial and domestic wastewater from North Attleborough as well as the Town of Plainville. It has a permitted annual average capacity of 4.61 mgd. The Attleboro Water Pollution Control Facility (WPCF) discharges to the Ten Mile River a short distance from the Rhode Island border. The Attleboro WPCF has a permitted annual average capacity of 8.6 mgd and serves the City of Attleboro with some septage collected from portions of North Seekonk and Attleboro.

The new NPDES Permit for the North Attleborough WWTF was jointly issued by the US EPA and the MA DEP in February 2008. The new permit contained reduced limits for nitrogen, phosphorus, and several metals including total aluminum and cadmium. Limits for total lead were unchanged from the 1999 permit. The new permit limit for total phosphorus, for the period from April 1 through October 31, was lowered from 1.0 mg/l to 0.1 mg/l. The new limits imposed on North Attleborough's Wastewater Treatment Facility required an upgrade to the existing treatment facilities. An interim phosphorus limit for years 2-5 of the upgrading schedule was set at 0.4 mg/l, expressed as a 90-day rolling average applicable from April 1- Oct 31. North Attleborough is nearly complete with their upgrade to meet their permit limits and was required to comply with nutrient limits by June 18, 2013 (EPA Administrative Order Docket #08-018).

The new NPDES permit, issued to the Attleboro facility in September of 2008 contained reduced limits for total phosphorus. Specifically, the average monthly limit for both permits was lowered to 0.1 mg/l during the critical period (April 1 through October 31). This was decreased from a limit of 1 mg/l for the same time period, for the previous permit. The limit for total phosphorus, for the period of November 1 through March 31, remained unchanged (1 mg/l). The upgrades are complete and both the total phosphorus and metals limits are being met. Attleboro had constructed a multi-point chemical addition scheme for total phosphorus removal in 2009 and 2010 during their upgrade which allowed them to meet the seasonal 0.1 mg/l total phosphorus limit. Additional removal of phosphorus and aluminum is anticipated to occur during the construction phase to meet nitrogen limits which may include advanced filtration.

As stated in Section 4.0 of this TMDL, both facilities were adjusting their dosages of aluminum and iron based coagulants between 2007 and 2009 sampling activities, which may have contributed to elevated levels of total aluminum and iron measured in the Ten Mile River at the state line. Aside from a small number of excursions, many of which occurred during the upgrades, both facilities are now meeting their metals and total phosphorus limits. Both facilities have permits that are now in the administrative continued status (i.e. expired and application submitted on time for renewal) If for some reason the permit limits are changed then there will be modifications to the schedule given in the orders.

Because past monitoring may not be reflective of current metal and phosphorus levels, pending availability of funding, RIDEM is willing to coordinate with MADEP in conducting follow-up monitoring to re-assess nutrient and metals concentrations at the state line monitoring station, located at Central Avenue in Pawtucket, RI. It is envisioned that these results will help guide additional implementation actions/adaptive management strategies, as needed in the Massachusetts portion of the watershed.

The TMDL acknowledges the fact that reductions in phosphorus loading have been achieved by both Attleboro and North Attleborough. It is noteworthy that for the most part, Attleboro was achieving the 0.1 limit during the 2007-2009 time period (by adjusting dosages of ferric salts and alum). It is also noted that although the seasonal permits for both facilities changed from 1.0 mg/l to 0.1 mg/l (a 90% reduction in effluent total phosphorus concentration) this did not result in a 90% phosphorus load reduction between 2007-2009 and 2013 time periods. Any pollutant load reductions achieved by the WWTFs to date will reduce the percent reduction required to meet ambient water quality criteria going forward, but does not change the calculation of Total Maximum Daily Load (water quality criteria X flow).

8.3 Sanitary Sewer Overflows

It does not appear that sanitary sewer overflows are a significant source of pathogens in the Ten Mile River watershed. However, as collection systems age, the frequency and severity of bypass or sanitary sewer overflows could also increase and become a more significant source. Also underground sanitary leaks, ultimately affecting surface waters, may go undetected. The Cities of East Providence and Pawtucket have programs in place to maintain, inspect, and upgrade this infrastructure.

The City of East Providence’s Water Pollution Control Facility and collection system is operated by an outside contractor-United Water. United Water has contracted with Inland Waterways to clean and TV inspect the sewer mains throughout the city. United Water, through Inland Waterways is responsible for cleaning the sewer mains and schedules 20% of the system for cleaning each year, such that the entire system is cleaned every five years. This work consists of a large Vactor type truck that jets the lines and vacuums the debris into a large tank on the back of the truck. The truck is required to set-up over a manhole, typically located in the middle of the roadway. Once the pipe is cleaned, a smaller van follows to televise the sewer pipe. This allows for a structural inspection of the pipeline to determine the condition of the pipe and allows the city to focus repairs/maintenance to specific areas.

The ultimate goal of this work is to provide the city with a detailed maintenance work plan, accurate locations of sewer laterals, improve the flow of water through the sewer lines, and to try and reduce areas of inflow and infiltration of groundwater (clean water) that surcharge our pipes during times of extreme storms.

At this time, RIDEM proposes no additional recommendations to the municipalities sanitary sewer inspection and maintenance programs.

8.4 Waterfowl, Wildlife, and Domestic Animals

As discussed previously, in section 4, non-migratory waterfowl are likely a source of pathogens and phosphorus to the Ten Mile River. Significant populations of swans and geese have been observed at the northern end of Central Pond, in and around the City of Pawtucket Slater Memorial Park Pond, Slater Park Pond near the Pawtucket Country Club, and along the southwestern shore of the Turner Reservoir at the Bridgham Farm Conservation Area. Large numbers of resident Canada Geese were also observed by DEM staff at the Agawam Hunt Club in East Providence and the Pawtucket Country Club in Pawtucket during the 2007-2008 field sampling.

Residents and other property owners can take several measures to minimize waterfowl-related impacts. They can allow tall, coarse vegetation to grow in areas along the shores of impacted streams that are frequented by waterfowl. Waterfowl, especially grazers like geese, prefer easy access to the water. Maintaining an uncut vegetated buffer along the shore will make the habitat less desirable to geese and encourage migration.

RIDEM acknowledges the fact that the city departments (namely Parks and Recreation, and/or Public Works) of both municipalities know where nuisance populations of waterfowl exist. Therefore, RIDEM recommends that appropriate staff within the cities of Pawtucket and East Providence work with staff from the RI Division of Fish and Wildlife and USDA Wildlife Services to develop a more comprehensive, aggressive, and publicly acceptable strategy of long term control.

Both the Agawam Hunt Club and the Pawtucket Country Club have made significant progress controlling goose populations on the golf courses. Both courses utilize border collies to chase birds away and hunting has also been used (on a limited basis) at the Pawtucket Country Club. Course managers have informed DEM staff that these measures have been extremely effective and have significantly reduced populations. During the 2007-2008 sampling period, DEM staff routinely observed large quantities of fecal material in the parking lot, along the shoreline, and on the putting greens at Pawtucket Country Club. When DEM staff met with the course manager in 2013, no droppings were observed along the shoreline of Slater Park Pond or in the course parking space. RIDEM strongly urges its MA agency partners to similarly engage and involve golf course managers with respect to nuisance goose populations in the Massachusetts portion of the watershed.

In response to the dramatic rise in the population of non-native swans in the northeast, changes were made to the federal jurisdiction and publication of the Migratory Bird Treaty Act Reform Act of 2004. As a result, states were given more flexibility in the management of mute swans. This prompted the recent adoption of a RI management plan for swans drafted in 2006. The RIDEM Division of Fish and Wildlife has developed a management plan to control the state's swan population, which includes the routine monitoring of swan populations (a summer aerial survey to identify swan nests and a fall productivity survey) as well as working to actively reduce the state's swan population from the currently estimated population of 1,400 to a target population of 300. This program has been successful in reducing the statewide mute swan population to less than 1000.

Implementation of the mute swan management plan is currently limited to major molt locations, which does include Turner Reservoir and Central Pond. However, the continuance of such programs to control non-native invasive waterfowl species is unlikely to continue in future years, given the recent reduction in resources including staff and the fact that monies derived for this work are not federally matched. To date, RIDEM has removed approximately 45 individuals as well as addled numerous eggs in Central Pond.

With few exceptions, Part XIV, Section 14.13 of Rhode Island's Hunting Regulations prohibits feeding wild waterfowl at any time in the state of Rhode Island. The cities of East Providence and Pawtucket should ensure that mention of this regulation is included in their SWMPPs.

The RIPDES Stormwater Phase II Permit requirements currently include an educational program to inform the public about the impact of stormwater. Education and outreach programs should highlight the importance of picking up after pets and not feeding waterfowl. Pet wastes should be disposed of away from any waterway or stormwater system. Towns should work with volunteers to map locations where pet waste is a significant and a chronic problem. This work should be incorporated into the municipalities' Phase II plans and should result in an evaluation of strategies to reduce the impact of pet waste on water quality.

In summary, the cities of East Providence and Pawtucket should identify those areas within the Ten Mile River watershed that are high pet use areas and install signage, provide pet waste receptacles or pet waste digester systems, if not already completed already, consider enacting ordinances requiring clean-up of pet waste, and targeting educational and outreach programs in problem areas.

Waterfowl, Wildlife, and Domestic Pets – Available Resources
RIDEM Canada Geese Management Plan
http://www.dem.ri.gov/programs/bnatres/fishwild/pdf/cangeese.pdf

RIDEM Mute Swan Management Plan
http://www.dem.ri.gov/programs/bnatres/fishwild/pdf/muswan07.pdf

RIDEM Mute Swan Fact Sheet - An example of the management of the mute swan population in Rhode Island.
Online: http://www.dem.ri.gov/programs/bnatres/fishwild/pdf/muteswan.pdf

RIDEM Waterfowl Feeding Fact Sheet – This fact sheet provides five reasons why feeding waterfowl is harmful.
Online: http://www.dem.ri.gov/programs/bnatres/fishwild/pdf/dontfeed.pdf

RIDEM Animal Waste Fact Sheet – This fact sheet provides background information on the effects of pet waste to a waterbody and the difficulties and effectiveness of developing a pet waste pollution program.
http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/stwater/t4guide/fact1.htm

URI NEMO Pet Waste Fact Sheet – This fact sheet provides information on the effects of pet waste on water quality and provides links to useful resources available from URI NEMO.
http://www.ristormwatersolutions.org/index.html

Rhode Island Dog-Friendly City Guide – This website provides a list of local dog parks.
http://www.dogfriendly.com/server/travel/uscities/guides/us/cities/usonlinecityRIProvidence.shtml

USEPA Source Water Protection Practices Bulletin – Managing wildlife and domestic animal waste to prevent contamination of drinking water.
http://www.epa.gov/safewater/sourcewater/pubs/fs_swpp_petwaste.pdf

8.5 Golf Course Management

There are two golf courses in Rhode Island located, at least partially, within the Ten Mile River watershed. These include the Agawam Hunt Club Golf in East Providence and the Pawtucket Country Club, a portion of which is located in Pawtucket Rhode Island, with the majority being located in Seekonk Massachusetts. There are also numerous golf courses in the Massachusetts portion of the watershed.

Both the Agawam Hunt Club and the Pawtucket Country Club report significantly decreased phosphorus fertilizer use on their golf courses from 2007 to the present. This is described in more detail in the Reasonable Assurance Section (Section 7.10) of this TMDL. DEM recommends a continuation of minimal phosphorus fertilizer applications to these golf courses, and implementation of other best management practices to maintain natural buffers along hydrologically connected waterways to the Ten Mile. RIDEM strongly urges MA state agency counterparts to engage and involve golf course managers with respect to appropriate fertilizer usage in the Massachusetts portion of the watershed.

Golf Course Management-Available Resources
Delaware Nutrient Management Commission-Water *Quality Best Management Practices Nutrient, Irrigation and Pesticides for Golf Course, Athletic Turf, Lawn*-This document is designed to provide information and guidance for the "green industry" on turfgrass and landscape plant production and maintenance practices to conserve and protect water resources. These practices include the establishment of new turf and landscapes, and the care of existing turf and landscapes, including construction activities, irrigation, nutrient anagement and pest management.
m
http://dda.delaware.gov/nutrients/forms/BMPnonagforprinter.pdf

USEPA Golf Course Superintendents Association of America's PESP (Pesticide Environmental Stewardship Program) Strategy- This website addresses pesticide risk reduction within the golf course maintenance industry.

http://www.epa.gov/pestwise/pesp/members/strategies/golf_course_superintendents_assoc_of_america.pdf

8.6 Uncontrolled Disposal of Wastes and Illegal Dumping
During its survey of the Ten Mile River, RIDEM staff observed various objects including: appliances, automotive debris including tires, shopping carts, bicycles, ladders, empty paint and herbicide containers, used motor oil and coolant containers and paper funnels, within the mainstem and on the banks and portions of floodplain of the river. Although it cannot be quantified, it is certainly possible that metals leach from these objects and are released into the water column.

The Ten Mile River Watershed Council (TMRWC) organizes an annual cleanup in the watershed to remove trash from the river. The sixth annual Daggett Cleanup occurred in Pawtucket on May 5, 2012. The cleanup took place in the woods and pond of the Ten Mile River Reservation. In 2012, the TMRWC also assisted in the sixth annual City of Attleboro's annual cleanup of the Ten Mile River as well as the Earth Day cleanup at Hunt's Mills in East Providence. In 2012 more than 80 volunteers participated in the Attleboro cleanup, collecting 40 garbage bags of trash as well as tires and other debris.

The Cities of East Providence and Pawtucket should work with the Ten Mile River Watershed Association to identify and map problem disposal sites that border the Ten Mile River. Once these sites are identified, the municipalities should develop aggressive plans to address these issues. RIDEM also recommends an effective integrated catchment-wide litter management strategy including educational campaigns to bring about greater public awareness and response to the litter problem, waste reduction to reduce the generation of urban waste, and an enforcement mechanism to insure compliance. Both municipalities need to actively investigate complaints, and take enforcement actions, as appropriate.

Citizens and watershed groups need to ensure that complaints are submitted and followed up on. Consideration should be given to placement and routine emptying of trash receptacles in areas of heavy pedestrian use and riparian access. Municipalities should also consider use of youth volunteers or interns to pick up trash on city streets. City officials should also conduct periodic inspections of commercial and industrial properties and document routine violations or problem areas to receive immediate notification of failure to comply and subsequent enforcement actions.

Uncontrolled Disposal of Wastes and Illegal Dumping -Available Resources
The Narragansett Bay Commission (NBC) and Rhode Island Resource Recovery Corporation (RIRRC)-A study contracted to the Affiliated Offices of Nicholson & Sands, LLC to research long-term solutions to ensure the proper disposal of "hard-to-dispose-of" items.

http://www.dem.ri.gov/programs/ombuds/litter/pdf/nbchard2.pdf

8.7 Waste Cleanup Sites

As previously discussed in section 4, there are numerous waste cleanup sites located within the Ten Mile River watershed. Waste cleanup sites include Superfund sites, federal facilities, brownfields, underground storage tank system releases, treatment, storage and disposal facility accidental releases, and oil spills. It is reasonable to assume that all old industrial sites within the watershed have some form of groundwater contamination. EPA New England's Office of Site Remediation and Restoration (OSRR) administers the region's waste site cleanup and reuse programs. Both RIDEM and MADEP have programs dedicated to various waste site cleanup areas. Many sites have not been investigated and still others have yet to be discovered. Continued investigations and waste remediation actions are anticipated to reduce the threat of contamination from these cleanup sites.

Waste Site Cleanup -Available Resources
EPA-Waste Site Cleanup & Reuse in New England-a web site to locate hazardous waste sites in New England, learn about EPA's cleanup programs, as well as to retrieve additional information regional cleanup efforts.
http://www.epa.gov/region1/cleanup/index.html

Massachusetts Bureau of Waste Site Cleanup is charged with ensuring immediate and effective response to environmental emergencies, such as oil spills, as well as timely assessment and cleanup of oil and hazardous waste disposal sites by parties responsible for them. The program can be found at the following link.
http://www.mass.gov/eea/agencies/massdep/cleanup/

8.8 Control of Internal Loading of Phosphorus

Since internal cycling may be at least an intermittent source of phosphorus in some of the impoundments, full attainment of phosphorus related designated uses may not occur without control of phosphorus release from pond sediments.

There are four primary techniques to reduce internal loading of phosphorus in waterbodies: dredging, aeration/oxygenation of the hypolimnion, complete circulation/destratification of the entire lake, and the application of alum (or other phosphorus-binding agents). Dredging is the most effective method but is extremely costly and may encounter regulatory prohibitions (Welch, 2005). Hypolimnetic aeration/oxygenation treats anoxic phosphorus release only and depends on iron availability to bind phosphorus and iron may not be inactivated itself in highly polluted sediments. Complete circulation/destratification has the same effect on sediment phosphorus as hypolimnetic aeration, but with a greater risk of increasing phosphorus availability in the epilimnion by removing the thermocline barrier. Also shallow lakes are generally already aerated. Aeration techniques also have no lasting effect and once the source of air is shut off the internal loading will return.

Since the impoundments in the Rhode Island portion of the Ten Mile River system are currently impaired for aluminum, the application of alum (an aluminum sulfate) is not recommended. However an alternative phosphorus-sequestering compound, such as a lanthanum-based product, could be used to immobilize phosphorus, if warranted. Any application of chemicals in a waterbody must be carefully evaluated and controlled to minimize the risk of potential negative chemical and biological impacts.

DEM recommends that a professional consultant with experience in the control of phosphorus release from pond sediments be hired to specifically address internal loading from this source. The consultant should confirm the significance of internal cycling as a source of phosphorus to the impoundments, and secondly, evaluate the most effective and feasible BMPs to control phosphorus release from the sediment. Lastly, many BMPs used to control the release of internal phosphorus may have undesirable effects on the waterbody if not properly conducted and therefore the consultant should also be retained to oversee implementation of the selected BMPs.

Internal Loading-Available Resources
Washington Department of Ecology-Lake Restoration and Management for Algae – This website includes a discussion of in-lake restoration techniques.

http://www.ecy.wa.gov/programs/wq/plants/algae/lakes/LakeRestoration.html

8.9 Contaminated Sediments

The origins of sediment contamination in the Ten Mile River can be generally divided between point and nonpoint sources of pollution. Point sources in the watershed include municipal sewage treatment plants, stormwater discharges, and both current and historic discharges from numerous industrial facilities. Nonpoint sources include dry and wet atmospheric deposition and unknown and/or unidentified leaks of metal containing substances, both intentional and unintentional.

Analysis of the in-stream metals data, collected in 2007 and 2008, shows that the wet-weather stormflow condition produces notably higher levels of particulate metals than the dry weather baseflow condition. The elevated levels of particulate metals, measured during the stormflow condition, are consistent for all of the metals sampled, including: cadmium, lead, copper, zinc, aluminum, and iron. The elevated levels of particulate metals may be the result of scouring and resuspension of contaminated sediment during periods of higher flows.

Much of the sediment transported downstream in the Ten Mile River likely settles out behind each of the many dams along its course. The sediments that have accumulated behind many of the dams have been found to contain elevated levels of several metals including copper, zinc, and cadmium (in Central Pond and the Turner Reservoir); arsenic, cadmium, chromium, lead, nickel, zinc, and mercury (at Slater Park Pond), and copper, zinc, cadmium, and nickel (in Omega Pond).

As a metals source, sediment and/or groundwater contamination is difficult to assess and control. The effects that these specific contaminants (cadmium, lead, and aluminum) are having on the Ten Mile River ecosystem are not known. There is no direct evidence linking these contaminants to restrictions on fish and wildlife consumption, fish tumors or other deformities, loss of fish and wildlife habitat, degraded invertebrate communities, and other beneficial use impairments. It is also acknowledged that metals are not the only contaminants documented in the sediments that have the potential to impact designated uses in the river.

Remediation of contaminated sediment may grow in importance as greater levels of source control are achieved-primarily through significant control of stormwater inputs, improvements and upgrades to wastewater treatment facilities, and closure of a vast majority of historic industrial discharges to the river. Sediment erosion/deposition zones have not been delineated or thoroughly assessed in the Ten Mile River basin. The adaptive management approach, described above recognizes the feedback loop of monitoring, evaluation, and management adjustments that focuses specifically on learning about the impacts of management actions that are implemented and their contribution toward the goal of restoring water quality in impaired waters. The adaptive management approach is particularly applicable to management decisions affecting metals sources in the Ten Mile River watershed since effluent based permit limits were imposed for metals on Massachusetts plants. Further monitoring is needed once other measures are fully implemented to identify if there is further need for further remediation.

There are gaps in understanding of the relationship between contaminated sediment and the benthic-macroinvertebrate bioassessment impairment identified in the upper Ten Mile River. As a result of these critical knowledge gaps, the RIDEM recommends that additional monitoring and research be conducted on this potential source. This additional research should evaluate the relationships between contaminated sediment and known use impairments, and to forecast ecological benefits of specific remediation measures.

There are no data available from the testing of tissue of fish caught in the Ten Mile River systerm. Given the industrial legacy in the watershed and the existence of elevated metals (and other pollutants) concentrations in the impoundment sediments, it is reasonable to assume that some general level of biomagnification occurs. As such, fish tissue sampling should also be conducted to identify any public health threats posed by the consumption of fish caught in the Ten Mile River.

9.0 Public Participation

RIDEM held a public meeting on July 12, 2012 at the Weaver Library in East Providence, Rhode Island. The purpose of the meeting was to inform the public of DEM's efforts to restore water quality in the Ten Mile River watershed. Specific topics included: (1) describe pertinent sections of the Federal Clean Water Act and introduce RIDEM's TMDL program to the audience, (2) discuss the findings of the various water quality studies conducted by RIDEM between 2007-2009 in the Ten Mile River watershed, (3) provide a summary of the various technical approaches to developing the TMDLs, (4) provide an overview of the pollution sources in the watershed, and (5) describe both the required and recommended pollution control strategies that the TMDL will contain.

Approximately 20 individuals attended the meeting including representatives from: Ten Mile River Watershed Council, City of Pawtucket, City of Attleboro, MA, Attleboro Water Pollution Control Facility (WPCF), Narragansett Bay Commission, Audubon Society, Northern RI Conservation District, Save the Bay, Brown University, RIDOT, East Providence Conservation Commission, and several residents of the cities of East Providence and Pawtucket. A draft data report was made available at the public meeting (via internet link). A robust discussion and question/answer session followed the presentation.

The draft TMDL was presented at a public meeting held on January 8th, 2014, also at the Weaver Library in East Providence. The draft TMDL was posted on December 23rd 2013 and was accompanied by a press release on DEM's website. Stakeholder letters were also sent out via email on December 23rd, 2013 which marked the beginning of the public comment period. Approximately 25 individuals attended the meeting, many of whom were present at the first meeting in 2012. Comments and RIDEM responses to those comments received during the public comment period, including those received by EPA, are in Appendix L.

10.0 Future Monitoring

The results of water quality monitoring will allow RIDEM to track compliance with the water quality objectives as the TMDL is implemented and remedial actions are accomplished. Water quality monitoring at the state line is especially important as upgrades are completed at North Attleborough WWTF and Attleboro WPCF to comply with newer NPDES permit requirements. As part of the state's Ambient River Monitoring Program, RIDEM will conduct biological, chemical, and physical monitoring in the Ten Mile River. This work is anticipated to occur during the 2014 sampling season.

The Narragansett Bay Commission's (NBC) Environmental Monitoring and Data Analysis (EMDA) Program conducts bi-monthly nutrient sampling in the Ten Mile River at the outlet of Omega Pond. In 2012, NBC instituted a nutrient monitoring location near the RI/MA border at Central Avenue. The data for these two locations is accessible on the NBC's water quality website, which is available at the following link: http://snapshot.narrabay.com/app/

RIDEM is also currently seeking additional funds to support future monitoring of the Ten Mile River with MADEP.

11.0 References

Alderserio, K., D. Wait and M. Sobsey. 1996. Detection and Characterization of Male-Specific RNA Coliphages in a New York City Reservoir to Distinguish Between Human and Non-human Sources of Contamination*.* *Proceedings of a Symposium on New York City Water Supply Studies, ed.* McDonnell et al. TPS-96-2. American Water Resources Association. Herndon, VA.

Art, H.W., 1993, Eutrophication, in Art, H.W., ed., A dictionary of ecology and environmental science (1st ed.): New York, New York, Henry Holt and Company, p. 196.

Baris, R.D., J. Lam, S.Z. Cohen, and N.L. Barnes. November 12, 2007. WaterQuality Impacts by Golf Courses: a Metastudy. Poster #MP 93, presented at SETAC North America 28th Annual Meeting, Milwaukee, WI. Environmental & Turf Services, Inc., Wheaton, MD.

Bland, J.K. 1996. *A Gaggle of Geese … or maybe a Glut.* Lakeline, North American Lake Management Society: 16(1): 10-11.

Browman, M.G., R.F. Harris, J.C. Ryden, and J.K. Syers. 1979. Phosphorus Loading From Urban Stormwater Runoff as a Factor in Lake Eutrophication: I. Theoretical Considerations and Qualitative Aspects. Journal of Environmental Quality. 8 (4): 561-566.

Cerco, C.F. and T.M. Cole. 1993. Three-dimensional Eutrophication Model of Chesapeake Bay. ASCE J. Environ. Engr., 119:1006-1025.

CH2MHILL. 1998. Highway Stormwater Runoff Study: Prepared for the Michigan Department of Transportation. 75pp.

Chapra, S.C., and Canale, R.P. 1991. Long-Term Phenomenological Model of Phosphorus and Oxygen for Stratified Lakes. Water Research. 25 (6): 707-715.

City of San Jose. 2008. Is your Roof Runoff Polluted? Online: http://www.sanjoseca.gov/archives/171/RoofRunoffFactSheet_4-08.pdf

CWP (2003). Impacts of Impervious Cover on Aquatic Systems. Center for Watershed Protection. Online: http://clear.uconn.edu/projects/tmdl/library/papers/Schueler_2003.pdf

CWP (2007). Urban Stormwater Retrofit Practices. Center for Watershed Protection. Online: http://www.cwp.org/Store/usrm.htm.

Davis, A.P., Shokouhian, M., Ni, S., 2001. Loading Estimates of Lead, Copper, Cadmium, and Zinc in Urban Runoff from Specific Sources. Chemosphere, 44(5):997-1009.

Di Toro, D. M., Mahony, J. D., Hansen, D. J., Scott, K. J., Carlson, A. R. and Ankley, G. T. 1992. *Acid volatile sulfide predicts the acute toxicity of cadmium and nickel in sediments.* Environmental Science and Technology. 26:96-101.

L Domagalski and Henry Johnson
Ford, T. and Ryan, D. 2005. Toxic Metals in Aquatic Ecosystems: A Microbiological Perspective. In: Environmental Health Perspectives. Volume 113. No. 3.

Fricker, H. 1981. Critical evaluation of the application of statistical phosphorus loading models to Alpine lakes. Diss. Swiss Federal Institute of Technology Zurich. 119 pp.

Garn, H. S., Olson, D. L., Seidel, T. L. and Rose, W. J. 1996. *Hydrology and Water Quality of Lauderdale Lakes, Walworth County, Wisconsin, 1993-94*. U. S. Geological Survey Water-Resources Investigations Report 96-4235, 29 p.

Garn, H.S., 2002. Effects of Lawn Fertilizer on Nutrient Concentration in Runoff from Lakeshore Lawns, Lauderdale Lakes, Wisconsin. USGS Water-Resources Investigations Report 02–4130, 6p.

Hagos. 2009. The status of Fish Hatcheries in Rhode Island: A scheme for improving effluent quality at the Lafayette Trout Hatchery. URI Coastal Institute IGERT Project. Prepared for RIDEM Division of Fish and Wildlife.

Hahn, S., Bauer, S., Klaassen, M. 2007. *Quantification of Allochthonous Nutrient Input into Freshwater Bodies by Herbivorous Waterbirds.* Freshwater Biology. 53:181-193.

Haith, D. A., Rossi, F. S. 2003. *Risk Assessment of Pesticide Runoff from Turf*. Journal of Environmental Quality 32(2):447-455.

Hellyer, G., *Ten Mile River Watershed-Massachusetts-An Assessment of Sediment Chemistry and Ecotoxicity.* Ecosystems Assessment Unit, USEPA, New England Regional Laboratory, Prepared for Massachusetts Department of Environmental Protection, 41 p.

Holdren, Jr., G.C., and David E. Armstrong. 1980. *Factors Affecting Phosphorus Release from Intact Lake Sediment Cores.* American Chemical Society. 14 (1): 79-87.

Hussong, D., Damare, J.M., Limpert, R.J., Sladen, W.J.L., Weiner, R.M., and Colwell, R.R. 1979. *Impact of Canada Geese (Branta canadensis) and Whistling Swans (Cygnus columbianus columbianus) on Aquatic Ecosystems.* Applied and Environmental Microbiology, 37(1):14-20.

HydroQual. 1991. Water Quality Modeling Analysis of Hypoxia in Long Island Sound. HydroQual, Mahwah, NJ.

Johnes, P. J., Moss, B., and Philips G.L., 1996. The Determination of Water Quality by Land Use, Livestock Numbers, and Population Data.–Testing a Model for Use in Conservation and Water Quality Management. Freshwater Biology. 36: 451-473.

Johnson, B. 2005. Diazinon and Pesticide-Related Toxicity in Bay Area Urban Creeks Water Quality Attainment Strategy and Total Maximum Daily Load (TMDL); Proposed Basin Plan Amendment and Staff Report. California Regional Water Quality Control Board, San Francisco Bay Region. November 9, 2005.

Keyes Associates, Baystate Environmental Consultants, and Ecological Associates. 1982. Gorton Pond; Warwick, Rhode Island; Lake Restoration Project Phase I Diagnostic/Feasibility Study.

King, K.W., Balogh, J.C., Hughes, K.L., and Harmel, R.D. 2007. Nutrient Load generated by Storm Event Runoff from a Golf Course Watershed. J. Environ. Qual. 36:1021-1030.

Kitchell, J.F., D.E. Schindler, B.R. Herwig, D.M. Post, M.H. Olson, and M. Oldham. 1999. Nutrient cycling at the landscape scale: the role of diel foraging migrations by geese at the Bosque del Apache National Wildlife Refuge, New Mexico. Limnology and Oceanography 44 (3-2): 828-836.

Kunimatsu, T., Sudo, M., and Kawachi, T., 1999. Loading Rates of Nutrients Discharging from a Golf Course and a Neighboring Forested Basin, Water Science Technology 39: 99-107.

Lee, G.F. and Jones-Lee. A. 1995. *Issues in Managing Urban Stormwater Runoff Quality*. Water Engineering & Management. 142 (5): 51-53.

Lee, G. F. and Jones-Lee, A. 1996. Evaluation of the Water Quality Significance of the Chemical Constituents in Aquatic Sediments: Coupling Sediment Quality Evaluation Results to Significant Water Quality Impacts. WEFTEC. Surface Water Quality and Ecology I & II, Vol 4, pp 317-328. Proc. Water Environ. Fed. Annual Conference.

Lim, S. and V. Olivieri. 1982. *Sources of Microorganisms in Urban Runoff*. John Hopkins School of Public Health and Hygiene. Jones Falls Urban Runoff Project. Baltimore, MD. 140 pp.

Ma, Q.L., Smith, A.E., Hook, J.E., Smith, R.E., and Bridges, D.C. 1999. *Water Runoff and Pesticide Transport from a Golf Course Fairway: Observations vs. Opus Model Simulations.* Journal of Environmental Quality. 28(5): 1463-1473.

MADEP. 2007. Final Pathogen TMDL for the Charles River Watershed. CN 0156.0. Massachusetts Department of Environmental Protection.

Manny, B. A., R. G. Wetzel, and W. C. Johnson. 1975. Annual Contribution of Carbon, Nitrogen, and Phosphorus by Migrant Canada Geese to a Hardwater Lake. Verh. Int.Ver. Limnol (19): 949–951.

Manny, B.A., Johnson, W.C., and Wetzel, R.G. 1994. Nutrient Additions by Waterfowl to Lakes and Reservoirs: Predicting their Effects on Productivity and Water Quality. Hydrobiologia. 279-280 (1): 121-132.

McCobb, T.D., D.R. LeBlanc, D.A. Walter, K.M. Hess, D.B. Kent, and R.L. Smith. 2003. *Phosphorus in a Groundwater Contaminant Plume Discharging to Ashumet Pond, Cape Cod, Massachusetts, 1999.* U.S. Geological Survey Water Resources Investigative Report. 02-4306. 79 pp.

Moore, M.V., P. Zakova, K.A. Shaeffer, R.P. Burton. 1998. Potential Effects of Canada Geese and Climate Change on Phosphorus Inputs to Suburban Lakes of the Northeastern U.S.A. Lake and Reservoir Management 14 (1) 52-59.

Morsison, G.M., Revitt, D.M., Ellis, J.B., 1990. Metal Speciation in Separate Stormwater Systems. Water Science and Technology, 22(10):53-60.

MPCA. 1999. Effects of Septic Systems on Ground Water *Quality in Baxter, Minnesota*. Minnesota Pollution Control Agency. St. Paul, MN 38 pp.

MPCA. 2000. Ground Water Quality under Three Unsewered Subdivisions in Minnesota. Minnesota Pollution Control Agency. St. Paul, MN 47 pp.

Nimick DA, Gammons CH, Cleasby TE, Madison JP, Skaar D, Brick CM. 2003. Diel cycles in dissolved metal concentrations in streams: Occurrence and possible causes. *Water Resources Research* **39**(9): Art. No. 1247.

Phillips, G.,Jackson, R., Bennett, C., and Chilvers, A. 1994. The Importance of Sediment Phosphorus Release in the Restoration of very Shallow Lakes (The Norfolk Broads, England) and Implications for Biomanipulation. 275-276 (1): 445-456.

Pitt, R. Demonstration of Nonpoint Pollution Abatement Through Improved Street *Cleaning Practices*. EPA-600/2-79-161. U.S. Environmental Protection Agency. Cincinnati, OH. August. 1979

Pitt, R., Williamson, D., Bannerman, R., and Clark, S. 2000. Sources of Pollutants in Urban Areas.

Portnoy, J. W. 1990. Gull Contributions of Phosphorus and Nitrogen to a Cape Cod Kettle Pond. Hydrobiologia. 202 (1-2): 61–69.

Purcell. S.L. 1999. *The Significance of Waterfowl Feces as a Source of Nutrients to Algae in a Prairie Wetland*. Master's Thesis. Department of Botany. University of Manitoba. Winnipeg, Manitoba.

RIDEM (2003a). Regulations for Rhode Island Pollutant Discharge Elimination System. Rhode Island Department of Environmental Management.

RIDEM (2003b). General Permit Rhode Island Pollutant Discharge Elimination System Storm Water Discharge from Small Municipal Separate Storm Sewer Systems and from Industrial Activity at Eligible Facilities Operated by Regulated Small MS4s RIR040000. Rhode Island Department of Environmental Management.

RIDEM, 2006. Mute Swan Management Plan.
Online: http://www.dem.ri.gov/programs/bnatres/fishwild/pdf/muswan07.pdf

RIDEM, 2007. Total Maximum Daily Load for Dissolved Oxygen and Nutrients to Mashapaug Pond, Rhode Island. Report submitted to USEPA Region 1, Boston, and RIDEM, Providence, RI.

RIDEM, 2008. General Permit Rhode Island Pollutant Discharge Elimination System Storm Water Discharge Associated with Construction Activity. Rhode Island Department of Environmental Management.

RIDEM, 2010. Total Maximum Daily Load to Address the Phosphorus Impairment to Belleville Ponds and Belleville Pond Upper Inlet. Report submitted to USEPA Region 1, Boston, and RIDEM, Providence, RI.

RIDEM and CRMC. 2010. Rhode Island Stormwater Design and Installation Manual. December 2010. Rhode Island Department of Environmental Management and Coastal Resources Management Council.
Online: http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm

Riley, E.T. and Prepas, E.E. 1984. *Role of Internal Phosphorus Loading in Two Shallow, Productive Lakes in Alberta, Canada.* Canadian Journal of Fisheries and Aquatic Sciences. 41 (6): 845-855.

Sabin, L. and Schiff, K. 2007. Metal Dry Deposition Rates Along a Coastal Transect in Southern California. Southern California Coastal Water Research Project. Technical Report 509.

Samadpour, M. and N. Checkowitz, 1998. Little Soos Creek microbial source tracking. Washington Water RESOURCE, Spring, 1998. University of Washington Urban Water Resources Center.

Schindler, D. W., Hesslein, R., and G. Kipphut. 1976. *Interactions between sediments and overlying waters in an experimentally eutrophied Precambrian shield lake.* In: Golterman, H. L., (Ed.) Interactions between Sediments and Fresh Water. pp. 235–243.

Søndergaard, M., Kristensen, P., and Jeppesen, E. 1992. Phosphorus Release from Rresuspended Sediment in the Shallow and Wind-exposed Lake Arresø, Denmark. Hydrobiologia. 228 (1): 91-99.

Søndergaard, M., Kristensen, P., and Jeppesen, E. 1993. Eight Years of Internal Phosphorus Loading and Changes in the Sediment Phosphorus Profile of Lake Søbygaard, Denmark. Hydrobiologia. 253 (1-3): 345-356.

Soranno, P.A., Carpenter, S.R., and Lathrop, R.C. 1997. *Internal Phosphorus Loading in Lake Mendota: Response to External Loads and Weather.* Canadian Journal of Fisheries and Aquatic Sciences. 54(8): 1883-1893.

Stambaugh, M.C. , Guyette, R.P., Grabner, K.W., and Kolaks, J. 2006 Understanding Ozark Forest Litter Variability Through a Synthesis of Accumulation Rates and Fire Events Fuels Management—How to Measure Success: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Conference Proceedings. Portland, OR.

Steinman, A. and Rediske, R. 2003. *Internal phosphorus loading in Spring Lake: Year 1.* Report for Spring Lake-Lake Board. Annis Water Resources Institute. MR-2003-115.

Trial, W., Slaughterbeck, C., Goldberg, J., and Samadpour, M. 1993. Bacterial Source Tracking: Studies in an Urban Seattle Watershed. *Puget Sound Notes*. 30:1-3.

Ullman, W. J., Scudlark, J. R., Volk, J. A., Savidge, K. B. 2005. *Is Atmospheric Deposition a Significant Source of Phosphorus to Coastal-plain Estuaries?* 2005 Estuarine Research Federation Conference. Oral Presentation.

USACOE. 2005. Ecosystem Restoration-Ten Mile River- East Providence, RI. 71 pp.

USEPA. 1983. Results of the Nationwide Urban Runoff Program. Water Planning Division. WH-554.

USEPA 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. US EPA, Office of Water. Washington, DC.

USEPA 2000. Prediction of sediment toxicity using consensus-based freshwater sediment quality guidelines.   EPA 905/R-00/007. June 2000.

USEPA 2001. Managing Pet and Wildlife Waste to Prevent Contamination of Drinking Water.
Online: http://www.epa.gov/safewater/sourcewater/pubs/fs_swpp_petwaste.pdf.

USEPA 2005. National management measures to control nonpoint source pollution from urban areas: Management measure 7: Bridges and highways. EPA 841-B-05-004.

Valiela, I., Alber, M., and Lamontagne, M., 1991. Fecal Coliform Loadings and Stocks in Buttermilk Bay, Massachusetts, USA, and Management Implications. Environmental Management 15(5): 659-674 .

Walker, W. W. (1996). "Simplified procedures for eutrophication assessment and prediction: User manual," Instruction Report W-96-2 (Updated April **1999),** U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Waschbusch, R.J., W.R. Selbig, and R.T. Bannerman. 1999. *Sources of Phosphorus in Stormwater and Street Dirt from Two Urban Residential Basins in Madison Wisconsin, 1994-1995*. U.S. Geological Survey, Water Resources Investigations Report 99-4021. 47 pp.

Welch, E.B. and Cooke, G.D. 1995. *Internal Phosphorus Loading in Shallow Lakes: Importance and Control.* Lake and Reservoir Management. 11 (3): 273-281

Welch, E.B. and Jacoby, J.M.. 2001. On Determining the Principal Source of Phosphorus Causing Summer Algal Blooms in Western Washington Lakes. Lake and Reservoir Management. 17 (1): 55-65.

Welch, E.B. 2005. *History of Alum Use in Lakes.* North American Lake Management Society. Lakeline. 25 (3): 11-12. 88

Winter, J.G., Dillon, P.J., 2005. Effects of golf course construction and operation on water chemistry of headwater streams on the Precambrian Shield. Environmental Pollution 133, 243-253.

APPENDIX A: Ten Mile River Pathogen Data

Instream Station Locations

Station ID	Description/Location
TM1	Ten Mile River at Central Avenue (State Line) sampled upstream side of bridge
TM2	Ten Mile River at Slater Park Pond outflow
TM3	Ten Mile River at Ten Mile River Greenway sampled on downstream side of railroad bridge
TM4	Route 152- Central Pond outflow/Turner Reservoir inflow sampled at downstream side of reservoir
TM5	Ten Mile River at Route 114A (Turner Reservoir outflow)
TM6	Ten Mile River at Route 114 (USGS gage) sampled upstream side of bridge
TM7	Ten Mile River at North Broadway sampled at downstream side of bridge
TM8	Ten Mile River at Omega Pond Spillway accessible via train tracks to bridge over Seekonk River

Pathogen Data Used to Develop TMDLs

Date	Wet Or Dry	Notes	TM1	TM2	TM3	TM4	TM5	TM6	TM7	TM8
Fecal Coliform Data (fc/100ml)										
5/22/07	W	receeding flow, 2.1" 6 days prior	250	150	160	200	100	100	130	150
6/19/07	D	recession, 0.11" 7 days prior	290	180	170	11	17	140	140	81
7/2/07	D	baseflow, 0.15" prev day	290	230	410	160	57	66	310	45
7/31/07	W	nr. peak, 1.5" previous day	1200	780	780	20	1	100	150	880
8/21/07	D	steady state, trace-10 days	310	30	720	10	16	45	37	7
9/4/07	D	steady state, trace-24 days	250	50	210	16	19	440	24	10
9/12/07	W	nr. peak,-receeding 2.1" 2-days prior	5100	860	1200	220	19	23	12	2000
3/6/08	W	rising, 0.75" 2 days prior	52	70	35	22	15	25	230	12
8/1/08	W	receeding storm hydrograph, 1" 5-days prior	350	370	390	69	1	110	130	30

Enterococci Data (MPN/100ml) STATION TM3 ONLY					
Date	**Wet Or Dry**	**MPN/100ml**	**Date**	**Condition**	**MPN/100ml**
5/8/08	D	21	5/15/2010	D	142
6/7/08	W	103	6/19/2010	D	87
7/11/08	D	71	7/15/2010	W	9678
8/16/08	D	2105	8/17/2010	D	35
9/20/08	D	130	9/15/2010	D	35
10/25/08	D	5	10/16/2010	W	3654
5/2/09	D	60	5/21/2011	W	183
6/13/09	W	4839	6/18/2011	W	456
7/18/09	W	4839	7/22/2011	D	108
8/16/09	D	8	8/17/2011	W	307
9/14/09	W	68	9/17/2011	D	89
10/17/09	W	26	10/15/2011	W	378

APPENDIX B: Ten Mile River Dissolved Metals Data

Table B. 1. May 22, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

										For QA QC check	
	Date of Collection:	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**	**TM8**	**TM8 Field Dup**
Constituent	RL										
Aluminum (Al)	5.0	9	**120**	31	**120**	**97**	**99**	**100**	**96**	**88**	79
Antimony (Sb)	0.5	ND	0.71			7.6					
Arsenic (As)	1.0	ND	ND								
Barium (Ba)	0.2	ND	19	18	19	17	17	18	17	17	18
Beryllium (Be)	0.2	ND									
Cadmium (Cd)	0.1	ND	0.23	0.13	0.3	0.26	0.37	0.41	0.38	0.37	0.39
Calcium (Ca mg/L)	0.1	ND	16	15	16	14	15	15	16	16	16
Chromium (Cr)	1.0	1.5	5.2	2.6	4.7	3.1	3.7	3.2	3.4	2.8	2.9
Cobalt (Co)	0.2	ND	0.58	0.4	0.54	0.42	0.46	0.49	0.47	0.42	0.41
Copper (Cu)	0.2	0.24	12	5.9	12	8.3	9	8.6	8.6	7.9	7.7
Iron (Fe)	50	ND	780	310	750	660	620	640	630	600	580
Lead (Pb)	0.2	ND	3.1	0.99	3	2.4	2.3	2.4	2.3	2.1	2.2
Magnesium (Mg mg/L)	0.1	ND	2.6	2.5	2.6	2.4	2.4	2.5	2.5	2.6	2.6
Manganese (Mn)	0.2	ND	150	130	150	130	150	170	170	170	170
Molybdenum (Mo)	0.5	ND	0.72	0.59	0.58	0.56	0.75	0.77	0.78	0.88	0.88
Nickel (Ni)	0.2	ND	16	14	15	14	15	16	16	16	16
Selenium (Se)	1.0	ND									
Silver (Ag)	0.2	ND	0.47		0.46				0.2		
Thallium (Tl)	0.5	ND									
Vanadium (V)	0.2	ND									
Zinc (Zn)	2.0	4.3	19	15	18	17	19	20	18	18	20

Table B. 2. June 19, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

				for QA QC check				for QA QC check				
	Date of Collection:	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM2 Lab Dup**	**TM3**	**TM4**	**TM5**	**TM5 Field Dup**	**TM6**	**TM7**	**TM8**
Constituent	**RL**											
Aluminum (Al)	5.0	ND	16	14	14	11	9.6	6.5	7.6	10	9.9	7.6
Antimony (Sb)	0.5	ND	ND	ND	ND	ND	ND	ND	0.58	ND	ND	0.69
Arsenic (As)	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Barium (Ba)	0.2	ND	24	23	23	23	14	14	15	15	16	15
Beryllium (Be)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.1	ND	0.11	0.17	0.16	0.18	ND	ND	ND	ND	ND	ND
Calcium (Ca mg/L)	0.1	ND	24	26	27	25	19	18	18	19	20	19
Chromium (Cr)	1.0	ND	2.1	1.7	1.8	1.3	1.1	1	1.1	1.1	1.1	1.1
Cobalt (Co)	0.2	ND	0.35	0.38	0.38	0.32	0.28	0.28	0.29	0.28	0.26	ND
Copper (Cu)	0.2	ND	6.9	6.3	6.4	5.6	**6.1**	**6**	6.3	**6**	5.9	**6.1**
Iron (Fe)	50	ND	510	430	440	350	390	320	340	340	330	310
Lead (Pb)	0.2	ND	**2.5**	**2.1**	2.1	1.6	1.3	0.96	1	1	0.97	0.9
Magnesium (Mg mg/L)	0.1	ND	3.4	3.3	3.3	3.2	3	2.8	2.9	3	2.9	2.9
Manganese (Mn)	0.2	ND	130	140	140	130	60	49	51	63	70	19
Molybdenum (Mo)	0.5	ND	1.2	1.3	1.3	1.2	1	1	1	1	1	1
Nickel (Ni)	0.2	ND	19	19	19	17	14	13	14	14	14	13
Selenium (Se)	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium (V)	0.2	ND	0.67	0.58	0.55	0.53	0.53	0.50	0.52	0.52	0.50	0.59
Zinc (Zn)	5.0	ND	13	10	11	9.9	ND	ND	ND	ND	ND	ND
Hardness as $CaCO_3$			73.9	78.5	81.0	75.6	59.8	48.9	56.9	59.8	61.9	59.4
Cd Acute Criteria			1.50	1.59	1.64	1.53	1.22	1.00	1.16	1.22	1.26	1.21
Cd Chronic Criteria			0.20	0.21	0.21	0.20	0.17	0.15	0.17	0.17	0.18	0.17
Cu Acute Criteria			10.1	10.7	11.0	10.3	8.3	6.8	7.9	8.3	8.6	8.2
Cu Chronic Criteria			6.9	7.3	7.5	7.1	5.8	4.9	5.5	5.8	5.9	5.7
Pb Acute Criteria			46.4	49.6	51.3	47.6	36.7	29.4	34.8	36.7	38.2	36.5
Pb Chronic Criteria			1.81	1.93	2.00	1.85	1.43	1.15	1.35	1.43	1.49	1.42

= Acute Violation

= Chronic Violation

Table B. 3. July 2, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

			For QA QC check				For QA QC check					
	Date of Collection:	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007
	Station	**TM1 Blank**	**TM1**	**TM1 Lab Dup**	**TM2**	**TM3**	**TM4**	**TM4 Field Dup**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	**RL**											
Aluminum (Al)	5.0	ND	9.9	10	7	7.4	7.4	9	8.1	6.5	ND	7.1
Antimony (Sb)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Arsenic (As)	0.5	ND	0.76	0.81	0.7	0.7	0.76	0.74	0.81	0.72	0.81	0.8
Barium (Ba)	0.2	ND	24	24	27	25	19	19	13	11	11	13
Beryllium (Be)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.1	ND	0.17	0.18	0.2	0.17	ND	ND	ND	ND	ND	ND
Calcium (Ca mg/L)	0.1	ND	24	24	27	26	23	23	22	22	24	22
Chromium (Cr)	0.5	ND	1	0.99	0.87	0.81	0.72	0.71	0.63	0.6	ND	ND
Cobalt (Co)	0.2	ND	0.37	0.37	0.35	0.26	0.29	0.29	0.35	0.36	0.35	0.21
Copper (Cu)	0.2	ND	6.5	6.5	6	5.9	6.1	6.2	6.2	6	6.2	5.8
Iron (Fe)	50	ND	280	280	200	190	160	140	160	130	56	63
Lead (Pb)	0.2	ND	1.3	1.3	0.76	0.69	0.49	0.42	0.46	0.38	ND	ND
Magnesium (Mg mg/L)	0.1	ND	3.5	3.5	3.5	3.5	3.1	3.1	3.1	3.2	3.1	3.2
Manganese (Mn)	0.2	ND	180	180	130	100	42	34	41	63	62	47
Molybdenum (Mo)	0.5	ND	1.4	1.4	1.8	1.6	1.6	1.7	1.6	1.6	1.6	1.6
Nickel (Ni)	0.2	ND	22	22	25	21	14	14	13	13	12	12
Selenium (Se)	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium (V)	0.2	ND	0.46	0.44	0.36	0.31	0.46	0.42	0.54	0.5	0.48	0.42
Zinc (Zn)	5.0	ND	10	9.8	11	10	ND	ND	ND	ND	ND	ND
Hardness as $CaCO_3$			74.3		81.8	79.3	70.2	70.2	67.7	68.1	72.7	68.1
Cd Acute Criteria			1.51		1.66	1.61	1.43	1.43	1.38	1.39	1.48	1.39
Cd Chronic Criteria			0.20		0.21	0.21	0.19	0.19	0.19	0.19	0.20	0.19
Cu Acute Criteria			10.2		11.1	10.8	9.6	9.6	9.3	9.4	10.0	9.4
Cu Chronic Criteria			7.0		7.5	7.3	6.6	6.6	6.4	6.5	6.8	6.5
Pb Acute Criteria			46.7		51.9	50.1	43.8	43.8	42.1	42.4	45.6	42.4
Pb Chronic Criteria			1.82		2.02	1.95	1.71	1.71	1.64	1.65	1.78	1.65

= Acute Violation

= Chronic Violation

Table B. 4. July 31, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

			For QA QC check						For QA QC check			
	Date of Collection:	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007
	Station	**TM1 Blank**	**TM1**	**TM1 Lab Dup**	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM6 Field Dup**	**TM7**	**TM8**
Constituent	**RL**											
Aluminum (Al)	5.0	ND	8.1	6.9	5.2	6.1	ND	ND	ND	ND	ND	6.2
Antimony (Sb)	0.5	ND	0.51		ND	0.53	ND	ND	ND	ND	ND	0.51
Arsenic (As)	0.5	ND	0.83	0.84	0.76	0.8	0.96	0.98	1	1	1	1
Barium (Ba)	0.2	ND	24	24	23	22	20	17	16	16	16	14
Beryllium (Be)	0.2	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.1	ND	**0.2**	0.18	0.14	0.11	ND	ND	ND	ND	ND	ND
Calcium (Ca mg/L)	0.1	ND	19	19	22	21	22	22	22	22	24	23
Chromium (Cr)	0.5	ND	0.97	1	0.92	0.89	ND	ND	ND	ND	ND	0.65
Cobalt (Co)	0.2	ND	0.38	0.39	0.32	0.25	0.32	0.3	0.32	0.31	0.33	0.3
Copper (Cu)	0.2	ND	**7.6**	7.7	**6.5**	**6.8**	4.9	5.2	5.3	4.9	5	4.9
Iron (Fe)	50	ND	180	190	120	130	ND	ND	ND	ND	ND	ND
Lead (Pb)	0.2	ND	**1.5**	1.5	0.63	0.8	ND	ND	ND	ND	ND	ND
Magnesium (Mg mg/L)	0.1	ND	2.9	3	2.8	2.9	3	3	3	3	3	2.7
Manganese (Mn)	0.2	ND	190	190	170	130	50	8.1	19	18	30	42
Molybdenum (Mo)	0.5	ND	1.9	1.9	2	1.9	1.9	1.9	2	2.1	1.9	1.8
Nickel (Ni)	0.2	ND	24	25	20	18	11	10	10	11	11	9.4
Selenium (Se)	1.0	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND
Vanadium (V)	0.2	ND	0.83	0.84	0.65	0.6	0.4	0.5	0.54	0.56	0.68	0.78
Zinc (Zn)	5.0	ND	8.2	7.9	6.6	5.7	ND	ND	ND	ND	ND	ND
Hardness as $CaCO_3$			59.4		66.5	64.4	67.3	67.3	67.3	67.3	72.3	68.5
Cd Acute Criteria			1.21		1.35	1.31	1.37	1.37	1.37	1.37	1.47	1.39
Cd Chronic Criteria			0.17		0.19	0.18	0.19	0.19	0.19	0.19	0.20	0.19
Cu Acute Criteria			8.2		9.1	8.9	9.3	9.3	9.3	9.3	9.9	9.4
Cu Chronic Criteria			5.7		6.3	6.1	6.4	6.4	6.4	6.4	6.8	6.5
Pb Acute Criteria			36.5		41.3	39.9	41.8	41.8	41.8	41.8	45.3	42.7
Pb Chronic Criteria			1.42		1.61	1.55	1.63	1.63	1.63	1.63	1.76	1.66

= Acute Violation

= Chronic Violation

Table B. 5. August 21, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

					For QA QC check						
	Date of Collection:	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM3**	**TM3 Field Dup**	**TM4**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	**RL**										
Aluminum (Al)	5.0	ND	ND	ND	14	ND	ND	ND	ND	ND	ND
Antimony (Sb)	0.5	ND	ND	ND	ND	0.52	ND	ND	ND	ND	ND
Arsenic (As)	0.5	ND	0.68	0.6	0.64	0.7	1.3	1.5	1.4	1.4	1.4
Barium (Ba)	0.2	ND	25	31	31	30	21	21	23	23	21
Beryllium (Be)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.1	ND	0.13	ND	ND	ND	ND	ND	ND	ND	ND
Calcium (Ca mg/L)	0.1	ND	33	34	31	31	24	23	25	28	27
Chromium (Cr)	0.5	ND	0.52	ND	0.61	ND	ND	ND	ND	ND	ND
Cobalt (Co)	0.2	ND	0.41	0.38	0.29	0.28	0.41	0.43	0.47	0.47	0.4
Copper (Cu)	0.2	ND	5.8	4.8	5.2	4.9	4.3	4.3	3.7	3.4	2.9
Iron (Fe)	50	ND	72	68	120	51	ND	ND	ND	ND	ND
Lead (Pb)	0.2	ND	0.42	0.32	**0.58**	**0.24**	ND	ND	ND	ND	ND
Magnesium (Mg mg/L)	0.1	ND	3.5	3.4	3.3	3.4	3.1	3.1	3.2	3.2	3.2
Manganese (Mn)	0.2	ND	190	180	170	170	63	88	200	240	290
Molybdenum (Mo)	0.5	ND	3.3	2	1.7	1.7	2.3	2.3	2.2	2.2	2.1
Nickel (Ni)	0.2	ND	20	18	16	16	12	12	12	12	11
Selenium (Se)	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium (V)	0.2	ND	0.31	0.29	0.28	0.24	0.44	0.43	0.32	0.42	0.34
Zinc (Zn)	5.0	ND	8.3	6.3	5.7	5.3	ND	ND	ND	ND	ND
Hardness as $CaCO_3$			96.8	98.9	91.0	91.4	72.7	70.2	75.6	83.1	80.6
Cd Acute Criteria			1.95	1.99	1.84	1.85	1.48	1.43	1.53	1.68	1.63
Cd Chronic Criteria			0.24	0.24	0.23	0.23	0.20	0.19	0.20	0.22	0.21
Cu Acute Criteria			13.0	13.3	12.3	12.3	10.0	9.6	10.3	11.3	11.0
Cu Chronic Criteria			8.7	8.9	8.3	8.3	6.8	6.6	7.1	7.6	7.4
Pb Acute Criteria			62.3	63.8	58.3	58.6	45.6	43.8	47.6	52.8	51.0
Pb Chronic Criteria			2.43	2.49	2.27	2.28	1.78	1.71	1.85	2.06	1.99

= Acute Violation
= Chronic Violation

Table B. 6. September 4, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

									For QA QC check		
	Date of Collection:	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**	**TM7 Field Dup**	**TM8**
Constituent	**RL**										
Aluminum (Al)	5.0	ND	8.2	ND	ND	5.6	7.5	ND	ND	ND	ND
Antimony (Sb)	0.5	ND	0.53	ND	0.51	ND	ND	ND	ND	ND	ND
Arsenic (As)	0.5	ND	0.8	0.74	0.7	1.2	1.3	1.3	1.3	1.3	1.2
Barium (Ba)	0.2	ND	27	36	33	27	28	32	31	31	22
Beryllium (Be)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.1	ND	0.13	ND	0.11	ND	ND	ND	ND	ND	ND
Calcium (Ca mg/L)	0.1	ND	40	39	39	29	28	28	32	32	31
Chromium (Cr)	0.5	ND	0.57	ND	ND	ND	ND	ND	ND	ND	ND
Cobalt (Co)	0.2	ND	0.42	0.43	0.3	0.46	0.48	0.44	0.45	0.45	0.42
Copper (Cu)	0.2	ND	6	5.2	5.7	3.9	3.5	3.3	3.3	3.3	3.3
Iron (Fe)	50	ND	73	80	52	60	74	74	60	59	ND
Lead (Pb)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Magnesium (Mg mg/L)	0.1	ND	3.9	3.9	3.8	3.6	3.6	3.6	3.6	3.7	3.7
Manganese (Mn)	0.5	ND	220	230	180	150	250	250	300	300	240
Molybdenum (Mo)	0.5	ND	2.8	3.3	3.3	2.5	2.5	2.2	2.2	2.2	2.2
Nickel (Ni)	0.2	ND	20	20	17	13	14	14	14	14	11
Selenium (Se)	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium (V)	0.2	ND	0.4	0.37	0.3	0.4	0.41	0.43	0.46	0.47	0.37
Zinc (Zn)	5.0	ND	7.4	ND	ND	ND	ND	56	ND	ND	ND
Hardness as $CaCO_3$			115.9	113.4	113.0	87.2	84.7	84.7	94.7	95.1	92.6
Cd Acute Criteria			2.33	2.28	2.27	1.76	1.71	1.71	1.91	1.92	1.87
Cd Chronic Criteria			0.27	0.27	0.27	0.22	0.22	0.22	0.24	0.24	0.23
Cu Acute Criteria			15.4	15.1	15.1	11.8	11.5	11.5	12.8	12.8	12.5
Cu Chronic Criteria			10.2	10.0	9.9	8.0	7.8	7.8	8.6	8.6	8.4
Pb Acute Criteria			75.8	74.1	73.8	55.6	53.9	53.9	60.9	61.2	59.4
Pb Chronic Criteria			2.96	2.89	2.87	2.17	2.10	2.10	2.37	2.38	2.32

= Acute Violation
= Chronic Violation

Table B. 7. September 12, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

				For QA QC check								
Date of Collection:		9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM2 Field Dup**	**TM2 Lab Dup**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	**RL**											
Aluminum (Al)	5.0	ND	9.1	9.3	9.1	8.7	9.6	8.5	5.2	7.8	7.9	7.8
Antimony (Sb)	0.5	ND	0.54	0.55	ND	0.55	ND	ND	ND	ND	ND	ND
Arsenic (As)	0.5	ND	0.79	0.73	0.68	0.7	0.74	0.86	1.1	1.1	1	1.1
Barium (Ba)	0.2	ND	31	30	30	30	29	36	28	28	27	25
Beryllium (Be)	0.5	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.1	ND	**0.54**	**0.27**	0.28	0.28	**0.22**	ND	ND	ND	ND	ND
Calcium (Ca mg/L)	0.1	ND	24	24	23	23	23	31	27	27	28	27
Chromium (Cr)	0.5	ND	0.69	0.62	0.66	0.65	0.71	ND	ND	ND	ND	0.56
Cobalt (Co)	0.2	ND	0.96	0.66	0.68	0.67	0.52	0.49	0.55	0.58	0.57	0.44
Copper (Cu)	0.2	ND	**9.7**	**7.9**	8.3	8.2	**7.6**	4.7	3.9	4.1	4.1	3.8
Iron (Fe)	50	ND	150	130	140	130	130	ND	77	80	76	71
Lead (Pb)	0.2	ND	1.4	0.93	1	0.95	1	0.24	0.26	0.29	0.28	0.33
Magnesium (Mg mg/L)	0.1	ND	3.5	3.1	3.1	3.2	3	3.5	3.2	3.3	3.3	2.9
Manganese (Mn)	0.2	ND	330	310	310	310	290	150	150	150	150	170
Molybdenum (Mo)	0.5	ND	2.1	2.1	2	2.1	2	3.2	2.6	2.5	2.5	2
Nickel (Ni)	0.2	ND	**43**	29	30	29	24	16	14	15	15	13
Selenium (Se)	1.0	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND
Vanadium (V)	0.5	ND	0.65	0.58	0.57	0.56	0.56	ND	0.51	0.5	ND	0.53
Zinc (Zn)	5.0	ND	26	16	15	16	12	ND	ND	ND	ND	ND
Hardness as $CaCO_3$			74.3	72.7	70.2		69.8	91.8	80.6	81.0	83.5	79.4
Cd Acute Criteria			1.51	1.48	1.43		1.42	1.85	1.63	1.64	1.69	1.61
Cd Chronic Criteria			0.20	0.20	0.19		0.19	0.23	0.21	0.21	0.22	0.21
Cu Acute Criteria			10.2	10.0	9.6		9.6	12.4	11.0	11.0	11.3	10.8
Cu Chronic Criteria			7.0	6.8	6.6		6.6	8.3	7.4	7.5	7.7	7.4
Pb Acute Criteria			46.7	45.6	43.8		43.6	58.8	51.0	51.3	53.0	50.2
Pb Chronic Criteria			1.82	1.78	1.71		1.70	2.29	1.99	2.00	2.07	1.95

= Acute Violation

= Chronic Violation

Table B. 8. March 6, 2008 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

			For QA QC check									
Date of Collection:		3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008
	Station	**TM1 Blank**	**TM1**	**TM1 Field Dup**	**TM1 Lab Dup**	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	**RL**											
Aluminum (Al)	10.0	ND	34	34	34	35	52	27	27	25	26	26
Antimony (Sb)	0.5	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND
Arsenic (As)	0.5	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND
Barium (Ba)	0.2	ND	25	24	24	24	20	23	23	23	24	24
Beryllium (Be)	0.2	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.1	ND	**0.2**	ND		ND	ND	**0.32**	**0.3**	**0.3**	**0.33**	**0.29**
Calcium (Ca mg/L)	0.1	ND	15	16	16	15	14	17	17	17	18	18
Chromium (Cr)	2.0	ND	ND	ND		ND	ND	2.2	2.1	2.1	2.1	2.2
Cobalt (Co)	0.2	ND	0.41	0.4	0.4	0.48	0.35	0.49	0.47	0.43	0.42	0.43
Copper (Cu)	0.5	ND	**5.5**	5.6	5.8	**5.6**	4.4	5	5.1	5.1	5.1	5.2
Iron (Fe)	50	ND	150	140	150	150	170	160	160	150	160	160
Lead (Pb)	0.5	ND	0.75	0.72	0.77	0.81	0.65	0.71	0.71	0.67	0.66	0.69
Magnesium (Mg mg/L)	0.1	ND	2.8	2.8	2.8	2.8	2.7	3	3	3	3.1	3.1
Manganese (Mn)	0.5	ND	90	90	91	94	81	130	130	130	130	130
Molybdenum (Mo)	0.5	ND	0.61	ND		1.5	ND	0.69	0.59	0.57	0.89	0.61
Nickel (Ni)	0.2	ND	11	11	11	11	8.1	14	14	13	13	13
Selenium (Se)	2.5	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND
Vanadium (V)	0.2	ND	0.2	0.2	0.2	ND	0.3	0.24	ND	ND	0.21	0.27
Zinc (Zn)	10.0	ND	20	20	20	25	18	19	19	18	18	21
Hardness as $CaCO_3$			49.0	51.5		49.0	46.1	54.8	54.8	54.8	57.7	57.7
Cd Acute Criteria			1.01	1.06		1.01	0.95	1.12	1.12	1.12	1.18	1.18
Cd Chronic Criteria			0.15	0.16		0.15	0.14	0.16	0.16	0.16	0.17	0.17
Cu Acute Criteria			6.9	7.2		6.9	6.5	7.6	7.6	7.6	8.0	8.0
Cu Chronic Criteria			4.9	5.1		4.9	4.6	5.4	5.4	5.4	5.6	5.6
Pb Acute Criteria			29.5	31.1		29.5	27.5	33.4	33.4	33.4	35.3	35.3
Pb Chronic Criteria			1.15	1.21		1.15	1.07	1.30	1.30	1.30	1.38	1.38

= Acute Violation

= Chronic Violation

Table B. 9. August 1, 2008 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

			For QA QC check				For QA QC check					
Date of Collection:		8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008
	Station	**TM1 Blank**	**TM1**	**TM1 Lab Dup**	**TM2**	**TM3**	**TM4**	**TM4 Field Dup**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	**RL**											
Aluminum (Al)	5.0	ND	22.00	22.00	19.00	20.00	11.00	10.00	ND	ND	ND	ND
Antimony (Sb)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Arsenic (As)	0.5	ND	1.20	1.20	1.20	1.20	1.20	1.10	1.00	1.10	1.00	0.99
Barium (Ba)	0.5	ND	25.00	25.00	24.00	25.00	19.00	19.00	17.00	17.00	17.00	15.00
Beryllium (Be)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.2	ND	**0.22**	0.21	ND	ND	ND	ND	ND	ND	ND	ND
Calcium (Ca mg/L)	0.1	ND	21.00	21.00	23.00	23.00	17.00	17.00	16.00	16.00	18.00	17.00
Chromium (Cr)	0.5	ND	2.10	2.10	2.10	1.80	1.20	1.20	0.67	0.68	0.69	0.58
Cobalt (Co)	0.2	ND	0.45	0.42	0.51	0.42	ND	ND	ND	0.22	0.24	0.22
Copper (Cu)	0.5	ND	**9.90**	10.00	**8.60**	**8.30**	**7.40**	7.20	**6.40**	**6.30**	**6.20**	**6.30**
Iron (Fe)	55	ND	680.00	670.00	640.00	630.00	370.00	370.00	110.00	140.00	170.00	72.00
Lead (Pb)	0.2	ND	**3.10**	3.20	**3.00**	**2.70**	1.20	1.20	0.39	0.47	0.57	0.28
Magnesium (Mg mg/L)	0.1	ND	3.30	3.20	3.20	3.30	2.70	2.80	2.50	2.60	2.70	2.70
Manganese (Mn)	0.5	ND	230.00	220.00	270.00	250.00	52.00	48.00	21.00	49.00	69.00	12.00
Molybdenum (Mo)	0.5	ND	2.30	2.30	2.90	2.70	1.60	1.70	1.70	1.70	1.70	1.90
Nickel (Ni)	1.0	ND	27.00	27.00	26.00	24.00	16.00	16.00	12.00	12.00	13.00	10.00
Selenium (Se)	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium (V)	0.2	ND	0.93	0.88	0.98	0.85	0.79	0.75	0.70	0.73	0.70	0.75
Zinc (Zn)	5.0	ND	11.00	12.00	8.40	9.30	ND	ND	ND	ND	ND	ND
Hardness as $CaCO_3$			66.0		70.6	71.0	53.6		50.2	50.7	56.1	53.6
Cd Acute Criteria			1.34		1.44	1.44	1.10		1.03	1.04	1.15	1.10
Cd Chronic Criteria			0.18		0.19	0.19	0.16		0.15	0.15	0.16	0.16
Cu Acute Criteria			9.1		9.7	9.7	7.5		7.0	7.1	7.8	7.5
Cu Chronic Criteria			6.3		6.7	6.7	5.3		5.0	5.0	5.5	5.3
Pb Acute Criteria			41.0		44.1	44.4	32.5		30.3	30.6	34.2	32.5
Pb Chronic Criteria			1.60		1.72	1.73	1.27		1.18	1.19	1.33	1.27

= Acute Violation

= Chronic Violation

APPENDIX C. Ten Mile River Total Metals Data

Table C. 1. May 22, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

										For QA QC check	
	Date of Collection:	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007	5/22/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**	**TM8**	**TM8 Field Dup**
Constituent	**RL**										
Aluminum (Al)	5.0	ND	30	86	27	35	28	29	30	21	18
Antimony (Sb)	0.5	ND	ND	ND	ND	ND	0.62	ND	ND	0.71	ND
Arsenic (As)	0.5	ND	0.57	0.67	0.63	0.6	0.56	0.59	0.57	0.57	0.62
Barium (Ba)	0.2	ND	19	21	19	16	17	17	18	18	17
Beryllium (Be)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (Cd)	0.1	ND	ND	**0.24**	ND	0.1	0.15	**0.21**	**0.21**	**0.17**	**0.17**
Calcium (Ca mg/L)	0.1	ND	17	17	17	15	16	16	17	17	17
Chromium (Cr)	0.5	ND	1.6	3	1.4	1.3	1.3	1.3	1.3	1.2	1
Cobalt (Co)	0.2	ND	0.42	0.52	0.39	0.37	0.4	0.37	0.35	0.35	0.33
Copper (Cu)	0.2	ND	**6.3**	**11**	**5.5**	**6**	**6.3**	**6.3**	**6.4**	**6.2**	5.9
Iron (Fe)	50	ND	360	660	310	320	300	320	330	270	190
Lead (Pb)	0.2	ND	1	**2.7**	0.86	1	0.89	1	1.1	0.87	0.71
Magnesium (Mg mg/L)	0.1	ND	2.7	2.7	2.7	2.5	2.6	2.6	2.6	2.6	2.7
Manganese (Mn)	0.2	ND	120	130	120	110	130	130	130	140	130
Molybdenum (Mo)	0.5	ND	0.74	0.67	0.63	0.61	0.78	0.8	0.72	0.92	0.93
Nickel (Ni)	0.2	ND	14	16	13	13	15	15	14	15	15
Selenium (Se)	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver (Ag)	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium (V)	0.2	ND	0.39	0.63	0.45	0.5	0.45	0.41	0.5	0.42	0.42
Zinc (Zn)	5.0	ND	11	13	10	9.2	14	10	9.9	15	11
Hardness as $CaCO_3$			53.6	53.6	53.6	47.8	50.7	50.7	53.2	53.2	53.6
Cd Acute Criteria			1.10	1.10	1.10	0.98	1.04	1.04	1.09	1.09	1.10
Cd Chronic Criteria			0.16	0.16	0.16	0.15	0.15	0.15	0.16	0.16	0.16
Cu Acute Criteria			7.5	7.5	7.5	6.7	7.1	7.1	7.4	7.4	7.5
Cu Chronic Criteria			5.3	5.3	5.3	4.8	5.0	5.0	5.2	5.2	5.3
Pb Acute Criteria			32.5	32.5	32.5	28.6	30.6	30.6	32.3	32.3	32.5
Pb Chronic Criteria			1.27	1.27	1.27	1.12	1.19	1.19	1.26	1.26	1.27

= Acute Violation

= Chronic Violation

Table C. 2. June 19, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

				for QA QC check				for QA QC check				
	Date of Collection:	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007	6/19/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM2 Lab Dup**	**TM3**	**TM4**	**TM5**	**TM5 Field Dup**	**TM6**	**TM7**	**TM8**
Constituent	RL											
Aluminum (Al)	5.0	ND	**94**	86		73	34	35	35	42	43	30
Antimony (Sb)	0.5	ND	0.57	1.4		0.67						
Arsenic (As)	1.0	ND										
Barium (Ba)	0.2	ND	24	24		25	16	17	16	16	16	16
Beryllium (Be)	0.2	ND										
Cadmium (Cd)	0.1	ND	0.32	0.39		0.35	0.17	0.22	0.18	0.21	0.21	0.19
Calcium (Ca mg/L)	0.1	ND	23	26		25	19	19	19	19	21	20
Chromium (Cr)	1.0	ND	4.9	4.3		3.6	1.9	1.9	2	1.9	2	1.8
Cobalt (Co)	0.2	ND	0.53									
Copper (Cu)	0.2	ND	12	11		10	6.3	6.5	6.5	6.4	9.7	6.1
Iron (Fe)	50	ND	920	790		790	620	620	640	590	580	530
Lead (Pb)	0.2	ND	5.3	4.5		4.1	2.2	2	2	2	2.1	1.7
Magnesium (Mg mg/L)	0.1	ND	3.3	3.2		3.3	3	2.9	2.9	3	3	3
Manganese (Mn)	0.2	ND	170	150		150	120	140	140	140	140	110
Molybdenum (Mo)	0.5	ND	1.3	1.4		1.3	1.1	1.1	1.1	1.1	1.1	1.1
Nickel (Ni)	0.2	ND	20	19		18	15	15	15	14	14	13
Selenium (Se)	1.0	ND										
Silver (Ag)	0.2	ND	0.54									
Thallium (Tl)	0.5	ND										
Vanadium (V)	0.2	ND										
Zinc (Zn)	2.0	ND	16	18		16	8	9.7	8.1	9.3	12	10

Table C. 3. July 2, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

			For QA QC check				For QA QC check					
	Date of Collection:	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007	7/2/2007
	Station	**TM1 Blank**	**TM1**	**TM1 Lab Dup**	**TM2**	**TM3**	**TM4**	**TM4 Field Dup**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	RL											
Aluminum (Al)	5.0		69		**94**	36	41	39	43	42	43	31
Antimony (Sb)	0.5								2.2			
Arsenic (As)	0.5											
Barium (Ba)	0.2		26		29	26	21	20	14	13	13	15
Beryllium (Be)	0.2											
Cadmium (Cd)	0.1		0.26		0.45	0.25		0.1	0.11	0.11		
Calcium (Ca mg/L)	0.1		24		28	26	24	24	23	23	24	24
Chromium (Cr)	0.5		3.3		4.5	2.6	2.1	2.2	2	1.7	2.1	1.6
Cobalt (Co)	0.2		0.52		0.51	0.3	0.37	0.36	0.47	0.47	0.46	0.34
Copper (Cu)	0.2		11		16	8.1	7.8	7.1	7	6.8	6.7	6.3
Iron (Fe)	50		790		730	580	420	400	470	430	390	310
Lead (Pb)	0.2		4.1		3.9	2.3	1.5	1.3	1.4	1.3	1.2	0.87
Magnesium (Mg mg/L)	0.1		3.4		3.4	3.3	3.2	3.2	3.1	3.1	3.2	3.2
Manganese (Mn)	0.2		190		140	110	95	90	140	150	150	150
Molybdenum (Mo)	0.5		1.4		1.8	1.6	1.7	1.7	1.7	1.6	1.6	1.6
Nickel (Ni)	0.2		26		29	24	17	16	16	15	15	14
Selenium (Se)	1.0											
Silver (Ag)	0.2		0.3		0.42							
Thallium (Tl)	0.5											
Vanadium (V)	0.2											
Zinc (Zn)	2.0		14		17	15	7.7	7.2	6.4	5.3	5.7	6.1

Table C. 4. July 31, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

			For QA QC check						For QA QC check			
	Date of Collection:	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007	7/31/2007
	Station	**TM1 Blank**	**TM1**	**TM1 Lab Dup**	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM6 Field Dup**	**TM7**	**TM8**
Constituent	RL											
Aluminum (Al)	5.0		**180**		72	**120**	57	48	79	80	**97**	**130**
Antimony (Sb)	0.5		1.1		1.4							1.1
Arsenic (As)	0.5											
Barium (Ba)	0.2		28		26	26	23	19	20	19	19	18
Beryllium (Be)	0.2											
Cadmium (Cd)	0.1		0.44		0.34	0.3			0.14	0.11	0.15	0.12
Calcium (Ca mg/L)	0.1		21		24	23	24	23	24	23	27	26
Chromium (Cr)	0.5		6.8		3.5	3.4	1.7			2	2	2
Cobalt (Co)	0.2		0.84		0.44	0.44	0.41	0.37	0.47	0.45	0.51	0.43
Copper (Cu)	0.2		20		13	12	5.2	4.8	5.8	5.4	5.7	5.7
Iron (Fe)	50		**1100**		590	620	400	230	310	310	330	350
Lead (Pb)	0.2		8.4		3.3	3.8	0.92	0.46	0.99	0.85	1.1	1.9
Magnesium (Mg mg/L)	0.1		3.3		3.1	3.2	3.2	3.3	3.3	3.3	3.3	2.9
Manganese (Mn)	0.2		290		210	210	230	140	190	190	210	230
Molybdenum (Mo)	0.5		2		2.1	2	1.9	1.9	2	2	2	1.8
Nickel (Ni)	0.2		30		22	21	13	12	13	13	13	11
Selenium (Se)	1.0											
Silver (Ag)	0.2		1.1		0.32	0.33						
Thallium (Tl)	0.5											
Vanadium (V)	0.2		0.61									
Zinc (Zn)	2.0		20		13	13	16	3.2	5.6	5.4	7.8	9.3

Table C. 5. August 21, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

					For QA QC check						
	Date of Collection:	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007	8/21/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM3**	**TM3 Field Dup**	**TM4**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	RL										
Aluminum (Al)	5.0		**89**	**93**	43		57	48	51	57	36
Antimony (Sb)	0.5										
Arsenic (As)	0.5						1.3	1.5	1.4	1.2	1.5
Barium (Ba)	0.2		26	33	31		26	25	26	25	25
Beryllium (Be)	0.2										
Cadmium (Cd)	0.1		0.25	0.2	0.18						
Calcium (Ca mg/L)	0.1		35	37	33		27	25	25	29	28
Chromium (Cr)	0.5		3.3	3	2.2						
Cobalt (Co)	0.2		0.55	0.48	0.34		0.49	0.51	0.55	0.57	0.53
Copper (Cu)	0.2		9.8	9	6.8		4.4	3.9	4.2	4.1	3.3
Iron (Fe)	50		650	640	540		390	380	360	350	500
Lead (Pb)	0.2		4	3.2	2.3		1.3	0.48	0.58	0.62	0.5
Magnesium (Mg mg/L)	0.1		3.9	3.7	3.7		3.5	3.4	3.5	3.5	3.5
Manganese (Mn)	0.2		240	220	200		250	300	350	360	480
Molybdenum (Mo)	0.5		3.3	2	1.7		2.3	2.2	2.2	2.1	2.1
Nickel (Ni)	0.2		21	20	18		14	13	14	13	12
Selenium (Se)	1.0										
Silver (Ag)	0.2		0.3								
Thallium (Tl)	0.5										
Vanadium (V)	0.2										
Zinc (Zn)	2.0		13		9.2		3.8		4.3	8.1	4.2

Table C. 6. September 4, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

									For QA QC check		
	Date of Collection:	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007	9/4/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**	**TM7 Field Dup**	**TM8**
Constituent	RL										
Aluminum (Al)	5.0	ND	82	**120**	38	48	41	31	33	35	31
Antimony (Sb)	0.5	ND	0.61	0.54					1.9		
Arsenic (As)	0.5	ND				1.2	1.3	1.3	1.2	1.1	1.3
Barium (Ba)	0.2	ND	29	38	34	30	29	33	32	32	25
Beryllium (Be)	0.2	ND									
Cadmium (Cd)	0.1	ND	0.24	0.32	0.19						
Calcium (Ca mg/L)	0.1	ND	41	39	38	28	27	28	32	32	30
Chromium (Cr)	0.5	ND	2.6	3.7							
Cobalt (Co)	0.2	ND	0.56	0.57	0.35	0.52	0.52	0.49	0.51	0.49	0.48
Copper (Cu)	0.2	0.27	16	12	7.1	4.5	4.4	3.8	3.6	3.5	3.2
Iron (Fe)	50	ND	530	600	370	340	280	280	260	250	310
Lead (Pb)	0.5	ND	3.6	3.4	1.7	1	0.64	0.59	0.62	0.54	3.2
Magnesium (Mg mg/L)	0.1	ND	4.1	4	3.9	3.6	3.6	3.8	3.8	3.8	3.7
Manganese (Mn)	0.5	ND	240	250	200	210	290	300	330	320	350
Molybdenum (Mo)	0.5	ND	3	3.4	3.4	2.5	2.5	2.3	2.3	2.2	2.3
Nickel (Ni)	0.2	ND	22	23	18	14	14	15	14	14	12
Selenium (Se)	1.0	ND									
Silver (Ag)	0.2	ND	0.3	0.4							
Thallium (Tl)	0.5	ND									
Vanadium (V)	0.2	ND									
Zinc (Zn)	2.0	2.2	15	12	8.9	4.6	5.5	4.4	4.8	5.3	4.4

Table C. 7. September 12, 2007 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

				For QA QC check								
Date of Collection:		9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007	9/12/2007
	Station	**TM1 Blank**	**TM1**	**TM2**	**TM2 Field Dup**	**TM2 Lab Dup**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	RL											
Aluminum (Al)	5.0	5.9	**160**	**170**	**170**		**170**	**88**	62	77	85	86
Antimony (Sb)	0.5											
Arsenic (As)	0.5								1.3	1.2	1.2	1.3
Barium (Ba)	0.2	0.29	36	33	33		32	38	31	31	31	30
Beryllium (Be)	0.5											
Cadmium (Cd)	0.1		0.93	0.78	0.78		0.61	0.23	0.15	0.2	0.25	
Calcium (Ca mg/L)	0.1		25	24	25		24	34	28	28	30	29
Chromium (Cr)	0.5		5	5.1	5.1		4.4	3.3	2			
Cobalt (Co)	0.2		1.5	1	0.98		0.84	0.6	0.67	0.74	0.74	0.62
Copper (Cu)	0.2		25	23	24		18	8.8	5.7	6.1	5.9	5
Iron (Fe)	50		1000	800	810		820	520	510	530	540	740
Lead (Pb)	0.2		9.3	6.9	7		6.6	2.1	1.3	1.5	1.7	2.3
Magnesium (Mg mg/L)	0.1		3.5	3.3	3.3		3.2	3.7	3.5	3.5	3.5	3.1
Manganese (Mn)	0.2		430	350	350		360	230	280	290	300	330
Molybdenum (Mo)	0.5		1.9	1.7	1.7		1.8	3.1	2.5	2.5	2.3	1.9
Nickel (Ni)	0.2		53	36	35		29	18	16	17	19	13
Selenium (Se)	1.0											
Silver (Ag)	0.2		0.31	0.25	0.24						0.61	
Thallium (Tl)	0.5											
Vanadium (V)	0.2											
Zinc (Zn)	2.0		39	27	28		23	8.1	5.5	8.6	9.8	13

Table C. 8. March 6, 2008 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

			For QA QC check									
Date of Collection:		3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008	3/6/2008
	Station	**TM1 Blank**	**TM1**	**TM1 Field Dup**	**TM1 Lab Dup**	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	RL											
Aluminum (Al)	10.0	ND	**95**	**100**		**120**	**120**	77	77	69	76	72
Antimony (Sb)	0.5	ND										
Arsenic (As)	0.5	ND										
Barium (Ba)	0.2	ND	26	25		25	23	23	24	25	25	25
Beryllium (Be)	0.2	ND										
Cadmium (Cd)	0.1	ND	0.29	0.24		0.35	0.28	0.35	0.38	0.39	0.41	**0.38**
Calcium (Ca mg/L)	0.1	ND	16	16		16	15	17	17	17	18	18
Chromium (Cr)	2.0	ND	3.8	4.5		4.9	4.2	4.3	4.2	4.8	4.2	4.2
Cobalt (Co)	0.2	ND	0.47	0.47		0.52	0.48	0.53	0.5	0.49	0.49	0.48
Copper (Cu)	0.5	ND	8.9	8.3		11	8.7	6.8	6.8	6.8	6.8	6.6
Iron (Fe)	50	ND	330	360		410	390	390	340	330	350	320
Lead (Pb)	0.5	ND	1.8	1.8		2.6	2.2	1.4	1.3	1.3	1.3	1.3
Magnesium (Mg mg/L)	0.1	ND	2.8	2.8		2.8	2.7	2.9	3	3	3.1	3
Manganese (Mn)	0.5	ND	99	98		100	100	140	140	140	140	140
Molybdenum (Mo)	0.5	ND		0.56				0.6	0.6	0.59	0.61	0.6
Nickel (Ni)	0.2	ND	12	11		13	10	14	14	14	14	14
Selenium (Se)	2.5	ND										
Silver (Ag)	0.2	ND	0.23	0.24		0.34	0.24					
Thallium (Tl)	0.5	ND										
Vanadium (V)	0.2	ND										
Zinc (Zn)	2.0	ND	23	23		24	22	22	23	22	22	24

Table C. 9. August 1, 2008 Survey

Ten Mile River Trace Metal Samples

All values are ug/L unless noted

			For QA QC check				For QA QC check					
	Date of Collection:	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008	8/1/2008
	Station	**TM1 Blank**	**TM1**	**TM1 Lab Dup**	**TM2**	**TM3**	**TM4**	**TM4 Field Dup**	**TM5**	**TM6**	**TM7**	**TM8**
Constituent	RL											
Aluminum (Al)	5.0	ND	**98**		**120**	**98**	59	59	59	64	62	51
Antimony (Sb)	0.5	ND										
Arsenic (As)	0.5	ND	1.30		1.40	1.50	1.40	1.20	1.40	1.30	1.10	1.30
Barium (Ba)	0.5	ND	27.00		27.00	27.00	24.00	23.00	24.00	21.00	21.00	21.00
Beryllium (Be)	0.2	ND										
Cadmium (Cd)	0.2	ND	0.41		0.45	0.39	0.22		0.22			
Calcium (Ca mg/L)	0.1	ND	22.00		24.00	24.00	18.00	17.00	18.00	17.00	18.00	19.00
Chromium (Cr)	0.5	ND	5.20		5.80	4.90	3.10	2.70	3.10	2.70	2.50	2.50
Cobalt (Co)	0.2	ND	0.60		0.66	0.56	0.29	0.28	0.29	0.36	0.37	0.34
Copper (Cu)	0.5	ND	16.00		18.00	14.00	9.50	9.30	9.50	7.60	7.60	7.00
Iron (Fe)	55	ND	**1100**		**1200**	**1100**	730	730	730	550	540	450
Lead (Pb)	0.2	ND	6.00		6.20	5.40	2.70	2.70	2.70	2.00	2.00	1.60
Magnesium (Mg mg/L)	0.1	ND	3.50		3.50	3.50	2.90	2.80	2.90	2.80	2.70	2.90
Manganese (Mn)	0.5	ND	240.00		290.00	270.00	190.00	180.00	190.00	190.00	200.00	180.00
Molybdenum (Mo)	0.5	ND	2.30		2.90	2.70	1.70	1.60	1.70	1.60	1.60	1.80
Nickel (Ni)	1.0	ND	30.00		30.00	27.00	19.00	19.00	19.00	16.00	16.00	16.00
Selenium (Se)	1.0	ND										
Silver (Ag)	0.2	ND	0.49		0.55	0.42	0.22	0.21	0.22			
Thallium (Tl)	0.5	ND										
Vanadium (V)	0.2	ND	0.76		0.73	0.54	0.55	0.60	0.55	0.45	0.41	0.34
Zinc (Zn)	2.0	ND	19.00		18	16	11	12	11			8.6

APPENDIX D. Flow Balance Calculations Using Drainage-Area Ratio Method

The drainage-area ratio method assumes that the streamflow at an ungaged site is the same per unit area as that at a nearby, hydrologically similar streamgaging station used as an index. Drainage areas for the ungaged site and the index station are determined from topographic maps. Streamflow statistics are computed for the index station, then the statistics (numerical values) are divided by the drainage area to determine streamflows per unit area at the index station. These values are multiplied by the drainage area at the ungaged site to obtain estimated statistics for the site. This method is most commonly applied when the index gaging station is on the same stream as the ungaged site because the accuracy of the method depends on the proximity of the two, on similarities in drainage area and on other physical and climatic characteristics of their drainage basins.

Several researchers have provided guidelines as to how large the difference in drainage areas can be before use of regression equations is preferred over use of the drainage-area ratio method.Because of uncertainty in an appropriate range for use of the drainage-area ratio method for streams in Massachusetts, an experiment was designed to determine the ratio range in which the method is likely to provide better estimates of low streamflow statistics than use of regression equations. Results of this study indicate that the appropriate ratio range is between 0.3 and 1.5. WWTF flows taken out prior to calculating cfs/mi2 and then added back into flow calculation. USGS gauging station is located at same location as RIDEM sampling station TM6. The resulting calculations of mean daily flow at each station for each survey were used for total phosphorus and metals loadings estimates.

Methods for Estimating Low-Flow Statistics for Massachusetts Streams By Kernell G. Ries, III, and Paul J. Friesz (2000). Water-Resources Investigations Report 00-4135

Drainage Area Ratio Calculations for Ten Mile River stations.

Station	DA in sq mi	DA ratio
TM1	42.0	0.808
TM2	42.8	0.823
TM3	45.9	0.883
TM4	50.8	0.977
TM5	51.3	0.987
TM6	**52.0**	**1.000**
TM7	52.9	1.017
TM8	53.5	1.029
All ratios within acceptable range and close to 1. Based on this…approach will be used to estimate flows.		
All drainage areas calculated using GIS (Paul Jordan 2013)		

Average Monthly WWTF Flows for Surveys in the Ten Mile River.

1 MGD = 1.547 cfs

Survey	Date	Attleboro mean mo av		N Attleboro mean monthly avg.		
		MGD	cfs	MGD	cfs	combined
pre-	3/22/2007	3.6	5.6	5.48	8.5	14.0
1	5/22/2007	4.5	7.0	4.68	7.2	14.2
2	6/19/2007	4.9	7.6	3.79	5.9	13.4
3	7/2/2007	4.4	6.8	2.94	4.5	11.4
4	7/31/2007	4.4	6.8	2.94	4.5	11.4
5	8/21/2007	4.7	7.3	2.71	4.2	11.5
6	9/4/2007	4.5	7.0	2.67	4.1	11.1
7	9/12/2007	4.5	7.0	2.67	4.1	11.1
8	3/6/2008	6.8	10.5	6.74	10.4	20.9
9	8/21/2008	2.9	4.5	3.24	5.0	9.5

Survey 1 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined wwtf cfs
TM1	42.0			156	14.2
TM2	42.8			159	
TM3	45.9			169	
TM4	50.8			186	
TM5	51.3			188	
TM6	52.0	190	3.65	190	
TM7	52.9		3.38	193	
TM8	53.5			195	

Survey 2 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined wwtf cfs
TM1	42.0			49	13.4
TM2	42.8			50	
TM3	45.9			53	
TM4	50.8			57	
TM5	51.3			57	
TM6	52.0	58	1.12	58	
TM7	52.9		0.86	59	
TM8	53.5			59	

Survey 3 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined wwtf cfs
TM1	42.0			32	11.4
TM2	42.8			32	
TM3	45.9			34	
TM4	50.8			36	
TM5	51.3			37	
TM6	52.0	37	0.71	37	
TM7	52.9		0.49	37	
TM8	53.5			38	

Survey 4 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined wwtf cfs
TM1	42.0			71	11.4
TM2	42.8			72	
TM3	45.9			76	
TM4	50.8			83	
TM5	51.3			84	
TM6	52.0	85	1.63	85	
TM7	52.9		1.42	86	
TM8	53.5			87	

Survey 5 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined w
TM1	42.0			18	11.5
TM2	42.8			18	
TM3	45.9			18	
TM4	50.8			19	
TM5	51.3			19	
TM6	52.0	19	0.37	19	
TM7	52.9		0.14	19	
TM8	53.5			19	

Survey 6 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined w
TM1	42.0			14	11.1
TM2	42.8			14	
TM3	45.9			15	
TM4	50.8			15	
TM5	51.3			15	
TM6	52.0	15	0.29	15	
TM7	52.9		0.08	15	
TM8	53.5			15	

Survey 7 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined w
TM1	42.0			65	11.1
TM2	42.8			66	
TM3	45.9			70	
TM4	50.8			76	
TM5	51.3			77	
TM6	52.0	78	1.50	78	
TM7	52.9		1.29	79	
TM8	53.5			80	

Survey 8 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined w
TM1	42.0			243	20.9
TM2	42.8			247	
TM3	45.9			264	
TM4	50.8			290	
TM5	51.3			292	
TM6	52.0	296	5.69	296	
TM7	52.9		5.29	301	
TM8	53.5			304	

Survey 9 Flow Calculations

Station	DA in sq mi	USGS mean daily flow in cfs	cfs/sq. mi	Estimated flow in cfs	Combined w
TM1	42.0			49	9.5
TM2	42.8			49	
TM3	45.9			52	
TM4	50.8			57	
TM5	51.3			57	
TM6	52.0	58	1.12	58	
TM7	52.9		0.93	59	
TM8	53.5			59	

APPENDIX E. Allowable and Observed Daily Metal Loads for 9 Surveys.

Allowable and Existing Dissolved Cadmium Loads in the Ten Mile River.

	Survey 1 (Q=190 cfs)		Survey 2 (Q=58 cfs)		Survey 3 (Q=37)		Survey 4 (Q=85 cfs)	
Station	ADL	EDL	ADL	EDL	ADL	EDL	ADL	EDL
TM1	0.13	0.04	0.05	0.03	0.03	0.03	0.06	**0.08**
TM2	0.14	0.11	0.06	0.05	0.04	0.04	0.07	0.05
TM3	0.15	0.05	0.06	0.05	0.04	0.03	0.07	0.05
TM4	0.15	0.10	0.05	0.02	0.04	0.010	0.08	0.02
TM5	0.16	0.15	0.05	0.02	0.04	0.010	0.08	0.02
TM6	0.14	**0.22**	0.05	0.02	0.04	0.010	0.09	0.02
TM7	0.15	**0.22**	0.06	0.02	0.04	0.010	0.09	0.02
TM8	0.15	**0.18**	0.05	0.02	0.04	0.010	0.09	0.02
	Survey 5 (Q=19 cfs)		Survey 6 (Q=15 cfs)		Survey 7 (Q= 78 cfs)		Survey 8 (Q=296 cfs)	
Station	ADL	EDL	ADL	EDL	ADL	EDL	ADL	EDL
TM1	0.02	0.01	0.02	0.01	0.06	**0.19**	0.20	QAQC
TM2	0.02	0.001	0.02	0.000	0.06	**0.10**	0.20	0.07
TM3	0.02	0.001	0.02	0.01	0.07	**0.08**	0.28	0.10
TM4	0.02	0.01	0.02	0.004	0.09	0.02	0.23	**0.50**
TM5	0.02	0.01	0.02	0.004	0.09	0.02	0.23	**0.47**
TM6	0.02	0.01	0.02	0.004	0.09	0.02	0.23	**0.48**
TM7	0.02	0.01	0.02	0.004	0.09	0.02	0.25	**0.54**
TM8	0.02	0.01	0.02	0.004	0.09	0.02	0.25	**0.48**

	Survey 9 (Q=58 cfs)	
Station	ADL	EDL
TM1	0.04	**0.06**
TM2	0.05	0.03
TM3	0.05	0.03
TM4	0.05	0.03
TM5	0.05	0.03
TM6	0.05	0.03
TM7	0.05	0.03
TM8	0.05	0.03

- *Surveys highlighted in blue conducted under a wet weather stormflow condition. 7Q10 conditions are represented by Survey 6.*
- *ADL is allowable daily load in lbs.*
- *EDL is existing daily load in lbs.*
- *ADL is inclusive of 10% MOS if criteria violated.*
- *Bold shading indicates that existing daily load exceeds the allowable daily load.*
- QAQC-data did not meet QAQC guidelines.

Allowable and Existing Dissolved Lead Loads in the Ten Mile River.

	Survey 1 (Q=190 cfs)		Survey 2 (Q=58 cfs)		Survey 3 (Q=37)		Survey 4 (Q=85 cfs)	
Station	ADL	EDL	ADL	EDL	ADL	EDL	ADL	EDL
TM1	1.07	0.84	0.43	**0.66**	0.31	0.22	0.49	**0.57**
TM2	1.09	0.85	0.47	**0.57**	0.35	0.13	0.62	0.24
TM3	1.15	0.78	0.53	0.46	0.36	0.13	0.64	0.33
TM4	1.12	1.00	0.44	0.40	0.33	0.10	0.73	0.05
TM5	1.21	0.90	0.35	0.30	0.33	0.09	0.74	0.05
TM6	1.22	1.02	0.45	0.31	0.33	0.08	0.75	0.05
TM7	1.31	1.14	0.47	0.31	0.35	0.02	0.82	0.05
TM8	1.32	0.91	0.45	0.29	0.34	0.02	0.78	0.05
	Survey 5 (Q=19 cfs)		Survey 6 (Q=15 cfs)		Survey 7 (Q= 78 cfs)		Survey 8 (Q=296 cfs)	
Station	ADL	EDL	ADL	EDL	ADL	EDL	ADL	EDL
TM1	0.24	0.04	0.22	0.02	0.64	0.49	1.50	0.98
TM2	0.24	0.03	0.22	0.02	0.63	0.33	1.53	1.08
TM3	0.22	QAQC	0.23	0.02	0.64	0.38	1.53	0.92
TM4	0.18	0.01	0.18	0.02	0.94	0.10	2.03	1.11
TM5	0.17	0.01	0.17	0.02	0.83	0.11	2.05	1.12
TM6	0.19	0.01	0.17	0.02	0.84	0.12	2.07	1.07
TM7	0.21	0.01	0.19	0.02	0.88	0.12	2.23	1.07
TM8	0.20	0.01	0.19	0.02	0.84	0.14	2.26	1.13
	Survey 9 (Q=58 cfs)							
Station	ADL	EDL						
TM1	0.38	**0.82**						
TM2	0.41	**0.79**						
TM3	0.44	**0.76**						
TM4	0.39	0.37						
TM5	0.36	0.12						
TM6	0.37	0.15						
TM7	0.42	0.18						
TM8	0.40	0.09						

- *Surveys highlighted in blue conducted under a wet weather stormflow condition. 7Q10 conditions are represented by Survey 6.*
- *ADL is allowable daily load in lbs.*
- *EDL is existing daily load in lbs.*
- *ADL is inclusive of 10% MOS if criteria violated.*
- *Bold shading indicates that existing daily load exceeds the allowable daily load.*
- QAQC-data did not meet QAQC guidelines.

Allowable and Existing Total Aluminum Loads in the Ten Mile River

	Survey 1 (Q=192 cfs)		Survey 2 (Q=62 cfs)		Survey 3 (Q=39)		Survey 4 (Q=88 cfs)	
Station	ADL	EDL	ADL	EDL	ADL	EDL	ADL	EDL
TM1	66	**101**	21	**25**	15	12	30	**69**
TM2	75	74	23	23	14	**16**	34	28
TM3	71	**109**	25	21	16	7	32	**49**
TM4	78	**97**	27	10	17	8	39	26
TM5	79	**100**	27	11	17	9	39	22
TM6	80	**102**	27	13	17	8	40	36
TM7	81	**100**	28	14	17	9	36	**45**
TM8	82	**93**	28	10	18	6	37	**61**
	Survey 5 (Q=20 cfs)		Survey 6 (Q=15 cfs)		Survey 7 (Q= 84 cfs)		Survey 8 (Q=307 cfs)	
Station	ADL	EDL	ADL	EDL	ADL	EDL	ADL	EDL
TM1	8	**9**	7	6	27	**56**	103	**124**
TM2	8	**9**	6	**9**	28	**60**	104	**160**
TM3	8	4	7	3	30	**64**	111	**171**
TM4	9	6	7	4	32	**36**	136	120
TM5	9	5	7	3	36	26	137	121
TM6	9	5	7	3	37	32	139	110
TM7	9	6	7	3	37	36	141	123
TM8	9	4	7	3	38	37	143	118
	Survey 9 (Q=60 cfs)							
Station	ADL	EDL						
TM1	21	**26**						
TM2	21	**32**						
TM3	22	**27**						
TM4	27	18						
TM5	27	17						
TM6	27	20						
TM7	28	20						
TM8	28	16						

- *Surveys highlighted in blue conducted under a wet weather stormflow condition. 7Q10 conditions are represented by Survey 6.*
- *ADL is allowable daily load in lbs.*
- *EDL is existing daily load in lbs.*
- *ADL is inclusive of 10% MOS if criteria violated.*
- *Bold shading indicates that existing daily load exceeds the allowable daily load.*
- QAQC-data did not meet QAQC guidelines.

Allowable and Existing Total Iron Loads in the Ten Mile River.

	Survey 1 (Q=192 cfs)		Survey 2 (Q=62 cfs)		Survey 3 (Q=39)		Survey 4 (Q=88 cfs)	
Station	ADL	EDL	ADL	EDL	ADL	EDL	ADL	EDL
TM1	841	656	264	243	172	136	344	**421**
TM2	857	566	270	213	172	126	388	229
TM3	911	683	286	226	183	106	410	254
TM4	1003	662	307	191	194	82	447	179
TM5	1013	628	307	191	199	94	453	104
TM6	1024	655	313	184	199	86	458	142
TM7	1040	655	318	184	199	78	464	153
TM8	1051	631	318	169	205	64	469	164
	Survey 5 (Q=20 cfs)		Survey 6 (Q=15 cfs)		Survey 7 (Q= 84 cfs)		Survey 8 (Q=307 cfs)	
Station	ADL	EDL	ADL	EDL	ADL	EDL	ADL	EDL
TM1	97	63	75	40	350	350	1310	432
TM2	97	62	75	45	356	285	1331	546
TM3	97	QAQC	81	30	377	309	1423	555
TM4	102	40	81	28	410	213	1563	610
TM5	102	39	81	23	415	212	1574	535
TM6	102	37	81	23	420	223	1595	527
TM7	102	36	81	21	426	230	1622	568
TM8	102	51	81	25	431	319	1639	524

	Survey 9 (Q=60 cfs)	
Station	ADL	EDL
TM1	238	**291**
TM2	238	**317**
TM3	252	**308**
TM4	307	224
TM5	307	166
TM6	313	172
TM7	318	172
TM8	318	143

- *Surveys highlighted in blue conducted under a wet weather stormflow condition. 7Q10 conditions are represented by Survey 6.*
- *ADL is allowable daily load in lbs.*
- *EDL is existing daily load in lbs.*
- *ADL is inclusive of 10% MOS if criteria violated.*
- *Bold shading indicates that existing daily load exceeds the allowable daily load.*
- QAQC-data did not meet QAQC guidelines.

APPENDIX F: Metals Load Reduction Calculations

Dissolved Cadmium

190 cfs	Survey 1	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.04				
	AL	0.13				
TM2	EL	0.11	AEL			
	AL	0.14	AL			
TM3	EL	0.05	AEL			
	AL	0.15	AL			
TM4	EL	0.1	AEL			
	AL	0.15	AL			
TM5	EL	0.15	AEL			
	AL	0.16	AL			
TM6	EL	0.22	AEL		0.08	36
	AL	0.14	AL			
TM7	EL	0.22	AEL	0.14		
	AL	0.15	AL	0.25		
TM8	EL	0.18	AEL	0.18	0	
	AL	0.15	AL	0.25		

36% reduction from TM6 sub-watershed .08 lbs
no net increase

58 cfs	Survey 2	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.03				
	AL	0.05				
TM2	EL	0.05				
	AL	0.06				
TM3	EL	0.05				
	AL	0.06				
TM4	EL	0.02				
	AL	0.05				
TM5	EL	0.02				
	AL	0.05				
TM6	EL	0.02				
	AL	0.05				
TM7	EL	0.02				
	AL	0.06		0.25		
TM8	EL	0.02		0.02		
	AL	0.06		0.25		

No reductions required
No net increase

37 cfs	Survey3	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.03				
	AL	0.03				
TM2	EL	0.04				
	AL	0.04				
TM3	EL	0.04				
	AL	0.04				
TM4	EL	0.04				
	AL	0.04				
TM5	EL	0.04				
	AL	0.04				
TM6	EL	0.01				
	AL	0.04				
TM7	EL	0.01				
	AL	0.04		0.25		
TM8	EL	0.01		0.01		
	AL	0.04		0.25		

no net increase

85 cfs	Survey 4	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.08			0.02	25
	AL	0.06				
TM2	EL	0.05	AEL	0.03	0	
	AL	0.07	AL	0.07		
TM3	EL	0.05	AEL	0.03		
	AL	0.07	AL			
TM4	EL	0.02	AEL			
	AL	0.08	AL			
TM5	EL	0.02	AEL			
	AL	0.08	AL			
TM6	EL	0.02	AEL			
	AL	0.09	AL			
TM7	EL	0.02	AEL			
	AL	0.09	AL	0.25		
TM8	EL	0.02	AEL	0.02		
	AL	0.09	AL	0.25		

25% Reduction at state line 0.02 lbs
no net increase remainder of river

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

19 cfs	Survey 5	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.01				
	AL	0.02				
TM2	EL	0.001				
	AL	0.02				
TM3	EL	0.001				
	AL	0.02				
TM4	EL	0.01				
	AL	0.02				
TM5	EL	0.01				
	AL	0.02				
TM6	EL	0.01				
	AL	0.02				
TM7	EL	0.01				
	AL	0.02		0.25		
TM8	EL	0.01		0.01		
	AL	0.02		0.25		

No reductions required
no net increase

15 cfs	Survey 6	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.01				
	AL	0.02				
TM2	EL	0.0001				
	AL	0.02				
TM3	EL	0.01				
	AL	0.02				
TM4	EL	0.004				
	AL	0.02				
TM5	EL	0.004				
	AL	0.02				
TM6	EL	0.004				
	AL	0.02				
TM7	EL	0.004				
	AL	0.02		0.25		
TM8	EL	0.004		0.004		
	AL	0.02		0.25		

No reductions required
no net increase

78 cfs	Survey 7	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.19			0.13	68
	AL	0.06				
TM2	EL	0.1	AEL	-0.03	0	
	AL	0.06	AL	0.06		
TM3	EL	0.08	AEL			
	AL	0.07	AL			
TM4	EL	0.02	AEL			
	AL	0.09	AL			
TM5	EL	0.02	AEL			
	AL	0.09	AL			
TM6	EL	0.02	AEL			
	AL	0.09	AL			
TM7	EL	0.02	AEL			
	AL	0.09	AL	0.25		
TM8	EL	0.02	AEL	0.02		
	AL	0.09	AL	0.25		

68% reduction at state line 0.13 lbs
no net increase remainder of river

296 cfs	Survey 8	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL					
	AL					
TM2	EL	0.07	AEL			
	AL	0.2	AL			
TM3	EL	0.1	AEL			
	AL	0.28	AL			
TM4	EL	0.5	AEL		0.27	54
	AL	0.23	AL			
TM5	EL	0.47	AEL	0.20	0	
	AL	0.23	AL	0.229		
TM6	EL	0.48	AEL	0.21		
	AL	0.23	AL	0.232		
TM7	EL	0.54	AEL	0.27		
	AL	0.25	AL	0.25		
TM8	EL	0.48	AEL	0.21	0	
	AL	0.25	AL	0.25		

54% reduction from TM4 sub-watershed 0.27 lbs
9% reduction from TM7 sub-watershed 0.025 lbs

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

58 cfs	Survey 9	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.06			0.02	33
	AL	0.04				
TM2	EL	0.03	AEL	0.01	0	
	AL	0.05	AL	0.05		
TM3	EL	0.03	AEL	0.01	0	
	AL	0.05	AL	0.05		
TM4	EL	0.03	AEL	0.01	0	
	AL	0.05	AL	0.05		
TM5	EL	0.03	AEL	0	0	
	AL	0.05	AL	0.05		
TM6	EL	0.03	AEL	0.01	0	
	AL	0.05	AL	0.05		
TM7	EL	0.03	AEL	0.01		
	AL	0.05	AL	0.25		
TM8	EL	0.03	AEL	0.03	0	
	AL	0.05	AL	0.25		

33% Reduction at state line 0.02 lbs
No net increase

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

Dissolved Lead

190 cfs	Survey 1	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.84				
	AL	1.07				
TM2	EL	0.85				
	AL	1.09				
TM3	EL	0.78				
	AL	1.15				
TM4	EL	1				
	AL	1.12				
TM5	EL	0.9				
	AL	1.21				
TM6	EL	1.02				
	AL	1.22				
TM7	EL	1.14				
	AL	1.31				
TM8	EL	0.91				
	AL	1.32				

No reductions required
No net increase

58 cfs	Survey 2	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.66			0.23	35
	AL	0.43				
TM2	EL	0.57	AEL	0.34	0	
	AL	0.47	AL	0.47		
TM3	EL	0.46	AEL			
	AL	0.53	AL			
TM4	EL	0.46	AEL			
	AL	0.44	AL			
TM5	EL	0.4	AEL			
	AL	0.35	AL			
TM6	EL	0.3	AEL			
	AL	0.45	AL			
TM7	EL	0.31	AEL			
	AL	0.47	AL			
TM8	EL	0.31	AEL			
	AL	0.45	AL			
		0.29				
35% Reduction required at state line					0.23 lbs reduction	
Remainder = no net increase						

37 cfs	Survey3	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.22				
	AL	0.31				
TM2	EL	0.13				
	AL	0.35				
TM3	EL	0.13				
	AL	0.36				
TM4	EL	0.1				
	AL	0.33				
TM5	EL	0.09				
	AL	0.33				
TM6	EL	0.08				
	AL	0.33				
TM7	EL	0.02				
	AL	0.35				
TM8	EL	0.02				
	AL	0.34				

No reductions required
No net increase

85 cfs	Survey 4	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.57			0.08	14
	AL	0.49				
TM2	EL	0.24	AEL	0.16	0	
	AL	0.62	AL	0.62		
TM3	EL	0.33	AEL	0.25		
	AL	0.64	AL			
TM4	EL	0.05	AEL	-0.03		
	AL	0.73	AL			
TM5	EL	0.05	AEL	0		
	AL	0.74	AL			
TM6	EL	0.05	AEL	-0.03		
	AL	0.75	AL			
TM7	EL	0.05	AEL	-0.03		
	AL	0.82	AL			
TM8	EL	0.05	AEL	-0.03		
	AL	0.78	AL			
14% Reduction required at state line					0.08 lbs	
No net increase remainder						

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

19 cfs	Survey 5	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.04				
	AL	0.24				
TM2	EL	0.03				
	AL	0.24				
TM3	EL					
	AL	0.22				
TM4	EL	0.01				
	AL	0.18				
TM5	EL	0.01				
	AL	0.17				
TM6	EL	0.01				
	AL	0.19				
TM7	EL	0.01				
	AL	0.21				
TM8	EL	0.01				
	AL	0.2				

No reductions required
no net increase

15 cfs	Survey 6	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.02				
	AL	0.22				
TM2	EL	0.02				
	AL	0.22				
TM3	EL	0.02				
	AL	0.23				
TM4	EL	0.02				
	AL	0.18				
TM5	EL	0.02				
	AL	0.17				
TM6	EL	0.02				
	AL	0.17				
TM7	EL	0.02				
	AL	0.19				
TM8	EL	0.02				
	AL	0.19				

No reductions required
no net increase

78 cfs	Survey 7	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.49				
	AL	0.64				
TM2	EL	0.33				
	AL	0.63				
TM3	EL	0.38				
	AL	0.64				
TM4	EL	0.1				
	AL	0.94				
TM5	EL	0.11				
	AL	0.83				
TM6	EL	0.12				
	AL	0.84				
TM7	EL	0.12				
	AL	0.88				
TM8	EL	0.14				
	AL	0.84				

No reductions required
no net increase

296 cfs	Survey 8	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.98				
	AL	1.5				
TM2	EL	1.08				
	AL	1.53				
TM3	EL	0.92				
	AL	1.53				
TM4	EL	1.11				
	AL	2.03				
TM5	EL	1.12				
	AL	2.05				
TM6	EL	1.07				
	AL	2.07				
TM7	EL	1.07				
	AL	2.23				
TM8	EL	1.13				
	AL	2.26				

No reductions required
No net increase

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

58 cfs	Survey 9	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	0.82			0.44	54
	AL	0.38				
TM2	EL	0.79	AEL	0.35	0	
	AL	0.41	AL	0.41		
TM3	EL	0.76	AEL	0.32	0	
	AL	0.44	AL	0.44		
TM4	EL	0.37	AEL			
	AL	0.39	AL			
TM5	EL	0.12	AEL			
	AL	0.36	AL			
TM6	EL	0.15	AEL			
	AL	0.37	AL			
TM7	EL	0.18	AEL			
	AL	0.42	AL			
TM8	EL	0.09	AEL			
	AL	0.4	AL			

54% reduction required at State Line 0.44 lbs reduction

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

Total Aluminum

192 cfs	Survey 1	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	101			31	31
	AL	70				
TM2	EL	74	AEL	43	0	
	AL	80	AL	80		
TM3	EL	109	AEL	78	2	3
	AL	76	AL	76		
TM4	EL	97	AEL	64	0	
	AL	78	AL	78		
TM5	EL	100	AEL	67	0	
	AL	79	AL	79		
TM6	EL	102	AEL	69	0	
	AL	80	AL	80		
TM7	EL	100	AEL	67	0	
	AL	81	AL	81		
TM8	EL	93	AEL	60	0	
	AL	82	AL	82		

31% Reduction at state line — 31 lbs reduction
3% reduction required in TM3 sub-catchment — 2 lbs reduction
no net increase remainder of river

62 cfs	Survey 2	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	25			4	16
	AL	21				
TM2	EL	23	AEL	19	0	no net increase
	AL	23	AL	23		
TM3	EL	21	AEL	17	0	no net increase
	AL	25	AL	25		
TM4	EL	10	AEL	6	0	no net increase
	AL	27	AL	27		
TM5	EL	11	AEL	11	0	no net increase
	AL	27	AL	27		
TM6	EL	13	AEL	13	0	no net increase
	AL	27	AL	27		
TM7	EL	14	AEL	14	0	no net increase
	AL	28	AL	28		
TM8	EL	10	AEL	10	0	no net increase
	AL	28	AL	28		

16% Reduction at state line — 4 lbs reduction
No net increase remainder of river

39 cfs	Survey 3	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	12			0	
	AL	15				
TM2	EL	16	AEL	16	2	13
	AL	14	AL	14		
TM3	EL	7	AEL	5	0	
	AL	16	AL	16		
TM4	EL	8	AEL	6	0	
	AL	17	AL	17		
TM5	EL	9	AEL	7	0	
	AL	17	AL	17		
TM6	EL	8	AEL	6	0	
	AL	17	AL	17		
TM7	EL	9	AEL	7	0	
	AL	17	AL	17		
TM8	EL	6	AEL	4	0	
	AL	18	AL	18		

13% Reduction in TM2 subcatchment — 2 lbs reduction
No net increase in remainder of river

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

88 cfs	Survey 4	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	69			39	57
	AL	30				
TM2	EL	28	AEL	-11	0	
	AL	34	AL	32.5		
TM3	EL	49	AEL	10	0	
	AL	32	AL	34.2		
TM4	EL	26	AEL	-13	0	
	AL	39	AL	39		
TM5	EL	22	AEL	-17	0	
	AL	39	AL	39		
TM6	EL	36	AEL	-3	0	
	AL	40	AL	40		
TM7	EL	45	AEL	6	0	
	AL	36	AL	36		
TM8	EL	61	AEL	22	0	
	AL	37	AL	37		

57% Reduction at state line — 39 lbs reduction
no net increase remainder of river

20 cfs	Survey 5	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	9			1	11.1
	AL	8				
TM2	EL	9	AEL	8	0	
	AL	8	AL	8		
TM3	EL	4	AEL	3	0	
	AL	8	AL	8		
TM4	EL	6	AEL	5	0	
	AL	9	AL	9		
TM5	EL	5	AEL	4	0	
	AL	9	AL	9		
TM6	EL	5	AEL	4	0	
	AL	9	AL	9		
TM7	EL	6	AEL	5	0	
	AL	9	AL	9		
TM8	EL	4	AEL	3	0	
	AL	9	AL	9		

11% reduction at state line — 1 lb reduction
no net increase in remainder of river

15 cfs	Survey 6	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	6				
	AL	7				
TM2	EL	9	AEL	9	3	33
	AL	6	AL	6		
TM3	EL	3	AEL	0		
	AL	7	AL	7		
TM4	EL	4	AEL	4		
	AL	7	AL	7		
TM5	EL	3	AEL	3		
	AL	7	AL	7		
TM6	EL	3	AEL	3		
	AL	7	AL	7		
TM7	EL	3	AEL	3		
	AL	7	AL	7		
TM8	EL	3	AEL	3		
	AL	7	AL	7		

33% Reduction required in TM2 sub-watershed — 3 lbs reduction
no net increase remainder of river

84 cfs	Survey 7	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	56			29	52
	AL	27				
TM2	EL	60	AEL	31	3	10
	AL	28	AL	28		
TM3	EL	64	AEL	32	2	6
	AL	30	AL	30		
TM4	EL	36	AEL	2	0	
	AL	32	AL	32		
TM5	EL	26	AEL	-8	0	
	AL	36	AL	36		
TM6	EL	32	AEL	-2	0	
	AL	37	AL	37		
TM7	EL	36	AEL	2	0	
	AL	37	AL	37		
TM8	EL	37	AEL	3	0	
	AL	38	AL	38		

52% Reduction at state line — 29 lbs
10% reduction required in TM2 sub-catchment — 3 lbs
6% reduction required in TM3 sub-catchment — 2 lbs
no net increase remainder of river

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

307 cfs	Survey 8	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	124			21	17
	AL	103				
TM2	EL	160	AEL	139	35	25
	AL	104	AL	104		
TM3	EL	171	AEL	115	4	3
	AL	111	AL	111		
TM4	EL	120	AEL	60	0	
	AL	136	AL	136		
TM5	EL	121	AEL	61	0	
	AL	137	AL	137		
TM6	EL	110	AEL	50	0	
	AL	139	AL	139		
TM7	EL	123	AEL	63	0	
	AL	141	AL	141		
TM8	EL	118	AEL	58	0	
	AL	143	AL	143		

17% Reduction at state line — 21 lbs
25% reduction required in TM2 sub-catchment — 35 lbs
3% reduction required in TM3 sub-catchment — 4 lbs

60 cfs	Survey 9	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	26			5	19
	AL	21				
TM2	EL	32	AEL	27	6	22
	AL	21	AL	21		
TM3	EL	27	AEL	16		
	AL	22	AL	22		
TM4	EL	18	AEL	7		
	AL	27	AL	27		
TM5	EL	17	AEL	6		
	AL	27	AL	27		
TM6	EL	20	AEL	9		
	AL	27	AL	27		
TM7	EL	20	AEL	9		
	AL	28	AL	28		
TM8	EL	16	AEL	5		
	AL	28	AL	28		

19% Reduction at state line	5 lbs
22% reduction required in TM2 sub-catchment	6 lbs

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

Total Iron

192 cfs	Survey 1	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	656				
	AL	841				
TM2	EL	566				
	AL	857				
TM3	EL	683				
	AL	911				
TM4	EL	662				
	AL	1003				
TM5	EL	628				
	AL	1013				
TM6	EL	655				
	AL	1024				
TM7	EL	655				
	AL	1040				
TM8	EL	631				
	AL	1051				

No reductions required
No net increase remainder of river

62 cfs	Survey 2	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	243			-21	-9
	AL	264				
TM2	EL	213	AEL	234	0	no net increase
	AL	270	AL	270		
TM3	EL	226	AEL	247	0	no net increase
	AL	286	AL	286		
TM4	EL	191	AEL	212	0	no net increase
	AL	307	AL	307		
TM5	EL	191	AEL	191	0	no net increase
	AL	307	AL	307		
TM6	EL	184	AEL	184	0	no net increase
	AL	313	AL	313		
TM7	EL	184	AEL	184	0	no net increase
	AL	318	AL	318		
TM8	EL	169	AEL	169	0	no net increase
	AL	318	AL	318		

No required reductions
No net increase remainder of river

39 cfs	Survey3	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	136				
	AL	172				
TM2	EL	126				
	AL	172				
TM3	EL	106				
	AL	183				
TM4	EL	82				
	AL	194				
TM5	EL	94				
	AL	199				
TM6	EL	184				
	AL	199				
TM7	EL	184				
	AL	199				
TM8	EL	169				
	AL	205				

No reductions required
No net increase remainder of river

88 cfs	Survey 4	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	421			77	18
	AL	344				
TM2	EL	229	AEL	152	0	
	AL	388	AL	32.5		
TM3	EL	254	AEL	177	0	
	AL	410	AL	34.2		
TM4	EL	179	AEL	102	0	
	AL	447	AL	447		
TM5	EL	104	AEL	27	0	
	AL	453	AL	453		
TM6	EL	142	AEL	65	0	
	AL	458	AL	458		
TM7	EL	153	AEL	76	0	
	AL	464	AL	464		
TM8	EL	164	AEL	87	0	
	AL	469	AL	469		

18% reduction at state line 77 lbs
No net increase remainder of river

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

20 cfs	Survey 5	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	63				
	AL	97				
TM2	EL	62				
	AL	97				
TM3	EL	226				
	AL	97				
TM4	EL	40				
	AL	102				
TM5	EL	39				
	AL	102				
TM6	EL	37				
	AL	102				
TM7	EL	36				
	AL	102				
TM8	EL	51				
	AL	102				

No reductions required
No net increase

15 cfs	Survey 6	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	40				
	AL	75				
TM2	EL	45				
	AL	75				
TM3	EL	30				
	AL	81				
TM4	EL	28				
	AL	81				
TM5	EL	23				
	AL	81				
TM6	EL	23				
	AL	81				
TM7	EL	21				
	AL	81				
TM8	EL	25				
	AL	81				

No reductions required
No net increase

84 cfs	Survey 7	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	350				
	AL	350				
TM2	EL	285	AEL			
	AL	356	AL			
TM3	EL	309	AEL			
	AL	377	AL			
TM4	EL	213	AEL			
	AL	410	AL			
TM5	EL	212	AEL			
	AL	415	AL			
TM6	EL	223	AEL			
	AL	420	AL			
TM7	EL	230	AEL			
	AL	426	AL			
TM8	EL	319	AEL			
	AL	431	AL			

No reductions required
No net increase

307 cfs	Survey 8	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	432				
	AL	1310				
TM2	EL	546				
	AL	1331				
TM3	EL	555				
	AL	1423				
TM4	EL	610				
	AL	1563				
TM5	EL	535				
	AL	1574				
TM6	EL	527				
	AL	1595				
TM7	EL	568				
	AL	1622				
TM8	EL	524				
	AL	1639				

No reductions required
No net increase

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

60 cfs	Survey 9	lbs/day	Load	lbs/day	lbs reduction	Expressed as %
TM1	EL	291			53	18
	AL	238				
TM2	EL	317	AEL	264	26	10
	AL	238	AL	238		
TM3	EL	308	AEL	229	0	
	AL	252	AL	252		
TM4	EL	224	AEL	145	0	
	AL	307	AL	307		
TM5	EL	166	AEL	87	0	
	AL	307	AL	307		
TM6	EL	172	AEL	93	0	
	AL	313	AL	313		
TM7	EL	172	AEL	93	0	
	AL	318	AL	318		
TM8	EL	143	AEL	64	0	
	AL	318	AL	318		

18% reduction at state line — 53 lbs reduction
10% reduction in TM2 sub-catchment — 26 lbs reduction

EPA TMDL- provide range of reductions (lbs/day)
Implementation- provide percent (%) reductions for waterbody segments
EL-Existing Daily Load
AL- Allowable Daily Load
AEL- Adjusted Daily Load (adjusted for upstream load reductions)

APPENDIX G. Flux Program Loading Calculation Methods

The FLUX application is described in detail in the following document: *Instruction Report 96-2 USACOE/Water Operations Technical Support Program, William Walker 1996*

Table 2.1 of the document (reprinted below) lists the equations used to calculate the mean loading and error variance using six alternative methods. Method applicability depends upon flow/ concentration dynamics and sampling program design in each application. Walker (1981,1987) provides details on the derivation and testing of each method. The FLUX procedure "Calculate/Loads" provides a one-page summary of loadings calculated using each method. The user must decide which method is most appropriate for each application, based upon factors discussed below. For references cited below, refer to the above USACOE report.

Table 2.1
Estimation Algorithms Used in FLUX Program

Method 1 - Direct Mean Loading
$W_1 = \text{Mean}(w)$

Method 2 - Flow-Weighted Concentration (Ratio Estimate)
$W_2 = W_1 \text{ Mean}(Q)/\text{Mean}(q)$

Method 3 - Modified Ratio Estimate (Bodo and Unny 1983)
$W_3 = W_2(1 + F_{wq}/n)/(1 + F_q/n)$

Method 4 - Regression, First-Order (Walker 1981)
$W_4 = W_1[\text{Mean}(Q)/\text{Mean}(q)]^{b+1}$

Method 5 - Regression, Second-Order (Walker 1987)
$W_5 = W_4(1 + r F_Q)/(1 + r F_q)$

Method 6 - Regression Applied to Individual Daily Flows
$W_6 = \sum_j \exp [a + (b+1)\ln(Q_j) + SE^2/2]$

where

c_i	=	measured concentration in sample i (mg/m^3)
q_i	=	measured flow during sample i (hm^3/year)
b	=	slope of ln(c) versus ln(q) regression
a	=	intercept of ln(c) versus ln(q) regression
w_i	=	measured flux during sample i = $q_i c_i$ (kg/year)
F_{wq}	=	Cov(w,q) / [Mean(w) Mean(q)]
F_q	=	Var(q) / [Mean(q) Mean(q)]
F_Q	=	Var(Q) / [Mean(Q) Mean(Q)]
Q_j	=	mean flow on day j (hm^3/year)
n	=	number of samples (i)
N	=	number of daily flows (j)
W_m	=	estimated mean flux over N days, method m (kg/year)
V_m	=	variance of estimated mean flux, method m $(kg/year)^2$
r	=	0.5 b (b + 1)
$\sum_j$	=	sum over N dates in daily flow record
SE	=	standard error of estimate for ln(c) versus ln(q) regression
Mean(x)	=	mean of vector x
Var(x)	=	variance of vector x
Cov(x,y)	=	covariance of vectors x and y

Method applicability depends upon the relationship between concentration and flow. In FLUX, this characteristic is represented by the slope of a log(Concentration) versus log(Flow) regression (C/Q slope) derived from the sample data set. Typically, the C/Q slope approaches -1 at monitoring stations which are downstream of major point sources. The slope may approach or exceed 1 at monitoring stations where the load is generated as a result of runoff or high-flow events, particularly for particulate components. In many watersheds, the C/Q slope for total phosphorus varies with flow (negative at low flows to positive at high flows). FLUX graphic and tabular output helps to characterize the concentratiordflow relationship; this characterization is essential to selecting the appropriate calculation method and developing reliable loading estimates.

Method 1 (direct load averaging) is the simplest of the calculation schemes. It gives unbiased results only if the samples are taken randomly with respect to flow regime. This method completely ignores the unsampled flow record and generally has higher variance than the other methods because the flow record on the unsampled days is not considered. This method is most appropriate for situations in which concentration tends to be inversely related to flow (C/Q slope approaching - 1; loading does not vary with flow). This might occur, for example, at a station which is below a major point source and the flow/concentration relationship is controlled by dilution.

Method 2 bases the loading estimate on the flow-weighted average concentration times the mean flow over the averaging period. This amounts to a “ratio estimate” according to classical sampling theory (Cochran 1977). This method performs best when flow and concentration are unrelated or weakly related. Some bias may occur for extreme flow/concentration relationships. In test simulations of a stream with a C/Q slope 0.75, Method 2 overestimated loadings by an average of 10 percent (Walker 1987). This bias can be substantially reduced by stratifying the samples into groups of relatively homogeneous concentration and applying the method separately to each group, as described in more detail below. This is perhaps the most robust and widely applicable method, especially when applied to stratified data sets.

Method 3 modifies the Method 2 estimate by a factor that is designed to adjust for potential bias in situations where concentration varies with flow. The factor was developed byBeale(1962) and applied in a load estimation method developed by the International Joint Commission(IJC)(1977), as described by Bodo andUnny(1983, 1984). Trial simulations indicate that, compared with Method 2, this procedure is moderately successful at reducing bias but tends to have slightly higher mean squared error for streams with C/Q slopes greater than or equal to zero (Walker 1987).

Method 4 is the regression method developed by Walker (1981). This method adjusts the flow-weighted mean concentration for differences between the average sampled flow and the average total flow using the C/Q slope. It should not be used in cases where the daily flow data set contains a significant number of zero flow values. This method petiorms well over a range of C/Q slopes. Some bias is introduced at high C/Q slopes. At a slope of 0.75, for example, simulated bias is 13 percent of the mean loading but accounts for only 6 percent of the total mean squared error (Walker 1987). Additional simulations indicate that bias also occurs if the C/Q slope is highly nonlinear (i.e., quadratic or higher order polynomial). This problem can be resolved by stratifying the sample so that the relationship is approximately linear within eachgroup.

Method 5 modifies the Method 4 estimate by a factor accounting for differences in variance between the sampled and total flow distributions (Walker 1987). The derivation of the method is based upon expected value theory (Benjamin and Cornell 1970). Method 5 should not be used in cases where the daily flow data set contains a significant number of zero flow values. As for Method 4, bias resulting from nonlinearity in the log (c) versus log (q) relationship can be reduced by stratifying the data. Method 6 is another regression-based calculation method. For each stratum, the C/Q regression equation is applied individually to each daily flow value. In contrast, Methods 4 and 5 use only the flow means and variances. A small correction for bias resulting from the log transformation is also included. This method is often appropriate for generating daily, monthly, or yearly load time series using an optional FLUX procedure designed for this purpose. Relatively intensive sample data sets and well- defined concentration/flow relationships are required for reliable application of this method.

Method 6 is generally preferred over the other regression-based methods when the flow/concentration relationship is well defined. In applications to small, flashy streams, special consideration must be given to the specification of sample flows to avoid bias in Method 6 estimates. Error analysis calculations are time-consuming relative to the other methods. An option to turn off the error analysis for Method 6 is included.

For each method, the jackknife procedure (Mosteller and Tukey 1978) is used to estimate error variance. This involves excluding each sampling event, one at a time, and recalculating loadings, as described in Table 2.2 of the manual. While alternative, direct estimators of variance are available from classical sampling theory for most of the methods (Cochran 1977; Walker 1981; Bodo and Unny 1983, 1984) such formulas tend to rely upon distributional assumptions. The direct estimators are generally applicable to large samples and normal distributions, neither of which is typical of this application. As described by Cochran (1977), the jackknife has improved properties for ratio estimators derived from small, skewed samples. Use of the jackknife procedure also provides a uniform basis for comparing calculation methods with respect to estimated variance.

APPENDIX H: Flux Software Flow and Total Phosphorus Loading Summaries

Upper Ten Mile River: FLUX Program Results

FLOW AND LOAD SUMMARIES FOR TP

UPPER TEN MILE RIVER

Method: Flw Wghted Conc. (2)

DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (lbs/d)	SLOPE LgC/LgQ	R^2	p > C/Q
Overall	642	19	19	100.0	81.09245	56.42105	0.072684	32.051	0.1424	0.00	0.3775

DAILY FLOW STATISTICS

Daily Flow Duration	642 Days = 1.758 Years
Daily Mean Flow Rate	81.09 (CFS)
Daily Total Flow Volume	4.4982E09 (Cubic Feet)
Daily Flow Date Range	04/01/2007 to 10/31/2009
Samples Date Range	05/22/2007 to 10/17/2009

LOAD ESTIMATES FOR TP

Method	Mass(lbs)	Flux(lbs/d)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1 Average Load	14316.296	22.29953	1732.06	0.051	0.145
2 Flw Wghted Conc.	**20576.425**	**32.05051**	**1437.32**	**0.0733**	**0.09191**
3 Flw Wghted IJC.	20505.97	31.94076	1593.07	0.073	0.09709
4 C/Q Reg1	21667.006	33.74923	7075	0.0771	0.1936
5 C/Q Reg2(VarAdj)	22388.332	34.87279	17261.4	0.0797	0.2927
6 C/Q Reg3(daily)	22746.386	35.43051	8467.7	0.081	0.2018
8 Time Series	20195.709	31.45749	N/A	0.0719	N/A

Central Pond: FLUX Program Results

FLOW AND LOAD SUMMARIES FOR TP

CENTRAL POND

Method: Flw Wghted Conc. (2)

DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (lbs/d)	SLOPE LgC/LgQ	R^2	p > C/Q
Overall	642	14	14	100.0	88.50948	66.92857	0.071429	33.625	-0.00158	0.00	0.9872

DAILY FLOW STATISTICS

Daily Flow Duration	642 Days = 1.758 Years
Daily Mean Flow Rate	88.51 (CFS)
Daily Total Flow Volume	4.90962E09 (Cubic Feet)
Daily Flow Date Range	04/01/2007 to 10/31/2009
Samples Date Range	05/22/2007 to 10/08/2009

LOAD ESTIMATES FOR TP

Method	Mass(lbs)	Flux(lbs/d)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1 Average Load	16323.913	25.42666	3729.76	0.0532	0.1866
2 Flw Wghted Conc.	**21587.506**	**33.6254**	**2785.03**	**0.0704**	**0.1219**
3 Flw Wghted IJC.	21488.585	33.47132	3234.28	0.0701	0.132
4 C/Q Reg1	21577.975	33.61055	5739.9	0.0704	0.1751
5 C/Q Reg2(VarAdj)	21571.362	33.60025	8864.74	0.0704	0.2177
6 C/Q Reg3(daily)	22036.984	34.32552	4787.21	0.0719	0.1566
8 Time Series	21655.221	33.73087	N/A	0.0706	N/A

Turner Reservoir: FLUX Program Results

FLOW AND LOAD SUMMARIES FOR TP

TURNER RESERVOIR

Method: Flw Wghted Conc. (2)
DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (lbs/d)	SLOPE LgC/LgQ	R²	p > C/Q
Overall	642	14	14	100.0	89.26942	67.63571	0.065214	30.890	-0.03336	0.00	0.7681

DAILY FLOW STATISTICS
Daily Flow Duration 642 Days = 1.758 Years
Daily Mean Flow Rate 89.27 (CFS)
Daily Total Flow Volume 4.95177E09 (Cubic Feet)
Daily Flow Date Range 04/01/2007 to 10/31/2009
Samples Date Range 05/22/2007 to 10/08/2009

LOAD ESTIMATES FOR TP

Method	Mass(lbs)	Flux(lbs/d)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1 Average Load	15025.585	23.40434	3189.84	0.0486	0.1875
2 Flw Wghted Conc.	**19831.612**	**30.89036**	**1525.43**	**0.0641**	**0.09824**
3 Flw Wghted IJC.	19777.66	30.80632	1724.62	0.064	0.1047
4 C/Q Reg1	19648.87	30.60572	2627.52	0.0635	0.1301
5 C/Q Reg2(VarAdj)	19527.066	30.41599	3638.89	0.0632	0.1541
6 C/Q Reg3(daily)	19796.691	30.83597	2250.78	0.064	0.1195
8 Time Series	19815.686	30.86555	N/A	0.0641	N/A

Omega Pond: FLUX Program Results

FLOW AND LOAD SUMMARIES FOR TP

OMEGA POND

Method: Flw Wghted Conc. (2)
DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (lbs/d)	SLOPE LgC/LgQ	R²	p > C/Q
Overall	642	13	13	100.0	92.61316	69.69231	0.073231	35.510	-0.05125	0.00	0.7158

DAILY FLOW STATISTICS
Daily Flow Duration 642 Days = 1.758 Years
Daily Mean Flow Rate 92.61 (CFS)
Daily Total Flow Volume 5.13725E09 (Cubic Feet)
Daily Flow Date Range 04/01/2007 to 10/31/2009
Samples Date Range 05/22/2007 to 10/08/2009

LOAD ESTIMATES FOR TP

Method	Mass(lbs)	Flux(lbs/d)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1 Average Load	17155.409	26.72182	4484.42	0.0535	0.1947
2 Flw Wghted Conc.	**22797.589**	**35.51026**	**2779.86**	**0.0711**	**0.1154**
3 Flw Wghted IJC.	22672.403	35.31527	3253.57	0.0707	0.1255
4 C/Q Reg1	22467.751	34.9965	4850.23	0.07	0.1546
5 C/Q Reg2(VarAdj)	22275.774	34.69747	6397.35	0.0694	0.1791
6 C/Q Reg3(daily)	22879.129	35.63727	4020.62	0.0713	0.1382
8 Time Series	22675.746	35.32048	N/A	0.0707	N/A

APPENDIX I: Calculated Growing Season Total Phosphorus Loads from NPDES Permitted Sources

	1	401	412	421
	Influent Total Flow	Fin Eff Flow	Final Phosphorus	Final Phosphorus Load
Date	MGD	MGD	mg/l	LBS/Day
4/1/2007	4.586			
4/2/2007	4.775			
4/3/2007	4.370			
4/4/2007	4.926			
4/5/2007	5.436			
4/6/2007	5.269			
4/7/2007	5.029			
4/8/2007	4.634			
4/9/2007	5.285			
4/10/2007	4.554			
4/11/2007	4.706			
4/12/2007	5.138			
4/13/2007	4.881			
4/14/2007	4.692			
4/15/2007	6.307			
4/16/2007	9.566			
4/17/2007	8.736			
4/18/2007	8.319			
4/19/2007	7.604			
4/20/2007	6.836			
4/21/2007	6.730			
4/22/2007	6.121			
4/23/2007	6.367			
4/24/2007	5.873		0.077	3.774
4/25/2007	5.297			
4/26/2007	5.527		0.089	4.105
4/27/2007	6.477			
4/28/2007	6.195			
4/29/2007	5.530			
4/30/2007	5.131		0.078	3.340
5/1/2007	4.737		0.052	2.056
5/2/2007	5.275		0.068	2.993
5/3/2007	5.124		0.060	2.566
5/4/2007	4.801			
5/5/2007	4.603			
5/6/2007	4.553			
5/7/2007	4.840		0.075	3.029
5/8/2007	5.040		0.024	1.009
5/9/2007	4.867			
5/10/2007	4.613		0.061	2.348
5/11/2007	4.681			
5/12/2007	4.776			
5/13/2007	4.701			
5/14/2007	4.644		0.057	2.209
5/15/2007	4.612		0.036	1.386
5/16/2007	4.300			
5/17/2007	4.000		0.106	3.538
5/18/2007	5.091			
5/19/2007	5.598			
5/20/2007	5.451			
5/21/2007	1.074		0.096	0.860
5/22/2007			0.053	
5/23/2007	5.208		0.076	3.303
5/24/2007	4.704		0.072	2.826
5/25/2007	4.658			
5/26/2007	4.586			
5/27/2007	4.434			
5/28/2007	4.769			
5/29/2007	5.141		0.057	
5/30/2007	4.690		0.095	
5/31/2007	5.281		0.219	
6/1/2007	4.579	3.712		
6/2/2007	4.367	3.595		
6/3/2007	4.854	3.843		
6/4/2007	5.734	4.673	0.060	2.340

6/5/2007	5.311	4.818	0.044	1.769
6/6/2007	5.213	4.471		
6/7/2007	4.962	4.463	0.037	1.378
6/8/2007	4.823	4.240		
6/9/2007	5.304	4.127		
6/10/2007	4.787	3.770		
6/11/2007	5.024	4.153	0.037	1.282
6/12/2007	4.989	4.237	0.030	1.061
6/13/2007	5.003	4.034		
6/14/2007	4.962	3.966	0.052	1.721
6/15/2007	4.918	3.752		
6/16/2007	4.664	4.032		
6/17/2007	4.571	3.931		
6/18/2007	5.485	4.695	0.034	1.332
6/19/2007	5.485	4.695	0.028	1.097
6/20/2007	4.858	4.236		
6/21/2007	4.756	4.102	0.050	1.712
6/22/2007	4.948	4.102		
6/23/2007	4.794	3.946		
6/24/2007	4.290	3.498		
6/25/2007	4.743	4.070	0.040	1.359
6/26/2007	4.919	4.329	0.050	1.806
6/27/2007	4.840	4.385		
6/28/2007	5.076	4.220	0.073	2.571
6/29/2007	5.109	3.634		
6/30/2007	4.922	3.127		
7/1/2007	4.344	2.886		
7/2/2007	4.703	2.743	0.059	1.351
7/3/2007	4.804	2.351	0.059	1.158
7/4/2007	4.094	2.822		
7/5/2007	4.690	3.992	0.062	2.065
7/6/2007	4.840	4.254		
7/7/2007	4.369	3.506		
7/8/2007	3.755	3.137		
7/9/2007	4.489	3.139	0.036	0.943
7/10/2007	4.354	3.444	0.040	1.150
7/11/2007	4.271	3.508		
7/12/2007	4.400	3.195	0.039	1.040
7/13/2007	4.457	3.094		
7/14/2007	4.136	3.012		
7/15/2007	3.947			
7/16/2007	4.066	3.498	0.063	1.839
7/17/2007	4.264	3.406	0.042	1.194
7/18/2007	4.484	3.831		
7/19/2007	4.664	3.702	0.054	1.668
7/20/2007	4.606	4.026		
7/21/2007	4.477			
7/22/2007	4.119			
7/23/2007	4.557	3.595	0.059	1.770
7/24/2007	4.385	3.433	0.046	1.318
7/25/2007	4.636	3.549		
7/26/2007	4.465	3.479	0.040	1.161
7/27/2007	4.169	3.525		
7/28/2007	3.905			
7/29/2007	4.150			
7/30/2007	5.876	4.320	0.027	0.973
7/31/2007	3.815	3.554	0.021	0.623
8/1/2007	4.376	3.451		
8/2/2007	2.075	1.439	0.035	0.420
8/3/2007	7.153	4.215		
8/4/2007	3.709	2.871		
8/5/2007	3.937	2.704		
8/6/2007	4.571	3.352	0.037	1.035
8/7/2007	4.572	3.353	0.043	1.203
8/8/2007	4.548	3.402		
8/9/2007	4.565	3.394	0.050	1.416
8/10/2007	4.719	3.253		
8/11/2007	3.937			
8/12/2007	4.191	2.722		
8/13/2007	5.117	3.288	0.042	1.152
8/14/2007	4.982	3.216	0.036	0.966
8/15/2007	5.049	3.711		
8/16/2007	5.012	3.604	0.044	1.323
8/17/2007	5.028	3.144		
8/18/2007	4.593	2.783		
8/19/2007	4.594	2.784		
8/20/2007	4.735	3.343	0.048	1.339
8/21/2007	4.877	3.355	0.042	1.176

8/22/2007	4.851	3.113		
8/23/2007	4.714	2.900	0.052	1.258
8/24/2007	5.091	2.911		
8/25/2007	4.754	2.711		
8/26/2007	4.237			
8/27/2007	4.897	3.380	0.048	1.354
8/28/2007	4.907	3.142	0.030	0.787
8/29/2007	4.799	3.487		
8/30/2007	4.866	3.089	0.038	0.980
8/31/2007	5.063	3.528		
9/1/2007	5.081			
9/2/2007	4.010			
9/3/2007	4.633	2.519		
9/4/2007	4.895	3.287	0.045	1.234
9/5/2007	4.982	3.074	0.035	0.898
9/6/2007	4.911	3.243	0.046	1.245
9/7/2007	5.071	2.775		
9/8/2007	4.348			
9/9/2007	4.131			
9/10/2007	5.269	3.372	0.079	2.223
9/11/2007	5.470	3.680	0.038	1.167
9/12/2007	4.667	3.155		
9/13/2007	4.657	3.627	0.075	2.270
9/14/2007	2.779	4.780		
9/15/2007	2.570	3.759		
9/16/2007	2.578	4.189		
9/17/2007	3.130	5.160		
9/18/2007	4.720	3.204	0.049	1.310
9/19/2007	5.136	3.099		
9/20/2007	5.147	3.388	0.061	1.725
9/21/2007	4.676	2.580	0.062	1.335
9/22/2007	4.990			
9/23/2007	5.030			
9/24/2007	4.928	3.117	0.063	1.639
9/25/2007	5.445	3.188	0.074	1.969
9/26/2007	5.375	3.165		
9/27/2007	5.361	3.294	0.071	1.952
9/28/2007	4.691	2.720		
9/29/2007	3.963	2.104		
9/30/2007	2.584	2.329		
10/1/2007	3.500	2.915	0.048	1.168
10/2/2007	4.479	3.229	0.062	1.671
10/3/2007	5.159	3.409		
10/4/2007	8.452	3.327	0.085	2.360
10/5/2007	4.626	3.067		
10/6/2007	6.234	2.417		
10/7/2007	1.014			
10/8/2007	7.995	3.171		
10/9/2007	2.920	3.238	0.053	1.432
10/10/2007	9.153	3.445		
10/11/2007	9.762	3.275	0.064	1.749
10/12/2007	1.890	2.533	0.060	1.268
10/13/2007	1.741	2.407		
10/14/2007	1.278	2.694		
10/15/2007	1.607	2.701	0.046	1.037
10/16/2007	1.708	3.204	0.047	1.257
10/17/2007	4.263	3.295		
10/18/2007	5.978	3.394	0.031	0.878
10/19/2007	6.418	3.407		
10/20/2007	8.082	2.799		
10/21/2007	6.022			
10/22/2007	6.355	3.407	0.044	1.251
10/23/2007	6.460	3.317	0.042	1.163
10/24/2007	6.463	2.476		
10/25/2007	4.935	2.656	0.050	1.108
10/26/2007	5.731	2.578		
10/27/2007	5.053	2.573		
10/28/2007	5.053	2.573		
10/29/2007	4.942	2.755	0.036	0.828
10/30/2007	3.787	2.622	0.036	0.788
10/31/2007	4.250	2.801		
4/1/2008	5.591	4.356		
4/2/2008	5.278	4.170		
4/3/2008	5.200	4.118		
4/4/2008	5.680	4.374		
4/5/2008	5.673	4.371		
4/6/2008	5.598	4.179		
4/7/2008	5.613	4.284		

4/8/2008	5.550	4.266		
4/9/2008	5.555	4.168		
4/10/2008	5.387	4.196		
4/11/2008	5.316	4.119		
4/12/2008	5.534	4.204		
4/13/2008	5.260	3.912		
4/14/2008	5.770	4.408		
4/15/2008	5.103	4.164		
4/16/2008	4.737	4.077		
4/17/2008	4.477	3.958	0.305	10.074
4/18/2008	4.106	3.827	0.150	4.790
4/19/2008	4.155	3.463		
4/20/2008	3.993	3.343		
4/21/2008	4.106	3.494		
4/22/2008	4.128	3.722	0.078	2.423
4/23/2008	4.422	3.940		
4/24/2008	4.479	4.089	0.129	4.402
4/25/2008	3.949	3.383	0.110	3.105
4/26/2008	3.530			
4/27/2008	3.372	3.232		
4/28/2008	4.209	3.997	0.105	3.502
4/29/2008	5.105	4.890	0.085	3.469
4/30/2008	4.697	4.408		
5/1/2008	4.562	4.311	0.130	4.677
5/2/2008	4.386	4.150		
5/3/2008	3.944	3.974		
5/4/2008	4.060	4.026		
5/5/2008	4.309	4.006	0.084	2.808
5/6/2008	4.690	4.386	0.069	2.525
5/7/2008	4.389	4.032		
5/8/2008	4.220	3.961	0.090	2.975
5/9/2008	4.081	3.882		
5/10/2008	3.907	3.683		
5/11/2008	3.907	3.683		
5/12/2008	3.823	3.700	0.127	3.921
5/13/2008	3.811	3.811	0.095	3.021
5/14/2008	3.857	3.446		
5/15/2008	3.617	2.931	0.089	2.177
5/16/2008	3.562	3.599		
5/17/2008	4.260	4.187		
5/18/2008	3.760	3.618		
5/19/2008	3.823	3.687	0.100	3.077
5/20/2008	3.826	3.850	0.061	1.960
5/21/2008	3.980	3.626		
5/22/2008	3.699	3.626	0.061	1.846
5/23/2008	3.370	3.393		
5/24/2008	3.168	3.144		
5/25/2008	2.903	2.982		
5/26/2008	3.021	3.079		
5/27/2008	3.682	3.348	0.058	1.620
5/28/2008	3.828	3.476		
5/29/2008	3.627	3.422	0.050	1.428
5/30/2008	3.246	3.131	0.065	1.698
5/31/2008	3.144	3.121		
6/1/2008	3.087	3.055		
6/2/2008	3.354	3.182	0.080	2.124
6/3/2008	3.387	3.231	0.064	1.726
6/4/2008	3.645	3.509		
6/5/2008	3.605	3.391	0.077	2.179
6/6/2008	3.419	3.172		
6/7/2008	3.539	3.105		
6/8/2008	3.585	3.212		
6/9/2008	3.467	3.178	0.101	2.679
6/10/2008	3.379	3.268	0.089	2.427
6/11/2008	3.528	3.333		
6/12/2008	3.386	3.159	0.103	2.715
6/13/2008	3.108	2.960		
6/14/2008	2.849	2.878		
6/15/2008	2.732	2.794		
6/16/2008	3.364	3.302	0.093	2.563
6/17/2008	3.310	3.320	0.088	2.438
6/18/2008	3.153	3.250		
6/19/2008	3.061	3.147	0.113	2.968
6/20/2008	2.708	2.899		
6/21/2008	2.584	2.822		
6/22/2008	2.756	2.884		
6/23/2008	3.123	3.200	0.093	2.483
6/24/2008	3.871	4.028	0.100	3.361

6/25/2008	3.714	3.697		
6/26/2008	3.541	3.627	0.103	3.118
6/27/2008	3.131	3.216		
6/28/2008	2.878	3.102		
6/29/2008	2.805	2.925		
6/30/2008	3.084	3.202		
7/1/2008	3.132	3.214	0.114	3.058
7/2/2008	2.843	3.084	0.129	3.320
7/3/2008	2.633	2.981	0.162	4.030
7/4/2008	2.515	2.870		
7/5/2008	2.588	2.952		
7/6/2008	2.659	2.906		
7/7/2008	2.935	3.121	0.274	7.136
7/8/2008	2.846	3.073	0.131	3.359
7/9/2008	2.992	3.163		
7/10/2008	2.889	3.078	0.107	2.748
7/11/2008	2.681	2.849		
7/12/2008	2.579	2.767		
7/13/2008	2.580	2.815		
7/14/2008	2.860	3.099	0.054	1.397
7/15/2008	2.951	3.128	0.040	1.044
7/16/2008	2.871	3.094		
7/17/2008	2.687	2.971	0.054	1.339
7/18/2008	2.538	2.841		
7/19/2008	2.425	2.779		
7/20/2008	2.436	2.780		
7/21/2008	2.529	2.810	0.061	1.430
7/22/2008	2.498	2.774	0.046	1.065
7/23/2008	2.935	3.200		
7/24/2008	4.056	4.297	0.067	2.403
7/25/2008	3.448	3.628		
7/26/2008	3.110	3.399		
7/27/2008	3.481	3.649		
7/28/2008	3.556	3.211	0.069	1.849
7/29/2008	3.282	3.440	0.055	1.579
7/30/2008	3.126	3.331		
7/31/2008	3.129	3.276	0.061	1.668
8/1/2008	3.048	3.219		
8/2/2008	2.807	3.088		
8/3/2008	2.759	3.059		
8/4/2008	2.903	3.070	0.088	2.254
8/5/2008	2.853	3.080	0.111	2.853
8/6/2008	3.078	3.264		
8/7/2008	3.029		0.100	
8/8/2008	3.138	3.116		
8/9/2008	2.863	3.020		
8/10/2008	2.762	2.935		
8/11/2008	2.863	3.007	0.079	1.982
8/12/2008	3.180	3.010	0.059	1.482
8/13/2008	3.126	2.970		
8/14/2008	3.115	2.921	0.069	1.682
8/15/2008	3.249	3.080		
8/16/2008	3.165	2.917		
8/17/2008	3.123	2.821		
8/18/2008	3.220	2.920	0.064	1.560
8/19/2008	3.185	3.066	0.056	1.433
8/20/2008	3.207			
8/21/2008	3.140	2.943	0.050	1.228
8/22/2008	3.118	2.863		
8/23/2008	2.994	2.798		
8/24/2008	2.671	2.928		
8/25/2008	2.751	2.890	0.059	1.423
8/26/2008	2.624	2.919	0.054	1.315
8/27/2008	2.723	2.871		
8/28/2008	2.682	2.902	0.055	1.332
8/29/2008	2.830	2.846		
8/30/2008	2.617	2.792		
8/31/2008	2.096	2.587		
9/1/2008	2.480	5.431		
9/2/2008	2.523	2.758	0.050	1.151
9/3/2008	2.446	2.768	0.066	1.525
9/4/2008	4.025	2.602	0.074	1.607
9/5/2008	3.990	2.508		
9/6/2008	6.136	4.239		
9/7/2008	5.800	3.874		
9/8/2008	5.077	3.521	0.068	1.998
9/9/2008	5.547	3.718	0.054	1.675
9/10/2008	5.834	4.048		

9/11/2008	5.192	3.651	0.065	1.980
9/12/2008	4.862	3.265		
9/13/2008	4.852	3.136		
9/14/2008	5.631	3.525		
9/15/2008	5.842	3.605	0.061	1.835
9/16/2008	5.679	3.614	0.057	1.719
9/17/2008	6.047	4.222		
9/18/2008	4.972	3.462	0.073	2.109
9/19/2008	4.716	3.230		
9/20/2008	4.560	3.104		
9/21/2008	4.672	3.116		
9/22/2008	4.695	3.186	0.049	1.303
9/23/2008	5.050	3.333	0.047	1.307
9/24/2008	5.148	3.337		
9/25/2008	5.067	3.246	0.055	1.490
9/26/2008	6.014	3.997		
9/27/2008	6.674	4.232		
9/28/2008	7.324	5.333		
9/29/2008	6.938	5.377	0.040	1.795
9/30/2008	6.657	4.995	0.034	1.417
10/1/2008	7.106	5.312		
10/2/2008	6.229	4.476	0.045	1.681
10/3/2008	5.671	3.976	0.059	1.958
10/4/2008	5.421	3.784		
10/5/2008	5.223	3.680		
10/6/2008	5.684	3.891	0.043	1.396
10/7/2008	5.381	3.775	0.046	1.449
10/8/2008	5.706	3.847		
10/9/2008	5.174	3.716	0.056	1.737
10/10/2008	4.963	3.468		
10/11/2008	4.891	3.253		
10/12/2008	4.500	3.164		
10/13/2008	5.079	3.477		
10/14/2008	4.803	3.477	0.059	1.712
10/15/2008	4.741	3.427		
10/16/2008	4.839	3.421	0.069	1.970
10/17/2008	4.562	3.095	0.083	2.144
10/18/2008	4.726	3.024		
10/19/2008	4.462	3.030		
10/20/2008	6.110	3.182	0.057	1.514
10/21/2008	6.258	3.284	0.051	1.398
10/22/2008	5.345	3.240		
10/23/2008	5.235	3.106	0.105	2.722
10/24/2008	4.843	2.946		
10/25/2008	4.832	3.195		
10/26/2008	5.398	3.239		
10/27/2008	5.708	3.395	0.091	2.578
10/28/2008	6.155	3.645	0.082	2.494
10/29/2008	6.468	3.448		
10/30/2008	5.950	3.236	0.113	3.051
10/31/2008	4.840	3.066		
4/1/2009	4.649	3.901		
4/2/2009	4.791	3.928		
4/3/2009	5.128	4.344		
4/4/2009	5.700	4.518		
4/5/2009	4.441	3.822		
4/6/2009	5.936	5.471	0.177	8.081
4/7/2009	5.677	5.201	0.193	8.377
4/8/2009	6.060	5.482		
4/9/2009	5.694	5.333		
4/10/2009	4.404	4.804		
4/11/2009	6.031	5.401		
4/12/2009	5.936	5.300		
4/13/2009	5.928	5.281	0.130	5.729
4/14/2009	5.765	5.105	0.138	5.879
4/15/2009	5.713	4.921		
4/16/2009	5.863	5.040	0.051	2.145
4/17/2009	5.590	4.673		
4/18/2009	5.611	4.346		
4/19/2009	5.319	4.048		
4/20/2009	5.340	4.538		
4/21/2009	6.336	5.620	0.082	3.846
4/22/2009	6.176	5.353		
4/23/2009	5.869	5.130	0.085	3.639
4/24/2009	5.830	4.828		
4/25/2009	6.456	5.168		
4/26/2009	5.074	4.109		
4/27/2009	5.808	4.976	0.079	3.280

4/28/2009	5.863	5.040	0.077	3.239
4/29/2009	5.674	4.194		
4/30/2009	5.541	3.987	0.065	2.163
5/1/2009	5.573	4.054		
5/2/2009	6.475	4.310		
5/3/2009	4.862	3.437		
5/4/2009	4.079	3.144	0.055	1.443
5/5/2009	5.894	4.940	0.049	2.020
5/6/2009	5.552	4.676		
5/7/2009	6.049	4.872	0.063	2.561
5/8/2009	5.672	4.480		
5/9/2009	5.696	4.494		
5/10/2009	5.626	4.046		
5/11/2009	5.442	4.108	0.056	1.920
5/12/2009	5.524	4.205	0.044	1.544
5/13/2009	5.328	4.145		
5/14/2009	5.462	4.062	0.053	1.797
5/15/2009	5.666	3.811		
5/16/2009	5.746	3.714		
5/17/2009	5.906	3.641		
5/18/2009	5.604	3.687	0.095	2.923
5/19/2009	5.867	3.777	0.074	2.332
5/20/2009	5.427	3.670		
5/21/2009	6.020	3.554	0.067	1.987
5/22/2009	6.850	3.426		
5/23/2009	9.012	3.289		
5/24/2009	8.031	3.274		
5/25/2009	6.960	3.175		
5/26/2009	6.030	3.556	0.066	1.959
5/27/2009	3.535	3.543		
5/28/2009	3.333	3.244	0.086	2.328
5/29/2009	3.146	3.370	0.072	2.025
5/30/2009	3.144	3.139		
5/31/2009	4.201	3.124		
6/1/2009	4.025	3.364	0.065	1.825
6/2/2009	3.360	3.413	0.062	1.766
6/3/2009	3.274	3.500		
6/4/2009	3.154	2.946	0.092	2.262
6/5/2009	3.186	3.353		
6/6/2009	2.995	3.086		
6/7/2009	2.984	2.988		
6/8/2009	3.256	2.699	0.046	1.036
6/9/2009	3.248	3.244	0.065	1.760
6/10/2009	3.289	3.413		
6/11/2009	3.774	3.923	0.100	3.274
6/12/2009	3.021	3.197		
6/13/2009	2.933	3.047		
6/14/2009	2.990	3.169		
6/15/2009	3.242	3.399	0.053	1.503
6/16/2009	3.823	3.363	0.079	2.217
6/17/2009	3.170	3.220		
6/18/2009	3.238	3.476	0.087	2.524
6/19/2009	3.333	3.541		
6/20/2009	3.159	3.283		
6/21/2009	3.114	3.279		
6/22/2009	3.594	3.691	0.062	1.910
6/23/2009	3.635	3.794	0.074	2.343
6/24/2009	3.521	3.740		
6/25/2009	3.272	3.415	0.074	2.109
6/26/2009	3.110	3.259		
6/27/2009	3.081	3.208		
6/28/2009	3.011	3.168		
6/29/2009	3.469	3.585	0.058	1.735
6/30/2009	3.423	3.484	0.059	1.715
7/1/2009	3.515	3.715		
7/2/2009	4.408	4.570	0.058	2.212
7/3/2009	3.975	4.181		
7/4/2009	3.064	3.770		
7/5/2009	3.514	3.652		
7/6/2009	3.532	3.638	0.121	3.673
7/7/2009	3.786	3.968	0.115	3.808
7/8/2009	3.826	3.711		
7/9/2009	3.499	3.278	0.098	2.681
7/10/2009	3.466	3.430		
7/11/2009	3.746	4.059		
7/12/2009	3.606	3.732		
7/13/2009	3.352	3.575	0.094	2.804
7/14/2009	3.944	4.165	0.052	1.807

7/15/2009	3.339	3.445		
7/16/2009	3.242	3.437		
7/17/2009	3.327	3.486		
7/18/2009	3.320	3.415		
7/19/2009	3.185	3.427		
7/20/2009	3.384	3.422	0.085	2.427
7/21/2009	3.551	3.549	0.154	4.561
7/22/2009	3.579	3.467		
7/23/2009	3.929	3.662	0.068	2.078
7/24/2009	5.522	5.022		
7/25/2009	4.739	4.593		
7/26/2009	4.531	4.358		
7/27/2009	4.192	4.201	0.103	3.611
7/28/2009	4.449	4.079	0.106	3.608
7/29/2009	4.358	4.344		
7/30/2009	4.042	4.075	0.095	3.231
7/31/2009	4.149	4.100		
8/1/2009	3.829	3.855		
8/2/2009	3.653	3.484		
8/3/2009	3.817	3.789	0.106	3.352
8/4/2009	4.373	3.789	0.069	2.182
8/5/2009	3.869	3.762		
8/6/2009	3.720	3.501	0.061	1.782
8/7/2009	3.585	3.317		
8/8/2009	3.387	3.141		
8/9/2009	3.421	3.192		
8/10/2009	3.831	3.490	0.045	1.311
8/11/2009	3.779	3.472	0.073	2.115
8/12/2009	3.737	3.490		
8/13/2009	3.545	3.333	0.035	0.973
8/14/2009	3.359	3.135		
8/15/2009	3.211	2.968		
8/16/2009	3.138	2.916		
8/17/2009	3.486	3.218	0.031	0.832
8/18/2009	3.521	3.240	0.032	0.865
8/19/2009	3.431	3.200		
8/20/2009	3.472	3.192	0.049	1.305
8/21/2009	3.230	3.039		
8/22/2009	3.212	2.964		
8/23/2009	3.137	2.874		
8/24/2009	3.438	3.160	0.050	1.319
8/25/2009	3.433	3.110	0.047	1.220
8/26/2009	3.380	3.119		
8/27/2009	3.313	2.993	0.062	1.549
8/28/2009	3.233	2.910		
8/29/2009	3.802	3.452		
8/30/2009	3.513	3.240		
8/31/2009	3.718	3.353	0.031	0.867
9/1/2009	3.667	3.293	0.041	1.127
9/2/2009	3.578	3.220		
9/3/2009	3.499	3.096	0.062	1.602
9/4/2009	3.217	2.884		
9/5/2009	3.046	2.714		
9/6/2009	2.936	2.585		
9/7/2009	3.188	2.813		
9/8/2009	3.465	3.075	0.044	1.129
9/9/2009	3.537	3.132	0.042	1.098
9/10/2009	3.530	3.102	0.046	1.191
9/11/2009	3.344	3.048		
9/12/2009	3.339	3.042		
9/13/2009	3.317	2.954		
9/14/2009	3.602	3.168	0.034	0.899
9/15/2009	3.572	3.117	0.030	0.780
9/16/2009	3.485	3.075		
9/17/2009	3.472	3.054	0.059	1.504
9/18/2009	3.209	2.789		
9/19/2009	3.144	2.732		
9/20/2009	3.223	2.736		
9/21/2009	3.553	2.954	0.072	1.775
9/22/2009	3.513	3.009	0.100	2.511
9/23/2009	3.594	3.129		
9/24/2009	3.375	2.993	0.077	1.923
9/25/2009	2.977	2.680		
9/26/2009	2.960	2.646		
9/27/2009	3.323	2.862		
9/28/2009	3.328	3.048	0.060	1.526
9/29/2009	3.469	3.108	0.058	1.504
9/30/2009	3.577	2.895		

10/1/2009	3.256	2.904	0.072	1.745
10/2/2009	3.077	2.593		
10/3/2009	3.750	3.077		
10/4/2009	3.335	2.873		
10/5/2009	3.520	3.174	0.081	2.145
10/6/2009	3.523	3.110	0.067	1.739
10/7/2009	3.878	3.508		
10/8/2009	3.585	3.070	0.099	2.536
10/9/2009	3.369	3.003		
10/10/2009	3.280	2.859		
10/11/2009	3.118	2.725		
10/12/2009	3.532	3.080		
10/13/2009	3.854	3.536	0.035	1.033
10/14/2009	3.455	3.074		
10/15/2009	3.335	3.031	0.096	2.428
10/16/2009	3.161	2.865	0.103	2.463
10/17/2009	3.132	2.883		
10/18/2009	3.778	3.433		
10/19/2009	3.874	3.443	0.068	1.954
10/20/2009	3.787	3.396	0.056	1.587
10/21/2009	3.727	3.352		
10/22/2009	3.623	3.253	0.061	1.656
10/23/2009	4.418	3.134		
10/24/2009	4.089	3.946		
10/25/2009	4.006	3.676		
10/26/2009	4.074	3.722	0.071	2.205
10/27/2009	4.131	3.809	0.044	1.399
10/28/2009	4.429	4.165		
10/29/2009	4.349	3.988	0.058	1.930
10/30/2009	4.135	3.780		
10/31/2009	4.024	3.617		

2007-2009 Average Growing Season TP load: Attleboro WPCF

Avg daily GS MGD	cfs	Avg GS TP mg/l	lbs/day GS (avg)	lbs GS (avg)
3.5	5.4	0.1	2.0	437.8

2007-2009 Average Growing Season TP load: North Attleborough WWTF

N. Attleborough	***Monthly Average***					
Month/Yr	***TP (mg/l)***	***Flow MGD***	Flow cfs	Load (lbs/day)		
Apr-07						
May-07	0.57	4.68	7.2	22.2		
Jun-07	0.2	3.79	5.9	6.3		
Jul-07	0.4	2.94	4.5	9.8		
Aug-07	0.4	2.71	4.2	9.0		
Sep-07	0.2	2.67	4.1	4.5		
Oct-07	0.2	2.82	4.4	4.7		
1-Apr	0.2	4.67	7.2	7.8		
1-May	0.5	4.42	6.8	18.4		
Jun-08	0.3	3.37	5.2	8.4		
Jul-08	0.2	3.28	5.1	5.5		
Aug-08	0.2	3.24	5.0	5.4		
Sep-08	0.4	3.96	6.1	13.2		
Oct-08	0.16	3.827	5.9	5.1		
Apr-09	0.17	6.08	9.4	8.6		
May-09	0.2	4.38	6.8	7.3		
Jun-09	0.1	3.51	5.4	2.9		
Jul-09	0.09	4.57	7.1	3.4		
Aug-09	0.1	3.63	5.6	3.0		
Sep-09	0.1	3.051	4.7	2.5		
Oct-09	0.06	3.57	5.5	1.8		
	0.238	**3.76**	**5.8**	**7.50**	average lbs/day	
				1606	lbs/Growing Season	

2007-2009 Average Growing Season TP load: North Attleborough National Fish Hatchery

North Attleborough National Fish Hatchery				
Avg. TP	0.1	mg/l		
Avg. flow	0.9	MGD		
	1.395	cfs		
	5.39	CF		
	214	days		
	161	lbs	**0.8**	lbs/day

APPENDIX J. EPA Waste Cleanup Sites

There are numerous waste cleanup sites located within the Ten Mile River watershed. Waste cleanup sites include Superfund sites, federal facilities, brownfields, underground storage tank system releases, treatment, storage and disposal facility accidental releases, and oil spills. EPA New England's Office of Site Remediation and Restoration (OSRR) administers the region's waste site cleanup and reuse programs. The EPA provides a web site (http://www.epa.gov/region1/cleanup/index.html) to locate hazardous waste sites in New England, learn about EPA's cleanup programs, as well as to retrieve additional information regional cleanup efforts.

A select list of cleanup sites is included below. This is by no means a complete listing of all sites in the watershed that may contribute contaminants to groundwater. Both RIDEM and MADEP have programs dedicated to various waste site cleanup areas. MADEP has a searchable database (http://db.state.ma.us/dep/cleanup/sites/search.asp) which is similar to the EPA website above. Many sites have not been investigated and still others have yet to be discovered. According to staff at RIDEM Office of Waste Management, it is reasonable to assume that all old industrial sites within the watershed have some form of groundwater contamination (Cynthia Gianfrancesco, personal communication).

Cooks Landfill-East Providence, RI

The Cook's Landfill (property) is located on Dey Street in East Providence. The approximately 5-acre property is currently owned by 15 parties, both public and private. The property was privately owned from the 1950s to 1985. Ownership history prior to the 1950s is not known. The landfill area is an unlined, inactive, private landfill which was used for solid and industrial waste disposal prior to 1961. Materials from off-site sources deposited at the property included asbestos waste, drummed hazardous waste, liquid hazardous waste deposited in on-site lagoons, abandoned vehicles, offset printing wastes, and gasoline station wastes. Historical reports indicated that three unlined lagoons on the property were used for liquid asphalt and un-drummed hazardous waste disposal prior to 1961. The specific years of waste disposal, the constituents of hazardous wastes disposed, waste quantities, and waste disposal practices are unknown. On-site activities between 1961 and 1981 are also unknown. Background information indicated that most landfilling activities ceased in 1961, but that some drummed wastes generated by the Providence Journal newspaper were deposited on-site after 1961. In 1985, the property was subdivided into 22 residential and commercial building lots.

Previous investigations at the property have included a complaint-driven site inspection by RIDEM in 1981; a Preliminary Assessment (PA) completed by RI DEM in 1984; an emergency removal action conducted in 1985; a Screening Site Inspection (SSI) completed in 1991; and a Site Inspection Prioritization (SIP) completed in 1996. Piles of empty drums (rusted and disintegrating) were observed adjacent to one lagoon. An area of stained soil measuring approximately 150 square feet was also observed near the empty drums. Landfill debris including scrap metal, rubber wastes, and glass were also noted during the on-site reconnaissance.

Analytical results of drum samples collected by RI DEM in 1984 indicated the presence of volatile organic compounds (VOCs) and metals. The drums were later removed from the property. During an on-site reconnaissance in 1995, two lagoons (1,500 and 150 square feet) were observed.

Groundwater occurs in overburden at depths of 2 to 5 feet below ground surface and groundwater flow is generally to the north, toward the Ten Mile River. No known groundwater sampling has been conducted on the property. As a result, no impacts to groundwater resources have been documented.

Due to the permeability of surficial geologic deposits and the uneven topography of the property, precipitation likely infiltrates to soil at the south and east sides of the property. Precipitation likely discharges as run-off to the on-site wetland at the west side of the property or to Ten Mile River at the north side of the property. The on-site wetland discharges to the unnamed tributary of Ten Mile River and represents one probable point of entry (PPE) for contamination. A second PPE is located at along the Ten Mile River at the north border of the property. The surface water pathway flows from the Ten Mile River to Omega Pond, Seekonk River, Providence River, and Narragansett Bay. Northern portions of the property are located within the 100- and 500-year floodplain of Ten Mile River. Extensive flooding in the empty drum disposal area and waste lagoon on the north side of the property were observed during previous investigations.

Analytical results of sediment samples collected in 1995 from wetlands located downstream of the property indicated the presence of VOCs, SVOCs, pesticides, and inorganic compounds. Based on this release, impacts to nearby sensitive environments have been documented. The last known action at the site was the SIP and subsequent EPA decision in 1996 that further site assessment activities are needed at the property. According to available sources, the property is not an active site under the RIDEM.

<u>Greenwood Avenue Disposal Area, East Providence, RI</u>

The Greenwood Avenue Disposal Area is located at 176 Greenwood Avenue in East Providence, Rhode Island. Land use in the vicinity of the property consists of a mixture of industrial, residential, and recreational. The disposal area is an undeveloped portion of an industrial park that has been owned by H.O.D. Corporation (HOD) since 1967. The area includes a vegetated landfill containing gypsum material and a small area of wetland. A small, perennial stream, which originates north of Greenwood Avenue, flows southward under the disposal area and emerges near the Agawam Hunt Golf Course.

Since the 1920s, several companies, including Rumford Chemical Co., Heyen Chemical Co., Hulman and Co., Essex Chemical Co. (Essex), and ITT Royal Electric, have operated in the industrial park. Several of these companies had cesspool overflows into the small stream and may have used the property as a disposal area. In addition, local residents and possibly other unknown parties have illicitly dumped items such as large household appliances and construction material in the area. Between 1966 and 1975, Essex produced various chemicals (mainly sulfuric acid) in the industrial park. Vanadium catalyst may have been utilized during production. Waste gypsum was deposited in the former depression of the disposal area. Untreated cooling water, obtained from a well in an unknown location, was stored in a cooling pond located north of the disposal area and then discharged into the small stream.

In 1973, cooling water eroded the walls of the cooling pond, dissolved waste salts previously deposited by the Rumford Chemical Co., and entered the small stream with contaminants. Severe skin burns for animals and minor skin irritations for humans upon direct contact with the stream water were documented. In 1985, the Agawam Hunt Golf Course filed a complaint with RI Department of Environmental Management (RIDEM) regarding the leaching of an oily substance from an embankment and the presence of buried drums. In response to a Notice of Violation and Order from RIDEM, HOD removed large household items from the disposal area and attempted, ineffectively, to block vehicular access with a chain across the dirt path. In 1988, an East Providence City Councilwoman registered a complaint which alleged that four children who used to play at the disposal area had died from cancer and two others had tumors.

Previous investigations of the disposal area have included: a 1988 Preliminary Assessment (PA), a 1990 Screening Site Inspection (SSI), a 1994 Site Inspection Prioritization (SIP), and a 1998 site investigation (SI) by Georges Bockstael Industrial Consultants (GBIC). Analytical results of surface soil samples collected from the property in 1990 documented the presence of several metals including lead, copper, chromium, zinc, mercury, beryllium, and thallium; and low levels of semivolatile organic compounds (SVOCs).

Approximately 14,990 people are served by drinking water supply wells located within 4-radial miles of the disposal area. The nearest public drinking supply well is located approximately 1.6 miles northeast of the disposal area. Some private wells are located within 1-radial mile north and east of the disposal area. Depth to groundwater in the disposal area is approximately 15 to 25 ft below ground surface. Groundwater flows southwest and discharges to surface water at the small stream located south of the disposal area. Four groundwater monitoring wells are located at the disposal area. Analysis of volatile organic compounds (VOCs) in groundwater samples collected in 1998 did not indicate the presence of VOCs. As a result, no impacts to nearby groundwater drinking water supply sources are known or suspected.

Stormwater runoff from the property flows to the small unnamed stream, which flows into Ten Mile River. There are no drinking water intakes located along the 15-mile surface water pathway. Analytical results of sediment samples collected in 1990 from the section of stream near the disposal area indicated the presence of several metals, including lead, associated with former operations at the industrial park. High acidity, high lead concentrations, and a condition of blue-colored turbidity with suspended black solids in the stream water were also documented. Based on analytical results, impacts to the surface water pathway have been documented. Analytical results of soil samples collected from the property in 1990 confirmed the presence of metals including lead, and SVOCs.

Leavans Awards Company

The Leavens Awards Company (Former) (Leavens Awards) site is located at 41 Summer Street, in Attleboro, Massachusetts. The Leavens Awards facility was used for electrochemical plating operations until its closure in 1999. The property consists of a single-story industrial building with a footprint area of approximately 30,000 square feet on a 2.72 acre lot. Leavens Manufacturing Co., Inc. began operations at the facility in 1953. The area immediately south and east of the building is asphalt paved. A dry-well, reportedly used to discharge steam condensate from manufacturing units and water from a sink in the parts casting room, is located on the southwest side of the building. A former drum storage area is located just west of the dry-well. Three capped surface impoundments (two sludge impoundments and one "continuous flow lagoon") are located along the eastern edge of the property. The continuous flow lagoon was the most northerly of the three impoundments, and formerly discharged via a pipe to the Ten Mile River. The area west of the building, north of Summer Street, and the capped surface impoundments are covered with vegetation.

Overall site topography slopes gradually downward to the southeast, toward the Ten Mile River. To the east of Summer Street, topography steeply grades downward to a wetland that borders the river. The Leavens Awards property is currently connected to municipal water and sewer. The property is zoned Industrial. Both Leavens Manufacturing Co., Inc. and Leavens Awards Co., Inc. manufactured pins, nameplates, emblems, class rings, and other metal items. These materials were electroplated with gold, nickel, copper, silver, and rhodium. Manufacturing processes included parts degreasing, soldering, assembly, electroplating, and polishing.

Chemicals utilized on site included cyanide, acid and alkaline plating baths, acetone, trichloroethylene (TCE), 1,1,1-trichloroethane (1,1,1-TCA), methylene chloride, ethyl acetate, mineral spirits, and "153 Stripper" (dichloromethane and hydroxybenzene). Wastes generated by the facility included wastewater, metal hydroxide sludge, acetone, TCE, naphtha, methylene chloride, and 1,I,I-TCA. Prior to 1968, wastewater was reportedly discharged directly to the wetland and/or adjacent Ten Mile River from a discharge pipe that reportedly ran parallel to the southern side of the building and crossed under Summer Street. From 1968 to 1983, wastewater was pretreated by cyanide destruction, pH adjustment, and precipitation of metal hydroxide sludge. The metal hydroxide sludge was discharged to two on-site surface impoundments. The effluent was discharged to an on- site "continuous flow lagoon" where additional suspended solids settled out before the supernatant was discharged to the Ten Mile River. National Pollution Discharge Elimination System (NPDES) permit number MA0005363 was issued to Leavens Manufacturing Co., Inc. in January 1980 for this discharge. After 1983, treated wastewater effluent was discharged to the City of Attleboro sewer system.

In 1993, an EPA contractor completed a RCRA Facility Assessment for the Leavens site. Four areas of concern (AOCs) were identified in the assessment, including the former surface impoundments (surface impoundments and continuous flow lagoon), the wastewater treatment system that was active at that time, the hazardous waste drum storage area, and the dry well. The TtNUS Draft Site Inspection Report identified eight sources, including the capped surface impoundments, NPDES discharge, dry-well, four tanks/containers associated with the wastewater treatment system, and four separate sources consisting of drums (55- and 30-gallon in size) containing various chemicals and wastes.

Lubrix Products, Inc.

The Lubrix Products, Inc. (Lubrx) property is located at 342 East Washington Street, North Attleborough, Massachusetts. The 0.72-acre property is owned by Lubrix, which had manufactured and recycled lubricating oils on the property from 1975 to 1994. The property is currently occupied by a canvas products manufacturing company, a brick recycling business, and an automobile repair business.

From 1915 to 1994, the property was occupied by several companies who were in the business of blending and containerizing oil for distribution. A tank farm was formerly located on the property; however, the number of aboveground storage tanks (ASTs) in the tank farm and their contents are unknown. Current known source areas on the property include several tanks and totes of varying volumes containing virgin and waste oil, an abandoned gasoline underground storage tank (UST), the former tank farm, and a debris pile containing used tires, automobile parts, wood debris, and empty plastic oil containers.

U.S. Environmental Protection Agency (EPA) investigations conducted to date include a Preliminary Assessment (PA) completed in July 1990, a Site Inspection (SI) completed in February 1991, a Site Inspection Prioritization (SIP) completed in March 1996, and another SIP completed in September 1997. Analytical results of surface soil and waste oil samples collected from the property in October 1996 indicated the presence of three volatile organic compounds (VOCs), eight semivolatile organic compounds (SVOCs), three pesticides, and eight metals, including elevated levels of chromium and lead.

Groundwater occurs in overburden at a depth of approximately 2.5 to 4.5 ft, and flows to the south. The estimated population served by public and private drinking water supply wells within 4-radial miles of the property is 32,304. The nearest public drinking water supply well is located approximately 1.3 miles north of the property. The nearest private drinking water supply well is located between 0.25 and 0.5 miles from the property; the exact location of this well is unknown. Analytical results of groundwater samples collected from the property in 1989 indicated the presence of several chlorinated VOCs, including vinyl chloride. Based on the direction of groundwater flow and the proximity of nearby groundwater drinking water supplies to the property, potential impacts to groundwater drinking water sources are unknown.

Stormwater runoff from the property flows westerly to the Ten Mile River. From this point, the downstream pathway flows along the Ten Mile River, which flows through Falls Pond, Farmers Pond, Mechanics Pond, and Dodgeville Pond. There are no surface water drinking water intakes located along the 15-mile downstream surface water pathway. Sensitive environments located downstream of the property include a Clean

Water Act (CWA)-protected water body, approximately 4.5 miles of wetland frontage, and a fishery.

Analytical results of sediment samples collected in October 1996 from along the Tenmile River indicated the presence of 13 SVOCs, four pesticides, and 11 inorganic elements, including chromium, lead, and mercury. Several of the substances detected in the sediment samples were also detected in on-site surface soil and waste oil samples.

<u>North Attleborough Landfill</u>
The North Attleborough Landfill (NAL) property is located off Mount Hope Street in North Attleborough, Massachusetts. The 48-acre property is owned by the Town of North Attleborough and is comprised of an office/maintenance building and an active, 20-acre landfill, which accepts municipal solid waste and sludge from the town's wastewater treatment plant. The property is bordered to the north by the Ledges Condominium Complex; to the west by Mount Hope Street, woodlands, and a residence; to the southwest by wetlands and the Mount Hope Street Stream; to the south by woodlands and Landry Avenue; and to the east by wetlands and Rattlesnake Brook.

Dumping on the property began in 1938 after a hurricane created the need for a disposal area. For an unknown number of years, the property was operated as an open burning dump. Sanitary landfill operations may have begun in the 1960s; however, sanitary landfill operations were not formally approved until 1978. In 1990, a concerned citizen reported to the U.S. Environmental Protection Agency (EPA) that wastes from local jewelry and metal finishing companies, such as spent jewelry solutions, settling tank sludges and slurries, acids, alkalies, chlorinated solvents, machining oils, lacquers, and enamels, had been historically disposed at the landfill. It was also reported that polychlorinated biphenyl (PCB) transformer wastes from the North Attleborough Electric Company and radium from local jewelry manufacturers had been potentially disposed at the landfill. Reportedly, the NAL was built directly on top of bedrock with no impervious liner, and approximately one third of the landfill was built by filling wetlands with refuse.

In August 1990, the EPA Removal Program collected leachate and soil/sediment samples from several locations around the toe of the landfill, which indicated the presence of numerous volatile organic compounds (VOCs) and semivolatile organic compounds
The estimated population served by private groundwater drinking water supply wells within 4-radial miles of the property is 65,151. The nearest public drinking water supply well is located approximately 0.95 miles northwest of the property. The nearest active private drinking water supply well is located approximately 0.5 miles north of the property. Groundwater occurs in overburden at a depth of approximately 2 to 4 ft, and a groundwater divide exists on the property. Groundwater on the western portion of the property flows west into the Mount Hope Street Stream and groundwater on the eastern portion of the property flows east to adjacent wetlands.

The analytical results of groundwater samples collected from the property in 1993 indicated the presence of several VOCs and inorganic elements, including benzene, tetrachloroethylene (PCE), and mercury, which were detected at concentrations greater than Federal Maximum Contaminant Levels (MCLs). In addition, xylenes were detected in two nearby private drinking water supply wells which are no longer used for drinking water. Due to the direction of groundwater flow and the proximity of nearby groundwater drinking water supply sources to on-site sources, impacts to groundwater drinking water supply targets are unknown.

Stormwater runoff from the landfill flows radially in all directions and discharges to either the Mount Hope Street Stream west of the property or to the wetlands and Rattlesnake Brook east of the property. Both of these pathways discharge into the Ten Mile River. There are no drinking water intakes located along the 15-mile downstream surface water pathway. Approximately 6.7 miles of wetland frontage occur along the downstream pathway. The analytical results of surface water and sediment samples collected between 1990 and 1993 from the Mount Hope Street Stream and from adjacent wetlands to the east have indicated the presence of several VOCs and inorganic elements. As a result, impacts to nearby sensitive environments (i.e., Clean Water Act-protected water body, wetlands, and a fishery) are suspected.

APPENDIX K. LID Checklist for East Providence and Pawtucket, RI

Low Impact Development Objectives	Pawtucket	Providence
development hydrology. Objective I: ***Protect as much undisturbed open space as possible to maintain***		
1. Has Conservation Development been adopted to protect open space and pre-	NA	No
2. Has a transfer of development rights ordinance been adopted to provide an	No	No
3. Are limits of disturbance required to be marked on all construction plans?	Yes	Yes
4. Are there limits on lawn area for residential lots to protect open space?	No	No
5. Are undisturbed vegetative areas required on new lots as visual screens?	NA	Yes
Objective II: ***Maximize the protection of natural drainage areas, streams,***		
6. Do regulations require or encourage new lots to exclude freshwater and /or	No	Yes
7. Do regulations direct building envelopes away from steep slopes, riparian	Yes	Yes
8. Has a community buffer program been created to establish or restore a	No	No
9. Are zoning setback distances flexible in residential districts to avoid requiring	Yes	Yes
Objective III: ***Minimize land disturbance, including clearing and grading,***		
10. Has your community adopted an erosion and sediment control ordinance?	Yes	Yes
11. Did your community adopt a grading ordinance to require applicants to	No	Yes
12. Has your community adopted a forest cover, tree protection, or tree canopy	No	No
13. Do you require permits before removing trees on new or re-development	No*	No
14. Have minimum tree preservation standards been established for new	No*	Yes
15. Do capital improvement plans include tree planting as part of project budgets?	Yes	No
16. Do you require that public trees removed or damaged during construction be	Yes	No
Objective IV: ***Minimize soil compaction as a result of construction activities***		
17. Have you adopted provisions within land development regulations that prohibit	No	No
18. Have you adopted requirements for construction site inspections to ensure that	No	No
volume, increase groundwater recharge, and minimize pollutant loadings Objective V: ***Provide low-maintenance, native vegetation that encourages***		
19. Have LID landscaping standards been adopted that require the preservation of	Yes	No
Objective VI: ***Minimize impervious surfaces.***		
20. Did your community adopt compact growth ordinances such as conservation	Yes	Yes
21. Has your community identified growth centers where increased density is	Yes	Yes
22. Are residential streets required to be as narrow as possible to accommodate	N/A	No
22B. Do you require road widths of 26 feet or less for subdivisions of 40-200	N/A	No
23. Are street right-of-way widths required to be less than 45 feet?	N/A	No
24. Are driveway lengths and width required to be reduced to the extent possible	No	No
24B. Do you allow pervious surfaces to be used for residential driveways?	No	Yes
24C. Do you allow shared driveways to be used in residential developments?	No	Yes
25. Do you allow the flexibility with curbs in residential streets to encourage side-	N/A	Yes
26. Where curbs are needed, do you allow opening in curbs that allow runoff to	N/A	N/A
27. Have flexible sidewalk design standards been adopted to limit impervious	N/A	No (5 ft)
27B. Do you require sidewalks on one side of the street only in low-density	Yes	No
27C. Are sidewalks required to be gently sloped so that they drain into the front	N/A	No
27D. Can alternative pedestrian access such as trails or unpaved footpaths be	Yes	No
27E. Can pervious surfaces be used for sidewalks?	No	No
28. Did your community modify the dimension, design, and surface material of cul-	No	No (50 ft)
28B. Can a landscaped island or native vegetation be within the cul-de-sac?	No	Yes
28C. Are alternative turnarounds allowed such as hammerheads or tees?	No	Yes
29. Have both minimum and maximum parking ratios been adopted to provide	Yes	Yes
30. Do you allow pervious materials to be used for parking areas and overflow	Yes	No
31. Are parking ratios reduced if the site is served by mass transit or has good	No	Yes

Low Impact Development Objectives	Pawtucket	Providence
32. Is shared parking encouraged and implemented wherever feasible in order to	Yes	Yes
33. Do off-site parking allowances exist to accommodate re-development and	Yes	Yes
34. Are parking stalls and aisles reduced to the extent feasible in order to decrease	Yes	No*
34B. Is 20% or more of the parking lot required to have smaller dimensions (8 feet	No	No
35. Are parking lot landscaping requirements flexible and do they encourage LID	Yes	Yes
35B. Is landscaping required within parking areas to "break up" pavement at fixed	Yes	Yes
35C. Is a 25-30% tree canopy coverage over on-site parking lots required?	No	No (20%)
36. Have impervious cover limits been adopted to reduce impervious cover on a	No	Yes
GOAL: Manage the impacts at the source. **Objective VII:** ***Infiltrate precipitation as close as possible to the point it***		
37. Have you amended regulations to require all development projects comply with	No	Yes
38. Have you revised regulations to allow and encourage LID vegetated treatment	Yes	Yes
Objective VIII: ***Break up or disconnect the flow of runoff over impervious***		
39. Have you amended regulations to encourage runoff to be diverted over	Yes	Yes
Objective IX: ***Provide source controls to prevent or minimize pollutants in***		
40. Do you encourage or require appropriate pet waste disposal to prevent pet	No	Yes
41. Are commercial and industrial developments required to sweep their	No	No
42. Is street sweeping done regularly on community streets to limit pollutant	Yes	Yes
43. Are community road salt storage piles covered?	Yes	Yes
44. Has a community wastewater management district been adopted to encourage	N/A	N/A*
45. Have you adopted a stormwater utility district to manage the existing impacts	No	No
Objective X: ***Re-vegetate previously cleared areas to help restore***		
46. Have regulations been adopted to encourage re-vegetation with native species,	Yes	Yes
BONUS		
47. Did you revise your comprehensive plan to include the three goals and then	No	No

APPENDIX L. Response to Public Comments

Don Pryor- Brown University
Following are 3 suggestions that might improve the TMDL:

1. A clearer graphic delineation of the watershed would be helpful. Figure 1 (p. 14) should include the watershed boundary.

RIDEM Response: The intent of Figure 1 was to generally show the locations of the five waterbody segments addressed in the TMDL in the Rhode Island portion only.

2. Figure 2 (p. 20) includes the watershed boundary but the resolution is not adequate to relate it to roads or other features. Figure 5 (p. 30) should also include the watershed boundary.

RIDEM Response: The intent of Figure 2 was to show, in a general sense, the location of the watershed relative to the states of MA and RI. Including the watershed boundary on Figure 5 would increase the scale such that the study area TMDL stations would not be clearly seen.

3. Graphic depictions of metals concentrations (figures 13-20, pages 47-54) should include water quality standards for reference. This would be particularly useful where standards vary with hardness. Table 32 (p. 108) shows ranges for the various sampling locations. At least those ranges could be shown in figures 13-20. Median values of concentrations with varying standards (as in table 10, p. 54) could be misleading.

RIDEM Response: Figures 12-20 show the median metal value in the downstream direction under dry weather baseflow and wet weather stormflow conditions. The actual criteria, which are determined using ambient hardness, varied at each station and with each survey. Median metal values were not compared to a single criteria in this TMDL. For purposes of 305b assessments, each metals sample value was compared to both the acute and chronic criteria. The intent of displaying the median value at a particular station was to show a relative 'magnitude' of change in the downstream direction. Since the median value is not used for purposes of determining compliance with criteria, adding the criteria to these graphs could be misleading and likely add confusion.

3. The assertion (p. 154) that "This TMDL has determined that the six minimum measures alone are insufficient to restore water quality and that structural BMPs are necessary" warrants a clear and explicit rationale. The MS4 program has been underway in East Providence and Pawtucket for 10 years. Implementation appears to vary among municipalities (and RIDOT) but systematic evaluation (other than self-evaluation) has not been made public. Requiring East Providence, Pawtucket and RIDOT to "assess the six minimum control measure BMPs for compliance with the TMDL provisions" quite possibly might produce only copies of annual report language. Some degree of

assessment by DEM as the permitting agency seems necessary for this TMDL. Also, permitees should be encouraged to consider non-structural BMPs as well as structural ones.

RIDEM Response: The statement that "six minimum measures alone are insufficient to restore water quality and that structural BMPs are necessary" is based upon the following rationale documented in the TMDL:

- **available data collected on the Ten Mile River document significant increases in wet weather concentrations of metals, bacteria (and phosphorus?) as compared to dry weather concentrations;**
- **reduction in wet weather sources of these pollutants is necessary to comply with water quality standards;**
- **the Rhode Island portion of the Ten Mile River watershed is highly impervious (42%) and as a result, a significant volume of runoff is created and discharged largely untreated into the Ten Mile River;**
- **numerous literature sources identify urban stormwater as a source of particulate and dissolved metals, bacteria and nutrients; and**
- **six minimum measures (e.g mapping of outfalls, annual street sweeping, inspection and cleaning of catch basins, dry weather sampling to identify illicit connections, and adoption of ordinances to prevent new stormwater pollution from construction sites and new development and redevelopment) establish sound management practices but are not expected to significantly reduce the existing wet weather load of metals, bacteria, and nutrients discharged into receiving waters.**

The TMDL outlines both non-structural and structural BMPs. Discussion of these non-structural and structural BMP's to address bacteria, metals, and phosphorus contributions from stormwater runoff begins on page 149 of the TMDL.

MEMORANDUM February 3, 2014

SUBJECT: EPA Region 1 review of RI Ten Mile River TMDLs

TO: RI DEM, Brian Zalewsky

FROM: Steven Winnett

Thank you for the opportunity to review the public review draft of DEM's Ten Mile River TMDLs for pathogens, metals, and phosphorus. Please let me know if you need clarification on any of our comments.

P. 15, the link to the MA 2012 Integrated Report is old and doesn't work. It should be www.mass.gov/eea/docs/dep/water/resources/07v5/12list2.pdf. Also, not all of the internet addresses are formatted correctly so they don't link to the site or the document intended. Suggest you check the links to see they work properly.
RIDEM Response: The link on Page 15, as well as all other links have been checked and re-formatted where necessary.

P. 20, 1st para: Suggest you delete second occurrence of "East Providence, Rhode Island where.."
RIDEM Response: Correction has been made

P. 26, 1st para: The last sentence discusses the upgrade on the N. Attleborough WWTF as of June 2013. Can you give us the status of that upgrade as of now? Was it completed as planned back in June?
RIDEM Response: Status of WWTF upgrades are given in the Implementation Section of the TMDL. To avoid duplicity, reference to upgrades was removed from this section.

P. 26, 2nd para: The last sentence discusses the upgrade on the Attleboro WWTF. What is the current status of that upgrade?
RIDEM Response: Status of upgrades are given in the Implementation Section of the TMDL. Reference to upgrades was removed from this section.

P. 35, 2nd para: Somewhere in this paragraph could you briefly state the danger cyanobacteria (and its toxin) poses to humans and pets (why we care about it)?
RIDEM Response: Additional language has been added to this section.

P. 44, 1st and 3rd para of sec. 35. Each last sentence ends with ", while the mean surface concentration is …" Do you mean "bottom concentration" in this last phrase of both paragraphs? "Surface concentration" is in both previous phrases.
RIDEM Response: Appropriate changes to this section have been made.

P. 45, 2nd to last para: Why were values of non-detect (ND) replaced with half of the detection limit?
RIDEM Response: The presence of non-detected values in a dataset hinders effective statistical analyses. Therefore, many procedures have been used to substitute reasonable values for these missing values. The most common methods include: ignore the non-detects, substitute with half of the detection limit, substitute with a zero, or substitute with the detection limit. Extensive literature exists on how to handle results which lie below the level of detection (non-detects) with discussions for and against each method. With no scientific consensus on the topic, researchers follow and document the method utilized in analysis of their dataset. Setting values of non-detect (ND) or below detection limit (BDL) to half the detection limit was the practice implemented by RIDEM when developing the Woonasquatucket and Blackstone River metals TMDLs. This approach was applied to the Ten Mile River.

P. 45, last para: Table 10 doesn't seem to show what the last sentence says. Do you mean Figure 20, or some other table or figure?
RIDEM Response: Appropriate changes were made

P. 46, 2nd para, 2nd sent: What <u>is</u> the level of non-detect for cadmium?
RIDEM Response: The detection limits for Cadmium ranged from 0.2 to 0.1 ug/l. To understand why the detection limit can change or be different over time, it is important to understand how the detection limit is determined.

P. 46, 2nd para: States that "This is due to the increased fraction of particulate cadmium, rather than dissolved." Is this indicative of something, source-wise or anything else?
RIDEM Response: The reason for this increase, albeit small, is unclear. There were no identified dry weather sources of particulate Cd in this reach. The sampling location at the outlet of Slater Park Pond is downstream of the spillway, and thus the water column experiences some turbulence. Resupension of sediments may the reason for baseflow increases in particulate Cd.

P.48, 3rd para, 1st sent: Same question as above for lead: with majority of it in particulate form under dry/baseflow conditions, is that indicative of something?
RIDEM Response: Again, the reason for this increase, albeit small, is unclear. There were no identified dry weather sources of Pb in this reach, however resuspension of particulate bound lead may occur downstream of spillways and still be present in mainstem stations.

P. 48, last sent: What is the non-detect value for lead?
RIDEM Response: See response for same question (above) regarding cadmium.

P. 50, 2nd para. Is the particulate aluminum majority indicative of something?
RIDEM Response: It is likely indicative of use of aluminum sulfate by the WWTF as a flocculent WWTF as part of phosphorus removal. This is discussed in Section 4.0 of the TMDL.

P. 52, 2nd para. Is the particulate iron in larger proportion in baseflow indicative of something?
RIDEM Response: It is likely indicative of use of ferric salts by the WWTF as a flocculent WWTF as part of phosphorus removal. This is discussed in Section 4.0 of the TMDL.

P. 53, 1st para: Do you have an interpretation for the situation of no acute and many chronic violations for all metals?
RIDEM: Levels of metals in the Ten Mile River were not elevated enough to exceed the acute criteria.

P. 54, Figure 20. The first vertical bar is missing a label. Also, "Dissolved or Total Metal" in horizontal axis legend is unclear. Which is which?
RIDEM Response: Appropriate edits made to this Figure.

P. 59, 1st para, last sent: Can you please define "broadcast" fertilization?
RIDEM Response: Appropriate edits made to this paragraph.

P. 85, Sec. 4.11, 1st para, last two sentences: Can you please clarify the wording and sequence of these two sentences about phosphorus, availability, and the phosphorus pool? It's a little unclear and is an important concept for the public to understand.
RIDEM Response: Text has been changed to reflect comment.

Chapter 6, metals TMDLs, total aluminum: The data in the Appendix E tables that show allowable and existing aluminum loads, for Survey 4 especially (and to a lesser extent for Survey 1) suggest an aluminum source above TM7 and 8, given the values of 45 and 61, after much lower values at stations up river from these. Can you please consider recognizing a source in the Lower Ten Mile and/or Turner Reservoir segment, with attendant reductions required in Tables 39 and 43 (for example), or provide an explanation of what those data could mean?
RIDEM Response: DEM acknowledges a possible source of aluminum between the outlet of the Turner Reservoir and the outlet of Omega Pond. This is most notable in Survey 4 which captured a wet weather-stormflow condition (Reference to Table 30: 1.51 inches of rainfall fell the previous day and the hourly hydrograph shows time of sample corresponding to rising limb/near peak flow). This trend is not evident under the other 4 wet weather influenced surveys.

It is unclear what the source of aluminum was during this survey. Dissolved aluminum concentrations remain static and the one-time increase in total aluminum is therefore explained by an increase in particulate aluminum. The Agawam Hunt Club drains to this segment of the river, as does historic industrial sites just north of the course. However, lacking consistent evidence, it is not possible to conclude that there is a source of aluminum in this reach of the river.   DEM is attempting to secure funds to conduct additional monitoring in the Ten Mile River to confirm

elevated levels of various pollutants at the state line, as well as other locations (including this segment).

P. 115, last para, 1st sent. Do you mean “Lower Ten Mile River” where “Omega Pond” appears?
RIDEM Response: Text has been changed to reflect comment.

P. 119, lat sentence: Can you please define “lentic” and “lotic?”
RIDEM Response: Text has been added to define these terms

P. 132, Table 49: Golf course export coefficient doesn’t appear to be in Table 7.8.
RIDEM Response: Text has been changed to reflect comment.

P. 134, Figure 27 and the related designation of Ledgemont CC to Upper Ten Mile River load in the pages that follow:

The Coles Brook watershed, which contains the Ledgemont CC, drains to Central Pond and is a significant contributor to its phosphorus load. The map and the load calculation in the pages that follow it assign its drainage, drainage area, and load to the Upper Ten Mile River segment. It appears that the calculations in Tables 51-55, and in the discussion throughout this section, especially on page 137-138, should show Ledgemont CC’s 238 kg/yr load (and flow) to Central Pond.
RIDEM Response: DEM was made aware of this delineation error early in the public comment period. To fix this error, the watershed area for Coles Brook was removed from the upper Ten Mile River watershed RLUM file and added to the Central Pond sub-watershed RLUM file. The RLUM was then re-run for these two waterbody segments. Changes in text and Tables were made starting at page 137 and ending at 139. A summary of the changes in required TP load reductions are presented in the following Tables. This was the TP reduction summary table presented at the final public meeting.

Original Total Phosphorus Loading and Reduction Estimates.

Waterbody/Location	Contributing Area (km^2)	Catchment/Subcatchment Growing Season TP Load (lbs)	Allowable Catchment/Subcatchment Growing Season TP Load (lbs)	Required Reduction (Percentage)
Upper Ten Mile River	127.3	7080 (5788)	2480 (1188)	79%
Central Pond	4.3	159 (115)	74 (30)	74%
Turner Reservoir	1.3	46 (23)	25 (2)	96%
Omega Pond	5.7	327 (305)	98 (77)	75%

New Total Phosphorus Loading and Reduction Estimates.

Waterbody/Location	Contributing Area (km^2)	Catchment/Subcatchment Growing Season TP Load (lbs)	Allowable Catchment/Subcatchment Growing Season TP Load (lbs)	Required Reduction (Percentage)
Upper Ten Mile River	119.0	6719 (5666)	2338 (1145)	80%
Central Pond	12.7	337 (251)	216 (130)	48%
Turner Reservoir	1.3	46 (23)	25 (2)	45%
Omega Pond	5.6	327 (305)	98 (77)	75%

February 6, 2014
Peter M. Willey
146 King Philip Rd.
Rumford, RI 02916

Rhode Island Department of Environmental Management
Office of Water Resources
Mr. Brian Zalewsky
235 Promenade Street
Providence, RI 02908

Re: Ten Mile River Draft TMDL – Public Comments

Dear Mr. Zalewsky:

After review of the draft TMDL's for the Ten Mile River Watershed, Omega Pond seems to be incorrectly classified as a lake type waterbody when it should be classified as a river type waterbody.

The Department used the EPA's Nutrient Criteria Technical Guidance Manual for Lakes and Reservoirs to reclassify Slater Park Pond to a river waterbody type, even though it had always historically been referred to a lake. The following is taken from pages 14 and 15 of the draft analysis:

> *"Slater Park Pond, located in Pawtucket, RI, is a 24 acre run-of-the-river impoundment of the Ten Mile River. According to the RIDEM dam database, the impoundment was created by the State of Rhode Island Metropolitan Park Commission in 1926 by transforming a large swampy area into a shallow impoundment. Recent staff surveys of the impoundment show it to have an average depth of approximately 2-3 feet. Water residence times of approximately 3 days and 0.3 days, respectively were calculated under the 7Q10 and mean annual flows of 12 cfs and 107 cfs.*
>
> *Based on water residence time, Slater Park Pond does not meet the definition of a "lake" as defined in EPA's April 2000 Nutrient Criteria Technical Guidance Manual for Lakes and Reservoirs ("natural and artificial impoundments with a surface area greater than 10 acres and a mean water residence time of 14 or more days"). Based on EPA guidance and staff field verification, RIDEM is correcting the identification of the run-of-the river area known as Slater Park Pond, from a lake to a river waterbody type. As of the 2012 Integrated Report, this run-of-the river area is now incorporated into the Upper Ten Mile River WBID# RI0004009R-01A. This resulted in the addition of total phosphorus as an impairment to the Upper Ten Mile River. It has been determined that portions of the*

Upper Ten Mile River, namely the run-of-the river area historically referred to as Slater Park Pond, contain undesirable and/or nuisance aquatic algal growth – thus violating the state's narrative nutrient criteria for freshwater rivers."

Omega Pond has a water residency time of approximately 10 days for the 7Q10 flow and between 1 and 2 days for the annual flow (107 cfm). Please refer to this excerpt taken from page 103 of the draft analysis:

"The lower segment of the Ten Mile River (RI0004009R-01B) begins at the outflow of the Turner Reservoir and ends at the inflow to Omega Pond. The total length of this lower segment is approximately 3.2 miles (5.2 km). Metals data collected from stations TM6 and TM7 were used to evaluate the lower Ten Mile River segment. ***Omega Pond (RI0004009L-03) has a surface area of approximately 30 acres (12 ha) and an average depth of nearly 9 feet (2.7 m). The residence time under the 7Q10 flow is approximately 10 days.*** *Omega Pond discharges to the left (east) bank of the Seekonk River approximately 0.75 miles (1.2 km) south of the Henderson Bridge. Sampling station TM8 was used to evaluate metals concentrations in Omega Pond."*

This is not even close to the 14 day water residence time to meet the definition of a lake. There is no reason this EPA guidance should be used to reclassify Slater Park Pond and the same standard not be applicable to Omega Pond. Omega Pond should be reclassified as a river waterbody type and subsequently incorporated into the lower segment of the Ten Mile River RI0004009-10B.

Given that the dam at Omega Pond is where the fish will enter the Ten Mile River system, it is imperative that this waterbody be classified correctly and the TMDL analysis be updated accordingly. I strongly urge the department to make this correction.

Kind regards,

Peter Willey

RIDEM Response:

Rhode Island does not have a statewide definition on what constitutes a lake, based on water residence time or other parameters. We do utilize a weight of evidence approach that takes into consideration EPA guidance (http://www2.epa.gov/nutrient-policy-data/criteria-development-guidance-lakes-and-reservoirs), and observed characteristics of the waterbody in making such decisions.

The excerpted text from the TMDL cited by the commenter describes that the primary reason for changing the classification of Slater Park Pond from a lake to a river was that it's observed shallow depth and short residence time was not consistent with a "lake" as defined by EPA guidance. Slater Park Pond was created by impounding a wetland area. Another important factor in this decision was the observation that this run of the river impoundment behaves more like a river than a lake (including excessive rooted aquatic plants but very low (avg ~ 3.0 ug/l) levels of

chlorophyll a). The document has been revised to more clearly describe the weight of evidence approach taken in making this decision.

In the case of Omega Pond, it was found to experience thermal stratification which resulted in the bottom waters exhibiting oxygen depletion, and elevated total phosphorus concentrations. It also shows other behaviors more common in lakes than rivers, namely that its response to nutrient enrichment is phytoplankton growth (as measured by elevated levels of chlorophyll and decreased secchi depth) vs periphyton growth. In conclusion, though Omega Pond's residence time is less than 14 days, it appears to behave more like a lake than a river system.

The Narragansett Bay Commission
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The Narragansett Bay Commission

Vincent J. Mesolella
Chairman

Raymond J. Marshall, P.E.
Executive Director

February 6, 2014

Brian Zalewsky
Office of Water Resources
Department of Environmental Management
235 Promenade Street
Providence, RI 02908

Dear Mr. Zalewsky,

This letter is to document comments the Narragansett Bay Commission (NBC) has on the draft Total Maximum Daily Load Analysis for the Ten Mile River Watershed report. The main comment the NBC has on the report is to clarify monitoring activities performed by the NBC and referenced in the report. On page 175 of the draft TMDL document, it states that the NBC conducts bacteria and nutrients sampling on the Ten Mile River, which is partially incorrect. The NBC currently does not routinely sample the Ten Mile River for bacteria. The NBC does, however, bi-monthly sample the Ten Mile River for nutrients at a location at the outlet of Omega Pond and in 2012 the NBC instituted a nutrient monitoring location near the RI/Massachusetts border at Central Ave. The data for these two locations, as well as the rest of the NBC routine monitoring is accessible on the NBC's water quality website, which is available at the following link: http://snapshot.narrabay.com/app/

The document is very informative; however there were a few items that the NBC would like to recommend. It would be beneficial to improve the quality of some of the maps, if possible. When printed, the images are slightly blurry and difficult to read. There are a few misprints contained in the document that should be addressed. It would be helpful to the reader to add "medians" to the figure captions for Figure 12 through 19 and Figure 20 is missing a horizontal axis label. In general, the document is well laid out and easily understandable.

Thank you for providing the NBC the opportunity to provide comments on this TMDL report. Please feel free to contact me at 401-461-8848, ext 470, with any questions regarding this matter.

Sincerely,

Pamela J. Reitsma
Environmental Scientist

RIDEM Response: DEM has made changes on page 175 of the draft and in Figures 12-20 to reflect the above comments.

Over 100 Years of Education, Conservation & Advocacy

Audubon Society of Rhode Island

February 7, 2014

Rhode Island Department of Environmental Management
Office of Water Resources
Mr. Brian Zalewsky
235 Promenade Street
Providence, RI 02908

Re: Ten-mile River TMDL

Dear Mr. Zalewsky:

Audubon is interested in providing healthy habitat for birds, aquatic life, and mammals and the primary production vegetation on which they live. We also promote recreation. I am familiar with the Ten-Mile River from concerns about mercury in the fish caught in the impoundments of the river, from the loss of the Turner Reservoir as a public drinking supply, and from anadromous fish restoration efforts.

We ask that the consideration for Anti-degradation on the Ten-Mile be changed. It was once a water supply. Negligence caused the loss of that use. Establishing a context for further acceptance of pollutants in applying only a Tier 1 Anti-degradation policy denies the possibility of future use of that water for supply. That "water quality criteria are violated in several locations" is a failure of federal and state protection agencies to control point source contamination from upstream industrial and sewage treatment sources, and lack of political will to control sources of phosphorus and bacterial sources.

The City of East Providence still has piping and pumps in place along the Turner Reservoir from the time it used the reservoir as city water supply. A great deal of uncertainty exists about the impacts of future climate change and water demand. In water supply documents from the City of East Providence and the state, Turner Reservoir is considered an asset for back-up emergency water supply. In February 2001, the U. S. Army Corps of Engineers reported:

> "The U. S. Army Corps of Engineers conducted an investigation of Turner Reservoir in East Providence, Rhode Island, in order to determine

its potential as a recreational area and a back-up water supply for the City of East Providence. In addition, the Corps of Engineers performed a preliminary groundwater investigation to determine the feasibility of potentially using the now abandoned Central Pond we11 field as a back-up water supply. Our preliminary investigation found that the Turner Reservoir and Central Pond Well fields may be suitable for a back-up water supply; however, both water supply alternatives will require thorough treatment of the water. Based on the Corps preliminary findings, treatment of water for the Turner Reservoir or Central Pond We11 Fields could be an expensive procedure. Comprehensive treatment of the Turner reasons: the presence of heavy aquatic plant growth, potential for coliform bacteria and elevated levels of contaminants, particularly cadmium in sediments. Similarly, to improve the esthetic qualities of the groundwater from the Central Pond we11 fields will require the use of water treatment methods. In particular, besides improving the taste and odor, treatment will remove the high levels of iron and manganese present in the water. Although the water's appearance is not attractive, the Corps of Engineers did not find any water quality problems that did not find any water quality problems that would prohibit using the Turner Reservoir tor recreation use, such as swimming. Turner Reservoir appears to support a good largemouth bass population, which could provide a recreational warm-water fishery."

We ask that RI DEM reconsider in order to leave the potential for restoration of this source for emergency back-up and potential future water supply by applying a Tier 1 Anti-degradation designation. We ask that drinking water use be mentioned as a use-classification in this TMDL. Further contamination of the water body does not serve the public interest. The purpose of the Clean Water Act is to "maintain and restore the biological, chemical, and physical" characteristics of the water.

Given the anadromous fish restoration efforts for river herring and the bass fishery in Turner Reservoir, Aquatic Life criteria is appropriately applied to the Rhode Island segment of the river, and we concur with concerns for benthic biota and dissolved oxygen. Aluminum in low pH waters contributes to fish mortality and have been documented in studies of herring deaths on Cape Cod.

Greater regional cooperation between Massachusetts and Rhode Island could better assure no exceedances of permitted effluents. Education in Massachusetts as to phosphorus in cleaning agents may reduce the load from the NPDES sources on the river. If necessary the U. S. EPA should intercede to assure Clean Water Act implementation in bi-state waters.

More field work or better documentation from the City of East Providence should be able to determine the number of directly storm-water outfalls into Omega Pond. Given the potential Phosphorus and other pollutants coming from stormwater in residential neighborhoods, a map of storm-water outfalls seems basic for correcting the problem. RI DOT permitted effluents may be improved through citizen education about excess phosphorus in lawn use.

We view the river and its impoundments as a flowing system which should be treated as an integral ecosystem and not divided into pond/lake and river subdivisions for other than identification purposes.

Thank you for your work to develop this TMDL. We appreciate this opportunity to comment and to suggest changes in the draft TMDL for improvements to the Ten Mile River. We will continue to support an adequate budget so that DEM may continue the monitoring and legal work to assure implementation to meet the standards laid out in this document.

Respectfully submitted,

Eugenia Marks, Senior Director for Policy

Hello, Brian,

Below are citations from RI Water Resources Board that came in after I emailed my comments on the Ten-Mile TMDL. I had asked the question only yesterday as I was unable to find sources on line, other than the U. S. Army Corps study that I cited in my comments. May the information from RI Water Resources Board be attached as supplements to my remarks to support the request that drinking water status should be noted in some way in the TMDL?
Thank you, Eugenia

- - - - - - - - - - - - - -

Eugenia Marks
Senior Director of Policy
Audubon Society of Rhode Island
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Tel: 401-949-5454 ext. 3003
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emarks@asri.org

From: Mendes, Romeo (DOA) [mailto:Romeo.Mendes@wrb.ri.gov]
Sent: Friday, February 07, 2014 3:45 PM
To: emarks@asri.org
Cc: Crawley, Kathleen (DOA); Burke, Ken (DOA)
Subject: RE: Turner Reservoir

Hello Eugenia,

Regarding your inquiry about the Turner Reservoir, the Board's Strategic Plan analysis determined that Northern Region supplies were adequate at present and into the future without utilization of the source. Also, the Supplemental water study looked at rehab costs for the Turner wellfield but did not include the reservoir as a potential supplemental source of supply. As far as any notation that the water supply resource might ever be restored, the most recently approved WSSMP indicates that the source is capable of being restored albeit at great cost.

The following excerpts come directly from the plan:

Section 2, Water Supply System Description, page 2-5

In 2001, the Army Corps of Engineers completed a study of the Turner Reservoir and Central Pond well field area for potential reuses (see Appendix C). The purpose of the study was to provide analysis that will assist in the evaluation of Turner Reservoir and the Central Pond wellfields as having potential to serve as the City's long term back-up water supply. The study determined both sources "may be suitable for a back-up water supply". However, the report also noted that both supplies would require thorough and expensive treatment processes due to heavy aquatic plant growth within Turner Reservoir, potential for coliform bacteria, and elevated levels of contaminants, particularly cadmium in sediments.

Section 4, Supply Management, page 4-9

Prior to 1970, East Providence had two main supply sources. These were the Turner Reservoir and the Turner Reservoir Wellfield, both of which have been abandoned. Because of PWSB"s desire that its wholesale customers use only PWSB water and not mix their water with other sources, practically all equipment for pumping and treating water from these sources has been removed or is beyond its useful life. Consequently, redevelopment of these two sources would have to proceed as if they were totally new sources.

The second part of your question may be able to be answered through review the East Providence community comprehensive plan. You would want to contact Kevin Nelson in Planning for information on the most recent plan.

Romeo N. Mendes, P.E.
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c: 401-527-3976

From: Eugenia Marks [mailto:emarks@asri.org]
Sent: Thursday, February 06, 2014 2:27 PM
To: Crawley, Kathleen (DOA)
Subject: Turner Reservoir

Hello, Kathy,
Is the Turner Reservoir noted in any documents as a water supply resource that might ever be restored? Does East Providence water supply consider it a resource?

- - - - - - - - - - - - - -
Eugenia Marks
Senior Director of Policy
Audubon Society of Rhode Island
12 Sanderson Road, Smithfield, RI 02917
Tel: 401-949-5454 ext. 3003
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emarks@asri.org

RIDEM Response:
The commenter asserts that applying only a Tier 1 Anti-degradation policy to the Turner Reservoir denies the possibility of future re-use of that water for supply and requests that RIDEM reconsider in order to leave the potential for restoration of the Turner Reservoir as a source for emergency back-up and potential future water supply that we apply a Tier 1 Anti-degradation designation, and that drinking water use be mentioned as a use-classification in this TMDL.

Tier 1 Anti-degradation policy applies to all surface waters and requires that existing uses and the level of water quality necessary to protect the existing uses be maintained and protected. The term, "existing use" is defined in the Water Quality Regulations as those designated uses and any other uses that do not impair the designated uses and that are actually attained in a waterbody on or after November 28, 1975. Turner Reservoir is classified as a Class B water, and therefore does not include water supply among its designated uses. Communication from the RI Water Resources Board provided as a supplement to the comment letter includes excerpts from the East Providence Water Supply Management Plan which states that the Turner Reservoir was abandoned as a water supply source in 1970. Since Turner Reservoir was abandoned as a source of supply prior to November 28, 1975, it does not meet the definition of an "existing use" for purposes of applying the anti-degradation policy.

The description of the Turner Reservoir in the TMDL document has been modified to reflect that it was once used as a water supply source, and has been found to be a suitable back-up source of supply (with extensive treatment and at considerable cost). Though water supply is not currently considered an existing use, the TMDL's water quality objectives are compatible with possible future use of the reservoir as a water supply source.

City of Attleboro, Massachusetts

DEPARTMENT OF WASTEWATER
Government Center, 77 Park Street
Attleboro, Massachusetts 02703
Phone 774-203-1820 • Fax 508-761-9837

Paul A. Kennedy
Superintendent
Department of Wastewater

Dear Mr. Zalewsky:

Thank you for the opportunity to comment on the above referenced report. The report presents a significant amount of information and analysis which will be very helpful in developing pollution abatement plans for the river. We do, however, have some concerns and make the following comments and suggestions. We look forward to your responses on these issues.

The TMDL relies mostly on outdated phosphorus information as the basis for its conclusions. More recent data should be used because of changed conditions in the watershed.

> **RIDEM Response: It should be noted based on available effluent data (From Tables 1 and 2 below) that the average combined growing season load from Attleboro and North Attleborough was estimated to be 2116 lbs during the 2007-2009. In 2013, the combined growing season load was estimated to be 2129 lbs.**
>
> **Aside from the two golf courses (Pawtucket Country Club and Agawam Hunt Club) in RI, the growing season total phosphorus load from various land uses such as urban, agriculture, the remaining golf courses, and the natural background load in the Upper Ten Mile River watershed predicted by the RLUM are assumed to be unchanged from 2007-2009 to present. Since the sources of phosphorus to the river are relatively unchanged over this time period, we do not have any reason to expect ambient water concentrations have significantly changed.**

The data supporting the development of the TMDL's was collected mainly in the period from 2007 through 2009. But, as you know, both Attleboro and North Attleboro have upgraded their wastewater treatment plants since then to respond to permits issued by the EPA in 2008 and 2009. Thus, significant reductions in pollutant loads have occurred since that time which should form the basis for a TMDL. For example, in 2013, our plant discharged phosphorus at an average concentration of 0.05 mg/l, roughly half the concentration that was established in the permit at RIDEM's request, and very much at the limit of available treatment technologies.

RIDEM Response: The TMDL acknowledges the fact that reductions in phosphorus loading have been achieved by both Attleboro and North Attleborough. Tables 1 and 2 below display effluent quality and flow data for the 2007-2009 and 2010 – 2013 time periods. The implementation section of the TMDL document was revised to incorporate this updated information. It is noteworthy that for the most part, Attleboro was achieving the 0.1 limit during the 2007-2009 time period (by adjusting dosages of ferric salts and alum). It is also noted that although the seasonal permits for both facilities changed from 1.0 mg/l to 0.1 mg/l (a 90% reduction in effluent total phosphorus concentration) this did not result in a 90% phosphorus load reduction between 2007-2009 and 2013 time periods. Any pollutant load reductions achieved by the WWTFs to date will reduce the percent reduction required to meet ambient water quality criteria going forward, but does not change the calculation of Total Maximum Daily Load (water quality criteria X flow).

Table 1.

Attleboro WPCF				
Year(s)	**Avg TP conc. (mg/l)**	**Avg. Flow (MGD)**	**Avg. Daily Load**	**GS Load (lbs/214 days)**
2007 - 2009	**0.073**	**4.07**	**2.47**	**530**
2010 - 2013	**0.062**	**3.50**	**1.50**	**322**
2013	**0.05**	**3.59**	**0.76**	**163**

(From effluent data provided by Attleboro WPCF)

Table 2.

North Attleborough WWTF				
Year(s)	**Avg TP conc. (mg/l)**	**Avg. Flow (MGD)**	**Avg. Daily Load**	**GS Load (lbs/214 days)**
2007 - 2009	**0.24**	**3.76**	**7.41**	**1586**
2010 - 2013	**0.19**	**3.55**	**5.61**	**1202**
2013	**0.32**	**3.48**	**9.19**	**1966**

(From the effluent data provided by the EPA Integrated Compliance Information System (ICIS) database)

This is particularly true since many of the analyses in the report rely on general, land use coefficients to assess the loadings from sources other than wastewater plants and no attempt was made to calibrate or validate the coefficients to observed data in the Ten Mile River

RIDEM Response: The U.S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency (USEPA) and the New England Interstate Water Pollution Control Commission (NEWIPCC), developed a water-quality model, called SPARROW (Spatially Referenced Regressions on Watershed Attributes), to assist in regional total maximum daily load (TMDL) and nutrient-criteria activities in New England. The export coefficients used in the Ten Mile River TMDL were derived from SPARROW model development (http://pubs.usgs.gov/sir/2004/5012/) and are thought to be sufficiently representative of physical processes of phosphorus generation and delivery in the New England Region which includes the Ten Mile River watershed.

The statement that 'there was no attempt to calibrate or validate the coefficients to observed data in the Ten Mile River' is inaccurate. The existing growing season total phosphorus load to each reservoir was calculated using the U.S. Army Corps of Engineers FLUX software (Walker 1999) from data collected during the 2007-2009 timeframe. The FLUX software allows estimation of tributary mass loadings from sample concentration data and continuous (e.g., daily) flow records. These loadings estimates were compared to those generated from the Reckhow Land Use Model (RLUM) model. The relative percent difference between the two estimates for all four applications (upper Ten Mile River, Central Pond, Turner Reservoir, and Omega Pond) was 2.1%. This lent confidence to RIDEM's use of the RLUM to estimate phosphorus loadings from the various land uses in the watershed because there was no need for additional calibration. As stated verbatim in the TMDL document:

"The RLUM was used as a secondary estimate of the growing season total phosphorus load to the upper Ten Mile River and downstream reservoirs, however the primary purpose of the model is to help to apportion the allowable growing season phosphorus load to various source categories (i.e. WLA and LA). As will be discussed in greater detail later in this section, the merit of the RLUM was based on how closely the results matched those of the FLUX model (Table 53), results of which was based on actual data. The mean relative percent difference between the two loading estimate methodologies for the three impoundments was very low: under 3%. As such, the RLUM was used with assurance when evaluating source categories of phosphorus (including percentages of total loads), required phosphorus reductions, and allocations of allowable loads."

While we understand that steps were taken to use what appeared to be the most reasonable coefficients, they have not been trued up to conditions in the Ten Mile. We believe that additional sampling, reflecting recent conditions, could serve as a very useful tool to validate the loading from other sources. Under the original TMDL analysis, the wastewater plants accounted for approximately 30 % of the total phosphorus load. Since our loadings have been reduced significantly, it will be much easier to validate the loadings from other sources.

RIDEM Response: It is unclear what the commenter means by 'trued up to conditions in the Ten Mile'. All export coefficients used were determined to provide a best estimate of loadings from various sources. The RLUM runs were validated with the FLUX software results which again, were based on actual concentration and flow data. Please refer to the above comment response.

The TMDL report clearly indicates that the sediments in the various ponds – reflecting legacy pollutants from past activities – are a potential source of elevated levels of phosphorus, and iron. While the levels of phosphorus observed near the bottom are only somewhat elevated compared to surface samples, phosphorus from this source can reach much higher levels If stratification and anoxia set up for any length of time. These sources have not been factored into the analysis.

RIDEM Response: To clarify, the phosphorus pool available for release from sediments has mostly anthropogenic origins. RIDEM believes that much of the legacy pollutants including phosphorus and various metals are the result of historic loadings from the wastewater treatment facilities and other industrial discharges. These historic discharges may continue to have an impact on water quality in the receiving waters through sediment storage and release and other biogeochemical mechanisms.

RIDEM does not feel confident that the release of phosphorus from sediments in the deeper parts of Turner Reservoir and Omega Pond constitute a source to the ponds themselves for the reasons given on page 87 of the TMDL. It is clear that more information is needed to be able to define this source. Phosphorus sources such as stormwater runoff, golf courses, and wastewater effluent are more easily quantified and controlled than phosphorus release from sediments. These external sources should be controlled first.

The TMDL analyses for metals are deficient because they do not quantify the load associated with MS4 discharges or nonpoint source activities in Rhode Island.

RIDEM Response: Quantifying metals loads from over 50 outfalls located in the Rhode Island portion of the watershed would be exceedingly difficult. A majority of metals violations occurred under the wet weather-stormflow condition which strongly suggests that stormwater containing metals constitute a significant load to the Ten Mile River. In the Rhode Island portion all of the reduction is placed in the wasteload allocation. The reduction is quantified and MS4's in the Rhode Island portion will be required to meet those reductions or, if a particular waterbody segment requires no reductions in metals, the will be a 'no net increase' requirement.

Rather, the report implies that the loads from these sources is the difference between the load observed at the MA/RI border, and load found by multiplying the concentration of various sampling points, and the flow "at" those sampling points. We put the term at in quotes because some sample points are in reservoirs or ponds, and there is not flow, in the conventional sense.

RIDEM Response: To clarify, flow <u>was observed at all stations during all surveys</u>. Station TM4, at Newman Avenue is located at a box culvert that separates Central Pond from the Turner Reservoir. Water must flow through this culvert in order for Turner Reservoir to exist.

Survey metal loads at each station are calculated as the product of flow, concentration, and a conversion factor. Allowable loads are calculated as the product of flow, criteria concentration, and a conversion factor. If a reduction is required at the state line, that reduction is taken into account at the next downstream station.

The concentration at those locations actually reflects the following:

- The flow and concentration entering the head of the pond or reservoir
- *Plus* the flow and load discharged from storm sewers and other nonpoint source activities in the watershed of the reservoirs
- *Minus* the effects of settling, burial and uptake that occur within the pond or reservoir.

The way the TMDL was developed combines the last two steps, and credits the storm sewers and runoff with the "treatment" provided by the reservoir. This leads to the counterintuitive result that there needs to be no reductions in metals pollution entering the Rhode Island pond and reservoir segments, even though the report clearly states that

The literature is replete with studies reporting elevated levels of metals in stormwater runoff and it has been clearly documented that surface waters located within highly urbanized watersheds suffer from degraded water quality due to impacts from this runoff. In addition, stormwater runoff is the most controllable of the identified sources of metals in the Ten Mile River. (page 113)

RIDEM Response: Tables 41-43 detail the required metals reductions to various waterbody segments in the Rhode Island portion of the Ten Mile River.

If the TMDL had followed the general approach of the phosphorus analysis, then more defensible goals would be set for these stormwater and nonpoint source discharges.

I think it would be interesting if possible, to remove Attleboro from the DEM model, then take a look at how the Ten Mile River and the impoundment's faired without Attleboro's influence.

Sincerely,

Paul A. Kennedy
Superintendent of Wastewater

Cc: Kevin J. Dumas, Mayor
Barry LaCasse, Director of Budget & Admin.
Thomas Hayes, Asst. Supt. of Wastewater