Merrimack River Watershed Assessment Study – Phase III

Final Monitoring Data Report

August 2017

Sponsor Communities:

Manchester, NH
Nashua, NH
Lowell, MA
Lawrence (GLSD), MA
Haverhill, MA

US Army Corps of Engineers®
New England District

CDM Smith

Executive Summary

This Merrimack River Watershed Assessment Study (Study) Monitoring Data Report presents the results of the comprehensive water quality study performed on the Lower Merrimack River from Hooksett, New Hampshire downstream to its confluence with the Atlantic Ocean in Newburyport, Massachusetts between June 2014 and August 2016. The purpose of this third and final phase of the Study was to collect additional data and refine the existing river models to further evaluate nonpoint source impacts to water quality. This phase also included identification of dry-weather contribution of pollutants from key tributaries into the mainstem. The purpose of this report is to present the findings of the phase III sampling events and the water quality data collected.

The sampling program included dry weather and wet weather (mainstem only) sampling of targeted river and tributary stations for nutrients, bacteria, and dissolved oxygen, as well as collection of field parameters. The purpose of this approach was two-fold: to collect baseline information during periods of dry weather with which to compare the wet weather results, when nonpoint source pollutant contributions into the river are increased; and to better quantify dry-weather contributions from key tributaries. Beginning in 2015, composite effluent samples were also collected at eleven Wastewater Treatment Plants (WWTPs) along the mainstem river, between Manchester, New Hampshire and Newburyport, Massachusetts to characterize the loads being discharged to the river.

Dry Weather Mainstem Sampling

Two dry weather surveys were conducted on the mainstem Merrimack River on 24 June 2014 and 10 August 2016. The August 2016 event was a hybrid event with collection of both dry weather and wet weather samples as predicted precipitation arrived earlier than predicted and overlapped with the sample collection process; however the first half of the event prior to the start of rain represents fully dry conditions at several stations along the entire length of the river. The average daily flows measured in the most downstream USGS gage in Lowell, Massachusetts on the days of sampling were 1,840 cfs and 1,046 cfs (pre-rain), respectively, both of which were between 28% and 35% of the historic mean monthly flows as targeted in the Mainstem Field Sampling Plan (FSP)(CDM Smith, 2013). For reference, the 7-day 10-year low flow value (7Q10) at Lowell is 930 cfs.

Wet Weather Mainstem Sampling

Two wet weather surveys were conducted on the mainstem Merrimack River on 1 October 2015 and 10 August 2016. The August 2016 event was a hybrid event with collection of both dry weather and wet weather samples. Rain was received throughout the watershed that day, approximately midway through the event, so those samples collected after rainfall began and after impacts to the flow were observed are considered representative of wet weather conditions. (Additional details about sample qualification are included in Section 2 of the report.) The average daily flows in Lowell, Massachusetts on the days of sampling were 10,602 cfs and 1,126 cfs (post-rain), respectively. Although there were no flow requirements established in the Mainstem FSP since it was a weather-focused sampling program, for comparative purposes these average daily flows are 228% and 37% of their respective historic mean monthly flows.

During both of these sampling events, composite effluent samples were collected from up to eleven WWTPs along the river representing wet-weather contributions.

Dry Weather Tributary Sampling

One dry weather survey was conducted on the Concord, Shawsheen, and Spicket Rivers on 21 July 2016. Note that each mainstem event included collection of samples at the mouths of 12 major tributaries near where they discharged into the Merrimack River, but this sampling differed since it extended up each of these three rivers to their starting point. The average daily flows measured in the most downstream USGS gage on each of these rivers were 32 cfs, 6.9 cfs, and 0.64 cfs, respectively, which were between 1% and 11% of their respective historic mean monthly flows as targeted in the Tributary FSP (CDM Smith, 2013). For reference, the 7Q10 flows at these gages are 32.2 cfs, 6.57 cfs, and 1.22 cfs, indicating that each tributary was at or below 7Q10 conditions on the day of sampling.

Results

Key findings of the Phase III Lower Merrimack River sampling are summarized below. Overall, Phase III results indicate that the Merrimack River is a healthy and dynamic system that exhibits some temporary impacts from various nonpoint sources. Generally, Phase III trends were consistent with those observed during prior phases of the Study. While detailed results are too voluminous to effectively summarize in this Executive Summary, they are discussed in Sections 3 and 4 and included in their entirety in tabular and graphical formats in the appendices of this report.

Nutrients

Elevated levels of nutrients (phosphorus and nitrogen) in rivers can be indicative of the likelihood of excessive in-stream organic production, which can deplete oxygen levels in the water and degrade aquatic habitat quality.

Total phosphorus concentrations in the mainstem river tended to increase slightly from upstream to downstream, and typically wet weather values (52-200 µg/L and one isolated result of 350 µg/L) were higher than dry weather values (15-136 µg/L). There are no enforceable numeric water quality standards for total phosphorus in New Hampshire or Massachusetts. However, EPA suggests that total phosphorus concentrations in streams not exceed 100 µg/L. This guideline is used for comparison purposes only. While some increases in total phosphorus concentrations were observed in select river stations downstream of WWTPs, spikes in concentrations may be attributed to other sources. The total phosphorus concentrations at the mouths of the major tributaries were generally below nearby mainstem levels, with the exception of the Spicket and Shawsheen Rivers during the wet weather August 2016 event, where the tributary contributions (565 and 385µg/L, respectively) were significantly greater than the mainstem Merrimack River near the confluence. Otherwise, total phosphorus levels at the mouths of the tributaries during both wet weather and dry weather were below 175 µg/L. It is important to note that phosphorus concentrations observed during the July and August 2016 event were collected during a period of extremely low flow, where flows were less than or equal to 7Q10 conditions. These may represent worst case rather than baseline conditions in the river.

Measuring orthophosphates along with total phosphorus in the river indicates how much of the nutrient is bioavailable for algal growth. The orthophosphate trends tended to show some variability and vary by event, but generally concentrations increased from upstream to downstream, and/or demonstrated spikes at select points of interest. The drop in orthophosphate concentrations in marine waters may be attributed to saltwater impacts. The ratio of orthophosphates to total phosphorus in the mainstem river and tributaries varied by event and typically ranged between 0.02 and 0.8, and did not demonstrate discernable trends between wet and dry weather.

There is a New Hampshire Class B Fresh Surface Water Criteria for Human Health of 10 mg/L (for water and fish ingestion) for nitrates. There are currently no numerical surface water quality standards for nitrogen in Massachusetts. Total nitrogen levels in the mainstem were generally below 2.0 mg/L, with some isolated exceptions between 2.15 and 4.16 mg/L during the July and August 2016 events, during which time flows in the mainstem were approaching 7Q10 conditions. Similar nitrogen values were observed in the tributaries, with the exception of the Concord River which consistently measured elevated levels of total nitrogen near its confluence with the Merrimack River during dry and wet weather sampling events (1.77 to 5.15 mg/L).

Levels of chlorophyll-a, another indicator of organic productivity in the water that can deplete oxygen supplies, were also measured. Wet weather and dry weather chlorophyll-a concentrations were consistent. Concentrations generally increased from upstream to downstream along the Lower Merrimack River, with the exception of a decrease in the lowest reach correlating to the increase in salinity and mixing with marine water at these stations. The state of New Hampshire uses 15 µg/L as a guideline threshold for maximum chlorophyll-a concentrations for primary contact recreation, but Massachusetts does not specify a chlorophyll-a surface water quality standard. Concentrations in New Hampshire ranged from 4.7 to 17 µg/L, levels which indicate algal growth is not excessive, despite some elevated total phosphorus concentrations. Concentrations in Massachusetts in non-marine waters were slightly higher and ranged between 6.8 and 57 µg/L. These levels may be suggestive of organic activity that may lead to degradation of aquatic habitat; however, algal blooms and other potential impacts were not observed during sampling events. Additionally, as indicated below, despite these elevated chlorophyll-a concentrations, dissolved oxygen levels consistently remained above regulatory standards. Generally, throughout the study area, the samples taken at the mouths of tributaries had lower chlorophyll-a concentrations than the mainstem receiving water of the Merrimack River at that location. Tributary sample concentrations at the mouth of the mainstem and further upstream along the three key tributaries ranged between 1.5 and 33 µg/L, with one outlying wet weather value of 90 µg/L in the sample collected from the mouth of the Little River during the August 2016 event.

Oxygen, Temperature, and pH

Dissolved oxygen levels in the river were measured in-situ using field water quality meters and in the laboratory using Winkler titration. Despite some of the elevated nutrient concentrations observed, dry weather and wet weather sampling results, with few exceptions, indicated healthy dissolved oxygen levels in the mainstem river, consistently above the applicable state standards of 5 mg/L. Over the course of the three mainstem surveys, only four select sampling stations during the August 2016 event did not comply with state standards for dissolved oxygen, with concentrations ranging from 3.93 to 4.94 mg/L. Two of these were mainstem locations in the upper reaches of the river in New Hampshire. The other two stations were at the mouths of tributaries (Stony Brook and Powwow River). Some deficiencies were also noted in the Spicket River during the July 2016 event. The extremely low flows in the both the mainstem river and tributaries at the time of sampling (approximately half of the 7Q10 flow in the Spicket River and approaching 7Q10 in the mainstem) may represent stressed conditions.

During the dry and wet weather events, temperatures were generally consistent throughout the study area between 14 and 27°C. As expected, the warmest temperatures were observed during late summer months, and the decreasing trend observed in marine waters was likely attributed to mixing with the cooler ocean waters.

The New Hampshire Class B water quality standards require pH to be between 6.6 and 8.2 SU. The Massachusetts Class B standards require pH to be from 6.5 to 8.3 SU, and the Massachusetts Class SB standards range from 6.5 to 8.5 SU. Field readings of pH in the mainstem river and key tributaries were generally neutral (approaching 7 SU) and within range with some exceptions. Dry and wet weather pH values were consistent, and fluctuated between 6.2 and 8.64 SU.

Bacteria

Dry weather and wet weather samples were collected for E. coli, fecal coliform, and enterococcus (marine waters only). Generally, bacteria levels at most mainstem stations during dry weather conditions suggested that the river has low baseline levels of bacteria and is close to complying with state water quality standards during normal dry-weather conditions; however, as was observed during Phase I, isolated instances of elevated concentrations during dry weather were observed downstream of major communities/WWTPs and at the mouths of select major tributaries. Elevated concentrations above applicable state water quality standards were also observed in the select dry weather tributary samples collected from the Concord, Shawsheen, and Spicket Rivers.

Bacteria levels during wet weather conditions were elevated, and a majority were above applicable state standards. Typically, as was observed during dry weather sampling, wet weather bacteria concentrations in tributaries were at or above nearby mainstem levels.

Remaining Study Tasks

With the conclusion of the final data collection phase of this Study, the next step will be the modeling tasks. The scope of the modeling work will include validation and refinement of the water quality model using the Phase III water quality data, development of water quality management alternatives and model scenarios, and evaluation of these alternatives relative to water quality objectives and existing uses. The technical reports for the Study, including this data report and modeling reports, are anticipated to be completed in 2017. Coupling of the technical reports will provide additional analysis of the data presented herein, and further investigation into potential sources of pollutants. The final Study document will be a Watershed Assessment Report, which is anticipated to be completed in 2018.

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Section 1

Background

The Lower Merrimack River Study is Phase III of the Merrimack River Watershed Assessment Study. Background for the study leading up to and including Phase III is detailed in this Section.

1.1 Merrimack River Watershed Assessment Study

The Merrimack River Watershed Assessment Study is a jointly funded effort between the Federal Government, through the United States Army Corps of Engineers (USACE), and local community sponsors including Manchester and Nashua, New Hampshire (NH); and Lowell and Haverhill, Massachusetts (MA). The interested regulatory agencies include the United States Environmental Protection Agency (USEPA), the Massachusetts Department of Environmental Protection (MassDEP), and the New Hampshire Department of Environmental Services (NHDES).

Over the past several decades, significant improvements have been made to the water quality of the Merrimack River. However, according to water quality assessment reports prepared by New Hampshire and Massachusetts agencies (NHDES 2012; MassDEP 2011 and 2012), portions of the mainstem Merrimack River downstream of Manchester, New Hampshire do not meet designated use requirements.

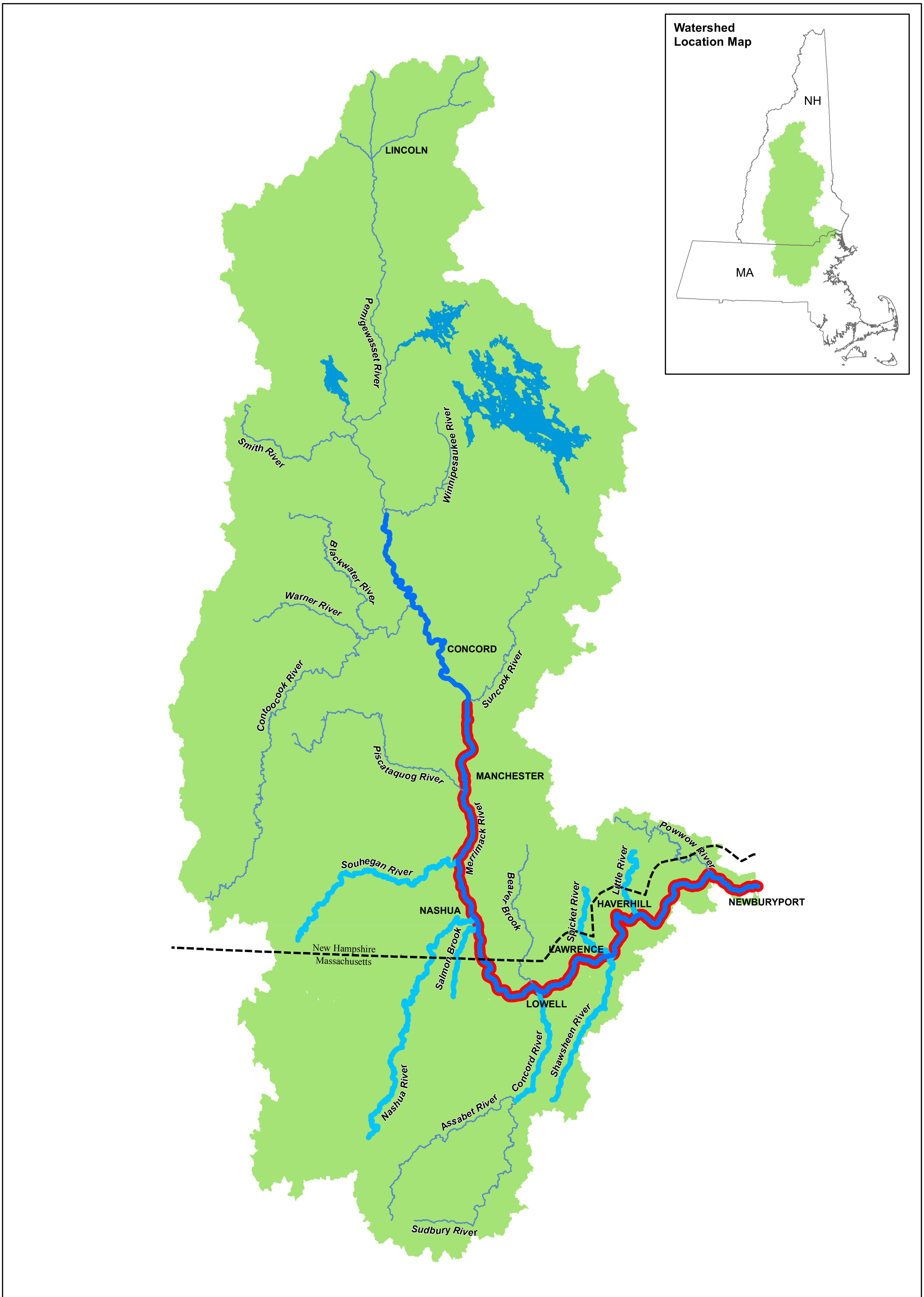
The overall purpose of the Watershed Assessment Study is to provide scientific information to help guide investments in the environmental resources and infrastructure of the basin that are aimed at achieving water quality and flow conditions that support designated uses, including drinking water supply, recreation, fisheries, hydropower, and aquatic life support. Due to the magnitude of the Study, it was divided into three phases (Phases I through III). Phase I encompassed the Lower Merrimack Watershed, Phase II encompassed the Upper Merrimack Watershed, and Phase III, which is the current phase, encompasses additional studies for the Lower Merrimack Watershed. The entire watershed area is shown on **Figure 1-1**, with the current Phase III areas shown in red.

Each of these phases is described below.

Phase I

Between 2003 and 2006, USACE, with sponsors in Massachusetts and New Hampshire, completed work on the Lower Merrimack River to compare the relative contributions and impacts of pollution from nonpoint sources and combined sewer overflows (CSOs), and to compare alternative bacteria abatement strategies in the watershed. The study area focused on the impacts of bacteria and nutrients in the portion of the river from Hooksett, NH downstream to its confluence with the Atlantic Ocean in Newburyport, MA.

The key findings of Phase I were detailed in the Final Phase I Report (CDM Smith, September 2006), and are summarized as follows:



Coordinate System: NAD83 Mass. State Plane Mainland FIPS 2001 Feet

Legend
- State Boundary
- Phase III River Study Area
- Tributaries Sampled
- Merrimack River Mainstem
- Other Tributaries
- Merrimack River Watershed

N W E S

Merrimack River Watershed
Assessment Study
Phase III

0 5 10 20 Miles

Figure 1-1
Merrimack River Watershed and Study Area

CDM Smith

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- The CSO control efforts of the communities – including a variety of future potential control strategies – would reduce the frequency, magnitude and duration of overflows, but would not significantly improve compliance with bacterial water quality standards. This is because overflow events occur for a very small percentage of the time in any given year. The remainder of the time the river is dominated by stormwater and background bacteria concentrations that often exceed standards. The Study showed that if all future potential CSO control strategies were implemented, the river would still not achieve bacteria water quality compliance because of background concentrations and stormwater.

- The Study results indicated that optimal improvement in bacterial water quality is best achieved through a balanced approach of CSO controls – reflecting the kinds of investments anticipated under various communities Phase I control strategies as defined in the plan – coupled with a 20 % reduction in nonpoint source bacteria (*E. coli*, fecal coliform, and enterococcus) and reduction of background levels of bacteria in tributaries to approximately 5,000 organisms per 100 ml. Under this investment strategy, the river would comply with water quality standards under most conditions.

In the years since the Phase I work began, the Lower Merrimack communities with CSOs (Manchester and Nashua, NH, and Lowell, Greater Lawrence and Haverhill, MA) have taken actions to comply with their individual CSO Long-Term Control Plans by improving their infrastructure, treatment facilities, efficiency, and stormwater management programs. These initiatives and environmental infrastructure programs all contribute to the betterment of the Merrimack River water quality, and the Merrimack River Watershed as a whole.

Phase II

The purpose of Phase II was to extend the evaluation of instream water quality in the mainstem Merrimack and Pemigewasset Rivers upstream to Lincoln, NH, close to the headwaters. One of the goals was to create a time dependent model of flow and water quality of the Upper Merrimack River that could be used to guide the following activities and decisions: 1) The model would be used as a tool to simulate dissolved oxygen dynamics in reaches of the river that are listed on the New Hampshire 303(d) list of impaired waters, and provide a scenario analyses that considered the expected needs of several wastewater treatment facilities for updated discharge permits. (Since that time, the focus has shifted to providing a better understanding of the river's assimilative capacity and the flexibility this could create for treated waste discharge.); 2) To assess the water quality and quantity impacts of potential future increases in water withdrawals from the mainstem Merrimack by communities south of Concord, NH; and, 3) To potentially evaluate alternative usage of USACE reservoirs in the watershed to lessen impacts of treated wastewater discharges and/or water supply withdrawals.

The performance of the model was tested against data collected from the mainstem Pemigewasset and Merrimack Rivers, and their primary tributaries in New Hampshire. The results of the Phase II monitoring program are included in the Upper Merrimack and Pemigewasset River Study- Field Program 2009-2012 Monitoring Data Report (CDM Smith, December 2012). While Upper Merrimack modeling efforts are ongoing, information may be found in the Model Development Report (CDM Smith, June 2014) and subsequent reports that are anticipated later in 2017.

Phase III

The purpose of the third and current phase of the Study is to collect additional data and refine the river models. Additionally, Phase III includes sampling of three of the major tributaries. One of the Phase III objectives is to augment Phase I and Phase II data and to further investigate the findings of Phase I, particularly with respect to nonpoint sources, where these sources originate, and how to better manage them. Select tributaries were identified in Phase I as being impaired with bacteria. Several others were requested by communities to be investigated. As such, Phase III sampling was extended further three tributaries where sampling was not previously conducted. Building on the Phase I efforts, the study is intended to gain a more detailed understanding of the causes and impacts of water-related issues and complete the assessment study.

This report presents the results and findings of the Phase III data collection in June 2014, October 2015, July 2016, and August 2016. Modeling results are anticipated to be submitted under separate cover later this year, and will provide additional analysis of the data and potential point and nonpoint sources.

1.2 Sampling Program Overview

Two field sampling programs were developed as part of the Phase III Lower Merrimack River Study, including one for the mainstem and one for key tributaries. For the purposes of this report, "Mainstem Field Sampling Plan (FSP)" will refer to the Mainstem Merrimack River Field Sampling Plan (CDM Smith, 2013), and "Tributary FSP" will refer to the Key Tributary Field Sampling Plan (CDM Smith, 2013). The primary objective of the field sampling programs is to provide an accurate and representative picture of the current water quality conditions at specific sampling stations along the mainstem, with particular emphasis on nonpoint sources and key tributaries. Data collected under this task will be used as input to the existing water quality and hydrologic/hydraulic models. These models will serve as the basis for future planning in the basin.

The executed Phase III field sampling program consisted of the following components:

- Dry Weather (Low-flow) water quality surveys – June 2014 (mainstem) and July 2016 (Tributaries; Concord, Shawsheen, and Spicket Rivers)
- Wet Weather (High-flow) water quality survey – October 2015 (mainstem)
- Hybrid Weather (Dry/Wet weather) water quality survey – August 2016 (mainstem)

The mainstem sampling stations were the same for both wet weather and dry weather events. The purpose of this approach was to collect baseline information during periods of dry weather with which to compare the wet weather results, when nonpoint source pollutant contributions into the river are increased. For consistency, the Phase III mainstem sampling locations were based on the same locations sampled during Phase I with minor changes, as previously established in the FSPs. While the sampling stations on the three tributaries had not been previously sampled, the most downstream station on each tributary corresponded with the confluence sample collected during the mainstem events. This is further detailed in Sections 3 and 4.

Mainstem samples (74 locations) were collected upstream and downstream of major communities, including the four sponsor communities, upstream and downstream of wastewater treatment plants (WWTPs) on the mainstem, at the mouth of 12 major tributaries, at two recreational areas (public beach and boat launch), upstream and downstream of the 3 dams (beginning at Amoskeag in Manchester, NH), at two shellfishing beds in the tidally influenced portion of the basin, and upstream and downstream of 10 stormwater outfalls (non-CSO). Stormwater outfalls were bracketed in Phase III, rather than being sampled directly, as was done in Phase I. Composite effluent samples were collected from the 11 WWTPs along the Lower Merrimack beginning with the 1 October 2015 wet weather survey and during the subsequent survey.

Tributary samples (30 locations) were collected along three key tributaries (Concord, Shawsheen, and Spicket Rivers), and included stations downstream of major communities, downstream of agricultural, residential, commercial/urban, and recreational areas, and upstream and downstream of two WWTPs on the Concord River.

Maps showing the approximate locations of sampling are shown in subsequent sections of this report; detailed location maps can be found in **Appendix A1**.

The approved Field Sampling Plans (both dated August 2013) and Quality Assurance Project Plan (QAPP) including the Standard Operating Procedure Compendium (May 2014; revised December 2014) served as the governing documents for implementation of the sampling program. Deviations from the approved documents are noted for each event in subsequent sections of this report.

All activities were performed by members of the CDM Smith team, which is comprised of CDM Smith and its subcontractors:

- Normandeau Associates, Inc. of Bedford, NH
- Eastern Analytical, Inc. (EAI) of Concord, NH
- University of Massachusetts School for Marine Science and Technology (SMAST) of New Bedford, MA

1.2.1 Study Area

For the purposes of the Phase III field sampling program, the study area is identified as the mainstem Merrimack River south of Hooksett, NH to the confluence of the River with the Atlantic Ocean. As shown on Figure 1-1, this area includes the major communities of Manchester and Nashua, NH, and Lowell, Lawrence, and Haverhill, MA. The final 22 miles of the mainstem Merrimack River in the study area downstream of Haverhill, MA are tidally influenced. This is the same study area as was sampled in Phase I, with the exception of the Concord, NH sampling locations

In addition to the mainstem sampling locations, 12 major tributaries were identified within the study area. Impacts of the tributary sub-basins were evaluated as part of this field sampling program by collecting water quality samples at the mouths of these key tributaries. **Table 1-1** lists the tributaries to the mainstem Lower Merrimack River that are to be included in the model along with the location of the confluence with the mainstem. Seven of these tributaries were identified in the Tributary FSP as key tributaries for potential sampling along their entire length; however, in consultation with stakeholders three were selected for sampling in 2016. The three selected were the Concord, Shawsheen, and Spicket Rivers. Figure 1-1 presents the location of all 12 major tributaries, with the three tributaries selected for sampling outlined in red.

Table 1-1: Major Tributaries to the Lower Merrimack River

Tributary	Location of Confluence
Piscataquog River	Manchester, NH
Cohas Brook	Manchester, NH
Souhegan River	Merrimack, NH
Nashua River	Nashua, NH
Salmon Brook	Nashua, NH
Stony Brook	Chelmsford, MA
Beaver Brook	Lowell, MA
Concord River[1]	Lowell, MA
Spicket River[1]	Lawrence, MA
Shawsheen River[1]	Lawrence, MA
Little River	Haverhill, MA
Powwow River	Amesbury, MA

1) Identified as key tributary for additional sampling along its entire length.

Based on stakeholder input, the sampling program was also amended beginning with the October 2015 wet weather survey to include the collection of effluent samples from 11 WWTPs along the Lower Merrimack River. These WWTPs are presented in **Table 1-2**.

Table 1-2: Wastewater Treatment Plants along the Lower Merrimack River

Wastewater Treatment Plant	Location
Manchester Wastewater Treatment Plant	Manchester, NH
Derry Wastewater Treatment Facility	Derry, NH
Merrimack Wastewater Treatment Facility	Merrimack, NH
Nashua Wastewater Treatment Facility	Nashua, NH
Lowell Regional Waste Water Utility (LRWWU)	Lowell, MA
Greater Lawrence Sanitary District (GLSD)	North Andover, MA
Haverhill Wastewater Treatment Plant	Haverhill, MA
Merrimac Wastewater Treatment Plant	Merrimac, MA
Amesbury Wastewater Treatment Facility	Amesbury, MA
Salisbury Wastewater Treatment Facility	Salisbury, MA
Newburyport Wastewater Treatment Facility	Newburyport, MA

1.2.2 Program Components

This report includes the results of all field program activities completed for this Phase III study. Up to three mainstem wet weather events and up to three mainstem dry weather events were anticipated in the FSP, contingent on budget, time, and resource constraints. In total, one dry weather mainstem event, one wet weather mainstem event, one "hybrid" dry/wet weather mainstem event, and one dry weather tributary event were conducted. **Table 1-3** lists the program components and the date of completion, followed by a summary of each program component.

Table 1-3: Status of Monitoring Program Components

Program Component	Dates of Field Activities
Mainstem Event #1- Dry Weather	25 June 2014
Mainstem Event #2- Wet Weather	1 October 2015
Mainstem Event #3- Hybrid (Dry/Wet) Weather	10 August 2016
Key Tributary Event- Dry Weather (Concord, Shawsheen, and Spicket Rivers)	21 July 2016

This report details the mainstem Merrimack River and key tributary sampling programs. Sampling criteria, data quality objectives, weather tracking, and other program logistics are consistent between sampling programs, as detailed below.

1.2.2.1 Dry Weather Water Quality Surveys

The main purpose of the dry weather surveys was to characterize the conditions during periods when the river was stressed with regard to dissolved oxygen, with particular emphasis on nutrient-driven processes that cause oxygen deficits. Dry weather surveys were intended to identify where there might be dry-weather exceedances of bacteria, as was observed during Phase I. Dry weather sampling on the mainstem Merrimack was conducted twice during the Phase III field program, during early and late summer, to capture varying seasonal impacts and trends. Dry weather tributary sampling was conducted once during Phase III during mid-summer low flow conditions. Dry weather sampling required antecedent dry conditions and flows at or below targeted mean monthly flow conditions. Dry weather target flows were established based on the historical flow records on the mainstem Merrimack River measured by available United States Geological Survey (USGS) gages.

The June 2014 dry weather sampling event captured representative dry, low-flow early summer conditions in the mainstem Merrimack River, while the dry weather portion of the August 2016 hybrid dry/wet weather sampling event captured representative dry, low flow (nearing 7Q10 flows) late summer conditions. Additional weather and flow details for the August 2016 hybrid event and are included later in this report. The July 2016 dry weather tributary sampling event captured representative dry, very low-flow mid-summer conditions throughout the Concord, Shawsheen, and Spicket Rivers. Flow and weather conditions are detailed in Section 2 of this report. Water quality analyses for the dry weather survey included field measurements, nutrients, bacteria, and oxygen demand measurements. **Table 1-4** shows the complete list of analytes and measurements. Methods for these analyses were detailed in the QAPP.

Table 1-4: Sampling Constituents and Field Measurements

Analytical Constituents	Field Measurements
Indicator Organisms ▪ Fecal coliform ▪ *E. Coli* ▪ Enterococcus (marine waters only) **Nutrients & Impacts** ▪ Total Phosphorus ▪ Orthophosphate [Dissolved Reactive Phosphate (DRP)) ▪ Nitrate/ Nitrite ▪ Total Kjeldahl Nitrogen (TKN) ▪ Ammonia-N ▪ Chlorophyll-a ▪ Total suspended solids (TSS) **Oxygen & Oxygen Demand** ▪ Dissolved Oxygen- Winkler Titration (select locations) ▪ CBOD5 ▪ CBOD20 (downstream of WWTPs)	**In situ Measurements** ▪ Temperature ▪ Dissolved Oxygen (DO) ▪ Salinity (marine waters only) ▪ pH ▪ Conductivity ▪ Turbidity

1.2.2.2 Wet Weather Water Quality Surveys

The purpose of the wet weather survey was to characterize the conditions in the river during a much higher flow regime to calibrate the dynamic flow and water quality simulation model. Wet weather sampling was performed as part of the Phase III field sampling program, during the late summer and early fall, to capture varying seasonal impacts and trends (Note, the wet weather portion of the hybrid August 2016 event is being considered the second wet weather event for the purposes of this report).

Wet weather precipitation targets and sampling criteria were established in the mainstem and tributary FSPs (mainstem and tributary) based on analysis of hourly precipitation records from 1948 to November 2011 for the only two long-term USGS gaging stations located within or adjacent to the watershed (Concord, NH and Worcester, MA). These precipitation stations were selected to provide a spatially representative view of precipitation patterns in and around the Merrimack River watershed. An analysis was performed to determine the number of storms during which specified precipitation volumes and antecedent dry conditions were met at both locations (less than 0.1 inches of precipitation); the analysis was performed over varying storm event durations.

As a result, the following three storm intensities were targeted:

- *Expected storm volume and duration*: Greater than 1 inch over a 12-hour period
- *Expected storm volume and duration*: Greater than 0.5 inches over a 6-hour period
- *Expected storm volume and duration*: Greater than 1 inch over a 6-hour period

The October 2015 wet weather sampling event captured representative wet, high-flow early fall conditions in the mainstem Merrimack River. The wet weather portion of the August 2016 hybrid dry/wet weather event allowed for capture of representative wet, first flush late summer conditions. This dataset provided unique conditions for modeling purposes, including dry and wet weather data comparison and immediate washoff data. Flow and weather conditions are detailed in Section 2 of this report. Water quality analyses for the wet weather surveys were the same as the dry weather surveys, as shown in Table 1-4.

1.2.2.3 Wastewater Treatment Plant Effluent Surveys

The purpose of the WWTP effluent surveys was to characterize the loads being discharged to the river. The October 2015 wet weather event was the first time that composite effluent WWTP samples were collected during Phase III; however, effluent samples were previously collected from Manchester and Nashua, NH, Lowell and Haverhill, MA, and Greater Lawrence Sanitary District (GLSD) during Phase I.

While effluent WWTP sampling was not included in the original field sampling plan, it was requested to be added by stakeholders after the June 2014 event, and was conducted as part of all subsequent mainstem events. Eleven WWTPs were targeted for sampling in association with Phase III events starting in October 2015 and continuing through August 2016. The eleven WWTPs included those along the Merrimack River from Manchester, NH to Newburyport, MA. Each of the WWTPs has an individual National Pollutant Discharge Elimination System (NPDES) permit to regulate discharge of their effluent, which includes compliance with permit-specific effluent limits. As a comparison to each individual plant's permit terms and effluent limits was not the intent of this sampling, concentrations observed in the WWTP effluent are mentioned for discussion purposes and comparison to those limits is not included in this report. It is also important to note that this sampling was limited and only represents effluent conditions on two select days in 2015 and 2016. Facility specific data is available in monthly discharge monitoring reports (DMRs), which are submitted to the appropriate regulatory agencies.

Several of the targeted WWTPs are CSO communities, and this mode of operation is to provide primary treatment to a certain volume of wastewater that would otherwise go to the waterways as raw sewage. While CSO contributions were not a targeted component of this sampling program, during significant storms CSO discharges were triggered in select communities; however this is representative of non-standard operating conditions at the WWTPs.

CDM Smith coordinated with each of the eleven targeted WWTPs regarding the event schedule and details for sampling, but the samples themselves were collected by WWTP staff, per the facility's typical sample collection method(s). For WWTPs with the capabilities to collect 24-hour composite samples (i.e. plants without lagoons), it was requested that composite sampling was started the morning of the scheduled sampling event and concluded between 12:00 and 10:30 AM the day after the event. For WWTPs with lagoon discharges or those unable to collect composite samples, it was requested that a grab sample be collected the morning after the event. In addition to collecting effluent samples for laboratory analysis, in-situ field measurements were collected when possible at 12-hour intervals within the 24-hour composite time frame.

Water quality analyses for the WWTPs were slightly different from the mainstem samples, as shown in **Table 1-5**. Bacteria samples were not collected due to hold time constraints and the availability of bacteria reporting data for NPDES permits. Chlorophyll-a was not collected because algae is not a constituent of concern in WWTP effluent. Winkler dissolved oxygen was not collected because the effluent is aerated (either intentionally or unintentionally) between the sample collection point and the discharge.

Table 1-5: Sampling Constituents and In-Situ Measurements for WWTP Effluent Samples

Analytical Constituents	In-Situ Measurements
Nutrients & Impacts	**In situ Measurements**
▪ Total Phosphorus	▪ Temperature
▪ Orthophosphate (DRP)	▪ Dissolved Oxygen (DO)
▪ Nitrate/ Nitrite	▪ pH
▪ Total Kjeldahl Nitrogen (TKN)	▪ Conductivity (where possible)
▪ Ammonia-N	▪ Turbidity
▪ Total suspended solids (TSS)	
Oxygen Demand	
▪ CBOD5	
▪ CBOD20	

1.2.3 Data Quality Objectives

Based on the sampling program objectives and the proposed data usage for the Lower Merrimack River Study, the following Data Quality Objectives (DQOs) were established for the Phase III sampling program:

- Collect water quality data sufficient for the calibration and validation of the existing water quality and hydrologic/hydraulic models of the Lower Merrimack River.
- Collect water quality data to develop a comprehensive database of water quality data with which to characterize the impacts of point source loads and non-point source loads on nutrient, dissolved oxygen, chlorophyll-a, and bacteria (i.e. *E.coli,* fecal coliform, enterococci) levels in the Lower Merrimack River.

These DQOs, along with the other quality objectives and criteria specified in the approved QAPP, will be used to assess the usability of the data in subsequent sections of this report.

1.3 Water Quality Standards and Guidelines

This Study uses Massachusetts and New Hampshire Surface Water Quality Standards (SWQS) to provide a general characterization of the water quality in the Merrimack and its tributaries. It was established in the QAPP that water quality data in the data collection phase would be compared to existing New Hampshire and Massachusetts SWQS. It is important to note that the comparison of collected data to Massachusetts and New Hampshire SWQS and guidelines is used in this report to provide a conceptual framework for the data presented and is not intended as regulatory determination of compliance. While the QAPP presents a full summary of the water quality standards and guidelines, a simplified table of the applicable SWQS used for comparison is presented in **Table 1-6.**

Table 1-6: Summary of State Surface Water Quality Standards
Merrimack River Watershed Study
Phase III Lower Merrimack River

Parameter	State Surface Water Quality Standard	Regulatory Reference
Ammonia-N		
	pH dependent- see Table 1703.4 A,B,C in Env-Wq 17004. Values apply unless naturally occurring [1]	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Aquatic Life
$CBOD_5/CBOD_{20}$		
	-	-
Chlorophyll-a		
	N/A for this project (NH has thresholds for aquatic life protection in lakes but not in rivers or impoundments)	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Aquatic Life
	Freshwater threshold for primary contact recreation: < 15 ppb[2] unless naturally occurring	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Human Health
Dissolved Oxygen (Winkler Titration)		
	Unless naturally occurring, daily average of >75% saturation and instantaneous >5.0mg/L (applicable in water column of free flowing rivers and top 25% of depth of thermally unstratified lakes, ponds, impoundments and reservoirs or within the epilimnion if stratified.)	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Aquatic Life
	≥5.0 mg/L	Massachusetts Surface Water Quality Standards Class A, Class B
	≥5.0 mg/L, unless natural background conditions are lower	Massachusetts Surface Water Quality Standards Class SB
E. Coli		
	<126 col/ 100mL (based on geometric mean[3]) or <406 col/100mL in any one sample; <1000 col/100mL at end of CSO pipe	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Human Health
	<126 col/ 100mL (based on geometric mean[4]) or <235 col/100mL in any one sample	Massachusetts Surface Water Quality Standards Class A, Class B
Enterococcus		
	N/A for this project (criteria only apply to NH tidal waters)	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Human Health
	<33 col/100mL (based on geometric mean[4]) or <61 col/100mL in any one sample	Massachusetts Surface Water Quality Standards Class A, Class B
	<35 coli/100mL (based on geometric mean[4]) or <104 col/100mL in any one sample	Massachusetts Surface Water Quality Standards Class SB
Fecal Coliform		
	N/A for this project (criteria only apply to NH tidal waters)	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Human Health
	At water supply intakes in unfiltered public water supplies, fecal coliform shall not exceed 20 fecal coliform organisms/ 100 ml in all samples taken in any 6 months period	Massachusetts Surface Water Quality Standards Class A
	Waters designated for shellfishing shall not exceed a fecal coliform median or geometric mean MPN of 88 col/100 ml, nor shall more than 10% of the samples exceed an MPN of 260 col/100 ml	Massachusetts Surface Water Quality Standards Class SB
Nitrate		
	10 mg/L unless naturally occurring (for water and fish ingestion)[1,5]	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Human Health
Nitrite		
	No numeric limits[1,5]	-
Particulate Organic Carbon & Nitrogen		
	No numeric limits[1,5]	-
Dissolved Organic N		
	No numeric limits[1,5]	-

Table 1-6: Summary of State Surface Water Quality Standards
Merrimack River Watershed Study
Phase III Lower Merrimack River

Parameter	State Surface Water Quality Standard	Regulatory Reference
Orthophosphate (DRP)		
	No numeric limits[1,5]	-
Total Phosphorus		
	No numeric limits[1,5]	-
TKN[6]		
	No numeric limits[1,5]	-
Total Suspended Solids		
	Free from suspended solids that would impair designated use, cause aesthetically objectionable conditions, impair benthic biota, or degrade chemical composition of the bottom.	Massachusetts Surface Water Quality Standards Class A, Class B, Class SB
Field Measurements:		
Conductivity		
	-	-
Dissolved Oxygen		
	Unless naturally occurring, daily average of >75% saturation and instantaneous >5.0mg/L (applicable in water column of free flowing rivers and top 25% of depth of thermally unstratified lakes, ponds, impoundments and reservoirs or within the epilimnion if stratified.	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Aquatic Life
	≥6.0 mg/L	Massachusetts Surface Water Quality Standards Class A, Class B
	≥5.0 mg/L, unless natural background conditions are lower	Massachusetts Surface Water Quality Standards Class SB
pH		
	6.5- 8.0 except when due to natural causes	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Aquatic Life
	6.5- 8.3	Massachusetts Surface Water Quality Standards Class A, Class B
	6.5- 8.5; ≤0.2 units outside natural background range	Massachusetts Surface Water Quality Standards Class SB
Salinity		
	-	-
Temperature		
	In accordance with RSA 485-A:8, II, & VIII	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Aquatic Life
	≤83°F (28.3°C)	Massachusetts Surface Water Quality Standards Class A, Class B
	≤85°F (29.4°C); Maximum daily mean ≤80°F (26.7°C)	Massachusetts Surface Water Quality Standards Class SB
Turbidity		
	< 10 NTUs above natural background	New Hampshire Class B Fresh Surface Water Criteria and Thresholds for Aquatic Life
	Free from turbidity that would impair designated use or cause aesthetically objectionable conditions.	Massachusetts Surface Water Quality Standards Class A, Class B, Class SB

1 Class B waters shall contain no phosphorous or nitrogen in such concentrations that would impair any existing or designated uses, unless naturally occurring.(NH Class B Fresh Surface Water Criteria and Thresholds for Aquatic Life and Human Health)

2 Thresholds are from the NH Consolidated Assessment and Listing Methodology (see http://des.nh.gov/organization/divisions/water/wmb/swqa/documents/calm.pdf)

3 Based on geometric mean of at least 3-samples obtained over a 60-day period

4 For bathing waters, based on geometric mean of the five most recent samples taken during the same bathing season. For other waters and during the nonbathing season, based on the geometric mean of all samples taken within the most recent six months, typically at least five samples.

5 Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses (MA Surface Water Quality Standards Class A, Class B, Class SB)

6 TKN = Particulate organic N + dissolved organic N + Ammonium;

For total phosphorus, one of the major Study components, comparisons are made to the federal guideline value since no numeric state standards exist. Review of EPA's National Recommended Water Quality Criteria (NRWQC) indicates there is no numeric criteria for phosphorus, but it references the 1986 Quality Criteria for Water (EPA 440/5-86-001), also known as the "Gold Book". The following regarding phosphorus is noted, "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 P (Mackenthun, 1973)." The document further states that, "The majority of the Nation's eutrophication problems are associated with lakes or reservoirs and currently there are more data to support the establishment of a limiting phosphorus level in those waters than in streams or rivers that do not directly impact such water. There are natural conditions, also, that would dictate the consideration of either a more or less stringent phosphorus level." While the guidance threshold of 100 ug/l will be presented for general comparison purposes in this report, it is important to note the context of this guidance and the statement in the guidance that system characteristics may tolerate higher or lower levels. As with the state standards, comparison to this EPA total phosphorus guidance value is not intended as regulatory determination of compliance.

In addition to the SWQS, Massachusetts and New Hampshire have established screening guidelines in their Consolidated Assessment and Listing Methodology (CALM) Guidance Manuals, which have a foundation in state SWQS. The guidelines are presented in **Table 1-7**. While comparison to CALM screening guidelines is used by states, these guidelines were not included in the QAPP, so for consistency comparison to these guidelines will not be included in this data report. However, it is noted that data collected in this Study suggests that even though some levels in the river exceed the values in Table 1-7, no evidence of cultural eutrophication or recurrent algae blooms have been observed. CALM guidelines will be further evaluated in Study modeling reports/memos.

Table 1-7: Thresholds Published in MA and NH CALM for Indication of Cultural Eutrophication for Water Quality Constituents that have Non-Numeric Criteria

Parameter	Massachusetts	New Hampshire
Phytoplankton chlorophyll-a	Rivers and Lakes: 16 ug/L Estuaries: 10 ug/L	Rivers: 15 ug/L Lakes: 11 ug/L Estuaries: 11 ug/L
Total phosphorus	Rivers: 100 ug/L Rivers entering lake/reservoir: 50ug/L Lakes: 25 ug/L	Lakes: 28 ug/L
Total Nitrogen	Estuaries: 0.5 mg/L	None

As previously mentioned, wastewater treatments plants, including those 11 along the river that were sampled during the mainstem events, have their own effluent limits established in their individual NPDES Permits. A comparison of this limited effluent sampling to NPDES effluent limits was not the intent of collection of these samples and a comparison Is not provided.

1.4 Data Report Overview

This report provides a summary of all sampling events for Phase III of the Lower Merrimack River Study, conducted in June 2014, October 2015, July 2016, and August 2016.

This report is organized as follows:

- Details on each program component, including a summary of the sampling and quality assurance/quality control (QA/QC) activities performed,
- Precipitation and streamflow conditions prior to and during the sampling event,
- Summary of any deviations from the approved QAPP and Field Sampling Plan during the field and analytical activities,
- Analytical results and field measurements for each program component (select results presented in the body of the report; complete results included in appendices),
- Comparison of the data to state water quality standards and guidelines in New Hampshire and Massachusetts to establish a general characterization of water quality in the river, and
- Appendices: Appendices included in this report include sampling overview maps and precipitation maps (Appendix A), data plots (Appendix B), data tables (Appendix C), Data Validation and Usability Report (Appendix D), field sheets with observations (Appendix E), laboratory data (Appendix F), and the response to comments document (Appendix G).

Section 2

Water Quality Survey Conditions

During Phase III of the study, one dry weather survey, one wet weather survey, and one hybrid dry/wet weather survey were conducted on the mainstem river to evaluate water quality conditions in the river under typical summer or early fall conditions. Additionally, one dry weather survey was conducted on three key tributaries (Concord, Shawsheen, and Spicket Rivers) during typical summer conditions. The objective of this third phase of the Study was to collect additional data and refine the river models to further evaluate nonpoint and point source impacts to water quality. The dry weather survey was conducted in the summer of 2014 (June 25), the wet weather survey was conducted in the early fall of 2015 (October 1), and the hybrid dry/wet weather survey was conducted in the summer of 2016 (August 10). The dry weather tributary survey was conducted in the summer of 2016 (July 21). A map showing the locations of the river and tributary sampling stations, major tributaries, and WWTPs is shown on **Figures 2-1, 2-2A, 2-2B, and 2-2C**; **Tables 2-1A and 2-1B** list the stations and descriptions. As noted in these tables, sample types included grab, spatial composite, and 24-hour composite. Grab samples are collected from the center point of all stations in the river, while spatial composites are collected from the quarter points and the banks of the river for all constituents (i.e. left, center, and right quarter point locations are defined as looking downstream). Most samples were grab samples, but composite samples were collected downstream of point source discharges, such as wastewater treatment plants, where the river was not completely mixed. 24-hour composite samples were collected by the WWTPs from their effluent discharge.

The water quality surveys consisted of the following activities:

Mainstem Sampling

- Collection of mainstem river samples (3 mainstem events) for water quality analysis from:
  - 42 mainstem river stations, including upstream of seven dams and upstream and downstream of eleven wastewater treatment plants (WWTPs);
  - 12 major tributary sampling stations at the mouths of the tributaries;
  - upstream and downstream of ten stormwater outfalls. CSO outfalls were not targeted for this Phase III work since the focus was more on nonpoint source pollution than on the CSOs, which were adequately characterized during Phase I;
  - collection of composite effluent samples for water quality analysis from eleven WWTPs (October 2015 and August 2016 only); and,
  - recording of field readings in-situ for dissolved oxygen, temperature, conductivity, turbidity, pH and salinity (where applicable) using field water quality meters (YSI multiparameter instrument and in select instances Hach Turbidimeters when turbidity probes were not available on the YSI).

Tributary Sampling

- Collection of tributary samples (1 tributary event) for water quality analysis from:
  - 30 tributary stations (8-11 per river), including downstream of major communities, downstream of agricultural, residential, commercial/urban, and recreational areas,

upstream and downstream of the WWTPs on the Concord River, and at the confluence with the Merrimack River; and,

- recording of field readings in-situ for dissolved oxygen, temperature, conductivity, turbidity, and pH using multiprobe field water quality meters.

Mainstem and tributary sampling were not conducted on the same day. Descriptions of precipitation and streamflow conditions, event summaries, deviations from the Quality Assurance Project Plan (QAPP) and Field Sampling Plans, and a discussion of observations based on the data are contained in Sections 2.1 through 2.4 for all dry weather and wet weather Phase III events.

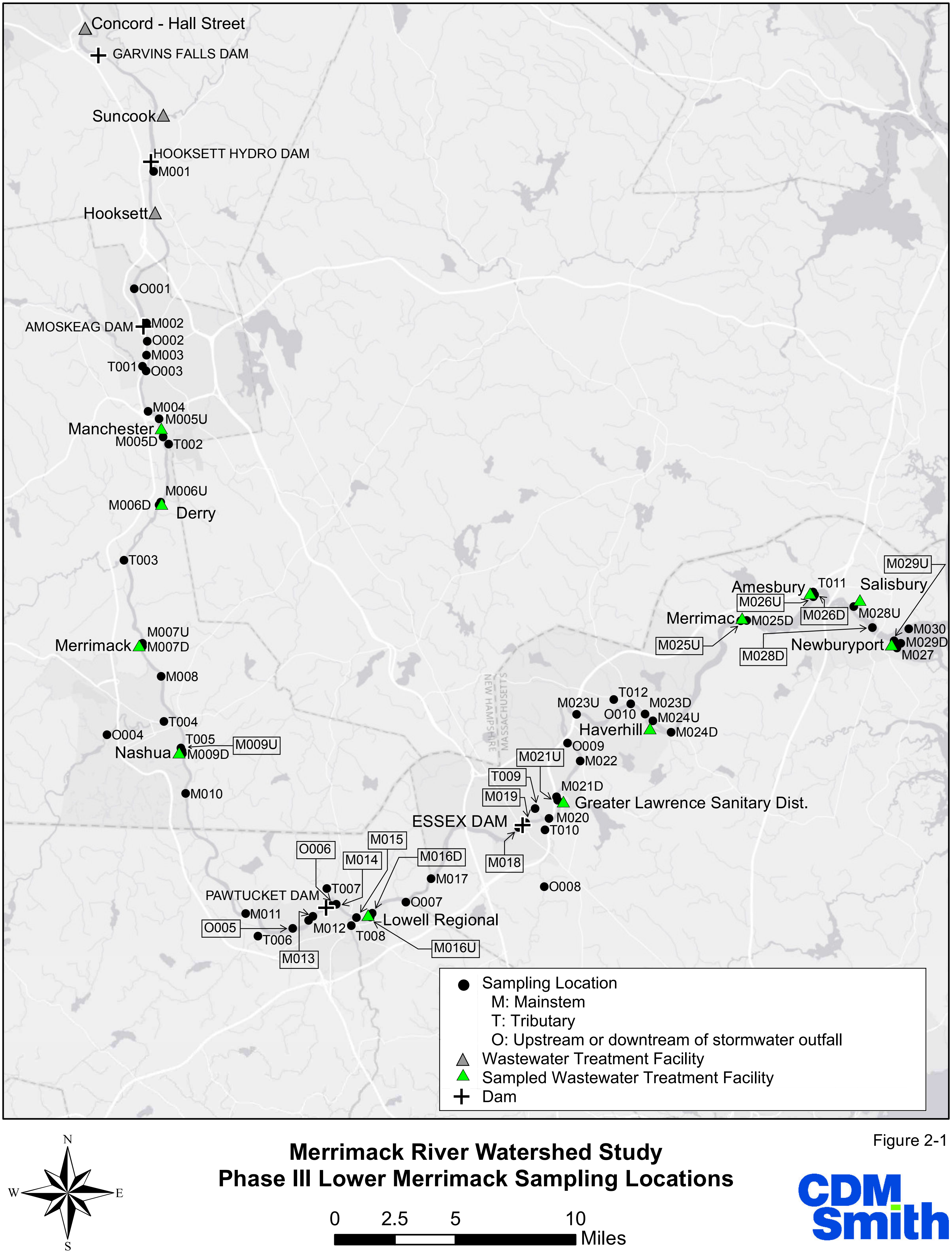
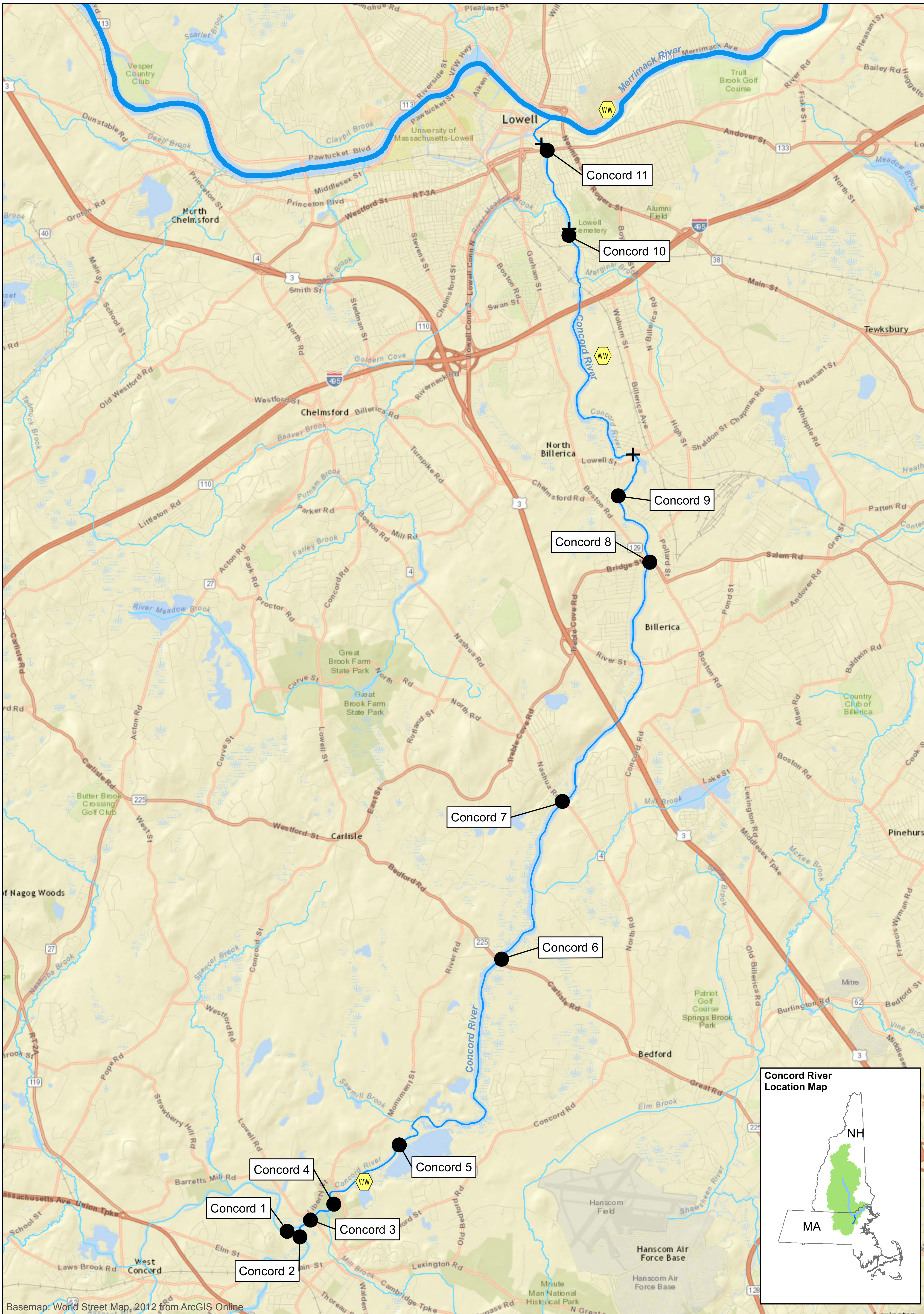


Figure 2-1

Merrimack River Watershed Study
Phase III Lower Merrimack Sampling Locations

CDM Smith



Legend

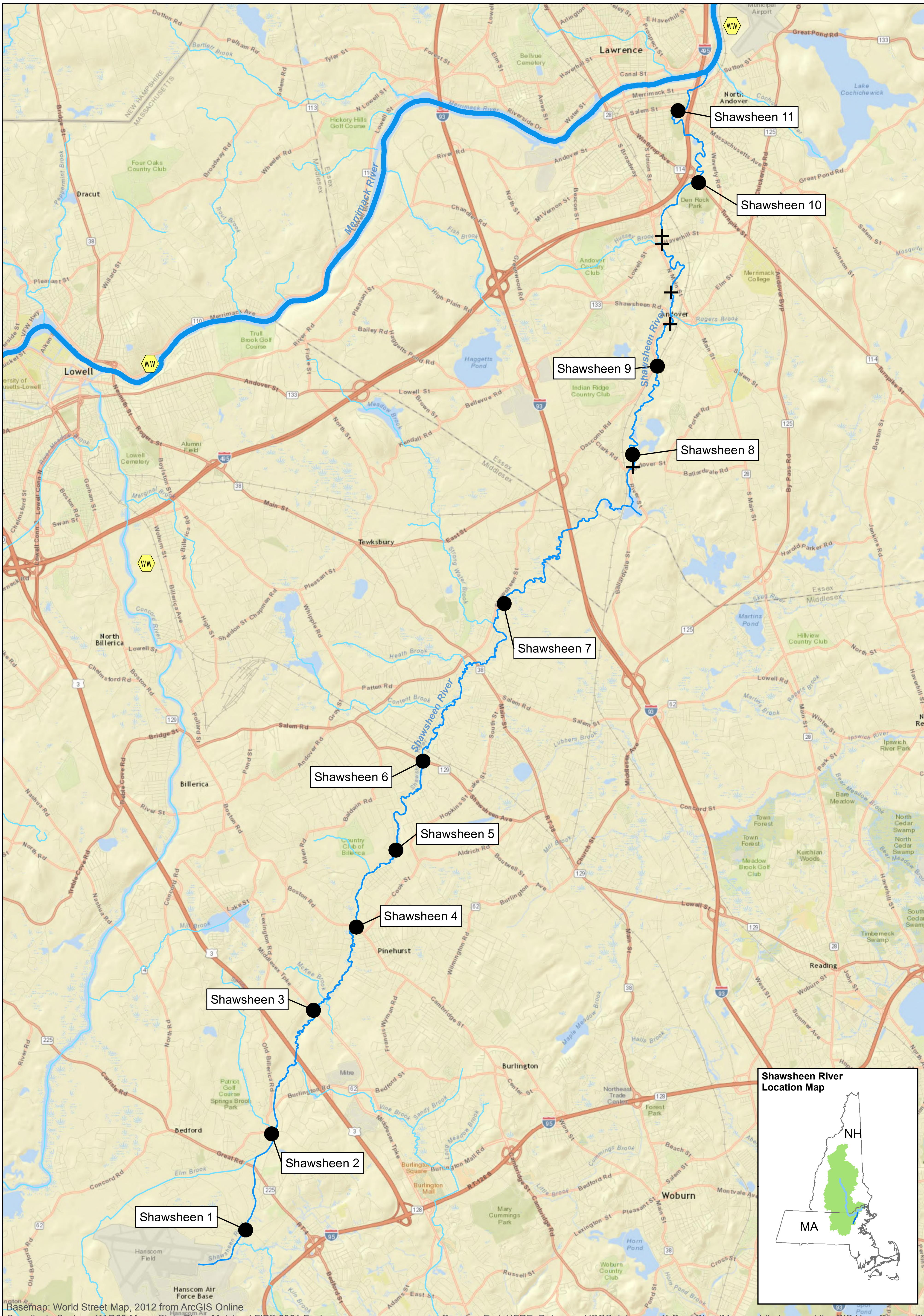
- Sampling Locations
- Merrimack River
- Concord River
- Dams
- Wastewater Treatment Plant (WWTP)

Merrimack River Watershed Study
Phase III - Lower Merrimack

0 0.5 1 2 Miles

Figure 2-2A
Tributary Event #1
Sampling Locations
Concord River

CDM Smith



Legend

- Sampling Locations
- Merrimack River
- Shawsheen River
- Dams
- Wastewater Treatment Plant (WWTP)

Merrimack River Watershed Study
Phase III - Lower Merrimack

0 0.5 1 2 Miles

Figure 2-2B
Tributary Event #1
Sampling Locations
Shawsheen River

CDM Smith

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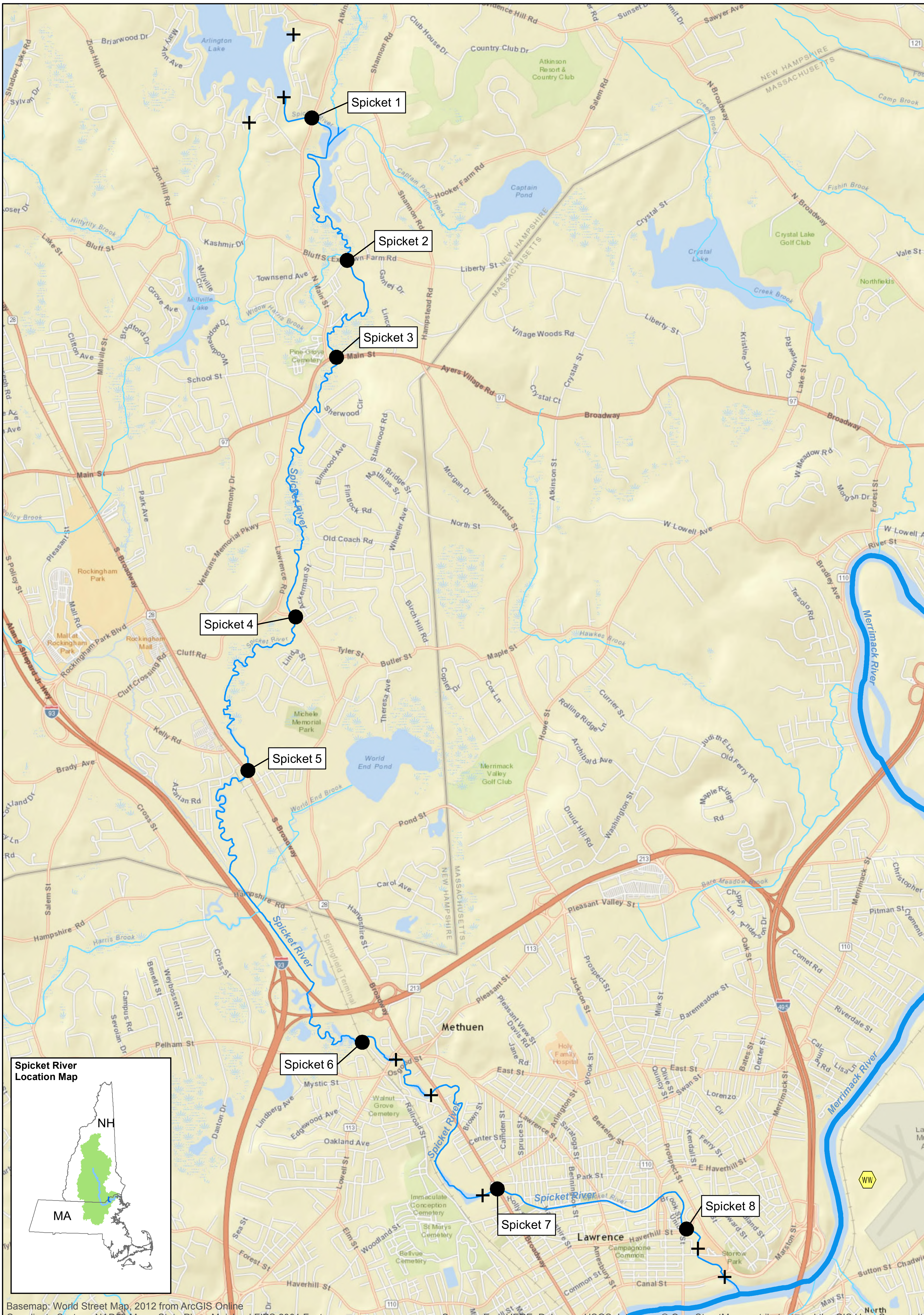

Legend

- Sampling Locations
- Merrimack River
- Spicket River
- Dams
- Wastewater Treatment Plant (WWTP)

Merrimack River Watershed Study
Phase III - Lower Merrimack

0 0.25 0.5 1 Miles

Figure 2-2C
Tributary Event #1
Sampling Locations
Spicket River

CDM Smith

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Table 2-1A: Mainstem Sampling Stations

Station ID	River Mile from Newburyport, MA	Location	Station Type	Sample Type[1]
M001	80.5	D/S Hooksett Dam	Mainstem	grab
O001U	74.8	U/S Chauncey Ave Outfall	Mainstem	grab
O001D	74.7	D/S Chauncey Ave Outfall	Mainstem	grab
M002	73.2	U/S Amoskeag Dam	Mainstem	grab
O002U	72.4	U/S Bridges St Stormdrain	Mainstem	grab
O002D	72.3	D/S Bridges St Stormdrain	Mainstem	grab
M003	71.7	D/S Amoskeag Dam	Mainstem	grab
T001	71.1	Piscataquog River	Tributary	grab
O003U	71.0	U/S Manchester Stormdrain	Mainstem	grab
O003D	70.9	D/S Manchester Stormdrain	Mainstem	grab
M004	68.9	D/S Manchester	Mainstem	grab
M005U	68.3	U/S Manchester WWTP	Mainstem	grab
Manchester	68.01	Manchester WWTP Effluent	WWTP Effluent	24-hour composite
M005D	67.7	D/S Manchester WWTP	Mainstem	spatial composite
T002	67.5	Cohas Brook	Tributary	grab
M006U	65.0	U/S Derry WWTP	Mainstem	grab
Derry	64.93	Derry WWTP Effluent	WWTP Effluent	24-hour composite
M006D	64.8	D/S Derry WWTP	Mainstem	spatial composite
T003	62.0	Souhegan River	Tributary	grab
M007U	58.3	U/S Merrimack WWTP	Mainstem	grab
Merrimack NH	58.20	Merrimack NH WWTP Effluent	WWTP Effluent	24-hour composite
M007D	58.1	D/S Merrimack WWTP	Mainstem	spatial composite
M008	56.6	U/S Nashua	Mainstem	grab
T004	54.5	Nashua River	Tributary	grab
O004U	54.5	U/S Mines Falls Stormdrain	Tributary	grab
O004D	54.5	D/S Mines Falls Stormdrain	Tributary	grab
T005	53.3	Salmon Brook	Tributary	grab
M009U	53.2	U/S Nashua WWTP	Mainstem	grab
Nashua	53.12	Nashua WWTP Effluent	WWTP Effluent	24-hour composite
M009D	53.0	D/S Nashua WWTP	Mainstem	spatial composite
M010	51.3	D/S Nashua	Mainstem	grab
M011	44.5	U/S Lowell	Mainstem	grab
T006	43.3	Stony Brook	Tributary	grab
O005U	42.2	U/S Lowell Stormdrain	Mainstem	grab
O005D	42.1	D/S Lowell Stormdrain	Mainstem	grab

Station ID	River Mile from Newburyport, MA	Location	Station Type	Sample Type[1]
M012	41.2	Lowell Public Beach	Mainstem	grab
M013	41.0	U/S Pawtucket Dam	Mainstem	grab
O006U	40.0	U/S Lowell Pawtucket Stormdrain	Mainstem	grab
O006D	39.9	D/S Lowell Pawtucket Stormdrain	Mainstem	grab
T007	39.9	Beaver Brook	Tributary	grab
M014	39.8	D/S Pawtucket Dam	Mainstem	grab
T008	39.0	Concord River	Tributary	grab
M015	38.8	D/S Lowell	Mainstem	grab
M016U	38.1	U/S Lowell WWTP	Mainstem	grab
LRWWU	38.03	Lowell Regional Waste Water Utility (LRWWU) Effluent	WWTP Effluent	24-hour composite
M016D	37.9	D/S Lowell WWTP	Mainstem	spatial composite
O007U	36.4	U/S Trull Brook Stormdrain	Mainstem	grab
O007D	36.2	D/S Trull Brook Stormdrain	Mainstem	grab
M017	34.8	U/S Lawrence	Mainstem	grab
M018	29.4	U/S Essex Dam	Mainstem	grab
M019	29.0	D/S Essex Dam	Mainstem	grab
T009	28.3	Spicket River	Tributary	grab
O008U	27.9	U/S Shawsheen Stormdrain	Tributary	grab
O008D	27.8	D/S Shawsheen Stormdrain	Tributary	grab
T010	27.8	Shawsheen River	Tributary	grab
M020	27.7	D/S Lawrence	Mainstem	grab
M021U	27.0	U/S GLSD WWTP	Mainstem	grab
GLSD	26.96	GLSD WWTP Effluent	WWTP Effluent	24-hour composite
M021D	26.9	D/S GLSD WWTP	Mainstem	spatial composite
M022	25.1	U/S Haverhill	Mainstem	grab
O009U	24.2	U/S Methuen Stormdrain	Mainstem	grab
O009D	24.0	D/S Methuen Stormdrain	Mainstem	grab
M023U	21.8	D/S Methuen	Mainstem	grab
T012	19.4	Little River	Tributary	grab
O010U	19.0	U/S Water St. Stormdrain	Mainstem	grab
O010D	18.9	D/S Water St. Stormdrain	Mainstem	grab
M023D	18.3	D/S Haverhill	Mainstem	grab
M024U	17.7	U/S Haverhill WWTP	Mainstem	grab
Haverhill	17.43	Haverhill WWTP Effluent	WWTP Effluent	24-hour composite
M024D	17.1	D/S Haverhill WWTP	Mainstem	spatial composite
M025U	10.8	U/S Merrimac WWTP	Mainstem	grab

Station ID	River Mile from Newburyport, MA	Location	Station Type	Sample Type[1]
Merrimac MA	10.73	Merrimac MA WWTP Effluent	WWTP Effluent	24-hour composite
M025D	10.7	D/S Merrimac WWTP	Mainstem	spatial composite
M026U	7.0	U/S Amesbury WWTP	Mainstem	grab
Amesbury	6.97	Amesbury WWTP Effluent	WWTP Effluent	24-hour composite
M026D	6.9	D/S Amesbury WWTP	Mainstem	spatial composite
T011	6.9	Powwow River	Tributary	grab
M028U	5.0	U/S Salisbury WWTP	Mainstem	grab
Salisbury	4.37	Salisbury WWTP Effluent	WWTP Effluent	24-hour composite
M028D	3.8	D/S Salisbury WWTP	Mainstem	spatial composite
M029U	2.7	U/S Newburyport WWTP	Mainstem	grab
Newburyport	2.64	Newburyport WWTP Effluent	WWTP Effluent	24-hour composite
M029D	2.5	D/S Newburyport WWTP	Mainstem	spatial composite
M027	2.5	Shellfish Bed	Mainstem	grab
M030	2.0	Shellfish Bed	Mainstem	grab

Note: 1) For all mainstem and tributary locations, all bacteria analyses were collected as a grab sample to avoid cross-contamination. Sample collection methods are detailed in the FSPs.

Table 2-1B: Tributary Sampling Stations

Station ID	River Mile from Merrimack River	Location	Station Type	Sample Type[1]
Concord 1	16.4	Assabet River Contribution	Tributary	Grab
Concord 2	16.4	Sudbury River Contribution	Tributary	Grab
Concord 3	16.1	Upstream/Background, Concord	Tributary	Grab
Concord 4	15.4	Upstream from Concord WWTP	Tributary	Grab
Concord 5	14.6	Downstream of Concord WWTP, Agricultural Fields, and orchards	Tributary	Composite
Concord 6	11.4	Downstream of residential and conservation areas	Tributary	Grab
Concord 7	8.2	Downstream of residential area, conservation land, and Rt. 3.	Tributary	Grab
Concord 8	6.0	Downstream of residential area, high school, sports fields, conservation land.	Tributary	Grab
Concord 9	4.4	Upstream Billerica WWTP	Tributary	Grab
Concord 10	4.0	Downstream of Billerica WWTP	Tributary	Composite
Concord 11	0.54	Downstream of city/residential area prior to discharge into Merrimack	Tributary	Grab
Shawsheen 1	25.7	Upstream/background location, downstream of Hanscom Air Force Base	Tributary	Grab
Shawsheen 2	24.4	Downstream of residential area, commercial areas.	Tributary	Grab
Shawsheen 3	21.9	Downstream of golf course.	Tributary	Grab
Shawsheen 4	20.0	Downstream of residential and industrial/commercial area	Tributary	Grab
Shawsheen 5	18.5	Downstream of Jones Brook/Billerica Country Club.	Tributary	Grab
Shawsheen 6	16.6	Downstream of residential/recreational area access	Tributary	Grab
Shawsheen 7	13.2	Downstream of residential area, Strong Water Brook, Tewksbury Country Club.	Tributary	Grab
Shawsheen 8	8.4	Downstream of residential area and 93.	Tributary	Grab
Shawsheen 9	6.4	Downstream of residential area and Indian Ridge Golf Club.	Tributary	Grab
Shawsheen 10	3.3	Downstream of Sacred Heard, residential area, town, sports fields, dams.	Tributary	Grab
Shawsheen 11	0.58	Downstream of residential area, 495, and sports field.	Tributary	Grab
Spicket 1	14.2	Upstream/background location, Salem, NH	Tributary	Grab
Spicket 2	13.7	Downstream of Hog Hill Brook and Atkinson Resort & Country Club	Tributary	Grab
Spicket 3	11.3	Downstream of residential area, town, greenspace, Policy Brook	Tributary	Grab
Spicket 4	9.0	Downstream of residential area/prior to commercial area	Tributary	Grab
Spicket 5	7.3	Downstream of residential area, Rockingham Park/Mall, Commercial area	Tributary	Grab
Spicket 6	5.7	Downstream of residential area, Rockingham Park/Mall, Commercial area	Tributary	Grab
Spicket 7	2.1	Downstream from 93, bird sanctuary, Nevins Farm & Equine Center	Tributary	Grab
Spicket 8	0.62	Downstream of city and residential area, prior to discharge in Merrimack	Tributary	Grab

Note: 1) For all mainstem and tributary locations, all bacteria analyses were collected as a grab sample to avoid cross-contamination. Sample collection methods are detailed in the FSPs

2.1 Mainstem Event #1 - Dry Weather Survey Description

The first dry weather water quality survey was conducted on 25 June 2014. Field crews collected samples and field readings from approximately 6:00 am to 6:15 pm. Sample runners transported bacteria samples from the sampling teams to EAI for *E. coli*, fecal coliform, and enterococcus (marine waters only) analysis throughout the day in order to meet the six hour hold time for those samples. Additional samples transported to EAI via sample runner or EAI courier included chlorophyll-a, total suspended solids (TSS), 5-day carbonaceous biological oxygen demand (CBOD5), and 20-day CBOD (CBOD20). All other samples for nutrient and dissolved oxygen (DO) analysis were transported to SMAST at UMASS Dartmouth at the conclusion of the day of sampling.

QA/QC samples were collected at four locations to achieve >5% frequency (out of 74 samples), consisting of field blanks, field duplicates, and equipment rinsate blanks. **Table 2-2** lists the sample times and analyses for each of the sample stations.

Table 2-2: Mainstem Event #1 - Dry Weather Survey Sampling Details
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Location	Station Type	Sample Type	Sample Time[1]	Field Readings[3]	Nutrients	Winkler DO	$CBOD_5$	$CBOD_{20}$	Total Suspended Solids	Chlorophyll-a	E. coli	Fecal Coliform	Enterococcus	Field Blank	Field Duplicate	Equip. Rinsate Blank
M001	D/S Hooksett Dam	Mainstem	grab	7:28 AM	X	X	X	X		X	X	X	X				
M002	U/S Amoskeag Dam	Mainstem	grab	9:30 AM	X	X		X		X	X	X	X				
O006U	U/S Lowell Pawtucket Stormdrain	Mainstem	grab	6:15 AM	X	X		X		X	X	X	X				
O006D	D/S Lowell Pawtucket Stormdrain	Mainstem	grab	6:50 AM	X	X		X		X	X	X	X				
M003	D/S Amoskeag Dam	Mainstem	grab	12:05 PM	X	X		X		X	X	X	X				
O001U	U/S Chauncey Ave Outfall	Mainstem	grab	8:44 AM	X	X	X	X		X	X	X	X				
O001D	D/S Chauncey Ave Outfall	Mainstem	grab	9:03 AM	X	X		X		X	X	X	X				
T001	Piscataquog River	Tributary	grab	6:35 AM	X	X		X		X	X	X	X				
O007U	U/S Trull Brook Stormdrain	Mainstem	grab	11:35 AM	X	X		X		X	X	X	X				
O007D	D/S Trull Brook Stormdrain	Mainstem	grab	12:00 PM	X	X		X		X	X	X	X				
M004	D/S Manchester	Mainstem	grab	2:42 PM	X	X	X	X		X	X	X	X		X	X	X
M005U	U/S Manchester WWTP	Mainstem	grab	9:50 AM	X	X		X		X	X	X	X				
M005D	D/S Manchester WWTP	Mainstem	Spatial composite	9:08 AM	X	X		X	X	X	X	X	X				
T002	Cohas Brook	Tributary	grab	10:26 AM	X	X		X		X	X	X	X				
M006U[2]	U/S Derry WWTP	Mainstem	grab	6:15 AM	X												
M006D	D/S Derry WWTP	Mainstem	Spatial composite	6:00 PM	X	X		X	X	X	X	X	X				
T003	Souhegan River	Tributary	grab	2:25 PM	X	X		X		X	X	X	X				
M007U	U/S Merrimack WWTP	Mainstem	grab	7:00 AM	X	X		X		X	X	X	X				
M007D	D/S Merrimack WWTP	Mainstem	Spatial composite	7:35 AM	X	X		X	X	X	X	X	X				
M008	U/S Nashua	Mainstem	grab	8:30 AM	X	X	X	X		X	X	X	X				
T004	Nashua River	Tributary	grab	3:10 PM	X	X		X		X	X	X	X				
O002U	U/S Bridges St Stormdrain	Mainstem	grab	7:32 AM	X	X		X		X	X	X	X				
O002D	D/S Bridges St Stormdrain	Mainstem	grab	7:07 AM	X	X		X		X	X	X	X				
T005	SalmonBrook	Tributary	grab	10:00 AM	X	X		X		X	X	X	X				
M009U	U/S Nashua WWTP	Mainstem	grab	10:30 AM	X	X		X		X	X	X	X				
M009D	D/S Nashua WWTP	Mainstem	Spatial composite	10:50 AM	X	X		X	X	X	X	X	X				
M010	D/S Nashua	Mainstem	grab	11:50 AM	X	X	X	X		X	X	X	X		X	X	X
M011	U/S Lowell	Mainstem	grab	6:14 AM	X	X		X		X	X	X	X				
T006	Stony Brook	Tributary	grab	3:16 PM	X	X		X		X	X	X	X				
O008U	U/S Shawsheen Stormdrain	Tributary	grab	3:25 PM	X	X		X		X	X	X	X				
O008D	D/S Shawsheen Stormdrain	Tributary	grab	2:50 PM	X	X		X		X	X	X	X				
M012	Lowell Public Beach	Mainstem	grab	7:54 AM	X	X		X		X	X	X	X				
M013	U/S Pawtucket Dam	Mainstem	grab	8:12 AM	X	X		X		X	X	X	X				
T007	Beaver Brook	Tributary	grab	3:47 PM	X	X		X		X	X	X	X				
M014	D/S Pawtucket Dam	Mainstem	grab	7:45 AM	X	X		X		X	X	X	X				

Table 2-2: Mainstem Event #1 - Dry Weather Survey Sampling Details
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Location	Station Type	Sample Type	Sample Time[1]	Field Readings[3]	Nutrients	Winkler DO	$CBOD_5$	$CBOD_{20}$	Total Suspended Solids	Chlorophyll-a	E. coli	Fecal Coliform	Enterococcus	Field Blank	Field Duplicate	Equip. Rinsate Blank
T008	Concord River	Tributary	grab	4:23 PM	X	X		X		X	X	X	X				
M015	D/S Lowell	Mainstem	grab	8:25 AM	X	X	X	X		X	X	X	X				
O003U	U/S Manchester Stormdrain	Mainstem	grab	12:54 PM	X	X		X		X	X	X	X				
O003D	D/S Manchester Stormdrain	Mainstem	grab	1:15 PM	X	X		X		X	X	X	X				
M016U	U/S Lowell WWTP	Mainstem	grab	10:10 AM	X	X		X		X	X	X	X				
M016D	D/S Lowell WWTP	Mainstem	Spatial composite	10:30 AM	X	X		X	X	X	X	X	X				
M017	U/S Lawrence	Mainstem	grab	12:55 PM	X	X	X	X		X	X	X	X				
M018	U/S Essex Dam	Mainstem	grab	1:40 PM	X	X		X		X	X	X	X				
M019	D/S Essex Dam	Mainstem	grab	9:50 AM	X	X		X		X	X	X	X				
O004U	U/S Mines Falls Stormdrain	Tributary	grab	12:45 PM	X	X		X		X	X	X	X				
O004D	D/S Mines Falls Stormdrain	Tributary	grab	11:52 AM	X	X		X		X	X	X	X				
T009	Spicket River	Tributary	grab	11:00 AM	X	X		X		X	X	X	X				
O009U	U/S Methuen Stormdrain	Mainstem	grab	11:30 AM	X	X		X		X	X	X	X				
O009D	D/S Methuen Stormdrain	Mainstem	grab	11:50 AM	X	X		X		X	X	X	X				
T010	Shawsheen River	Tributary	grab	11:35 AM	X	X		X		X	X	X	X		X	X	X
M020	D/S Lawrence	Mainstem	grab	8:00 AM	X	X	X	X		X	X	X	X				
M021U	U/S GLSD WWTP	Mainstem	grab	9:20 AM	X	X		X	X	X	X	X	X				
M021D	D/S GLSD WWTP	Mainstem	Spatial composite	9:00 AM	X	X		X		X	X	X	X				
M022	U/S Haverhill	Mainstem	grab	10:30 AM	X	X	X	X		X	X	X	X				
M023U	D/S Methuen	Mainstem	grab	12:30 PM	X	X		X		X	X	X	X				
O005U	U/S Lowell Stormdrain	Mainstem	grab	6:50 AM	X	X		X		X	X	X	X				
O005D	D/S Lowell Stormdrain	Mainstem	grab	7:15 AM	X	X		X		X	X	X	X				
T012	Little River	Tributary	grab	1:40 PM	X	X		X		X	X	X	X				
O010U	U/S Water St. Stormdrain	Mainstem	grab	1:15 PM	X	X		X		X	X	X	X				
O010D	D/S Water St. Stormdrain	Mainstem	grab	1:25 PM	X	X		X		X	X	X	X				
M023D	D/S Haverhill	Mainstem	grab	1:40 PM	X	X	X	X		X	X	X	X				
M024U	U/S Haverhill WWTP	Mainstem	grab	2:45 PM	X	X		X		X	X	X	X				
M024D	D/S Haverhill WWTP	Mainstem	Spatial composite	3:10 PM	X	X		X	X	X	X	X	X	X	X	X	X
M025U	U/S Merrimac WWTP	Mainstem	grab	9:06 AM	X	X		X		X	X	X	X				
M025D	D/S Merrimac WWTP	Mainstem	Spatial composite	9:30 AM	X	X		X	X	X	X	X	X	X			
M026U	U/S Amesbury WWTP	Mainstem	grab	10:15 AM	X	X		X		X	X	X	X				
M026D	D/S Amesbury WWTP	Mainstem	Spatial composite	10:54 AM	X	X		X	X	X	X	X	X	X			
T011	Powwow River	Tributary	grab	11:11 AM	X	X		X		X	X	X	X				
M028U	U/S Salisbury WWTP	Mainstem	grab	11:55 AM	X	X		X		X	X	X	X				
M028D	D/S Salisbury WWTP	Mainstem	Spatial composite	12:56 PM	X	X		X		X	X	X	X	X			
M029U	U/S Newburyport WWTP	Mainstem	grab	2:49 PM	X	X		X		X	X	X	X				

Table 2-2: Mainstem Event #1 - Dry Weather Survey Sampling Details
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Location	Station Type	Sample Type	Sample Time[1]	Field Readings[3]	Nutrients	Winkler DO	CBOD$_5$	CBOD$_{20}$	Total Suspended Solids	Chlorophyll-a	E. coli	Fecal Coliform	Enterococcus	Field Blank	Field Duplicate	Equip. Rinsate Blank
M029D	D/S Newburyport WWTP	Mainstem	Spatial composite	3:28 PM	X	X		X	X	X	X	X	X	X			
M027	Shellfish Bed	Mainstem	grab	1:20 PM	X	X	X	X		X	X	X	X	X			
M030	Shellfish Bed	Mainstem	grab	3:40 PM	X	X	X	X	X	X	X	X	X	X			

Notes:

1 - Sample time given for grab sample. Multiple field readings were taken approximately 10 minutes apart.

2 - Grab samples were not collected at M006U due to safety concerns

3 - Field readings include: pH, DO, temperature, conductivity, turbidity, and salinity (if applicable)

2.1.1 Precipitation and Streamflow Conditions

The precipitation totals for five locations within or adjacent to the watershed are shown in **Table 2-3**. The upper watershed received more rain in the seven days preceding the first dry weather sampling event than the lower watershed. Two relatively minor rain events occurred in the upper watershed in the seven days before the event. One occurred in the northern watershed on 18 June 2014, and one sudden local storm occurred in the Nashua area on 24 June 2014. The two minor rain events in the upper watershed resulted in less than a total of 0.25 inches of rain. The very dry antecedent conditions throughout the watershed minimized the impact of these rain events on streamflow. Flows in the upper watershed remained below average summer flow levels and did not cause the lower watershed gages to increase above average summer flow levels, see **Figure 2-3**. As shown in Table 2-3, there was some rain reported the evening of the dry weather event; however, this rain did not start until sampling was almost entirely completed and did not impact the river until after sampling was completed.

Table 2-3: Precipitation Totals for Event #1 – Dry Weather Survey

Date	Total Daily Precipitation (inches)				
	Location				
	Concord, NH (N of study area)	Manchester, NH	Nashua, NH	Worcester, MA (SW of study area)	Lawrence, MA
	Source: NOAA, Weather Underground	*Source: Weather Underground*	*Source: Weather Underground*	*Source: NOAA*	*Source: Weather Underground*
6/18/2014	0.19	0.13	0.09	0.12	0.01
6/19/2014	0.00	0.00	0.00	0.00	0.00
6/20/2014	0.00	0.00	0.00	0.00	0.00
6/21/2014	0.00	0.00	0.00	0.00	0.00
6/22/2014	0.00	0.00	0.00	0.00	0.00
6/23/2014	0.00	0.00	0.00	0.00	0.00
6/24/2014	0.00	0.00	0.06	0.00	0.00
6/25/2014	2.32[1]	0.17[1]	0.02[1]	0.00	0.00
7 Day Total (in)	0.19[2] (2.51[3])	0.13[2] (0.30[3])	0.15[2] (0.17[3])	0.12	0.01
3 Day Total (in)	0.00[2] (2.32[3])	0.00[2] (0.17[3])	0.06[2] (0.08[3])	0.00	0.00

Notes:

1) Rainfall was reported within the northern portion of the watershed on the evening of 25 June 2014; however, rainfall did not start until after sampling was almost entirely completed. Streamflows indicate that the rain did not impact the river in the study area until after the teams collected all samples. Rain start times are as follows: Concord- 4:15 pm; Manchester- 9:30 pm; and, Nashua - 9:45 pm.
2) Total before evening rainfall on 6/25
3) Total after evening rainfall on 6/25

The decision to conduct the first dry weather sampling event was made by USACE based on data review and interpretation, and recommendation from CDM Smith. Temperatures in the fall 2013 season and early spring 2014 season were too cold for ideal river conditions. When flows approached the targets (less than the mean monthly streamflow) at the two mainstem tracking gages after a warm and dry May and June, the project team decided that conditions were sufficient to conduct the dry weather sampling. **Table 2-4** shows the average flows on the day of the June 2014 dry weather event with comparisons to the target flow for each gage. Target flows were met at the two USGS gages on the Merrimack River (Goffs Falls and Lowell, MA). In addition, while comparison to the 7-day 10-year low flow value (7Q10) was not a requirement of this field sampling plan, at the time of the event, flows were between 2.0 and 2.3 times the 7Q10 flows at the two gages.

Table 2-4: Mainstem Streamflow Conditions for Event #1 – Dry Weather Survey

Gage	Daily Average Flow 6/25/2014 (cfs)	Mean Monthly Streamflow[3] (cfs)	Target Flow: Daily Average Flow < Mean Monthly Streamflow	USGS 7Q10 Flow (cfs)	Daily Average Flow Compared to 7Q10[6]
Merrimack River near Goffs Falls, below Manchester, NH (Gage # 01092000)	1,500[1]	4,680	Target met 1,500 < 4,680	644[4]	2.3 x 7Q10
Merrimack River below Concord River at Lowell, MA (Gage #01100000)	1,840[2]	6,650	Target met 1,840 < 6,650	930[5]	2.0 x 7Q10

Notes:

1) USGS Data: http://waterdata.usgs.gov/nh/nwis/uv/?site_no=01092000&PARAmeter_cd=00065,00060
2) USGS Data: http://waterdata.usgs.gov/nwis/uv?site_no=01100000
3) A month is defined as a calendar month. Mean monthly streamflows for the Goffs Falls gage (USGS 01092000) and Lowell, MA gage (USGS 01100000) were determined as part of the prior Field Sampling Plan efforts, based on USGS data dating back to 1936 and 1923, respectively, through November 2012. Since that time, additional data has been aggregated by USGS causing the mean monthly streamflows to vary over time. For consistency, the mean monthly streamflow established in the FSP will be referenced herein.
4) NH DES June, 2013 (http://des.nh.gov/organization/divisions/water/dam/drought/documents/201305-drought-pack.pdf)
5) USGS StreamStats Data (http://streamstatsags.cr.usgs.gov/gagepages/html/01100000.htm)
6) Comparison to 7Q10 for reference only. 7Q10 comparison is not a field sampling plan requirement.

cfs – cubic feet per second

Figure 2-3 shows the spring/summer 2014 streamflow time series at each gage and the date when the first dry weather event took place. Streamflows were generally below average at both gages before the event occurred during the months of May and June, except for relatively minor storm events that caused flows to temporarily rise in the watershed in early and mid-May. The two minor rain events in the upper watershed within seven days of the event resulted in minimal precipitation totals, and flows did not respond dramatically, and therefore did not cause postponement of the sampling event. The sampling event occurred on the receding limbs of the hydrographs as flows were below average for late June.

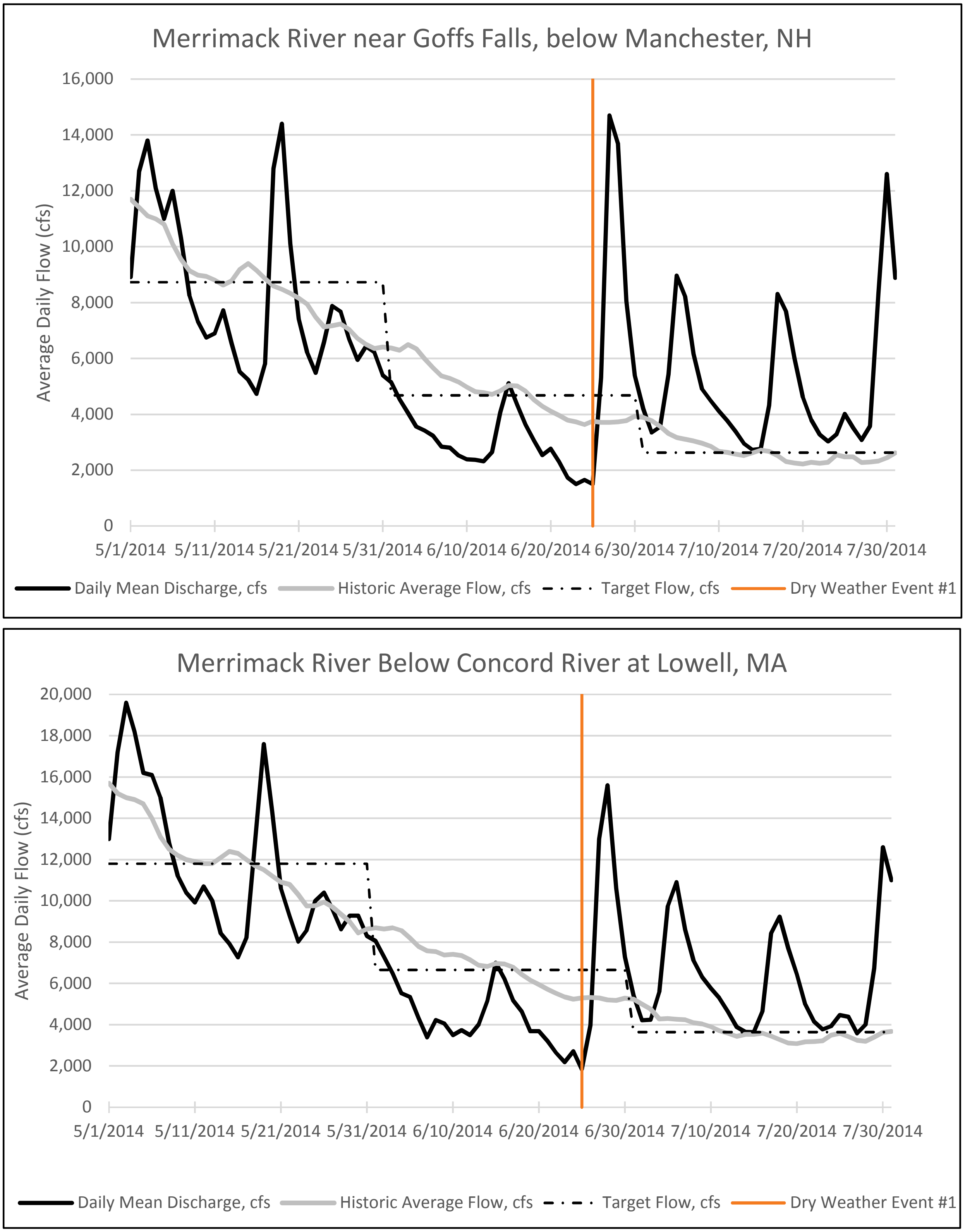


Figure 2-3: Streamflow Conditions for Event #1 – Dry Weather Survey

Flows at the sampled tributaries were obtained using available USGS gage flows. **Table 2-5** provides a summary of the active USGS gaging stations in select tributaries.

Table 2-5: Summary of Active Gaging Stations on Tributaries

Tributary	USGS Gaging Station(s)
Piscataquog River	South Branch Piscataquog River Near Goffstown, NH (01091000)
Cohas Brook	None
Souhegan River	Souhegan River (Site WLR-1) Near Milford, NH (01093852); and Souhegan River at Merrimack, NH (01094000)*
Nashua River	Nashua River at East Pepperell, MA (01096500)
Salmon Brook	None
Stony Brook	None
Beaver Brook	Beaver Brook at North Pelham, NH (010965852)
Concord River	Concord River Below River Meadow Brook at Lowell, MA (01099500)
Spicket River	Spicket River at North Salem, NH (01100505); Spicket River near Methuen, MA (01100561)*
Shawsheen River	Shawsheen River at Hanscom Field near Bedford, MA (01100568); Shawsheen River near Wilmington, MA (01100600); and Shawsheen River at Balmoral Street at Andover, MA (01100627)*
Little River	None
Powwow River	None

*Indicates gage located closest to confluence with Merrimack River.

Table 2-6 shows the measured flows at each tributary on 25 June 2014, if available, using the gages closest to the point of confluence with the mainstem river. The Nashua River contributed the largest volume of flow on the day of the first dry weather sampling event.

Table 2-6: Gaged Tributary Streamflow for Event #1 – Dry Weather Survey

Location	Station ID	Flow	
		Daily Average Flow 6/25/2014 (cfs)	Mean Monthly Streamflow - June (cfs)[1]
Piscataquog River	T001	33	124
Cohas Brook	T002	-	-
Souhegan River	T003	53	227
Nashua River	T004	264	528
Salmon Brook	T005	-	-
Stony Brook	T006	-	-
Beaver Brook	T007	8.0	62
Concord River	T008	160	566
Spicket River	T009	9.0	96
Shawsheen River	T010	26	107
Little River	T012	-	-
Powwow River	T011	-	-

Notes: cfs – cubic feet per second

1. A month is defined as a calendar month. Mean monthly streamflows for these tributaries were determined as part of the November 2012 Field Sampling Plan efforts, based on historic USGS gage data. Since that time, additional data has been aggregated by USGS causing the mean monthly streamflows to vary over time. For consistency, the mean monthly streamflow established in the FSP will be referenced herein.

2.1.2 QAPP and Field Sampling Plan Deviations

Overall, sampling during the first dry weather event on 25 June 2014 followed the sample protocol as described in the QAPP and Field Sampling Plan. Minor deviations were reported, as follows:

Sampling Locations

Of the 74 sampling locations, only one station could not be sampled and one station had to be slightly modified. M006U, located upstream of the Derry WWTP, could not be accessed by the boat team due to low water levels and rapids. M006D, located downstream of the Derry WWTP, was sampled as close as possible to the downstream station as presented in the Field Sampling Plan, but was slightly downstream from there due to low water levels and rapids.

Sample Collection Method

M021D, located downstream of the GLSD WWTP was collected as a grab sample, rather than a spatial composite sample. As stated in the Field Sampling Plan, spatial composite samples were to be collected downstream of point source discharges, such as wastewater treatment plants, if the river was not completely mixed. It is important to note that the effluent flow passes to a straight underwater diffuser section that is approximately 90-feet long, which terminates roughly one-quarter of the way out from the eastern shore. The flow is discharged to the river through ten lateral outlet ports. Therefore, the mid-channel grab sample collected approximately 300-ft downstream is believed to be well mixed and representative of downstream conditions.

Sample Analyses

Per the Field Sampling Plan, CBOD20 was to be collected downstream of all wastewater treatment plants; however, CBOD20 was inadvertently collected from upstream of the GLSD WWTP (M021U) instead of downstream (M021D).

Field Readings

Due to instrument calibration issues, initial and final turbidity readings at some stations were outside the acceptable range, with readings ranging from -1.90 NTU to -7.40 NTU. Negative readings were measured at the stations listed in **Table 2-7**, and were rejected during data validation activities. It should be noted that, as feasible, malfunctioning field water quality instruments were switched out on the day of sampling.

Table 2-7: Negative Turbidity Readings for Event #1 – Dry Weather Survey

Station	Station Name	Station	Station Name
M001	D/S Hooksett Dam	M028D	D/S Salisbury WWTP
M002	U/S Amoskeag Dam	M029U	U/S Newburyport WWTP
M003	D/S Amoskeag Dam	M029D	D/S Newburyport WWTP
M004	D/S Manchester	M030	Shellfish Bed (Newburyport)
M005U	U/S Manchester WWTP	O001U	Stormwater Outfall (U/S)
M005D	D/S Manchester WWTP	O00DU	Stormwater Outfall (D/S)
M006D	D/S Derry WWTP outfall	O002U	Stormwater Outfall (U/S)
M011	U/S Lowell	O002D	Stormwater Outfall (D/S)
M025U	U/S Merrimac WWTP	O003U	Stormwater Outfall (U/S)
M025D	D/S Merrimac WWTP	O003D	Stormwater Outfall (D/S)
M026U	U/S Amesbury WWTP	O005U	Stormwater Outfall (U/S)
M026D	D/S Amesbury WWTP	T001	Piscataquog River
M027	Shellfish Bed/Newburyport boat ramp	T002	Cohas Brook
M028U	U/S Salisbury WWTP	T011	Powwow River (Amesbury)

Tidally Influenced Samples

Locations downstream of Haverhill are tidally influenced. Sampling conducted at Stations M027, M028U/D, M029U/D, and M030 may be heavily influenced by tidal effects as they are located at the mouth of the river as it discharges to the Atlantic Ocean. As a result, sampling performed at these six stations should be collected on an outgoing tide. Also, it is preferred that stations M024U/D, M025U/D, M026U/D, and T011 are collected on an outgoing tide, but is not required as they are located further upstream from the mouth. When sampling cannot be done during the outgoing tide, vertical profiling may be done to determine if there are any saltwater impacts. The intent is to ensure that the samples being collected are representative of river conditions, and to minimize collection of non-representative saltwater samples. The low tide on 25 June 2014 was at approximately 5:45 pm, and the high tide was at approximately 11:15 am. Therefore, the falling tide was between 11:15 am and 5:45 pm. As shown in **Table 2-8**, samples were collected from M025U/D and M-26U/D before this time range. Due to time constraints while sampling, vertical profiling could not be performed; however, given their location further upstream from the mouth of the ocean, saltwater impacts were expected to be minimal, and field readings from the field data sheets for salinity and conductivity corroborate this assumption.

Table 2-8: Tidally Influenced Samples Not Collected during the Outgoing Tide for Event #1 Dry Weather Survey

Station ID	Sample Time
M025U	9:06 AM
M025D	9:30 AM
M026U	10:15 AM
M026D	10:54 AM

Hold Times/Sample Preservation

There are no hold time deviations to report. Bacteria analysis require samples be relinquished to the laboratory within 6-hours of sample collection in order to be analyzed within 8-hours of sample collection. All samples were submitted to the laboratories within required hold times, including those analyses with short 6-8-hour or 24-hour hold times.

All samples collected on the day of sampling were preserved on ice during sampling and transportation, and were transported to the laboratory within hold times, but there are 11 samples that were reported as being received between 10.2°C and 11°C. All of these samples were collected between 6:15 am and 8:30 am, and were in transit to the lab by 9:45 am. It is estimated that all of these samples were in laboratory custody within 2 to 4.5 hours after sample collection, and any temperature impacts during that brief time period would be minimal. It is suspected that the warmer temperatures measured at receipt may be a result of consolidation of sample bottles into fewer coolers to facilitate transportation and the time required for that cooler's temperature to fully acclimate.

2.2 Mainstem Event #2 - Wet Weather Survey Description

The first wet weather water quality survey was conducted on 1 October 2015. Field crews collected samples and field readings from approximately 6:00 am to 6:00 pm. Sample runners transported bacteria samples from the sampling teams to EAI for *E. coli*, fecal coliform, and enterococcus (marine waters only) analysis throughout the day in order to meet the six-hour hold time for those samples. Additional samples transported to EAI via sample runner or EAI courier included chlorophyll-a, TSS, 5-CBOD5, and CBOD20. All other samples for nutrient and DO analysis were transported to SMAST the day after the event. Effluent samples provided by each of the eleven WWTPs were collected by sample runners the day after the event upon conclusion of the 24-hour compositing period, and bottles were transported to either EAI or SMAST as applicable.

QA/QC samples were collected at four or five locations to achieve >5% frequency (4 out of 74 samples/5 out of 85 samples, depending on the analysis), consisting of field blanks, field duplicates, and equipment rinsate blanks. **Table 2-9** lists the sample times and analyses for each of the sample stations.

Table 2-9: Mainstem Event #2 - Wet Weather Survey Sampling Details
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Location	Station Type	Sample Type	Sample Time[1]	Field Readings[3]	Nutrients	Winkler DO	CBOD$_5$	CBOD$_{20}$	Total Suspended Solids	Chlorophyll-a	E. coli	Fecal Coliform	Field Blank	Field Duplicate	Equip. Rinsate Blank
M001	D/S Hooksett Dam	Mainstem	grab	6:10 AM	X	X	X	X		X	X	X	X			
M002	U/S Amoskeag Dam	Mainstem	grab	8:06 AM	X	X		X		X	X	X	X			
O006U	U/S Lowell Pawtucket Stormdrain	Mainstem	grab	6:45 AM	X	X		X		X	X	X	X			
O006D	D/S Lowell Pawtucket Stormdrain	Mainstem	grab	7:20 AM	X	X		X		X	X	X	X			
M003	D/S Amoskeag Dam	Mainstem	grab	11:20 AM	X	X		X		X	X	X	X			
O001U	U/S Chauncey Ave Outfall	Mainstem	grab	7:10 AM	X	X		X		X	X	X	X			
O001D	D/S Chauncey Ave Outfall	Mainstem	grab	7:40 AM	X	X		X		X	X	X	X			
T001	Piscataquog River	Tributary	grab	6:04 AM	X	X		X		X	X	X	X			
O007U	U/S Trull Brook Stormdrain	Mainstem	grab	1:45 PM	X	X		X		X	X	X	X			
O007D	D/S Trull Brook Stormdrain	Mainstem	grab	2:00 PM	X	X		X		X	X	X	X			
M004	D/S Manchester	Mainstem	grab	1:35 PM	X	X	X	X		X	X	X	X	X	X	X
M005U	U/S Manchester WWTP	Mainstem	grab	10:30 AM	X	X		X		X	X	X	X			
M005D	D/S Manchester WWTP	Mainstem	Spatial composite	10:00 AM	X	X		X	X	X	X	X	X			
T002	Cohas Brook	Tributary	grab	11:00 AM	X	X		X		X	X	X	X			
M006U[2]	U/S Derry WWTP	Mainstem	grab	---	X											
M006D	D/S Derry WWTP	Mainstem	Spatial composite	4:03 PM	X	X		X	X	X	X	X	X			
T003	Souhegan River	Tributary	grab	3:50 PM	X	X		X		X	X	X	X			
M007U	U/S Merrimack WWTP	Mainstem	grab	8:25 AM	X	X		X		X	X	X	X			
M007D	D/S Merrimack WWTP	Mainstem	Spatial composite	9:05 AM	X	X		X	X	X	X	X	X			
M008	U/S Nashua	Mainstem	grab	9:40 AM	X	X	X	X		X	X	X	X			
T004	Nashua River	Tributary	grab	3:05 PM	X	X		X		X	X	X	X			
O002U	U/S Bridges St Stormdrain	Mainstem	grab	8:10 AM	X	X		X		X	X	X	X			
O002D	D/S Bridges St Stormdrain	Mainstem	grab	7:00 AM	X	X	X	X		X	X	X	X	X	X	X
T005	SalmonBrook	Tributary	grab	2:00 PM	X	X		X		X	X	X	X			
M009U	U/S Nashua WWTP	Mainstem	grab	2:25 PM	X	X		X		X	X	X	X			
M009D	D/S Nashua WWTP	Mainstem	Spatial composite	2:45 PM	X	X		X	X	X	X	X	X			
M010	D/S Nashua	Mainstem	grab	3:20 PM	X	X	X	X		X	X	X	X			
M011	U/S Lowell	Mainstem	grab	7:15 AM	X	X	X	X		X	X	X	X			
T006	Stony Brook	Tributary	grab	5:10 PM	X	X		X		X	X	X	X			
O008U	U/S Shawsheen Stormdrain	Tributary	grab	3:30 PM	X	X		X		X	X	X	X			
O008D	D/S Shawsheen Stormdrain	Tributary	grab	3:00 PM	X	X		X		X	X	X	X			
M012	Lowell Public Beach	Mainstem	grab	9:20 AM	X	X		X		X	X	X	X			
M013	U/S Pawtucket Dam	Mainstem	grab	9:45 AM	X	X		X		X	X	X	X			
T007	Beaver Brook	Tributary	grab	4:55 PM	X	X		X		X	X	X	X			
M014	D/S Pawtucket Dam	Mainstem	grab	8:15 AM	X	X		X		X	X	X	X			
T008	Concord River	Tributary	grab	6:00 PM	X	X		X		X	X	X	X			
M015	D/S Lowell	Mainstem	grab	9:20 AM	X	X	X	X		X	X	X	X			
O003U	U/S Manchester Stormdrain	Mainstem	grab	11:45 AM	X	X		X		X	X	X	X			
O003D	D/S Manchester Stormdrain	Mainstem	grab	12:05 PM	X	X		X		X	X	X	X			
M016U	U/S Lowell WWTP	Mainstem	grab	12:40 PM	X	X		X		X	X	X	X			
M016D	D/S Lowell WWTP	Mainstem	Spatial composite	1:15 PM	X	X		X	X	X	X	X	X	X	X	X
M017	U/S Lawrence	Mainstem	grab	3:45 PM	X	X	X	X		X	X	X	X			
M018	U/S Essex Dam	Mainstem	grab	4:30 PM	X	X		X		X	X	X	X			
M019	D/S Essex Dam	Mainstem	grab	11:15 AM	X	X		X		X	X	X	X			
O004U	U/S Mines Falls Stormdrain	Tributary	grab	12:15 PM	X	X		X		X	X	X	X			
O004D	D/S Mines Falls Stormdrain	Tributary	grab	12:45 PM	X	X		X		X	X	X	X			
T009	Spicket River	Tributary	grab	11:50 AM	X	X		X		X	X	X	X			
O009U	U/S Methuen Stormdrain	Mainstem	grab	9:25 AM	X	X		X		X	X	X	X			
O009D	D/S Methuen Stormdrain	Mainstem	grab	9:15 AM	X	X		X		X	X	X	X			
T010	Shawsheen River	Tributary	grab	12:30 PM	X	X		X		X	X	X	X	X	X	X
M020	D/S Lawrence	Mainstem	grab	6:42 AM	X	X	X	X		X	X	X	X			
M021U	U/S GLSD WWTP	Mainstem	grab	7:31 AM	X	X		X		X	X	X	X			
M021D	D/S GLSD WWTP	Mainstem	Spatial composite	7:45 AM	X	X		X	X	X	X	X	X			
M022	U/S Haverhill	Mainstem	grab	8:30 AM	X	X	X	X		X	X	X	X			
M023U	D/S Methuen	Mainstem	grab	11:25 AM	X	X		X		X	X	X	X			
O005U	U/S Lowell Stormdrain	Mainstem	grab	8:20 AM	X	X		X		X	X	X	X			
O005D	D/S Lowell Stormdrain	Mainstem	grab	8:35 AM	X	X		X		X	X	X	X			
T012	Little River	Tributary	grab	1:40 PM	X	X		X		X	X	X	X			

Table 2-9: Mainstem Event #2 - Wet Weather Survey Sampling Details
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Location	Station Type	Sample Type	Sample Time[1]	Field Readings[3]	Nutrients	Winkler DO	$CBOD_5$	$CBOD_{20}$	Total Suspended Solids	Chlorophyll-a	E. coli	Fecal Coliform	Field Blank	Field Duplicate	Equip. Rinsate Blank
O010U	U/S Water St. Stormdrain	Mainstem	grab	11:55 AM	X	X		X		X	X	X	X			
O010D	D/S Water St. Stormdrain	Mainstem	grab	12:07 PM	X	X		X		X	X	X	X			
M023D	D/S Haverhill	Mainstem	grab	12:34 PM	X	X		X		X	X	X	X			
M024U	U/S Haverhill WWTP	Mainstem	grab	1:00 PM	X	X		X		X	X	X	X			
M024D	D/S Haverhill WWTP	Mainstem	Spatial composite	1:30 PM	X	X		X	X	X	X	X	X	X	X	X
M025U	U/S Merrimac WWTP	Mainstem	grab	2:10 PM	X	X		X		X	X	X	X			
M025D	D/S Merrimac WWTP	Mainstem	Spatial composite	1:35 PM	X	X		X	X	X	X	X	X			
M026U	U/S Amesbury WWTP	Mainstem	grab	12:28 PM	X	X		X		X	X	X	X			
M026D	D/S Amesbury WWTP	Mainstem	Spatial composite	12:10 PM	X	X		X	X	X	X	X	X			
T011	Powwow River	Tributary	grab	11:08 AM	X	X		X		X	X	X	X			
M028U	U/S Salisbury WWTP	Mainstem	grab	10:30 AM	X	X		X		X	X	X	X			
M028D	D/S Salisbury WWTP	Mainstem	Spatial composite	9:45 AM	X	X		X	X	X	X	X	X			
M029U	U/S Newburyport WWTP	Mainstem	grab	8:21 AM	X	X		X		X	X	X	X			
M029D	D/S Newburyport WWTP	Mainstem	Spatial composite	7:35 AM	X	X		X	X	X	X	X	X			
M027	Shellfish Bed	Mainstem	grab	6:41 AM	X	X	X	X		X	X	X	X			
M030	Shellfish Bed	Mainstem	grab	8:51 AM	X	X	X	X		X	X	X	X			
Manchester	Manchester WWTP Effluent	WWTP Effluent	Composite[4]	11:50 PM	X	X		X	X	X						
Derry	Derry WWTP Effluent	WWTP Effluent	Composite[4]	7:30 AM	X	X		X	X	X						
Merrimack NH	Merrimack, NH WWTP Effluent	WWTP Effluent	Composite[4]	9:00 AM	X	X		X	X	X						
Nashua	Nashua WWTP Effluent	WWTP Effluent	Composite[4]	7:30 AM	X	X		X	X	X						
LRWWU	LRWWU Effluent	WWTP Effluent	Composite[4]	8:00 AM	X	X		X	X	X						
GLSD	GLSD Effluent	WWTP Effluent	Composite[4]	12:00 AM	X	X		X	X	X						
Haverhill	Haverhill WWTP Effluent	WWTP Effluent	Composite[4]	7:30 AM	X	X		X	X	X						
Merrimac MA	Merrimac, MA WWTP Effluent	WWTP Effluent	Composite[4]	8:00 AM	X	X		X	X	X						
Amesbury	Amesbury WWTP Effluent	WWTP Effluent	Composite[4]	8:00 AM	X	X		X	X	X						
Salisbury	Salisbury WWTP Effluent	WWTP Effluent	Composite[4]	8:00 AM	X	X		X	X	X						
Newburyport	Newburyport WWTP Effluent	WWTP Effluent	Composite[4]	7:30 AM	X	X		X	X	X						

Notes:

1 - Sample time given for grab sample. Multiple field readings were taken approximately 10 minutes apart.

2 - Grab samples were not collected at M006U due to safety concerns

3 - Field readings include: pH, DO, temperature, conductivity, turbidity, and salinity (if applicable)

4 - All WWTP samples are 24-hour composite samples. Sample time relfects when the composite was stopped and sample bottles filled.

2.2.1 Precipitation and Streamflow Conditions

The precipitation totals for five locations within or adjacent to the watershed are shown in **Table 2-10**. As shown, the entire watershed received sufficient precipitation between the evenings of September 29 and 30 to be considered a full coverage wet weather event. Event #2 falls within the first category of storm intensities, as greater than 1 inch of rain was received over a 12-hour period prior to the sampling event. CSOs were activated in all five major communities during the heavy rainstorm on September 29-30, 2015.

Table 2-10: Precipitation Totals for Event #2 – Wet Weather Survey

Date	Total Daily Precipitation (inches)				
	Location				
	Concord, NH (N of study area)	Manchester, NH	Nashua, NH	Worcester, MA (SW of study area)	Lawrence, MA
	Source: NOAA, Weather Underground	*Source: Weather Underground*	*Source: Weather Underground*	*Source: NOAA, Weather Underground*	*Source: Weather Underground*
9/24/2015	0.00	0.00	0.00	0.00	0.00
9/25/2015	0.00	0.00	0.00	0.00	0.00
9/26/2015	0.00	0.00	0.00	0.00	0.00
9/27/2015	0.00	0.00	0.00	0.00	0.00
9/28/2015	0.00	0.00	0.00	0.00	0.00
9/29/2015	0.23	0.74	0.07	0.13	0.00
9/30/2015	3.60	2.16	2.23	2.39	2.70
10/1/2015	0.00	Trace	0.00	0.03	0.01
7 Day Total (in)	3.83	2.90	2.30	2.52	2.70
3 Day Total (in)	3.83	2.90	2.30	2.52	2.70

The decision to conduct the first wet weather sampling event was made by USACE based on data review and interpretation, and recommendation from CDM Smith. Weather conditions and laboratory availability in the summer of 2015 prevented a dry weather event from occurring. When a significant rainstorm was forecasted throughout the watershed and it was confirmed that flows had receded at least 75% after the prior storm at the two mainstem tracking gages, the project team decided that conditions were appropriate to conduct the wet weather sampling. **Table 2-11** shows the average flows on the day of the first wet weather event with comparisons to the mean monthly streamflow for each gage (Goffs Falls and Lowell, MA). While a minimum target flow for sampling was not a requirement of the Field Sampling Plan for wet weather surveys, it is important to note that there were high flow conditions on the day of sampling.

Table 2-11: Mainstem Streamflow Conditions for Event #2- Wet Weather Survey

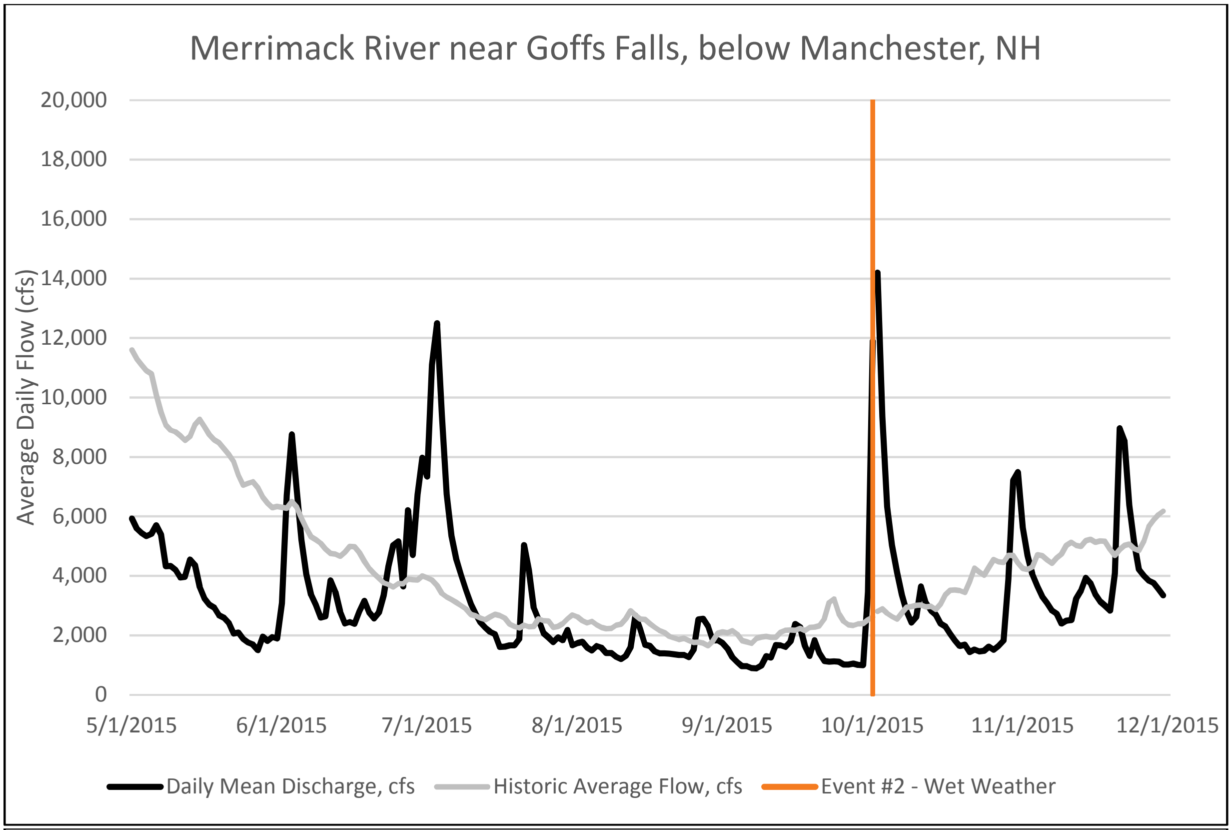
Gage	Daily Average Flow 10/1/2015 (cfs)	Mean Monthly Streamflow[1] (cfs)	Daily Average Flow Compared to Mean Monthly Streamflow
Merrimack River near Goffs Falls, below Manchester, NH (Gage # 01092000)	12,111[2]	3,390	12,111 > 3,390
Merrimack River below Concord River at Lowell, MA (Gage #01100000)	10,602[3]	4,650	10,602 > 4,650

Notes:

2. A month is defined as a calendar month. Mean monthly streamflows for the Goffs Falls gage (USGS 01092000) and Lowell, MA gage (USGS 01100000) were determined as part of the prior Field Sampling Plan efforts, based on USGS data dating back to 1936 and 1923, respectively, through November 2012. Since that time, additional data has been aggregated by USGS causing the mean monthly streamflows to vary over time. For consistency, the mean monthly streamflow established in the FSP will be referenced herein.
3. USGS Data: http://waterdata.usgs.gov/nh/nwis/uv/?site_no=01092000&PARAmeter_cd=00065,00060
4. USGS Data: http://waterdata.usgs.gov/nwis/uv?site_no=01100000

cfs – cubic feet per second

Figure 2-4 shows the summer/fall 2015 streamflow time series at each gage and the date when the first wet weather event took place. While streamflows were typically at or below average at both gages during the summer months leading up to the event on 1 October 2015, there were multiple significant rainstorms that caused flows to temporarily rise. The graphs show the river's response to the targeted storm event observed the evening of September 29 into September 30, and illustrate that the wet weather survey captured the targeted wet weather and high flow conditions.



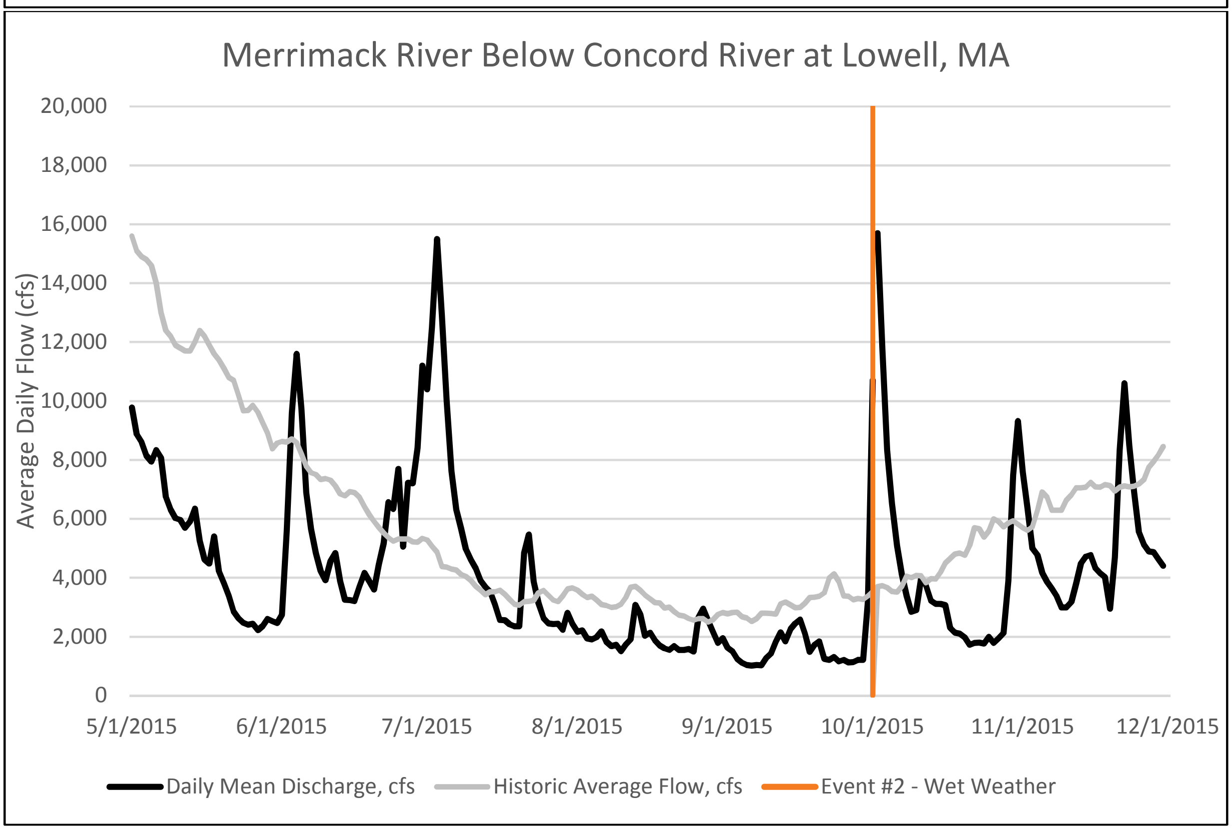


Figure 2-4: Streamflow Conditions for Event #2 - Wet Weather Survey

Flows at the sampled tributaries were measured using available USGS gage flows. Table 2-5 provided a summary of the active USGS gaging stations in select tributaries. **Table 2-12** shows the measured flows at each tributary for 1 October 2015, if available, using the gages closest to the point of confluence with the mainstem river. The Nashua River contributed the largest volume of flow on the day of the first wet weather sampling event. Three tributary gauges recorded daily average flow on October 1st below the mean monthly flows (Beaver Brook, Concord River, Spicket River); however, there are no flow targets for the tributaries required in the FSP. The only flow related requirements for a wet weather event in the FSP is that the previous storm's hydrograph must have receded by at least 75% before a new storm can be tracked and identified for a sampling opportunity.

Table 2-12: Gaged Tributary Streamflow for Event #2 – Wet Weather Survey

Location	Station ID	Flow	
		Daily Average Flow 10/1/2015 (cfs)	Mean Monthly Streamflow - October (cfs)[1]
Piscataquog River	T001	673	73
Cohas Brook	T002	-	-
Souhegan River	T003	615	128
Nashua River	T004	729	356
Salmon Brook	T005	-	-
Stony Brook	T006	-	-
Beaver Brook	T007	47	49
Concord River	T008	308	347
Spicket River	T009	50.49	141
Shawsheen River	T010	148	85
Little River	T012	-	-
Powwow River	T011	-	-

Notes: cfs – cubic feet per second

1. A month is defined as a calendar month. Mean monthly streamflows for these tributaries were determined as part of the November 2012 Field Sampling Plan efforts, based on historic USGS gage data. Since that time, additional data has been aggregated by USGS causing the mean monthly streamflows to vary over time. For consistency, the mean monthly streamflow established in the FSP will be referenced herein.

2.2.2 QAPP and Field Sampling Plan Deviations

Overall, sampling during the first wet weather event on 1 October 2015 followed the sample protocol as described in the QAPP and Field Sampling Plan. Minor deviations were reported, as follows:

Sampling Locations

As previously mentioned, effluent sampling of eleven WWTPs was added to the sampling program beginning with the 1 October 2015 event, per request from stakeholders. This brought the total number of samples from 74 to 85. Of the 85 sampling locations, only one station could not be sampled and one station had to be slightly modified. M006U, located upstream of the Derry WWTP, could not be accessed by the boat team due to rapids and high flow safety concerns. Location M005U, upstream of the Manchester WWTP, could not be sampled at the original station accessed from the WWTP property due to the presence of multiple active hornet nests. An alternative location for M005U was identified for sample collection. This station was located on the other side of the river (at the end of Station Road), and met the requirements of the Field Sampling Plan for a sample station upstream of the WWTP discharge point.

Sample Analyses

The sample bottle for *E. coli* at station M015 did not contain a sodium thiosulfate tablet. CDM Smith contacted EAI, the laboratory that performs this analysis, and was informed that they have observed missing tablets in bacteria collection bottles resulting from errors in the sample bottle manufacturing process. EAI confirmed that the purpose of the sodium thiosulfate tablet is to neutralize any residual chlorine in a chlorinated water sample, and since these samples are river water rather than chlorinated drinking water, the absence of the sodium thiosulfate tablets would not adversely affect the analytical results.

Field Readings

Due to the limited time available to collect the sample on the evening of October 1, field parameters were not collected at station T007. Additionally, WWTP facilities were unable to collect all field parameters. Parameters collected were based on available instrumentation at each facility. In-situ measurement field worksheets were not collected from the LRWWU or Merrimack, NH facilities.

Tidally Influenced Samples

Locations downstream of Haverhill are tidally influenced. Sampling conducted at Stations M027, M028U/D, M029U/D, and M030 may be heavily influenced by tidal effects as they are located at the mouth of the river as it discharges to the Atlantic Ocean. As a result, sampling of these six stations should be collected on an outgoing tide to the extent practicable. Also, it is preferred that stations M024U/D, M025U/D, M026U/D, and T011 are collected on an outgoing tide, but is not required as they are located further upstream from the mouth. Alternately, vertical profiling may be done to ensure no saltwater impacts in that sample. The intent is to ensure that the samples being collected are representative of river conditions, and to minimize collection of non-representative saltwater samples. The low tide on 1 October 2015 was at approximately 8:43 am/9:17pm, with the high tide at approximately 2:19am/2:40 pm. Therefore, the falling tides were between 2:19 am and 8:43 am, and 2:40 pm and 9:17 pm. Priority for sampling events must be placed on river flows and precipitation totals, and as such sampling during the falling low tide at select locations may only be performed as feasible. If sampling conditions necessitate a sample be collected outside of the prescribed outgoing tide window, vertical profiling of salinity and conductivity is done to a sufficient depth in order to ensure that the surface sample being collected is representative of river water, without saltwater impacts. As shown in **Table 2-13**, samples were collected from M024U/D, M025U/D, M026U/D, and M028U/D outside of the outgoing tide window. Therefore, vertical profiling was conducted for these locations. Results indicated no saltwater impacts and that the samples collected were representative of river conditions at those stations.

Table 2-13: Tidally Influenced Samples Not Collected during the Outgoing Tide for Event #2 Wet Weather Survey

Station ID	Sample Time
M024U	1:00 PM
M024D	1:30 PM
M025U	2:10 PM
M025D	1:35 PM
M026U	12:28 PM
M026D	12:10 PM
M028U	10:30 AM
M028D	9:45 AM

Hold Times

There are no significant hold time deviations to report. Bacteria analysis require samples be relinquished to the laboratory within 6-hours of sample collection in order to be analyzed within 8-hours of sample collection. All samples were submitted to the laboratories within required hold times, including those analyses with short 6-8-hour or 24-hour hold times; however, the Merrimac, MA WWTP Effluent CBOD5 and CBOD20 samples and reanalyzed M027 enterococcus sample were analyzed by the laboratory slightly outside of their respective hold times. Because of established weekly sampling procedures at the Merrimac, MA WWTP, composite sampling occurred one day earlier than the other locations (September 30-October 1). Due to a laboratory oversight, the Merrimac, MA WWTP Effluent sample was analyzed for CBOD and CBOD20 50 hours and 45 minutes after sampling, which is 2 hours and 45 minutes past the hold time of 48 hours. The M027-G-EVENT2 enterococcus sample was diluted and re-analyzed just outside the hold time of 8 hours (8 hours and 54 minutes after sample collection). Since sample preservation was maintained and these hold time exceedances were negligible, no adverse impacts to the sample results are anticipated.

2.3 Mainstem Event #3 – Hybrid (Dry/Wet) Weather Survey Description

The third water quality survey was conducted on 10 August 2016. It was intended to be a dry weather event; however, an unexpected and short, but intense rainstorm commenced after sampling was approximately half-way completed, and the decision was made to continue the event and transition to a hybrid dry/wet weather event. Approximately half of the samples collected during the first half of the event are representative of dry weather conditions, while the remainder of the samples are considered wet as they were collected after the start of rain and/or after impacts in the river were observed. Additional details on field conditions and sample qualification are provided later in this section.

Field crews collected samples and field readings from approximately 6:00 am to 6:00 pm. Sample runners transported bacteria samples from the sampling teams to EAI for *E. coli*, fecal coliform, and enterococcus (marine waters only) analysis throughout the day in order to meet the six-hour hold time for those samples. Additional samples transported to EAI via sample runner or EAI courier included chlorophyll-a, TSS, CBOD5, and CBOD20. All other samples for nutrient and DO analysis were transported to SMAST the day after the event. Effluent samples provided by ten participating WWTPs were collected by sample runners the day after the event upon conclusion of the 24-hour compositing period, and bottles were transported to either EAI or SMAST as applicable.

QA/QC samples were collected at four or five locations to achieve >5% frequency (4 out of 74 samples/5 out of 85 samples, depending on the analysis), consisting of field blanks, field duplicates, and equipment rinsate blanks. **Table 2-14** lists the sample times and analyses for each of the sample stations.

Table 2-14: Mainstem Event #3 - Dry/Wet Weather Survey Sampling Details
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Location	Station Type	Sample Type	Sample Time[1]	Field Readings[3]	Nutrients	Winkler DO	$CBOD_5$	$CBOD_{20}$	Total Suspended Solids	Chlorophyll-a	E. coli	Fecal Coliform	Field Blank	Field Duplicate	Equip. Rinsate Blank	Enterococcus
M001	D/S Hooksett Dam	Mainstem	grab	6:03 AM	X	X	X	X		X	X	X	X				
M002	U/S Amoskeag Dam	Mainstem	grab	8:10 AM	X	X		X		X	X	X	X				
O006U	U/S Lowell Pawtucket Stormdrain	Mainstem	grab	10:10 AM	X	X		X		X	X	X	X				
O006D	D/S Lowell Pawtucket Stormdrain	Mainstem	grab	3:00 PM	X	X		X		X	X	X	X				
M003	D/S Amoskeag Dam	Mainstem	grab	10:15 AM	X	X		X		X	X	X	X				
O001U	U/S Chauncey Ave Outfall	Mainstem	grab	7:04 AM	X	X		X		X	X	X	X				
O001D	D/S Chauncey Ave Outfall	Mainstem	grab	7:20 AM	X	X		X		X	X	X	X				
T001	Piscataquog River	Tributary	grab	6:15 AM	X	X		X		X	X	X	X				
O007U	U/S Trull Brook Stormdrain	Mainstem	grab	1:10 PM	X	X		X		X	X	X	X				
O007D	D/S Trull Brook Stormdrain	Mainstem	grab	1:25 PM	X	X		X		X	X	X	X				
M004	D/S Manchester	Mainstem	grab	12:55 PM	X	X	X	X		X	X	X	X	X	X	X	
M005U	U/S Manchester WWTP	Mainstem	grab	8:15 AM	X	X		X		X	X	X	X				
M005D	D/S Manchester WWTP	Mainstem	Spatial composite	9:05 AM	X	X		X	X	X	X	X	X				
T002	Cohas Brook	Tributary	grab	9:40 AM	X	X		X		X	X	X	X				
M006U	U/S Derry WWTP	Mainstem	grab	10:10 AM	X	X		X		X	X	X	X				
M006D	D/S Derry WWTP	Mainstem	Spatial composite	3:00 PM	X	X		X	X	X	X	X	X				
T003	Souhegan River	Tributary	grab	1:20 PM	X	X		X		X	X	X	X				
M007U	U/S Merrimack WWTP	Mainstem	grab	7:15 AM	X	X		X		X	X	X	X				
M007D	D/S Merrimack WWTP	Mainstem	Spatial composite	7:50 AM	X	X		X	X	X	X	X	X				
M008	U/S Nashua	Mainstem	grab	8:10 AM	X	X	X	X		X	X	X	X				
T004	Nashua River	Tributary	grab	2:25 PM	X	X		X		X	X	X	X				
O002U	U/S Bridges St Stormdrain	Mainstem	grab	6:35 AM	X	X		X		X	X	X	X				
O002D	D/S Bridges St Stormdrain	Mainstem	grab	7:00 AM	X	X	X	X		X	X	X	X	X	X	X	
T005	SalmonBrook	Tributary	grab	10:10 AM	X	X		X		X	X	X	X				
M009U	U/S Nashua WWTP	Mainstem	grab	11:40 AM	X	X		X		X	X	X	X				
M009D	D/S Nashua WWTP	Mainstem	Spatial composite	11:25 AM	X	X		X	X	X	X	X	X				
M010	D/S Nashua	Mainstem	grab	11:00 AM	X	X	X	X		X	X	X	X				
M011	U/S Lowell	Mainstem	grab	6:30 AM	X	X	X	X		X	X	X	X				
T006	Stony Brook	Tributary	grab	1:00 PM	X	X		X		X	X	X	X				
O008U	U/S Shawsheen Stormdrain	Tributary	grab	1:30 PM	X	X		X		X	X	X	X				
O008D	D/S Shawsheen Stormdrain	Tributary	grab	1:15 PM	X	X		X		X	X	X	X				
M012	Lowell Public Beach	Mainstem	grab	8:20 AM	X	X		X		X	X	X	X				
M013	U/S Pawtucket Dam	Mainstem	grab	8:40 AM	X	X		X		X	X	X	X				
T007	Beaver Brook	Tributary	grab	1:30 PM	X	X		X		X	X	X	X				
M014	D/S Pawtucket Dam	Mainstem	grab	7:45 AM	X	X		X		X	X	X	X				
T008	Concord River	Tributary	grab	2:15 PM	X	X		X		X	X	X	X				
M015	D/S Lowell	Mainstem	grab	8:20 AM	X	X	X	X		X	X	X	X				
O003U	U/S Manchester Stormdrain	Mainstem	grab	10:45 AM	X	X		X		X	X	X	X				
O003D	D/S Manchester Stormdrain	Mainstem	grab	10:57 AM	X	X		X		X	X	X	X				
M016U	U/S Lowell WWTP	Mainstem	grab	11:30 AM	X	X		X		X	X	X	X				
M016D	D/S Lowell WWTP	Mainstem	Spatial composite	11:55 AM	X	X		X	X	X	X	X	X	X	X	X	
M017	U/S Lawrence	Mainstem	grab	1:40 PM	X	X	X	X		X	X	X	X				
M018	U/S Essex Dam	Mainstem	grab	2:20 PM	X	X		X		X	X	X	X				
M019	D/S Essex Dam	Mainstem	grab	10:00 AM	X	X		X		X	X	X	X				
O004U	U/S Mines Falls Stormdrain	Tributary	grab	11:40 AM	X	X		X		X	X	X	X				
O004D	D/S Mines Falls Stormdrain	Tributary	grab	12:10 PM	X	X		X		X	X	X	X				
T009	Spicket River	Tributary	grab	10:50 AM	X	X		X		X	X	X	X				
O009U	U/S Methuen Stormdrain	Mainstem	grab	3:45 PM	X	X		X		X	X	X	X				
O009D	D/S Methuen Stormdrain	Mainstem	grab	3:35 PM	X	X		X		X	X	X	X				
T010	Shawsheen River	Tributary	grab	10:50 AM	X	X		X		X	X	X	X	X	X	X	
M020	D/S Lawrence	Mainstem	grab	5:30 PM	X	X	X	X		X	X	X	X				
M021U	U/S GLSD WWTP	Mainstem	grab	5:50 PM	X	X		X		X	X	X	X				
M021D	D/S GLSD WWTP	Mainstem	Spatial composite	5:25 PM	X	X		X	X	X	X	X	X				

Table 2-14: Mainstem Event #3 - Dry/Wet Weather Survey Sampling Details
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Location	Station Type	Sample Type	Sample Time[1]	Field Readings[3]	Nutrients	Winkler DO	CBOD$_5$	CBOD$_{20}$	Total Suspended Solids	Chlorophyll-a	E. coli	Fecal Coliform	Field Blank	Field Duplicate	Equip. Rinsate Blank	Enterococcus
M022	U/S Haverhill	Mainstem	grab	2:25 PM	X	X	X	X		X	X	X	X				
M023U	D/S Methuen	Mainstem	grab	8:00 AM	X	X		X		X	X	X	X				
O005U	U/S Lowell Stormdrain	Mainstem	grab	7:20 AM	X	X		X		X	X	X	X				
O005D	D/S Lowell Stormdrain	Mainstem	grab	7:40 AM	X	X		X		X	X	X	X				
T012	Little River	Tributary	grab	12:15 PM	X	X		X		X	X	X	X				
O010U	U/S Water St. Stormdrain	Mainstem	grab	6:40 AM	X	X		X		X	X	X	X				
O010D	D/S Water St. Stormdrain	Mainstem	grab	7:00 AM	X	X		X		X	X	X	X				
M023D	D/S Haverhill	Mainstem	grab	8:40 AM	X	X		X		X	X	X	X				
M024U	U/S Haverhill WWTP	Mainstem	grab	11:45 AM	X	X		X		X	X	X	X				X
M024D	D/S Haverhill WWTP	Mainstem	Spatial composite	9:30 AM	X	X		X	X	X	X	X	X	X	X	X	X
M025U	U/S Merrimac WWTP	Mainstem	grab	1:20 PM	X	X		X		X	X	X	X				X
M025D	D/S Merrimac WWTP	Mainstem	Spatial composite	2:35 PM	X	X		X	X	X	X	X	X				X
M026U	U/S Amesbury WWTP	Mainstem	grab	12:00 PM	X	X		X		X	X	X	X				X
M026D	D/S Amesbury WWTP	Mainstem	Spatial composite	11:50 AM	X	X		X	X	X	X	X	X				X
T011	Powwow River	Tributary	grab	11:20 AM	X	X		X		X	X	X	X				X
M028U	U/S Salisbury WWTP	Mainstem	grab	10:51 AM	X	X		X		X	X	X	X				X
M028D	D/S Salisbury WWTP	Mainstem	Spatial composite	10:06 AM	X	X		X	X	X	X	X	X				X
M029U	U/S Newburyport WWTP	Mainstem	grab	8:12 AM	X	X		X		X	X	X	X				
M029D	D/S Newburyport WWTP	Mainstem	Spatial composite	9:07 AM	X	X		X	X	X	X	X	X				
M027	Shellfish Bed	Mainstem	grab	6:16 AM	X	X	X	X		X	X	X	X				
M030	Shellfish Bed	Mainstem	grab	7:54 AM	X	X	X	X		X	X	X	X				
Manchester	Manchester WWTP Effluent	WWTP Effluent	24-hour composite [3]	12:00 AM	X	X		X	X	X							
Derry	Derry WWTP Effluent	WWTP Effluent	24-hour composite [3]	7:00 AM	X	X		X	X	X							
Merrimack NH	Merrimack, NH WWTP Effluent	WWTP Effluent	24-hour composite [3]	11:15 AM	X	X		X	X	X							
Nashua	Nashua WWTP Effluent	WWTP Effluent	24-hour composite [3]	10:00 AM	X	X		X	X	X							
LRWWU	LRWWU Effluent	WWTP Effluent	24-hour composite [3]	9:50 AM	X	X		X	X	X							
GLSD[2]	GLSD Effluent	WWTP Effluent	24-hour composite [3]	--	X	X		X	X	X							
Haverhill	Haverhill WWTP Effluent	WWTP Effluent	24-hour composite [3]	7:30 AM	X	X		X	X	X							
Merrimac MA	Merrimac, MA WWTP Effluent	WWTP Effluent	24-hour composite [3]	9:00 AM	X	X		X	X	X							
Amesbury	Amesbury WWTP Effluent	WWTP Effluent	24-hour composite [3]	7:00 AM	X	X		X	X	X							
Salisbury	Salisbury WWTP Effluent	WWTP Effluent	24-hour composite [3]	8:00 AM	X	X		X	X	X							
Newburyport	Newburyport WWTP Effluent	WWTP Effluent	24-hour composite [3]	7:45 AM	X	X		X	X	X							

Notes:

1 - Sample time given for grab sample. Multiple field readings were taken approximately 10 minutes apart.

2 - GLSD samples were not collected.

3 - Field readings include: pH, DO, temperature, conductivity, turbidity, and salinity (if applicable)

4 - All WWTP samples are 24-hour composite samples. Sample time relfects when the composite was stopped and sample bottles filled.

2.3.1 Precipitation and Streamflow Conditions

Dry weather sampling criteria is twofold and requires meeting both low flow and antecedent dry weather conditions. While summer 2016 flows and drought conditions may have been ideal for low flow conditions, there was difficulty meeting the second and more critical dry weather criteria typically targeted in warmer months. Colder than average temperatures were reported in June and July, which shortened the window for ideal sampling conditions. Additionally, frequent rainstorms/thunderstorms occurred in June, July, and August. These short but significant storms prevented sampling opportunities due to the antecedent dry weather requirement of no more than 0.1" of rain in the 7 days before an event to ensure steady state conditions in such a large river.

Ultimately, mainstem Merrimack River sampling was completed on Wednesday August 10th. The decision to sample this day was a result of numerous factors including:

- Very low river flow approaching 7Q10 conditions,
- Acceptably low amounts of rain during the prior seven days, (See **Table 2-15**),
  - Between 0.01" and 0.10" across the watershed in the 7 days prior to the event
  - Between 0.00" and 0.01" across the watershed in the 3 days prior to the event
- A forecast calling for a chance of storms in the afternoon with moderate expectancy, the majority of which were predicted after sampling was to be completed,
- Significant rain forecasted the following weekend that would have further postponed sampling, and
- Being in mid-August, the available window for sampling was beginning to close.

The intent was to capture ideal dry weather low flow conditions before the end of the summer; however, an intense but brief storm moved through the watershed midway through the sampling event in the late morning, during which time rain in excess of the forecasted totals was reported. That is, the event commenced in dry conditions, but rain came earlier and more heavily than the predictions had indicated. As a majority of the samples has already been collected, the decision was made to continue the event. It was determined that samples collected during the event would be qualified based on if they were collected during dry conditions or wet conditions, taking into account both the timing of recordable rain and the response of the river based on USGS stream gages. The pre-rain samples would be indicative of a dry weather survey while the post-rain samples would be more indicative of a wet weather survey. In those instances where a definitive dry/wet designation could not be made (i.e. "transitional" samples), samples were conservatively qualified as wet weather survey samples for the purposes of this data report as they did not represent the dry steady state conditions initially targeted. While not the initial intent of this third mainstem sampling event, this transitional phase information will be useful in model calibration, and will provide the added benefit of being able to compare dry and wet conditions during the same timeframe, and possibly better understand cause-and-effect relationships within the watershed.

Table 2-15 presents the precipitation totals observed across the watershed in the 7 days prior to the event and the day of the August 10th event. The intensity of the precipitation during the second half of mainstem Event #3 was greater than 0.5 inches over 6 hours, throughout the majority of the study area, with a slightly more intense precipitation event in the southern portion, with just over 1 inch over a 6-hour period. CSOs were activated in four of the five major communities during the rainstorm on 10 August 2016.

Table 2-15: Precipitation Totals for Mainstem Event #3 – Dry/Wet Weather Survey

Date	Total Daily Precipitation (inches)				
	Location				
	Concord, NH (N of study area)	Manchester, NH	Nashua, NH	Worcester, MA (SW of study area)	Lawrence, MA
	Source: NOAA, Weather Underground	*Source: NOAA, Weather Underground*	*Source: Weather Underground*	*Source: NOAA, Weather Underground*	*Source: Weather Underground*
8/3/2016	0.00	0.00	0.00	0.00	0.00
8/4/2016	0.00	0.00	0.00	0.00	0.00
8/5/2016	0.00	0.00	0.00	0.00	0.00
8/6/2016	T	0.10	0.05	0.06	0.01
8/7/2016	0.01	T	0.00	0.00	0.00
8/8/2016	0.00	0.00	0.00	0.00	0.00
8/9/2016	0.00	0.00	0.00	0.00	0.00
8/10/2016[1]	0.11	0.37	0.98	0.36	1.06
7 Day Total (in) through start of event	0.01	0.10	0.05	0.06	0.01
3 Day Total (in) through start of event	0.01	T	0.00	0.00	0.00
7 Day Total (in) including rain during event	0.12	0.47	1.03	0.42	1.07
3 Day Total (in) including rain during event	0.11	0.37	0.98	0.36	1.06

Notes:

1. Rainfall began between 8:30 and 10:00 am on 10 August 2016.

T- Trace

Table 2-16 shows the pre- and post-rain average flows on 10 August 2016 with comparisons to the mean monthly streamflow for each active gage (Goffs Falls and Lowell, MA). Even with the precipitation, the average flows displayed minor fluctuations and remained significantly below the mean monthly streamflow target. Additionally, while comparison to the 7Q10 was not a requirement of the FSP and is only informational, it is important to note that daily flows were approaching the 7Q10 flows at both gages on the day of the event, indicating very low flow conditions before and after the rain.

Table 2-16: Mainstem Streamflow Conditions for Mainstem Event #3- Dry/Wet Weather Survey

Gage	Average Flow (cfs)	Mean Monthly Streamflow[1] (cfs)	Dry Weather Target: Average < Mean Monthly	USGS 7Q10 Flow (cfs)	Average Flow Compared to 7Q10[6]
Merrimack River near Goffs Falls, below Manchester, NH (Gage # 01092000)					
Pre-Rain (8/10/16)	721[2]	2,170	Target met 792 < 2,170	644[4]	1.1 x 7Q10
Post-Rain (8/10/16)	841[2]	2,170	No wet weather target	644[4]	1.3 x 7Q10
Merrimack River below Concord River at Lowell, MA (Gage #01100000)					
Pre-Rain (8/10/16)	1,046[3]	3,040	Target met 1,046 < 3,040	930[5]	1.1 x 7Q10
Post-Rain (8/10/16)	1,126[3]	3,040	No wet weather target	930[5]	1.2 x 7Q10

Notes:

1. A month is defined as a calendar month. Mean monthly streamflows for the Goffs Falls and Lowell, MA gages were determined as part of the prior FSP efforts, based on USGS data dating back to 1936 and 1923, respectively, through November 2012. Since that time, additional data has been aggregated by USGS causing the mean monthly streamflows to vary over time. For consistency, the mean monthly streamflow established in the FSP will be referenced herein.
2. USGS Data: http://waterdata.usgs.gov/nh/nwis/uv/?site_no=01092000&PARAmeter_cd=00065,00060
3. USGS Data: http://waterdata.usgs.gov/nwis/uv?site_no=01100000
4. NH DES June, 2013 (http://des.nh.gov/organization/divisions/water/dam/drought/documents/201305-drought-pack.pdf)
5. USGS StreamStats Data (http://streamstatsags.cr.usgs.gov/gagepages/html/01100000.htm)
6. Comparison to 7Q10 for reference only. 7Q10 comparison is not a field sampling plan requirement.

cfs – cubic feet per second

Figure 2-5A shows the summer 2016 streamflow time series at both active gage and the date when the August 2016 event took place. While streamflows were typically below average at both gages during the summer months leading up to the event on 10 August 2016, there were multiple minor rainstorms, as previously discussed, that caused flows to temporarily rise. The sampling event, even after rain began, was completed while the flows were below the monthly average and after the hydrographs had receded from prior events. A closer review of the flows measured at USGS gages indicate only a temporary increase in flows in Lowell corresponding with the few hours after the rainstorm, but no impacts in flows were observed in Manchester. **Figure 2-5B** shows the streamflow time series at each gage the week of the August 2016 hybrid dry/wet weather event. As shown, flows the week of the sampling were very low. The flow variations near Manchester are likely attributed to cycling at the Amoskeag Hydroelectric Plant, located just upstream of the gage. The rain received the day of sampling resulted in a temporary increase to the flows in Lowell, while no measurable impacts were observed in Manchester when compared to the typical daily flow patterns. This suggests that the river system may not have fully responded to the precipitation at the time of afternoon sampling, and that results should be viewed as predominantly representative of dry conditions in the more northern reaches of the sampling area.

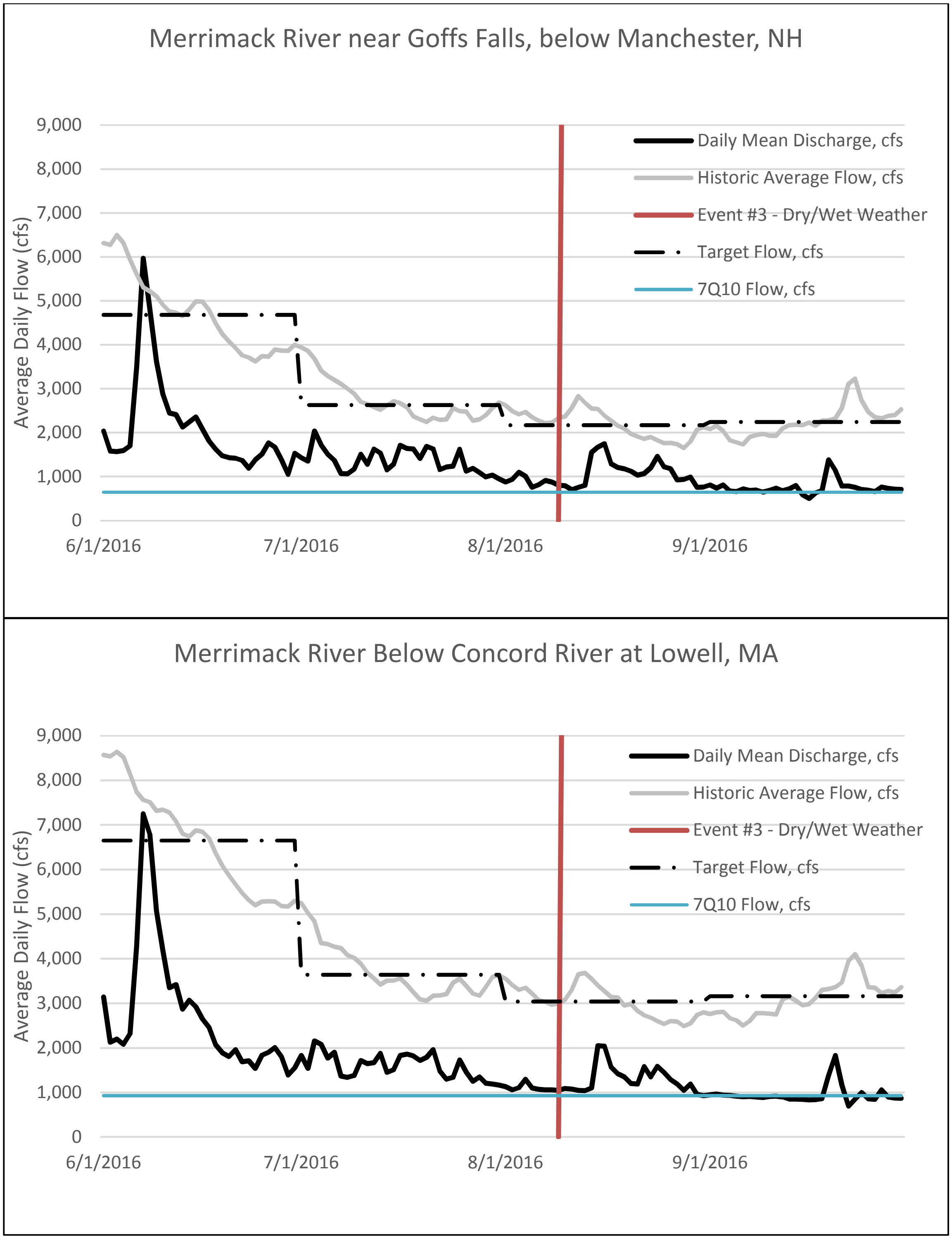
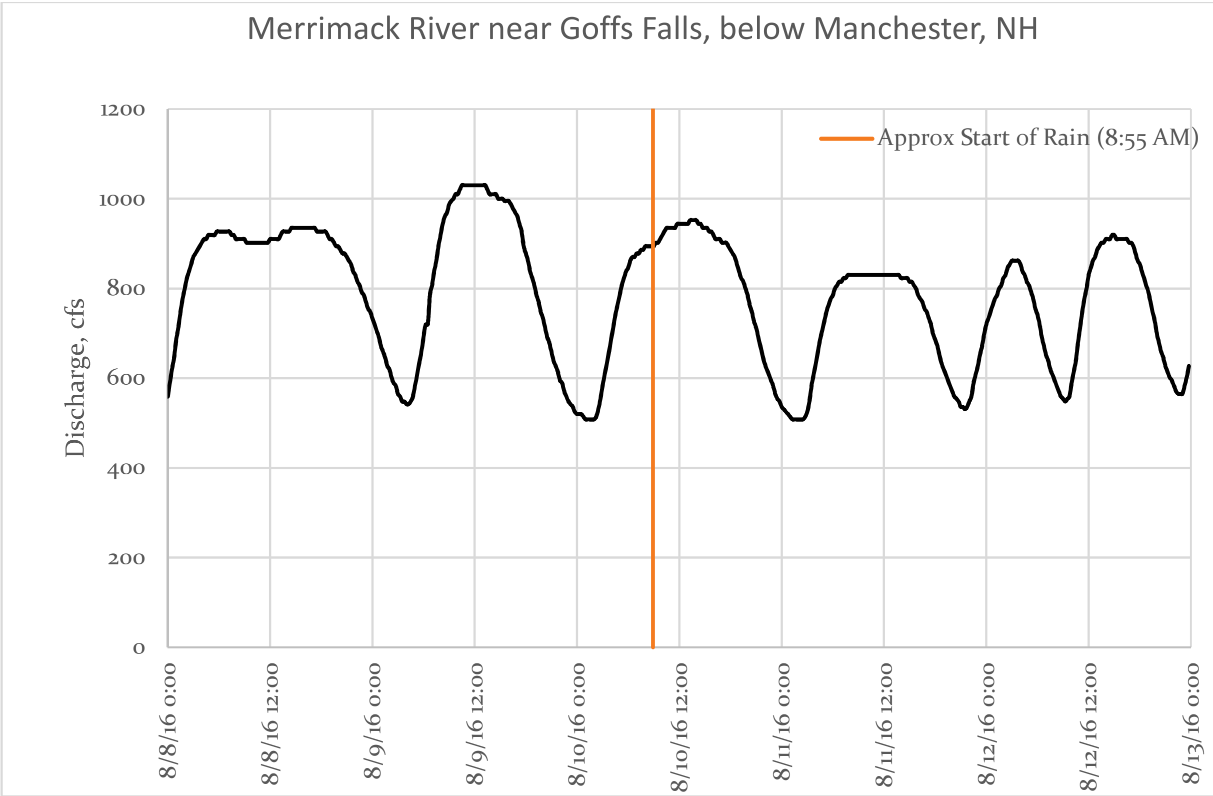


Figure 2-5A: Seasonal Streamflow Conditions for Mainstem Event #3 – Dry/Wet Weather Survey



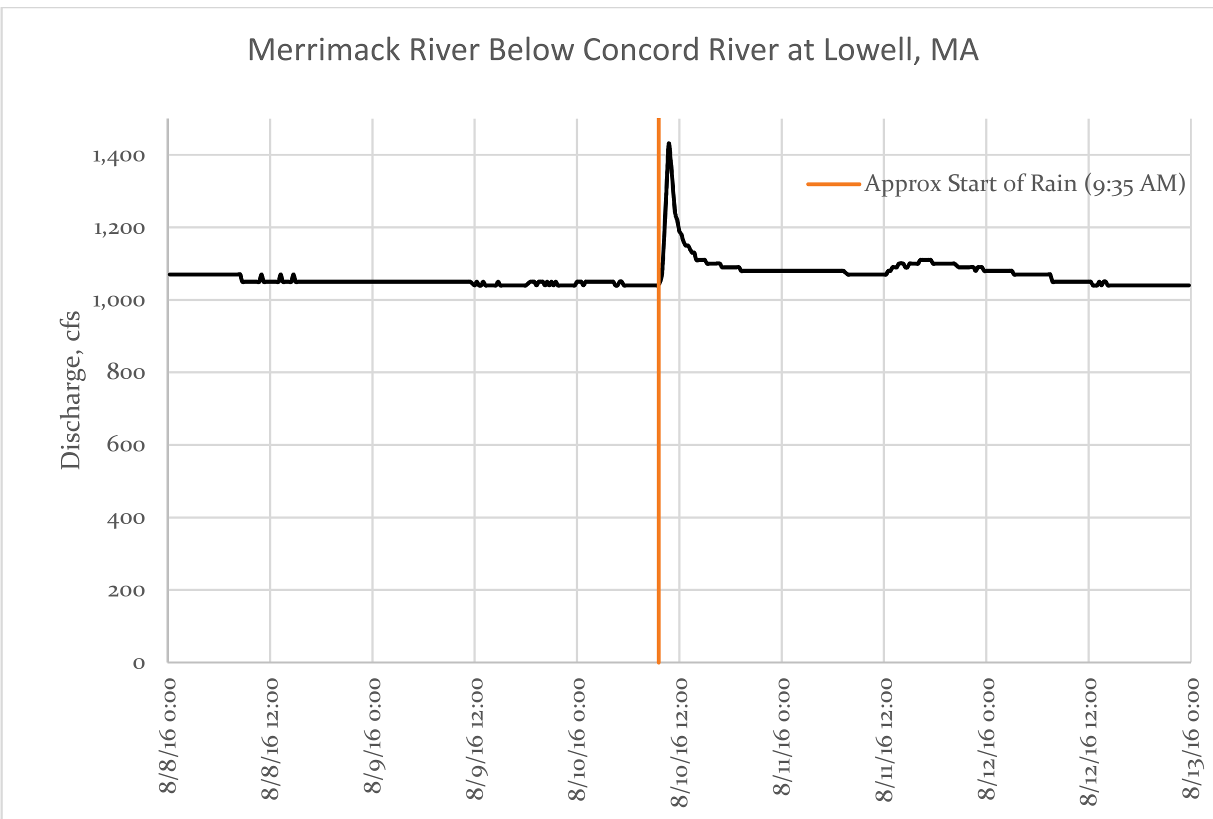


Figure 2-5B: Weekly Streamflow Conditions for Mainstem Event #3 – Dry/Wet Weather Survey

Of critical importance was the condition of the tributaries when they were sampled at the confluence, so rainfall totals and available USGS gage information were also evaluated in their respective basins at the time of sampling to determine whether they represent dry weather tributary inputs. Table 2-5 provided a summary of the active USGS gaging stations in select tributaries. **Table 2-17** shows the measured flows at each tributary for 10 August 2016, if available, using the gages closest to the point of confluence with the mainstem river. As shown, flows in all tributaries with available gage information remained well below mean monthly streamflow targets.

Table 2-17: Gaged Tributary Streamflow for Mainstem Event #3 – Dry/Wet Weather Survey

Location	Station ID	Flow	
		Average Daily Flow 8/10/2016 (cfs)	Mean Monthly Streamflow[1] - August (cfs)
Piscataquog River	T001	-	-
Cohas Brook	T002	-	-
Souhegan River	T003	15	83
Nashua River	T004	70	233
Salmon Brook	T005	-	-
Stony Brook	T006	-	-
Beaver Brook	T007	1.4	21
Concord River	T008	32	248
Spicket River	T009	1.7	38
Shawsheen River	T010	14	62
Little River	T012	-	-
Powwow River	T011	-	-

Notes: cfs – cubic feet per second

1. A month is defined as a calendar month. Mean monthly streamflows for these tributaries were determined as part of the November 2012 Field Sampling Plan efforts, based on historic USGS gage data. Since that time, additional data has been aggregated by USGS causing the mean monthly streamflows to vary over time. For consistency, the mean monthly streamflow established in the FSP will be referenced herein.

This precipitation and flow data throughout the watershed was used to assess the conditions of the mainstem river and its major tributaries. Precipitation radar maps from NOAA[1] in 15-minute increments on 10 August 2016 are included in **Appendix A2**. Based on evaluation of the hourly precipitation data, it was determined that almost half of the samples (were collected prior to the start of any rain by multiple teams stationed throughout the length of the study area, covering a comprehensive cross-section of stations from Manchester through Newburyport. The remaining samples were collected during or after the heaviest period of rain; however, some of these were collected prior to any observed impacts to flows the river. For the purposes for this report, transitional samples (those collected after the rain but where impacts to flows could not be fully evaluated) were conservatively qualified as wet since they do not represent dry steady state conditions. Additional

[1] http://www.srh.noaa.gov/ridge2/RFC_Precip/

analysis of this transitional data will be evaluated as part of the modeling phase, and will be utilized for model calibration.

While the intent was to be a fully dry event and the forecast supported this, the result was a hybrid event. Based on weather and flow analysis, just over half of the samples were qualified as dry (41/74, including 4 tributaries) and just under half as wet (33/74, including 8 tributaries), with coverage throughout the entire study area during both conditions. However, it is important to recognize that not all areas within the river system may have fully responded to the wet weather prior to sampling (that is, runoff and washoff of pollutants may not have peaked, or even reached the sampling locations). For this reason, it is important to consider those transitional samples classified as “wet weather” samples during this event as representative of the onset of a storm, rather than a full response to the storm. Refer to **Table 2-18**. All mainstem samples are representative of wet weather after the observed flow spike in Lowell just before noon, with the exception of stations in and near Manchester, where the river did not exhibit a noticeable increase in flow as it did in Lowell. For the tributaries at their confluence, their status was qualified either wet or dry based on NOAA rainfall coverages of their respective basins and any available gage information at the time each was sampled. All WWTP effluent samples are representative of wet weather conditions since they were taken over a 24-hour period during which there was significant rain.

Table 2-18: Sample Qualification for Mainstem Event #3 - Dry/Wet Weather Survey

Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Station Name	Station Type	River Mile	Sample Time	Wet or Dry	Weather Station
M001	D/S Hooksett Dam	M	80.54	6:03	Dry	MANCH (RAIN: Began 9AM, 0.19" by 9:53 AM); No response in flows in mainstem.
O001U	Chauncey Ave Outfall	M	74.77	7:04	Dry	
O001D	Chauncey Ave Outfall	M	74.72	7:20	Dry	
O002U	Bridges St Stormdrain	M	73.25	6:35	Dry	
M002	U/S Amoskeag Dam	M	73.15	8:10	Dry	
O002D	Bridges St Stormdrain	M	72.26	7:00	Dry	
M003	D/S Amoskeag Dam	M	71.66	10:15	Dry	
T001	Piscataquog River	T	71.05	6:15	Dry	
O003U	Manchester Stormdrain	M	70.96	10:45	Dry	
O003D	Manchester Stormdrain	M	70.9	10:57	Dry	
M004	D/S Manchester	M	68.91	12:55	Dry	
M005U	U/S Manchester WWTP	M	68.27	8:15	Dry	
M005D	D/S Manchester WWTP	M	67.74	9:05	Dry	
T002	Cohas Brook	T	67.46	9:40	Dry	
M006U	U/S Derry WWTP outfall	M	65.02	10:10	Dry	
M006D	D/S Derry WWTP outfall	M	64.84	15:00	Wet	
T003	Souhegan River	T	61.99	13:20	Dry	
M007U	U/S Merrimack WWTP	M	58.27	7:15	Dry	
M007D	D/S Merrimack WWTP	M	58.12	7:50	Dry	
M008	U/S Nashua	M	56.56	8:10	Dry	NASHUA (RAIN: Begin 9AM, 0.23" by 9:29 AM)[1]
T004	Nashua River	T	54.54	14:25	Wet	
O004U	Mine Falls Stormdrain	T	54.53	11:40	Wet	
O004D	Mine Falls Stormdrain	T	54.52	12:10	Wet	
T005	SalmonBrook	T	53.27	10:10	Wet	
M009U	U/S Nashua WWTP	M	53.21	11:40	Wet	
M009D	D/S Nashua WWTP	M	53.02	11:25	Wet	
M010	D/S Nashua	M	51.29	11:00	Wet	
M011	U/S Lowell	M	44.5	6:30	Dry	
O005U	Lowell Stormdrain	M	43.42	7:20	Dry	LAWRENCE (RAIN: 10AM, 0.10" by 9:54 AM,0.22" by 10:10 AM); Flows in Lowell observed to increase between 10 & 11 am. Gage height in Lawrence increased after 12:00 pm.
T006	Stony Brook	T	43.32	13:00	Wet	
O005D	Lowell Stormdrain	M	42.13	7:40	Dry	
M012	Lowell Public Beach	M	41.22	8:20	Dry	
M013	U/S Pawtucket Dam	M	40.99	8:40	Dry	
O006U	Lowell Pawtucket Stormdrain	M	40	6:30	Dry	
O006D	Lowell Pawtucket Stormdrain	M	39.9	7:15	Dry	
T007	Beaver Brook	T	39.9	13:30	Wet	
M014	D/S Pawtucket Dam	M	39.82	7:45	Dry	
T008	Concord River	T	38.96	14:15	Wet	
M015	D/S Lowell	M	38.79	8:20	Dry	
M016U	U/S Lowell WWTP	M	38.11	11:30	Wet	
M016D	D/S Lowell WWTP	M	37.94	11:55	Wet	
O007U	Trull Brook Stormdrain	M	36.3	13:10	Wet	
O007D	Trull Brook Stormdrain	M	36.2	13:25	Wet	
M017	U/S Lawrence	M	34.77	13:40	Wet	
M018	U/S Essex Dam	M	29.43	14:20	Wet	
M019	D/S Essex Dam	M	29.02	10:00	Dry	
O008U	Shawsheen Stormdrain	T	28.36	13:30	Wet	
T009	Spicket River	T	28.26	10:50	Wet	
O008D	Shawsheen Stormdrain	T	27.75	13:15	Wet	

Table 2-18: Sample Qualification for Mainstem Event #3 - Dry/Wet Weather Survey
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Station Name	Station Type	River Mile	Sample Time	Wet or Dry	Weather Station
T010	Shawsheen River	T	27.75	10:50	Wet	LAWRENCE (RAIN: 10AM, 0.10" by 9:54 AM,0.22" by 10:10 AM); Flows in Lowell observed to increase between 10 & 11 am. Gage height in Lawrence increased after 12:00 pm.
M020	D/S Lawrence	M	27.66	17:30	Wet	
M021U	U/S GLSD WWTP	M	27.03	17:50	Wet	
M021D	D/S GLSD WWTP	M	26.88	17:25	Wet	
M022	U/S Haverhill	M	25.08	14:25	Wet	
O009U	Methuen Stormdrain	M	24.2	15:45	Wet	
O009D	Methuen Stormdrain	M	24	15:35	Wet	
M023U	D/S Methuen	M	21.75	8:00	Dry	
O010U	Water St. Stormdrain	M	19.51	6:40	Dry	
T012	Little River	T	19.41	12:15	Wet	
O010D	Water St. Stormdrain	M	18.94	7:00	Dry	
M023D	D/S Haverhill	M	18.26	8:40	Dry	
M024U	U/S Haverhill WWTP	M	17.72	11:45	Wet	
M024D	D/S Haverhill WWTP	M	17.14	9:30	Dry	
M025U	U/S Merrimac WWTP	M	10.79	13:20	Wet	
M025D	D/S Merrimac WWTP	M	10.67	14:35	Wet	
M026U	U/S Amesbury WWTP	M	7.02	12:00	Wet	
M026D	D/S Amesbury WWTP	M	6.92	11:50	Wet	
T011	Powwow River	T	6.89	11:20	Dry	
M028U	U/S Salisbury WWTP	M	4.97	10:51	Dry	
M028D	D/S Salisbury WWTP	M	3.76	10:06	Dry	
M029U	U/S Newburyport WWTP	M	2.74	8:12	Dry	
M029D	D/S Newburyport WWTP	M	2.54	9:07	Dry	
M027	Shellfish Bed	M	2.45	6:16	Dry	
M030	Shellfish Bed	M	2.02	7:54	Dry	

Notes:
1. There is no USGS gage in the Nashua reach of the river, therefore flows could not be assessed in this area.
The closest gage is in Manchester, NH, where there was no response in flow

2.3.2 QAPP and Field Sampling Plan Deviations

Aside from the unexpected rain, sampling during the third event on 10 August 2016 followed the sample protocol as described in the QAPP and Field Sampling Plan. Minor deviations were reported, as follows:

Sampling Locations

As with the October 2015 wet event, effluent sampling of eleven WWTPs was anticipated during the 10 August 2016 event, bringing the station total to 85. Of the 85 total intended sampling locations, only one WWTP effluent location was not sampled. A GLSD effluent sample was not collected because it was not representative of dry weather conditions, which was the initial intent of the event.

Sample Analyses

Due to various circumstances, slight deviations to the sample analyses were required, as follows. The LRWWU autosampler malfunctioned, reducing the collection of samples to only five over a 2.5-hour period instead of 24 over a 24-hour compositing period as intended. As a result, there was only enough sample volume to analyze for Total Phosphorus and other nutrients. That is, the LRWWU sample was not submitted for analysis of CBOD5, CBOD20, or TSS. The autosampler unit at the Salisbury WWTP also malfunctioned, so instead of a 24-hr composite sample on 10 August 2016, grab samples were taken the morning of 11 August 2016. The glass sample bottles for the Winkler DO analysis for stations M017 and M027 broke during sampling or transport. Due to the specialized nature of the analysis and specific bottle type, the sample could not be recollected at these locations. Upon completion of the event, a large air bubble was discovered in the Winkler DO bottle for sampling location M001, however, no impacts to the DO were observed based on comparison to field readings and nearby DO concentrations.

Tidally Influenced Samples

Locations downstream of Haverhill are tidally influenced, and sampling conducted at locations M027, M028U/D, M029U/D, and M030 may be the most heavily influenced by tidal changes as they are located at the mouth of the river as it discharges to the Atlantic Ocean. As a result, sampling of these six stations should be collected on an outgoing tide to the extent practicable. Also, it is preferred that stations M024U/D, M025U/D, M026U/D, and T011 are also collected on an outgoing tide, but is not required as they are located further upstream from the mouth. Alternately, vertical profiling of salinity and conductivity to a sufficient depth may be done to ensure no saltwater impacts in that surface sample and that the sample being collected is representative of river water rather than ocean water. The high tide on 10 August 2016 was at approximately 5:30 am, with the low tide at approximately 11:30 am. Therefore, the falling tides and ideal sample time were between those times. Priority for sampling events must be placed on river flows and precipitation totals, and as such sampling during the falling tide at select locations may only be performed as feasible. As shown in **Table 2-19**, select samples were collected outside of the outgoing tide window. Therefore, vertical profiling was conducted for these locations. Results indicated no saltwater impacts and that the samples collected were representative of river conditions at those stations.

Table 2-19: Tidally Influenced Samples Not Collected during the Outgoing Tide for Mainstem Event #3 Dry/Wet Weather Survey

Station ID	Sample Time
M025U	1:40 PM
M025D	2:15 PM
M026U	12:50 PM
M026D	12:40 PM
M028U	3:30 PM
M028D	4:05 PM

Field Readings

The YSI used by Boat Team 5 (sampling locations M025U through M030, plus T011) malfunctioned while sampling. Calibration was ineffective, and the team was unable to repair it in the field despite troubleshooting, so they were given a different YSI later in the day. The new YSI was unable to measure turbidity since it did not have a turbidity sensor, so any field reading taken with the new YSI did not have turbidity readings (M025U, M025D, M026U, M026D, and M028U). They were able to return to location M028D after sampling to complete field measurements.   The YSI used by Boat Team 1 was exhibiting acceptable DO measurements over the course of the day (acceptable DO measurements typically range from 5-12 mg/L or 60-130% saturation, depending on temperature and other factors) , however they tended toward the higher end of the acceptable range despite multiple calibrations (e.g., results ranging from 10.23 mg/L to 11.21 mg/L, and saturations ranging from 124 to 137%). After sampling was completed, results were compared to Winkler DO results. Based on the variability, all DO results for Beat Team 1 were qualified as estimated, but all are considered acceptable. Additionally, WWTP facilities were unable to collect all field parameters. Parameters collected were based on available instrumentation at each facility.

2.4 Key Tributary Event - Dry Weather Survey Description

The tributary dry weather water quality survey was conducted on 21 July 2016. Field crews collected samples and field readings on the Concord, Shawsheen, and Spicket Rivers from approximately 6:45 am to 3:20 pm. Sample runners transported bacteria samples from the sampling teams to EAI for *E. coli* and fecal coliform analysis throughout the day in order to meet the six hour hold time for those samples. Additional samples transported to EAI via sample runner or EAI courier included chlorophyll-a, TSS, CBOD5, and CBOD20. All other samples for nutrient and DO analysis were transported to SMAST at UMASS Dartmouth at the conclusion of the day of sampling.

Quality assurance/quality control (QA/QC) samples were collected at two locations per river to achieve >5% frequency (8-11 sampling locations/river), consisting of field blanks, field duplicates, and equipment rinsate blanks. **Table 2-20** lists the sample times and analyses for each of the sample stations.

Table 2-20: Triburary Event #1 - Dry Weather Survey Sampling Details
Merrimack River Watershed Study
Phase III Lower Merrimack River

Station ID	Location	Station Type	Sample Type	Sample Time[1]	Field Readings[2]	Nutrients	Winkler DO	$CBOD_5$	$CBOD_{20}$	Total Suspended Solids	Chlorophyll-a	E. coli	Fecal Coliform	Field Blank	Field Duplicate	Equip. Rinsate Blank
Concord 1	Assabet River Contribution	Tributary	Grab	8:05 AM	X	X	X	X		X	X	X	X			
Concord 2	Sudbury River Contribution	Tributary	Grab	8:40 AM	X	X		X		X	X	X	X			
Concord 3	Upstream/Background, Concord	Tributary	Grab	6:45 AM	X	X		X		X	X	X	X			
Concord 4	Upstream from Concord WWTP	Tributary	Grab	8:05 AM	X	X		X		X	X	X	X			
Concord 5	Downstream of Concord WWTP, Ag. Fields, and orchards	Tributary	Grab	10:00 AM	X							X	X	X	X	X
Concord 5			Spatial composite	10:00 AM	X	X		X	X	X	X					
Concord 6	Downstream of residents and conservation areas	Tributary	Grab	12:30 PM	X	X		X		X	X	X	X			
Concord 7	Downstream of residents, conservation land, and Rt. 3	Tributary	Grab	9:00 AM	X	X		X		X	X	X	X			
Concord 8	Downstream of residents, high school, sports fields, conservation land	Tributary	Grab	10:05 AM	X	X		X		X	X	X	X			
Concord 9	Upstream Billerica WWTP	Tributary	Grab	10:30 AM	X	X		X		X	X	X	X			
Concord 10	Downstream of Billerica WWTP	Tributary	Grab	12:10 PM	X							X	X			
Concord 10			Spatial composite	12:00 PM	X	X		X	X	X	X					
Concord 11	Downstream of city/residents prior to discharge into Merrimack	Tributary	Grab	12:40 PM	X	X	X	X		X	X	X	X		X	
Shawsheen 1	Upstream/background location, downstream of Hanscom	Tributary	Grab	7:30 AM	X	X	X	X		X	X	X	X		X	
Shawsheen 2	Downstream of residents, commercial areas	Tributary	Grab	8:25 AM	X	X		X		X	X	X	X			
Shawsheen 3	Downstream of gold course	Tributary	Grab	9:05 AM	X	X		X		X	X	X	X			
Shawsheen 4	Downstream of residents and industrial/commercial area	Tributary	Grab	2:00 PM	X	X		X		X	X	X	X			
Shawsheen 5	Downstream of Jones Brook/Billerica Country Club	Tributary	Grab	2:40 PM	X	X		X		X	X	X	X			
Shawsheen 6	Downstream of residents/recreational area access	Tributary	Grab	11:00 AM	X	X		X	X	X	X	X	X	X	X	X
Shawsheen 7	Downstream of residents, Strong Water Brook, Tewksbury Country Club	Tributary	Grab	12:10 PM	X	X		X		X	X	X	X			
Shawsheen 8	Downstream of residents and 93	Tributary	Grab	12:50 PM	X	X		X		X	X	X	X			
Shawsheen 9	Downstream of residents and Indian Ridge Golf Club	Tributary	Grab	1:30 PM	X	X		X		X	X	X	X			
Shawsheen 10	Downstream of Sacred Heard, residents, town, sports fields, dams	Tributary	Grab	2:30 PM	X	X		X		X	X	X	X			
Shawsheen 11	Downstream of residents, 495, and sports field	Tributary	Grab	3:20 PM	X	X		X		X	X	X	X			
Spicket 1	Upstream/background location, Salem, NH	Tributary	Grab	7:20 AM	X	X	X	X		X	X	X	X		X	
Spicket 2	Downstream of Hog Hill Brook and Atkinson Resort & Country Club	Tributary	Grab	8:55 AM	X	X		X		X	X	X	X			
Spicket 3	Downstream of residents/town/greenspace/policy brook	Tributary	Grab	9:30 AM	X	X		X		X	X	X	X			
Spicket 4	Downstream of residents/prior to commercial area	Tributary	Grab	10:15 AM	X	X		X		X	X	X	X			
Spicket 5	Downstream of residents, Rockingham Park/Mall, Commercial area	Tributary	Grab	12:00 PM	X	X		X	X	X	X	X	X	X	X	X
Spicket 6	Downstream of residents, Rockingham Park/Mall, Commercial area	Tributary	Grab	1:00 PM	X	X		X		X	X	X	X			
Spicket 7	Downstream from 93, bird sanctuary, Nevins Farm & Equine Center	Tributary	Grab	1:50 PM	X	X		X		X	X	X	X			
Spicket 8	Downstream of city and residents, prior to discharge in Merrimack	Tributary	Grab	2:30 PM	X	X	X	X		X	X	X	X			

Notes:

1 - Sample time given for grab sample. Multiple field readings were taken approximately 10 minutes apart.

2 - Field readings include: pH, DO, temperature, conductivity, turbidity, and salinity (if applicable)

2.4.1 Precipitation and Streamflow Conditions

The precipitation totals for five locations within or adjacent to the watershed are shown in **Table 2-21**. Two relatively minor rain events occurred in the upper watershed in the seven days before the event. One occurred on 14 July 2016, and one on 18 July 2016, resulting in less than 0.15" of precipitation.

Table 2-21: Precipitation Totals for Tributary Event #1 – Dry Weather Survey

Date	Total Daily Precipitation (inches)		
	Location		
	Nashua, NH (W/ NW of Tributary Study Area)	Bedford, MA	Lawrence, MA
	Source: Weather Underground	*Source: Weather Underground*	*Source: Weather Underground*
7/14/2016	0.01	0.02	0.02
7/15/2016	0.00	0.00	0.00
7/16/2016	0.00	0.00	0.00
7/17/2016	0.00	0.00	0.00
7/18/2016	0.13	0.13	0.04
7/19/2016	0.00	0.00	0.00
7/20/2016	0.00	0.00	0.00
7/21/2016	0.00	0.00	0.00
7 Day Total (in)	0.14	0.15	0.06
3 Day Total (in)	0.00	0.00	0.00

The decision to conduct the first dry weather sampling event was made by USACE based on data review and interpretation, and recommendation from CDM Smith. When flows approached the targets (less than the mean monthly streamflow) at each most downstream USGS gage on the Concord, Shawsheen, and Spicket Rivers, the project team decided that conditions were sufficient to conduct the dry weather sampling. **Table 2-22** shows the average flows during the July 2016 dry weather event with comparisons to the target flow for each gage. Target flows were met at the three tributary gages. In addition, while comparison to the 7-day 10-year low flow value (7Q10) was not a requirement of this field sampling plan, at the time of the event, flows were less than or approximately equal to the 7Q10 flows at each gage.

Table 2-22: Streamflow Conditions for Tributary Event #1 – Dry Weather Survey

Gage	Daily Average Flow 6/25/2014 (cfs)	Mean Monthly Streamflow[1] (cfs)	Daily Average Flow Compared to Mean Monthly Streamflow (Target: Daily Average < Mean Monthly)	USGS 7Q10 Flow (cfs)	Daily Average Flow Compared to 7Q10[2]
Concord River below River Meadow Brook at Lowell, MA (Gage # 01099500)	32[3]	288	Target met 32 < 288	32.2[4]	1.0 x 7Q10
Shawsheen River at Balmoral Street at Andover, MA (Gage # 01100627)	6.9[5]	91	Target met 6.9 < 91	6.57[6]	1.1 x 7Q10
Spicket River near Methuen, MA (Gage # 01100561)	0.64[7]	67	Target met 0.64 < 67	1.22[6]	0.52 x 7Q10

Notes:

1) A month is defined as a calendar month. Mean monthly streamflows for these tributaries were determined as part of the November 2012 Field Sampling Plan efforts, based on historic USGS gage data. Since that time, additional data has been aggregated by USGS causing the mean monthly streamflows to vary over time. For consistency, the mean monthly streamflow established in the FSP will be referenced herein.
2) Comparison to 7Q10 for reference only. 7Q10 comparison is not a field sampling plan requirement.
3) USGS Data (https://waterdata.usgs.gov/ma/nwis/uv/?site_no=01099500&PARAmeter_cd=00065,00060)
4) USGS StreamStats Data (https://streamstatsags.cr.usgs.gov/gagePages/html/01099500.htm)
5) USGS Data (https://waterdata.usgs.gov/ma/nwis/uv/?site_no=01100627&PARAmeter_cd=00065,00060)
6) The 7Q10 flows were calculated for the Spicket and Shawsheen Rivers from available USGS gaging data using USGS DFLOW. Note that there is considerable uncertainty with 7Q10 estimates at the Spicket River and the Shawsheen River at Andover gages due to the relatively short period of record. While the 7Q10 estimates are representative of the available data, it is possible that additional data collection would change the calculated 7Q10 flow,
7) USGS Data: https://waterdata.usgs.gov/ma/nwis/uv/?site_no=01100561&PARAmeter_cd=00065,00060

cfs – cubic feet per second

Figure 2-6A/B shows the spring/summer 2016 streamflow time series at each gage and the date when the dry weather tributary event took place. Streamflows were stable and consistently below average during May and June at all gages before the event occurred, except for the storm events that caused flows to temporarily rise in the watershed in early June. The two minor rain events in the upper watershed within seven days of the July 2016 event resulted in minimal precipitation totals, and flows did not respond significantly, and therefore did not cause postponement of the sampling event. The sampling event occurred on the receding limbs of the hydrographs as flows were below average for late July.

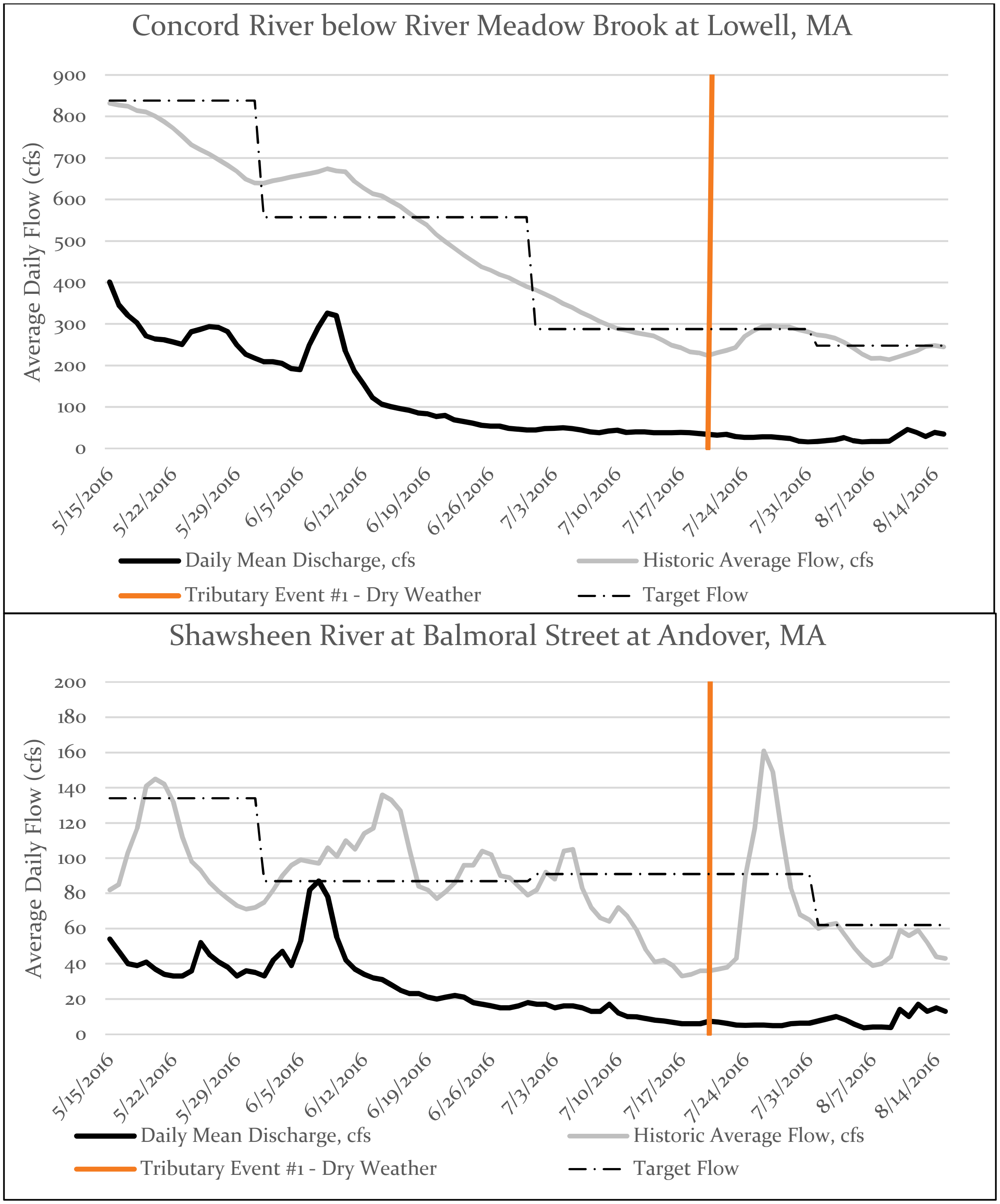


Figure 2-6A: Streamflow Conditions for Tributary Event #1 – Dry Weather Survey (Concord and Shawsheen Rivers)

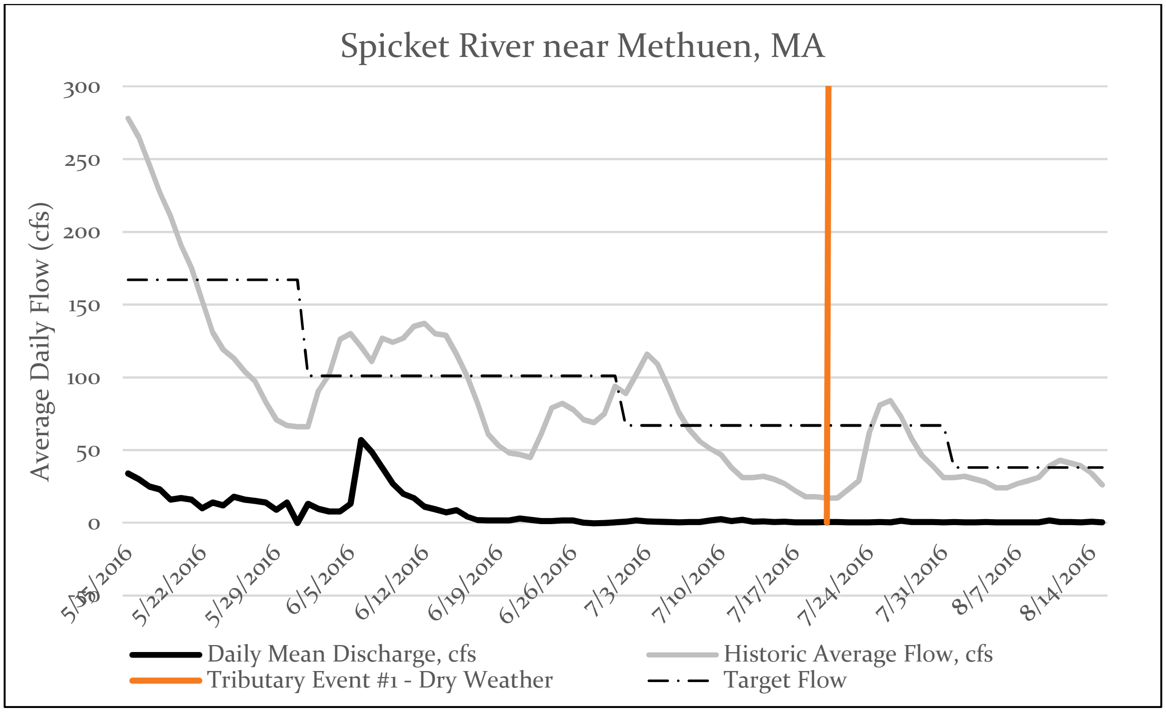


Figure 2-6B: Streamflow Conditions for Tributary Event #1 – Dry Weather Survey (Spicket River)

2.4.2 QAPP and Field Sampling Plan Deviations

Sampling procedures during the first dry weather event on 21 July 2016 followed the sample protocol as described in the QAPP and Field Sampling Plan. No deviations were reported.

Section 3

Mainstem Water Quality Survey Data Summary and Observations

The following subsections offer summaries of the data collected during the June 2014 mainstem dry weather event (Event #1), October 2015 mainstem wet weather event (Event #2), and August 2016 mainstem hybrid (dry/wet weather) event (Event #3). The results from each event are discussed separately, and then laboratory results for all mainstem events (Events #1, 2, and 3) are graphed together for comparison purposes. Fold-out panels containing plots of data described herein can be found at the end of Section 3, following the discussion of all events. Also included on these plots, for reference, are the results from the furthest downstream sampling stations on the Concord, Shawsheen, and Spicket Rivers during the July 2016 dry weather tributary event that correspond with mainstem stations. That is, T008 corresponds to Concord 11, T010 corresponds to Shawsheen 11, and T009 corresponds to Spicket 8. Details on the July 2016 tributary water quality survey can be found in Section 4.

It should be noted that Section 3 focuses on the select few parameters that were determined to be the most critical and most representative of river health. A complete set of data plots can be found in **Appendix B.** Comprehensive data tables for mainstem Event #1 – Dry Weather, Event #2 – Wet Weather, and Event #3- Dry/Wet Weather are included in **Appendix C**. Results of the data validation and evaluation, including the assessment of data usability is included in **Appendix D**. Field data sheets and laboratory results are included in **Appendix E** and **Appendix F**, respectively. A summary of the field observations for the three mainstem events, as recorded on the field data sheets, is included in **Table 3-1**. These observations include tree coverage, algae, wildlife, and other noteworthy conditions or features observed during the sampling events.

Table 3-1: Summary of Mainstem Sample Locations Field Observations
Merrimack River Watershed Study
Phase III Lower Merrimack River

Sample Location			Observations		
Sample ID	Description	River Mile	Event #1 (June 25, 2014)	Event #2 (October 1, 2015)	Event #3 (August 10, 2016)
M001	D/S Hooksett Dam	80.54	Pigeons on bridge (trestle), sampled under bridge	-	Other Observations: Near railroad truss
O001U	Chauncey Ave Outfall	74.77	-	-	-
O001D	Chauncey Ave Outfall	74.72	Two ducks observed	-	-
M002	U/S Amoskeag Dam	73.15	-	-	-
O002U	Bridges St Stormdrain	73.25	Seagulls	Tree cover along water edge, seagull, slight foam	Tree Cover: Along shore, but not at sample location
O002D	Bridges St Stormdrain	72.26	Seagulls	Some tree cover along edge, birds, slight sewage smell, raging river	-
M003	D/S Amoskeag Dam	71.66	Pigeons under bridge, sampled below bridge	Fast current	Wildlife: Mallards, Cormorant
O003U	Manchester Stormdrain	70.96	-	Fast current	Other Observations: lots of trash/film on surface
O003D	Manchester Stormdrain	70.9	-	Ducks, fast current	Wildlife: Mallards
M004	D/S Manchester	68.91	-	-	Wildlife: Bald Eagle
M005U	Manchester WWTP	68.27	Tree cover: edge lined	Tree cover along edge, bees, smell of sewage	Tree cover: along banks Wildlife: Chipmonk Other: No more bees (as was observed during previous events)
M005D	Manchester WWTP	67.74	-	Tree cover along edge of river	-
M006U	Derry WWTP outfall	65.02	Not Sampled	Not Sampled	Tree Cover: yes, along banks Wildlife: Moths and bugs
M006D	Derry WWTP outfall	64.84	Could not ascend rapids above this point in boat	-	Wildlife: Geese
M007U	Merrimack WWTP	58.27	Deciduous/evergreen trees (somewhat dense), birds	-	-
M007D	Merrimack WWTP	58.12	Trees on banks intermittently dense, birds, squirrels, minnows, heavy-duty pump on eastern shore (presumably taking water out of river, loud generator)	Smells like WWTP	-
M008	U/S Nashua	56.56	Tree cover moderately dense at shoreline, birds, rocky outcrops on western shore	-	-
M009U	Nashua WWTP	53.21	Dense tree cover on sides of river, blue heron, other birds, foam from an outfall just upstream	-	-
M009D	Nashua WWTP	53.02	Moderate tree cover, dense along shoreline, blue heron, birds, hawk	-	Wildlife: Kingfisher
M010	D/S Nashua	51.29	Dense tree cover, birds, blue heron	-	-
M011	U/S Lowell	44.5	Rowers, fish	-	Algae Coverage: Some along banks, none visible mid-channel Tree Cover: Wooded along river banks Wildlife: Geese

Phase III Lower Merrimack River

Sample Location			Observations		
Sample ID	Description	River Mile	Event #1 (June 25, 2014)	Event #2 (October 1, 2015)	Event #3 (August 10, 2016)
O005U	Lowell Stormdrain	43.42	Ducks, rowers/boathouse nearby	Gulls on shore, pigeons, rowing down on shore	Tree Cover: Along south bank only Wildlife: Few birds
O005D	Lowell Stormdrain	42.13	-	Gulls, dock and rowers nearby	Tree Cover: Some along south bank, none along north bank near outfall Wildlife: Some birds
M012	Lowell Public Beach	41.22	Chimney swifts	-	Tree cover: Along both shorelines
M013	U/S Pawtucket Dam	40.99	Ducks, blue heron	-	Tree cover: Along both banks
O006U	Lowell Pawtucket Stormdrain	40	Ducks, trees on bank, lots of reaeration u/s canal	Deep and fast river, minimal tree cover, seagulls, sewage smell	Algae Coverage: Substantial attached algae Wildlife: Fish, birds and insects
O006D	Lowell Pawtucket Stormdrain	39.9	Ducks, some tree cover, muck has strong organic decomp. Smell	Minimal tree cover, seagulls	Algae Coverage: Substantial attached algae Wildlife: Fish, birds and insects Other: Lots of trash and trash smell
M014	D/S Pawtucket Dam	39.82	Bridge cover, fish, water has clear color	Fast water, submerged trees	Wildlife: Ducks
M015	D/S Lowell	38.79	Bridge cover	Minimal tree cover	Other observations: Oily sheen
M016U	Lowell WWTP	38.11	Ducks on shore, rocky	Cormorants, mallards, fast moving water, high turbulance	Tree cover: Both banks Wildlife: Heron, Osprey
M016D	Lowell WWTP	37.94	Turtle, ducks	Ducks on shore, high flow, fast water, high turbulance	Tree cover: Both banks Wildlife: Heron, Osprey
O007U	Trull Brook Stormdrain	36.3	-	-	Tree cover: Along river bank Wildlife: Ducks
O007D	Trull Brook Stormdrain	36.2	-	-	Tree cover: Along river bank, deciduous, thick Wildlife: Ducks
M017	U/S Lawrence	34.77	-	-	Tree cover: Deciduous trees overhanging both banks
M018	U/S Essex Dam	29.43	Ducks, geese, seagulls, blue heron	Gulls, mormorans, ducks	Algae Coverage: Along south river bank tree cover: Deciduous trees overhanging both banks Wildlife: Ducks, Geese
M019	D/S Essex Dam	29.02	Minimal algae, bridge cover, herring and seagulls	Minimmal tree cover, sewage smell, debris (mattress) in water	Wildlife: Many birds
M020	D/S Lawrence	27.66	Light tree cover along edge	Crested cormorant, herring gull, some tree cover	Algae Coverage: None Wildlife: Geese, gulls and herons
M021U	GLSD WWTP	27.03	Light tree cover	Edge of river heavily wooded, bald eagle	Other: Train passing
M021D	GLSD WWTP	26.88	Thick tree cover on edge, birds	Heavy tree cover on wwtp side, two bald eagle	-
M022	D/S Methuen	25.08	Thick tree cover on edge, slight organics smell	Bald eagle	Algae Coverage: Algae/duckweed and aquatic grass on south side of river expand from shore 10-12 feet out Wildlife: Cormorants, ducks, eagle and blue herons

Phase III Lower Merrimack River

Sample Location			Observations		
Sample ID	Description	River Mile	Event #1 (June 25, 2014)	Event #2 (October 1, 2015)	Event #3 (August 10, 2016)
O009U	Methuen Stormdrain	24.2	Thin tree cover on edges, Bank appears to be collapsed 200' upstream	Some tree cover, osprey	Algae Coverage: Pocket of algae/aquatic veg. behind bedrock bar on south side of river Wildlife: Blue herons
O009D	Methuen Stormdrain	24	Light tree cover on edges, see O009U- sampled 200' downstream of new GPS location	Bald eagle	Algae Coverage: Slight algae/plant matter build up on southern shore Wildlife: Blue herons
M023U	U/S Haverhill	21.75	Thick tree cover on edges	Mallards	Algae Coverage: No Algae but flating foam, feathers and aquatic grass Wildlife: Gulls, geese, ducks, blue herons and fish jumping Other: Fishy smell just downstream of sample location
O010U	Water St. Stormdrain	19.51	Light tree cover on sides	Mallards	Wildlife: Ducks, pigeons Other: location is near a bridge
O010D	Water St. Stormdrain	18.94	Light tree cover on edges, parking lot on right looking upstream	-	Wildlife: Fish jumping, ducks (mallards)
M023D	D/S Haverhill	18.26	Thick tree cover on one side, thin on the other	Location is next to road	Wildlife: ducks
M024U	Haverhill WWTP	17.72	Thick tree cover on one side, thin on the other	Crow	Wildlife: Gulls and comorants
M024D	Haverhill WWTP	17.14	Thick tree cover on edges	Cormorant, bridge	Wildlife: Geese (Canada), fish jumping
M025U	Merrimac WWTP	10.79	-	Smells like freshwater	Wildlife: Ducks and gulls
M025D	Merrimac WWTP	10.67	-	Cormorants	Wildlife: Ducks and gulls
M026U	Amesbury WWTP	7.02	-	-	-
M026D	Amesbury WWTP	6.92	-	-	-
M028U	Salisbury WWTP	4.97	Two mallards	2-3 cormorants, smell of fresh water	Wildlife: Gulls
M028D	Salisbury WWTP	3.76	-	-	-
M029U	Newburyport WWTP	2.74	Double-crested cormorants, great black-backed gulls	Seals on rocks next to station, cormorants upstream on rocks	Wildlife: Some gulls
M029D	Newburyport WWTP	2.54	-	Seals upstream	-
M027	Shellfish Bed	2.45	-	Terns, gulls	Wildlife: Few gulls
M030	Shellfish Bed	2.02	Gulls	Seals upstream	
T001	Piscataquog River	71.05	Tree cover: edge of bank Ducks	Tree cover along rivers edge, heron, ducks, slight foam	Tree Cover: Along banks Wildlife: Ducks Other: Water suds when disturbed
T002	Cohas Brook	67.46	70% tree cover	Tree cover	Tree Cover: Yes
T003	Souhegan River	61.99	Scattered tree cover along bank, birds, evidence of dogs, human footprints all over bank	Minimal algae coverage, tree cover along edge	Tree Cover: 15% Wildlife: Crow Other: Water very low-walkout on 30ft sandbar to waters edge
T004	Nashua River	54.54	Spotted tree cover, more dense upstream, birds and fish, can hear traffic	Tree cover along edge	Tree Cover: 15% Other: Some submerged aquatic vegetation at edge

Phase III Lower Merrimack River

Sample Location			Observations		
Sample ID	Description	River Mile	Event #1 (June 25, 2014)	Event #2 (October 1, 2015)	Event #3 (August 10, 2016)
O004U	Mine Falls Stormdrain	54.53	Tree cover: edge of bank	Slight algae cover, tree cover along water edge	Tree cover: Along bank Other: Cannot access area upstream of outfall
O004D	Mine Falls Stormdrain	54.52	Tree cover: edge tree lined	Algae coverage minimal, tree cover on waters edge	Tree cover: On rivers edge, not at sample location
T005	SalmonBrook	53.27	Some aquatic vegetation but no algae, dense tree cover in wetland area but past ridge it is dense, birds and turtules, beaver dam approx 50' upstream near a manmade dam	Little algae coverage, little tree cover	Algae Coverage: 30% Tree Cover: None, bridge above Other: Sampling under railroad bridge - channel blocked
T006	Stony Brook	43.32	-	50% tree cover, river slow moving, very turbid, unknown algae	Algae Coverage: Moderate to severe Tree Cover: Along banks
T007	Beaver Brook	39.9	Good tree cover	-	Tree Cover: Yes
T008	Concord River	38.96	Ducks, river tree lined	Minimal tree cover, bridge	Tree Cover: Along banks
T009	Spicket River	28.26	Full tree cover, lots of trash	Complete tree cover, lots of ripples in water	Algae Coverage: Unknown, too much silt Tree Cover: almost full Other: trash
O008U	Shawsheen Stormdrain	28.36	Full tree cover	Moderate tree cover, fast water	Tree Cover: 80% Other Observations: High flow, turbid
O008D	Shawsheen Stormdrain	27.75	Med-full tree cover, birds	Moderate tree cover, fish, fast water	Tree Cover: Full Other Observations: Slow flow, turbid
T010	Shawsheen River	27.75	Slow moving (river)	Partial tree cover (25%)	Tree Cover: 50% Other Observations: Turbid runoff from storm
T012	Little River	19.41	Minimal algae, mostly covered by trees, fish	Moderate tree cover, sewage smell, periphyite/some submerged vegetation	Algae Coverage: Some on the rocks on the side of river Tree Cover: 80% Other: trash/ homeless camp
T011	Powwow River	6.89	-	-	-

Notes:
River mile "0" starts at the mouth of each tributary, at its confulence with the Merrimack River
 - : No observations noted

3.1 Event #1- Dry Weather Data Summary and Observations

Section 3.1 provides the data summary and observations for the 25 June 2014 dry weather water quality survey. While Section 3 is separated by sampling event, results from all mainstem events are included on each data plot (Figures 3-1 to 3-14) for comparison purposes.

3.1.1 Carbonaceous Biological Oxygen Demand

Concentrations of CBOD5 in the river were mostly non-detect (laboratory reporting limit: 2 mg/L; see **Figure 3-1**). While CBOD5 was non-detect in the majority of samples, there were 16 samples where it was detected at or above the laboratory reporting limit, as follows: Downstream of the Manchester WWTP (1 site, at reporting limit); Upstream and downstream of the Mines Falls Stormdrain on the Nashua River (2 sites, 2-3 mg/L); Upstream of the GLSD WWTP (1 site, at reporting limit); Upstream and downstream of the Methuen Stormdrain (2 sites, 4-6 mg/L); Upstream and downstream of the city of Haverhill (3 sites, 4-6 mg/L); Upstream and downstream of the Water Street Stormdrain in Haverhill (2 sites, 5 mg/L); Upstream and downstream of the Haverhill WWTP (2 sites, 3 mg/L); Upstream of Salisbury WWTP (1 site, at reporting limit); At the mouth of Concord River (1 site, 3 mg/L); and at the mouth of Powwow River (1 site, at reporting limit).

CBOD20 was analyzed downstream of WWTPs, with the exception of the GLSD WWTP where it was inadvertently analyzed only at the upstream location due to field error. CBOD20 concentrations ranged from non-detect (laboratory reporting limit: 3 mg/L) to 6 mg/L (indicated with X-markers in **Figure 3-1**). There were five samples measured at or above the reporting limit, including samples collected downstream of the Manchester WWTP (1 site, 4 mg/L), upstream of the GLSD WWTP (1 site, 4 mg/L), downstream of the Haverhill WWTP (1 site, 6 mg/L), downstream of the Merrimac WWTP (1 site, 4 mg/L), and downstream of the Amesbury WWTP (1 site, 4 mg/L).

3.1.2 Chlorophyll-a

Chlorophyll-a concentrations generally increased from upstream to downstream along the Lower Merrimack River during the first dry weather event (**Figure 3-2**). This trend was also observed in the data collected on the Lower Merrimack River as part of the 2002 to 2006 Phase I Merrimack River Watershed Assessment Study, as well as the 2009 to 2012 Pemigewasset and Upper Merrimack River Study. Concentrations ranged from 4 to 35 µg/L in mainstem riverine samples, and 1.5 to 32 µg/L in tributary samples.

It is important to note that after all Phase III sampling was complete it was determined that the laboratory did not fully annotate select chlorophyll-a results that may have had pheophytin interferences. Pheophytin is a degradation product of chlorophyll-a, which has the potential to cause a high bias in the chlorophyll-a result. While the analytical method only requires a qualitative annotation for the potential high bias, the laboratory took an additional step to adjust select chlorophyll-a results based on the calculated interferences. Reductions in chlorophyll-a concentrations averaged approximately 45%. The original and revised results and reductions are included in the Data Validation and Usability Report in Appendix D, which includes six samples collected during the June 2014 round, as well as an additional 32 samples collected during the 2015 and 2016 events discussed later in this section. Only adjusted concentrations are reflected in data tables and plots as they are most representative of chlorophyll-a results. Generally, throughout the study area, the samples taken at the mouths of tributaries had lower chlorophyll-a concentrations than the mainstem receiving water of the Merrimack River at that location. The exceptions were the Concord River and Nashua River, where tributary concentrations were higher than the mainstem.

Chlorophyll-a concentrations increased, at least slightly, within the impoundments behind the Amoskeag Dam, the Pawtucket Dam, and the Essex Dam. However, the dams may act as a break in the run of the river. The chlorophyll-a concentrations dropped 50% after the Amoskeag Dam, 36% after the Pawtucket Dam, and 9% after the Essex Dam with no signs of algae growth behind these dams at the time of sampling. The concentrations fell in the few miles upstream of the Pawtucket Dam.

Chlorophyll-a concentrations dropped significantly downstream of the Powwow River as the Merrimack River approaches the Atlantic Ocean. This drop correlates with the increase in salinity and mixing with marine water at these stations.

The state of New Hampshire uses 15 µg/L as a guideline threshold for maximum chlorophyll-a concentrations for primary contact recreation. Massachusetts does not specify a Surface Water Quality Standard for chlorophyll-a. One sample collected in New Hampshire exceeded the applicable guideline threshold of 15 µg/L. Additionally, while there is no Massachusetts standard, for comparison and discussion purposes, chlorophyll-a concentrations in 36 of the 57 mainstem stations and 2 of the 16 tributary samples in Massachusetts were above the New Hampshire threshold.

3.1.3 Dissolved Oxygen and Temperature

Dissolved Oxygen

Dissolved oxygen levels in the river were measured in-situ using field water quality meters and in the laboratory using Winkler titration. Winkler titration values are used to validate the field meters, which can fall out of calibration while being used in the field. The field-measured values and the Winkler titration values of both dissolved oxygen concentration and percent saturation are shown in **Figures 3-3 and 3-4** (Winkler dissolved oxygen concentration indicated with X-markers in Figure 3-3).

Concentrations of dissolved oxygen measured in the mainstem during the first event ranged from 8.3 to 10.6 mg/L (87 to 125 percent saturation) and 8.1 to 10.2 mg/L (93 to 126 percent saturation) in the tributaries. High dissolved oxygen levels, indicating supersaturation (>100%) may be due to algal photosynthesis. As shown in the data tables in Appendix C, no field readings or Winkler samples showed concentrations less than the New Hampshire Class B or Massachusetts Class B and SB water standards of 5 mg/L, nor percent saturation readings less than the NH Class B average daily saturation standard of 75%[2]. Due to the volume of data and for simplicity and consistency of reporting, the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets.

[2] The percent saturation standard is for daily average dissolved oxygen readings, not single point measurements as were taken during the low flow events.

Winkler values for percent saturation were calculated using the field measured water temperature and specific conductance according to USGS methods[3]. The Winkler samples analyzed for concentration and calculated for percent saturation confirmed the field readings, as evidenced by the similarity of the results in Figure 3-3 and 3-4, and as shown in the data tables in Appendix C. Variations up to 0.5 mg/L are expected since dissolved oxygen conditions can change rapidly in the field due to air-water interactions during the sampling procedure.

Temperature

During the dry weather event, temperatures were generally consistent throughout the study area between 20 and 25°C (**Figure 3-5**). Temperatures decreased towards the confluence with the Atlantic Ocean, ranging from 12 to 19°C downstream of the Powwow River. The average temperature of all mainstem locations upstream of the last site that appears to be influenced by the cooler Atlantic Ocean waters was 22.8°C. The average for all tributary locations was 23.2°C. These temperatures are consistent with those typically seen during summer months and those measured during previous sampling events from 2002 to 2012. Due to the volume of data and for simplicity and consistency of reporting, the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets.

3.1.4 Nitrogen

Total nitrogen concentrations were steady to slightly increasing from upstream to downstream within the study area (**Figure 3-6**). The range of observed total nitrogen concentrations are presented in **Table 3-2**, and results at each station are presented in Appendix C.

Total nitrogen generally increased from upstream to downstream in the river. Upstream of the Manchester WWTP, total nitrogen concentrations were below 1.0 mg/L. Between Manchester and North Andover/Lawrence (GLSD WWTP), concentrations were generally between 1.0 and 1.5 mg/L. Downstream of Lawrence, until the Powwow River confluence where the Atlantic Ocean exerts greater influence, the concentrations were generally between 1.5 and 2.0 mg/L. The highest mainstem concentration of total nitrogen was observed downstream of the GLSD WWTP, 1.97 mg/L. The highest tributary concentration was observed at the Concord River, 1.77 mg/L. There was no observable trend of the tributaries showing higher or lower nitrogen concentrations than the nearby mainstem locations. There is no numeric MA or NH surface water quality standard for total nitrogen; however, there is a NH Class B Fresh Surface Water Criteria for Human Health of 10 mg/L (for water and fish ingestion) for nitrate. Nitrate is one of many components of total nitrogen. All total nitrogen results were below the 10 mg/L NH surface water criteria for nitrate, which indicates that nitrate must also be below that standard.

[3] U.S. Geological Survey, 2011, Change to solubility equations for oxygen in water: Office of Water Quality Technical Memorandum 2011.03, accessed January 13, 2015, at http://water.usgs.gov/admin/memo/QW/qw11.03.pdf.

Table 3-2: Total Nitrogen Concentration Summary for Mainstem Event #1 (mg/L)

Location Type	Minimum	Maximum	Average
Mainstem Freshwater	0.57	1.97	1.15
Mainstem Saltwater (downstream of Powwow River)	0.47	0.78	0.64
Tributary	0.61	1.77	1.18

Note: Reporting limit = 0.001 mg/L

Ammonia concentrations in the river were low, ranging from 0.004 to 0.57 mg/L NH_3-N (**Figure 3-7**). By comparison, the 2013 published EPA[4] ammonia limits for toxicity to aquatic life, at pH 7 and 20 degrees Celsius, are 17 mg/L acute and 1.9 mg/L chronic. The highest concentration in the Merrimack River was one-third of the EPA chronic exposure criterion.

3.1.5 Phosphorus

Total phosphorus concentrations were generally constant throughout the study area, with slightly higher concentrations observed downstream of Manchester, NH (**Figure 3-8**). There are no numeric surface water quality standards for total phosphorus in New Hampshire or Massachusetts. However, EPA suggests that total phosphorus concentrations in streams not exceed 100 µg/L[5]. This is a non-enforceable guidance value that is used in this report for comparison purposes only, it is not a regulatory action level. There are several increases in total phosphorus concentration downstream of WWTPs, however a direct cause and effect cannot be made as multiple other factors may contribute to total phosphorus, including non-point sources.

The tributary total phosphorus concentrations were generally below nearby mainstem levels, with the exception the Concord River, where the tributary concentration was greater than the mainstem Merrimack River near the confluence. There are limited stations near the confluence of the Souhegan River and the nearest upstream mainstem station showed a slightly greater concentration than that observed in the tributary while the nearest downstream station showed a lower concentration than the tributary.

Table 3-3 summarizes the total phosphorus concentrations observed during the first Phase III dry weather sampling event.

Table 3-3: Total Phosphorus Concentration Summary for Mainstem Event #1 (µg/L)

Location Type	Minimum	Maximum	Average
Mainstem Freshwater	18	112	55
Mainstem Saltwater (downstream of Powwow River)	39	62	46
Tributary	15	66	41

Note: Reporting limit = 2 µg/L

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[4] U.S. EPA Office of Water, 2013, Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater. EPA-822-R-13-001

[5] US EPA, 1986. Quality Criteria for Water. US-EPA 440/5-86-001. Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D.C.

Algal growth in the Merrimack River is limited by multiple factors, including nutrient availability, light availability, and water temperature. Either phosphorus or nitrogen is the limiting nutrient depending on which compound is more abundantly available based on the stoichiometry of algal nutrient uptake. The less-available nutrient limits the growth of algae if other factors are favorable for growth. A molar ratio of total nitrogen to total phosphorus of greater than 20 indicates that phosphorus is the limiting nutrient[6]. The molar TN:TP ratio in the Merrimack River during this sampling event ranged from 26 to 153, with a mean of 52 and median of 50. These values indicate that the system is phosphorus-limited.

Orthophosphates

Measuring orthophosphates along with total phosphorus in the river indicates how much of the nutrient is bioavailable for algal growth (**Figure 3-9**). Orthophosphate is the inorganic, dissolved portion of phosphorus, and is bioavailable. Typically, the fraction of total phosphorus that is orthophosphate in rivers is 0.5, but it can vary depending on the sources of phosphorus and the algal activity.

The orthophosphate concentrations during the sampling event followed a similar pattern as the total phosphorus concentrations: generally constant throughout the study area with some significant spikes downstream of select WWTPs.

The ratio of orthophosphates to total phosphorus (**Figure 3-10**) in the mainstem river and tributaries was generally less than 0.5 during the sampling event (average of 0.23 for all sites). The ratio is generally declining from upstream to downstream in the study area, corresponding to the generally increasing trend of chlorophyll-a concentration. These results do not conclude that phosphorus is limiting algal growth (other potential limiting factors include water temperature, residence time, and light penetration) but the lower OP:TP ratio corroborates the potential for increased algal growth in the more downstream portion of the study area. That is, higher chlorophyll-a concentrations (more algal growth) and less remaining bioavailable phosphorus in the same region suggest that algae has used the phosphorus to multiply. When the algal multiply to excessive amounts, the population becomes an aggregate formation and begins decomposition. This process results in reduced dissolved oxygen levels and is the precursor to an algal bloom, however no algal bloom was evident during this study.

3.1.6 pH

Field readings of pH in the mainstem river were generally above neutral (7 standard units), with values fluctuating between 6.6 and 8.6 (**Figure 3-11**). The tributary field readings of pH ranged from 6.6 to 8.2. The lowest pH value of 6.6 was observed at sample O007U (upstream of the Trull Brook Outfall in Tewksbury, MA), and the highest pH value of 8.6 was observed at M007U (upstream of the Merrimack WWTP in Merrimack, NH). Due to the volume of data and for simplicity and consistency of reporting,

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[6] Borchardt, M. A. (1996). Nutrients. In: Stevenson, R.J., Bothwell, Max L. and Lowe, Rex L. (Eds) Algal Ecology: Freshwater Benthic Ecosystems. Academic Press, San Diego, USA. pp 184-228.

the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets.

The New Hampshire Class B water quality standards require pH to be between 6.6 and 8.2. There were three readings in New Hampshire greater than 8.2 and none less than 6.6. The Massachusetts Class B standards require pH to be from 6.5 to 8.3, and the Massachusetts Class SB standards range from 6.5 to 8.5. There was one reading in Massachusetts greater than 8.3, no readings less than 6.5, and no readings in the shellfish beds greater than 8.5.

3.1.7 Bacteria

New Hampshire Class B water quality standards for bacteria in freshwater are as follows: not more than either a geometric mean based on at least three samples obtained over a 60-day period of 126 *E. coli* colonies per 100 mL, or greater than 406 *E. coli* colonies per 100 mL in any one sample (RSA 485-A:8).

Massachusetts Class B water quality standards for bacteria in freshwater are as follows: not more than either a geometric mean based on samples obtained during the previous six months (typically at least five samples) of 126 *E. coli* colonies per 100 mL, or not greater than 235 *E. coli* colonies per 100 mL in any one sample.

Massachusetts Class SB water quality standards for bacteria in saltwater are as follows: for shellfishing beds, not more than a median or geometric mean of samples of 88 fecal coliform colonies per 100 mL; for non-designated beach areas, not more than either a geometric mean based on samples obtained during the previous six months (typically at least five samples) of 235 *E. Coli* colonies per 100 mL, or not greater than 104 enterococci colonies per 100 mL in any one sample.

The relevant state standards are summarized in **Table 3-4**, along with a count of relevant sample results above stated criteria. It should be noted that all results are for single samples and any comparisons to means or median standards is for information only. Further, comparisons to shellfishing bed (saltwater only) standards are provided for all saltwater samples regardless of use designation at the location of the sample. As there are no Massachusetts Class saltwater (Class SB) standards for *E. coli*, all Massachusetts station samples, with the exception of two stations designated as shellfishing beds (saltwater only), are compared to Freshwater (Class B) standards for informational purposes only.

Figures 3-12 through **3-14** show the results of the bacteria analyses during the first sampling event, and **Figure 3-15** presents a graphical representation of locations with bacteria concentrations above relevant state water quality criteria.

Table 3-4: Count of Bacteria Concentrations Above New Hampshire and Massachusetts Water Quality Criteria for Freshwater and Saltwater Relevant Classes for Mainstem Event #1

(# above/total samples)	New Hampshire Freshwater Class B	Massachusetts Freshwater Class B	Massachusetts Saltwater	
Station Type	Single Sample, Non-Beach	Single Sample, Bathing Beach & Non-Beach	Median or Mean, Shellfishing	Single Sample, Class SB Bathing Beach & Non-Beach
	E. coli 406 mpn/100 mL [1]	*E. coli* 235 mpn/100 mL[1]	*Fecal coliform 88 mpn/100 mL*[2]	*Enterococci 104 mpn/100 mL*[1]
Mainstem	0/19	2/36	0/12	0/12
Tributary	1/6	4/10	0/1	0/1

Notes:

1. Water quality standards are for single sample thresholds
2. This standard is for a median or geometric mean, however only one samples was collected. Comparisons for information purposes only.

The highest *E. coli* sample was collected at the site upstream of the Mine Falls Stormdrain in the Nashua River in Nashua, NH; the concentration was 770 MPN per 100 mL. This site also had the second highest fecal coliform concentration of 727 MPN per 100 mL. The site with the highest fecal coliform concentration was the Little River, with 1,046 MPN per 100 mL. The highest observed enterococci concentration was 27 MPN per 100 mL at the site upstream of the Merrimac WWTP in Merrimac/West Newbury, MA.

3.2 Event #2 - Wet Weather Data Summary and Observations

Section 3.2 provides the data summary and observations for the 1 October 2015 wet weather water quality survey. Refer to the end of this section and Appendix B for fold-out panels containing data plots and Appendix C for complete data tables. For the purposes of mainstem event discussions herein, “tributary samples” include samples at the mouths of tributaries as well as upstream and downstream of outfalls located on tributaries (O004U/D and O008U/D).

3.2.1 Carbonaceous Biological Oxygen Demand

Concentrations of CBOD5 in the river were mostly non-detect (laboratory reporting limit: 2 mg/L; see Figure 3-1). CBOD5 was detected, at or above the laboratory reporting limit in 13 of the river and/or WWTP effluent samples. CBOD5 was detected downstream of the Pawtucket Dam in Lowell, MA (1 site, at laboratory reporting limit), downstream of the Essex Dam in Lawrence, MA (1 site, 4 mg/L), and downstream of a stormwater outfall in Nashua, NH (1 site, at laboratory reporting limit). It was also detected at the mouth of the Shawsheen River in Lawrence, MA (1 site, 4 mg/L), and at nine of the eleven WWTP Effluent samples including; Manchester, NH; Merrimack, NH; Nashua, NH; LRWWU in Lowell, MA; GLSD in North Andover, MA; Haverhill, MA; Merrimac, MA; Amesbury, MA; and Newburyport, MA. Results ranged from 3 mg/L to 9 mg/L.

CBOD20 was analyzed downstream of WWTPs and from the WWTP effluent samples. CBOD20 concentrations ranged from non-detect (reporting limit: 3 mg/L) to 30 mg/L (indicated with X-markers in Figure 3-1). There were nine samples measured at or above the laboratory reporting limit, and all nine were from the composite effluent WWTP samples. CBOD20 was detected in samples from the following WWTPs: Manchester, NH; Merrimack, NH; Nashua, NH; LRWWU; GLSD; Haverhill, MA; Merrimac, MA; Amesbury, MA; and Newburyport, MA. Concentrations ranged from 6 mg/L to 30 mg/L at the LRWWU.

3.2.2 Chlorophyll-a

Chlorophyll-a concentrations generally increased from upstream to downstream along the Lower Merrimack River. This follows the trend seen during Event #1 – Dry Weather Survey conducted in June 2014 (Figure 3-2). This trend was also observed in the data collected on the Lower Merrimack River as part of the 2002 to 2006 Phase I Merrimack River Watershed Assessment Study, as well as the 2009 to 2012 Pemigewasset and Upper Merrimack River Study. Concentrations ranged from 4.9 to 25 µg/L in mainstem riverine samples, and 2.8 to 23 µg/L in tributary samples. Chlorophyll-a concentrations from the October 2015 wet weather event were typically lower than or comparable to those observed during the June 2014 dry weather event; however, they are higher than would be expected for a wet weather event based on the timing relatively late in the season and high flows in the river. As mentioned in Section 3.1, select chlorophyll-a results had to be adjusted due to pheophytin interferences. Original and revised results are included in Appendix D, and revised concentrations are reflected in data tables and plots.

Generally, throughout the study area, the samples taken at the mouths of tributaries had lower chlorophyll-a concentrations than the mainstem receiving water of the Merrimack River at that location. The exceptions were the Cohas Brook, Concord River, Nashua River, and Powwow River where tributary concentrations were higher than the mainstem.

As was observed during the previous dry weather survey, chlorophyll-a concentrations dropped significantly downstream of the Powwow River as the Merrimack River approaches the Atlantic Ocean. This drop correlates with the increase in salinity at these stations.

The state of New Hampshire uses 15 µg/L as a guideline threshold for maximum chlorophyll-a concentrations for primary contact recreation, but Massachusetts does not specify a chlorophyll-a surface water standard. For comparison and discussion purposes, all results were compared to the New Hampshire threshold value. Concentrations of chlorophyll-a in 20 of the 57 mainstem stations and two of the 16 tributary results were at or above the 15 µg/L guideline threshold. However, no samples collected in New Hampshire were above the threshold.

3.2.3 Dissolved Oxygen and Temperature

Dissolved Oxygen

Dissolved oxygen levels in the river were measured in-situ using field water quality meters and in the laboratory using Winkler titration. Winkler titration values are typically used to validate the field meters, which can fall out of calibration while being used in the field. The field-measured values and the Winkler titration values of both dissolved oxygen concentration and percent saturation are shown in Figures 3-3 and 3-4 (Winkler dissolved oxygen concentration indicated with X-markers in Figure 3-3).

Concentrations of dissolved oxygen measured in the mainstem during the second event ranged from 6.8 to 11.8 mg/L (73 to 116 percent saturation) and 7.5 to 10.2 mg/L (78 to 107 percent saturation) in the tributaries. One of the Winkler dissolved oxygen concentrations was less than the NH Class B or MA Class B and SB water standards of 5 mg/L at the location downstream of the Hooksett Dam (1.93 mg/L); however, this result appears to be an outlier since it varies significantly from the average field reading (9.14 mg/L) at this location and generally from concentrations at nearby locations. As a result, both of these dissolved oxygen results at this location are considered estimated. Two locations (downstream of the Hooksett Dam and downstream of the City of Lowell) had a percent saturation reading less than the NH Class B average daily saturation standard of 75%[7], with readings of 18.68% (calculated from Winkler dissolved oxygen concentration and considered estimated based on variability from field reading) and 73% (field measured), respectively. Only one of these locations was collected in New Hampshire. Due to the volume of data and for simplicity and consistency of reporting, the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets.

Winkler values for percent saturation were calculated using the field measured water temperature and specific conductance according to USGS methods[8]. With the exception of the results at the station downstream of the Hooksett Dam, the Winkler samples analyzed for concentration and calculated for percent saturation confirmed the field readings, as evidenced by the similarity of the results in Figure 3-3 and 3-4, and as shown in the data tables in Appendix C. Variations up to 1.9 mg/L are expected since dissolved oxygen conditions can change rapidly in the field due to air-water interactions during the sampling procedure.

Temperature

During the wet weather event (Event #2), temperatures were generally consistent throughout the study area between 14 and 21°C (Figure 3-5). Given the high flows and cooler temperatures in the Merrimack during the October 2015 event, there appeared to be less of an impact to water temperature towards the confluence with the Atlantic Ocean, as compared to the June 2014 dry weather event. The average temperature of all mainstem locations was 18.6°C. The average for all tributary locations was 18.2°C. These temperatures are consistent with those typically seen during fall months and those measured during previous sampling events from 2002 to 2012. Due to the volume of data and for simplicity and consistency of reporting, the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets.

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[7] The percent saturation standard is for daily average dissolved oxygen readings, not single point measurements as were taken during the low flow events.

[8] U.S. Geological Survey, 2011, Change to solubility equations for oxygen in water: Office of Water Quality Technical Memorandum 2011.03, accessed March 30, 2016, at http://water.usgs.gov/admin/memo/QW/qw11.03.pdf.

3.2.4 Nitrogen

Total nitrogen concentrations were typically steady to slightly increasing from upstream to downstream within the study area (Figure 3-6). The range of observed total nitrogen concentrations are presented in **Table 3-5**.

Total nitrogen concentrations for stations in New Hampshire were at or below 0.76 mg/L. Total nitrogen generally increased from upstream to downstream in the river. Between the state line and downstream of the Essex Dam (Lawrence), concentrations were generally between 1.0 and 1.56 mg/L. Downstream of Lawrence, until downstream of the Salisbury WWTP where the Atlantic Ocean exerts greater influence, the concentrations were generally between 1.6 and 2.0 mg/L. The highest mainstem concentration of total nitrogen was observed downstream of the Merrimac, MA WWTP, 1.98 mg/L. The highest tributary concentration was observed at the Concord River, 2.35 mg/L. There was no observable trend of the tributaries showing higher or lower nitrogen concentrations than the nearby mainstem locations. There is no numeric MA or NH surface water quality standard for total nitrogen; however, there is a NH Class B Fresh Surface Water Criteria for Human Health of 10 mg/L (for water and fish ingestion) for nitrate. Nitrate is one of many components of total nitrogen. All total nitrogen results were below the 10 mg/L NH surface water criteria for nitrate, which indicates that nitrate must also be below that standard.

Total nitrogen observed in WWTP effluent showed no observable trend and ranged from 3.36 mg/L at the Haverhill WWTP to 17.95 mg/L at the Nashua WWTP. This large discrepancy from other nitrogen concentrations is likely due to the operation of an anaerobic digester that is part of the Nashua process.

Table 3-5: Total Nitrogen Concentration Summary for Event #2 (mg/L)

Location Type	Minimum	Maximum	Average
Mainstem Freshwater	0.45	1.98	1.19
Mainstem Saltwater (downstream of Powwow River)	0.70	1.68	1.27
Tributary	0.43	2.35	1.06
WWTPs	3.36	17.95	12.13

Note: Reporting limit = 0.01 mg/L

Ammonia concentrations in the river (mainstem and tributaries) were low, ranging from 0.007 to 0.54 mg/L NH_3-N (Figure 3-7). By comparison, the 2013 published EPA[9] ammonia limits for toxicity to aquatic life, at pH 7 and 20 degrees Celsius, are 17 mg/L acute and 1.9 mg/L chronic. The highest concentration in the Merrimack River was less than one-third of the EPA chronic exposure criterion. Ammonia concentrations in the WWTP effluent samples ranged from 0.071 mg/L to 12.1 mg/L; however, the EPA ammonia aquatic life toxicity limits are not applicable.

[9] U.S. EPA Office of Water, 2013, Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater. EPA-822-R-13-001

3.2.5 Phosphorus

Total phosphorus concentrations were generally constant and less than 100 µg/L upstream of the Essex Dam, when concentrations increased but then remained typically steady between 115 and180 µg/L (Figure 3-8). There are no numeric water quality standards for total phosphorus in New Hampshire or Massachusetts. However, EPA suggests that total phosphorus concentrations in streams not exceed 100 µg/L[10]. This is a non-enforceable guidance value that is used in this report for comparison purposes only. Total phosphorus concentrations in the WWTP composite effluent samples ranged from approximately 186 µg/L to 6,700 µg/L. While some increases in total phosphorus concentrations were observed in select river stations downstream of WWTPs, spikes in concentrations may be attributed to other nonpoint sources. Nonpoint sources, including tributaries, will be further evaluated during the modeling phase. It should be noted that phosphorus concentrations observed in river and tributary stations during the October 2015 event were generally higher than those observed during the June 2014 dry weather event, and are higher than would typically be expected for a wet weather and high flow event. The high phosphorus concentrations in October may be attributed to heavy fertilization during the month of September in the surrounding areas. The additional fertilizer could have been transferred to the river from land mass runoff.

The tributary total phosphorus concentrations were generally below nearby mainstem levels, with the exception of the Powwow River, where the tributary concentration was slightly greater than the mainstem Merrimack River near the confluence. **Table 3-6** summarizes the total phosphorus concentrations observed during the first wet weather event.

Table 3-6: Total Phosphorus Concentration Summary for Event #2 (µg/L)

Location Type	Minimum	Maximum	Average
Mainstem Freshwater	52.3	179.8	102.2
Mainstem Saltwater (downstream of Powwow River)	62.7	157.1	107.0
Tributary	23.0	143.7	54.5
WWTPs	186.1	6,693	2,339

Note: Reporting limit = 2 µg/L

Algal growth in the Merrimack River is limited by multiple factors, including nutrient availability, light availability, and water temperature. Either phosphorus or nitrogen is the limiting nutrient depending on which compound is more abundantly available based on the stoichiometry of algal nutrient uptake. The less-available nutrient limits the growth of algae if other factors are favorable for growth. A molar ratio of total nitrogen to total phosphorus of greater than 20 indicates that phosphorus is the limiting nutrient[11]. The molar TN:TP ratio in the Merrimack River during this sampling event ranged from 15.4 to 131, with a mean of 31.6 and median of 26.5. These values indicate that the majority of the system is phosphorus-limited.

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[10] US EPA, 1986. Quality Criteria for Water. US-EPA 440/5-86-001. Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D.C.

[11] Borchardt, M. A. (1996). Nutrients. In: Stevenson, R.J., Bothwell, Max L. and Lowe, Rex L. (Eds) Algal Ecology: Freshwater Benthic Ecosystems. Academic Press, San Diego, USA. pp 184-228.

Orthophosphates

Measuring orthophosphates along with total phosphorus in the river indicates how much of the nutrient is bioavailable for algal growth (Figure 3-9). Orthophosphate is the inorganic, dissolved portion of phosphorus, and is bioavailable. Typically, the fraction of total phosphorus that is orthophosphate in rivers is 0.5, but it can vary depending on the sources of phosphorus and the algal activity.

The orthophosphate concentrations during the sampling event followed a similar pattern as the total phosphorus concentrations: generally constant throughout the upper sections of the study area, but increasing further downstream and into Massachusetts, especially after the Essex Dam. Orthophosphates observed in the river during the October 2015 wet weather event were generally higher than the June 2014 dry weather event, and generally higher than would be expected during a wet weather event. The drop in orthophosphate concentrations downstream of the Powwow River may be attributed to saltwater impacts. Orthophosphate concentrations in WWTPs followed a similar pattern as the total phosphorus concentrations.

The ratio of orthophosphates to total phosphorus (Figure 3-10) in the mainstem river and tributaries was at or below 0.5 during the sampling event (average of 0.32 for all sites), with the exception of the sample collected from the Powwow River (1.10). Since this ratio should not be greater than 1, this may represent some slight variability between the sample volume collected for the total phosphorus and orthophosphate analysis at this location. The ratio is generally increasing slightly from upstream to downstream in the study area. These results indicate that phosphorus is the limiting nutrient, but not the limiting factor in algal growth. Other potential limiting factors include water temperature, residence time, and light penetration. Higher chlorophyll-a concentrations (more algal growth) and less remaining bioavailable phosphorus (ratio less than 0.5) in the same region may suggest that algae has used the phosphorus to multiply. When the algae multiply to excessive amounts, the population becomes an aggregate formation and begins decomposition. This process results in reduced dissolved oxygen levels and is the precursor to an algal bloom, however no algal bloom was evident during this study. The ratio of orthophosphates to total phosphorus in the WWTP effluent was greater than 0.5 during the sampling event (average of 0.70 for all sites).

3.2.6 pH

Field readings of pH in the mainstem river were generally above neutral (7 standard units), with average values (average of initial and final readings) fluctuating between 6.32 and 8.25 (Figure 3-11). The tributary field readings of pH ranged from 6.50 to 7.86. The lowest pH value of 6.32 was observed downstream of the Lowell Pawtucket storm drain, and the highest pH value of 8.25 was observed at M028U (upstream of the Salisbury WWTP). Field readings of pH in the WWTP effluent were only available for select WWTPs, and ranged from 6.11 to 7.66. Due to the volume of data and for simplicity and consistency of reporting, the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets.

The New Hampshire Class B water quality standards require pH to be between 6.6 and 8.2. There were no readings in New Hampshire greater than 8.2 and none less than 6.6. The Massachusetts Class B standards require pH to be from 6.5 to 8.3, and the Massachusetts Class SB standards range from

6.5 to 8.5. There were no readings in Massachusetts greater than 8.3, two readings less than 6.5, and no readings in the shellfish beds greater than 8.5.

3.2.7 Bacteria

New Hampshire Class B water quality standards for bacteria in freshwater, MA Class B water quality standards for bacteria in freshwater, and Massachusetts Class SB water quality standards for bacteria in saltwater were defined in Section 3.1.7. The relevant state standards are summarized in **Table 3-7**, along with a count of relevant sample results above stated criteria. It should be noted that all results are for single samples and any comparisons to means or median standards is for information only. Further, comparisons to shellfishing bed (saltwater only) standards are provided for all saltwater samples regardless of use designation at the location of the sample. As there are no Massachusetts Class saltwater (Class SB) standards for *E. coli*, all Massachusetts station samples, with the exception of two stations designated as shellfishing beds (saltwater only), are compared to Freshwater (Class B) standards for informational purposes only.

Figures 3-12 through **3-14** show the results of the bacteria analyses during the first wet weather survey of the Phase III work, and **Figure 3-16** presents a graphical representation of locations with bacteria concentrations above relevant state water quality criteria.

Table 3-7: Count of Bacteria Concentrations Above New Hampshire and Massachusetts Water Quality Criteria for Freshwater and Saltwater Relevant Classes for Event #2

(# above/total samples)	New Hampshire Freshwater Class B	Massachusetts Freshwater Class B	Massachusetts Saltwater	
Station Type	Single Sample, Non-Beach[1]	Single Sample, Bathing Beach & Non-Beach[1]	Median or Mean*, Shellfishing[2]	Single Sample, Class SB Bathing Beach & Non-Beach[1]
	E. coli 406 mpn/100 mL	*E. coli* 235 mpn/100 mL	Fecal coliform 88 mpn/100 mL	Enterococci 104 mpn/100 mL
Mainstem	18/19	34/36	12/12	9/12
Tributary	3/7	9/9	1/1	1/1

Notes:

1. Water quality standards are for single sample thresholds
2. This standard is for a median or geometric mean, however only one samples was collected. Comparisons for information purposes only.

E. coli was detected at all mainstem and tributary locations. The highest *E. coli* result was reported as >2420 mpn/100mL, which was detected at 10 locations along the mainstem and tributaries. An additional 9 *E. coli* results were reported as 2420 mpn/100 mL. Fecal coliform was detected at all mainstem and tributary locations, with 17 locations reporting a concentration of >2420 mpn/100mL and 9 concentrations reporting at 2420 mpn/100mL. It is important to note that *E. coli* and fecal coliform samples were not diluted by the laboratory prior to incubation and analysis, thus 2420 mpn/100 mL was the maximum achievable reporting limit during the October 2015 event. The highest observed enterococci concentration was 648 mpn/100 mL at the station downstream of the Newburyport WWTP. These bacteria results are significantly higher than those observed during the June 2014 dry weather event, which may likely be attributed to tributary discharges as well as the CSO discharges from multiples WWTPs during this major rainstorm.

3.3 Mainstem Event #3 – Dry/Wet Weather Data Summary and Observations

Section 3.3 provides the data summary and observations for the 10 August 2016 dry/wet weather water quality survey. Refer to the end of this section and Appendix B for fold-out panels containing data plots and Appendix C for complete data tables. For the purposes of Mainstem Event discussions herein, "tributary samples" include samples at the mouths of tributaries as well as upstream and downstream of outfalls located on tributaries (O004U/D and O008U/D). Generally, higher concentrations or spikes in concentration were observed during the first flush, wet weather conditions, and near 7Q10 flows may be representative of worst case nutrient conditions in the river.

3.3.1 Carbonaceous Biological Oxygen Demand

Concentrations of CBOD5 in the river were mostly non-detect for both dry weather and wet weather samples (new 2016 laboratory reporting limit: 3 mg/L; see Figure 3-1). CBOD5 was detected above the laboratory reporting limit in 12 river and/or WWTP effluent samples, all classified as wet weather survey samples. CBOD5 was detected: downstream of the Lowell WWTP, in the parent and the duplicate samples (8 mg/L and 5 mg/L, respectively); upstream (7mg/L) and downstream (5 mg/L) of a stormwater outfall, O008U and O008D (located on the Shawsheen River, upstream and downstream of the Shawsheen stormdrain); at the mouth of the mouth of the Spicket River (1 site, 19 mg/L); at the mouth of the Shawsheen River, in the parent and duplicate (1 site; 14 mg/L and 13 mg/L, respectively); and the mouth of the Little River (1 site, 4 mg/L). It was also detected at four of the ten WWTP Effluent samples collected including; Manchester, NH; Merrimack, NH; Nashua, NH; and Newburyport, MA. Results ranged from 4 mg/L to 7 mg/L.

CBOD20 was analyzed downstream of WWTPs and from the WWTP effluent samples. CBOD20 concentrations ranged from non-detect (laboratory reporting limit: 3 mg/L) to 18 mg/L (indicated with X-markers in Figure 3-1). There were twelve samples measured at or above the reporting limit, five from river samples and seven from the composite effluent WWTP samples. CBOD20 was detected in river water samples at the following locations, all of which are considered wet weather samples except for one: the Nashua WWTP (1 site, 7 mg/L, wet weather); downstream of the Lowell WWTP, in the parent and duplicate sample (12 mg/L and 9 mg/L, respectively, wet weather); downstream of the GLSD WWTP (1 site, at the reporting limit of 3 mg/L, wet weather); and downstream of the Salisbury WWTP (1 site, at the reporting limit of 3mg/L, dry weather)

CBOD20 was also detected in wet weather samples from the following WWTPs: Manchester, NH; Merrimack, NH; Nashua, NH; Haverhill, MA; Amesbury, MA; Salisbury, MA and Newburyport, MA. Concentrations ranged from 5 mg/L to 18 mg/L.

3.3.2 Chlorophyll-a

Chlorophyll-a concentrations in both wet and dry weather samples generally increased from upstream to downstream along the Lower Merrimack River. This follows the trend seen during Event #1 – Dry Weather Survey conducted in June 2014 and Event #2 – Wet Weather Survey conducted on October 2015 (Figure 3-2). This trend was also observed in the data collected on the Lower Merrimack River as part of the 2002 to 2006 Phase I Merrimack River Watershed Assessment Study, as well as the 2009 to 2012 Pemigewasset and Upper Merrimack River Study. Detected concentrations in the August 2016 Event #3 Dry/Wet Weather Survey ranged from:

- Dry Weather Samples
  - 4.3 to 57 µg/L in dry weather mainstem riverine samples
  - 2.9 to 33 µg/L in dry weather tributary samples
- Wet Weather Samples
  - 6.6 to 29 µg/L in wet weather mainstem riverine samples
  - 3.3 to 90 µg/L in wet weather tributary samples

Chlorophyll-a concentrations from the August 2016 hybrid dry/wet weather event were typically lower than or comparable to those observed during the first two events for mainstem samples, with the exception of the dry weather samples collected downstream of the Pawtucket Dam and downstream of the Salisbury WWTP. Additionally, the highest chlorophyll-a concentration observed to date during Phase III was the wet weather sample collected from the Little River at 90 µg/L. The flow at this location was unknown as there are no active USGS gages on the Little River, but the water level was low (approximately 1' deep) and algae was observed on some rocks along the bank (no algal blooms in the river). All other tributary sample concentrations were comparable to those observed during previous events.

As mentioned in Section 3.1, select chlorophyll-a results had to be adjusted due to pheophytin interferences. Original and revised results are included in Appendix D, and revised concentrations are reflected in data tables and plots.

Generally, throughout the study area, the samples taken at the mouths of tributaries had lower chlorophyll-a concentrations than the mainstem receiving water of the Merrimack River at that location. The exceptions were the Spicket River and Little River (wet weather) and Powwow River (dry weather), where tributary concentrations were higher than the mainstem.

As was observed during prior events, chlorophyll-a concentrations dropped significantly in the most downstream portion of the Merrimack River as it approaches the Atlantic Ocean. This drop correlates with the increase in salinity at these stations.

The state of New Hampshire uses 15 µg/L as a guideline threshold for maximum chlorophyll-a concentrations for primary contact recreation, but Massachusetts does not specify a chlorophyll-a surface water standard. For comparison and discussion purposes, all results were compared to the New Hampshire threshold value. Concentrations of chlorophyll-a in 29 of the 64 detected mainstem samples (15 wet, 14 dry) and five of the 13 detected tributary results (4 wet, 1 dry) were at or above the 15 µg/L guideline threshold. However, none of the samples with concentrations greater than 15 ug/L were collected in New Hampshire.

3.3.3 Dissolved Oxygen and Temperature

Dissolved Oxygen

Dissolved oxygen levels in the river were measured in-situ using field water quality meters and in the laboratory using Winkler titration. Winkler titration values are typically used to validate the field meters, which can fall out of calibration while being used in the field. The field-measured values and the Winkler titration values of both dissolved oxygen concentration and percent saturation are shown in Figures 3-3 and 3-4 (Winkler dissolved oxygen concentration and saturation indicated with X-markers).

Field measured concentrations of dissolved oxygen during the third event ranged from:

- Dry Weather Samples
  - 3.93 to 11.22 mg/L in dry weather mainstem samples
  - 4.51 to 8.58 mg/L in dry weather tributary samples, and
- Wet Weather Samples
  - 5.69 to 12.3 mg/L in wet weather mainstem samples,
  - 4.57 to 8.63 mg/L in wet weather tributary samples.

Due to the volume of data and for simplicity and consistency of reporting, the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets.

Dissolved oxygen readings at 4 of the 74 sample locations were just below the acceptable range of 5 mg/l (minimum). With the exception of concentrations measured at dry weather locations downstream of the Manchester, NH WWTP, upstream of the Derry NH WWTP, the Powwow River and the wet weather sample collected from Stony Brook, all other results were above the NH Class B and MA Class B and SB standard of 5 mg/L. All 11 of the Winkler dissolved oxygen results for dry and wet weather samples were above the NH Class B and MA Class B and SB standard of 5 mg/L, ranging from 6.59 to 8.39 mg/L. Even in near 7Q10 conditions, no consistent deficiencies were observed.

Field measured dissolved oxygen percent saturation ranged from 45.7 to 149.1% in the mainstem samples and 51.9 to 101.9% in the tributary samples, with comparable saturations observed between wet and dry weather samples. Field dissolved oxygen percent saturation readings at 3 dry weather mainstem locations, 3 wet weather mainstem locations, 2 dry weather tributary locations, and 6 wet weather tributary locations were below the applicable NH State standard of 75%. Of these locations, two of the mainstem samples and four of the tributary samples were collected in NH. In addition to the field readings, Winkler values for percent saturation were calculated using the field measured water temperature and specific conductance according to USGS methods[12]. None of the locations during Event #3 had calculated percent saturation readings less than the NH Class B average daily saturation standard of 75%[13]. Calculated percent saturation dissolved oxygen based on the Winkler values ranged from 78.5% to 102.2%.

The Winkler samples analyzed for concentration (mg/L) and calculated for percent saturation (%) generally confirmed the field readings, as evidenced by the similarity of the results in Figure 3-3 and 3-4, and as shown in the data tables in Appendix C. Variations between the concentrations recorded in the field and via Winkler analysis (as represented by the difference in the plot line from the "X" at that same location) ranged from 0.46 to 3.38 mg/L. Percent saturation in the field varied from calculated results by approximately 7-40%. While some variations are expected the difference between field and Winkler results in samples collected by Boat Team #1 are somewhat elevated. Although individual results are within acceptable levels, all field and Winkler dissolved oxygen results for dissolved oxygen readings collected by Boat Team #1 were qualified as estimated as a conservative measure (Stations M001, M002, M003, M004, M006D, O001U, O001D, O003U, and O003D). All results are considered acceptable.

Temperature

During the dry/wet weather event (Event #3), temperatures were generally consistent throughout the study area between 16.1 and 26.3°C (Figure 3-5). Temperatures observed during Event #3 were the highest of the three events, which is expected given the late summer timeframe when compared to the early summer and early fall timing of prior events. The average temperatures were as follows:

- Dry Weather Samples
  - 24.35°C in dry weather mainstem locations
  - 23.77°C in dry weather tributary locations, and
- Wet Weather Samples
  - 25.49°C in wet weather mainstem locations,
  - 23.05°C in wet weather tributary locations.

As was observed with previous events, temperatures during Event #3 dropped downstream of the Salisbury WWTP, where the confluence with the Atlantic Ocean influences the river temperature. These temperatures are consistent with those typically seen during the late summer months and those measured during previous sampling events from 2002 to 2012. Temperatures measured in the WWTP Effluents ranged from 14.0 to 26.5 °C. Due to the volume of data and for simplicity and

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[12] U.S. Geological Survey, 2011, Change to solubility equations for oxygen in water: Office of Water Quality Technical Memorandum 2011.03, accessed March 30, 2016, at http://water.usgs.gov/admin/memo/QW/qw11.03.pdf.

[13] The percent saturation standard is for daily average dissolved oxygen readings, not single point measurements as were taken during the low flow events.

consistency of reporting, the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets.

3.3.4 Nitrogen

Total nitrogen concentrations were typically steady to slightly increasing from upstream to downstream within the study area, with the exception of select elevated nitrogen concentrations further detailed below. The range of observed total nitrogen concentrations are presented in **Table 3-8,** and shown on Figure 3-6. Statistics on the total nitrogen concentrations are split up based on the designations made in Table 2-18, determining which samples were collected during dry conditions versus wet conditions. For statistics, when results are nondetect, the laboratory reporting limit was used.

Wet and dry weather concentrations in New Hampshire were generally at or below 1.3 mg/L. Between the state line and downstream of the Essex Dam (Lawrence), wet and dry weather concentrations were generally between 1.0 and 1.65 mg/L. Downstream of Lawrence, until downstream of the Salisbury WWTP where the Atlantic Ocean exerts greater influence, the concentrations were generally between 1.25 and 2.0 mg/L. Exceptions to these trends are as follows:

- The wet weather sample collected downstream of the Nashua WWTP (3.42 mg/L),
- The wet weather sample collected downstream of the Lowell WWTP (2.71 mg/L),
- The two wet weather samples collected downstream of the city of Methuen and upstream of the stormdrain outfall in Methuen (4.16 and 3.21 mg/L, respectively), and
- The wet weather tributary samples collected from the mouth of the Concord and Spicket Rivers (5.15 and 4.63 mg/L, respectively), and to a lesser extent the Shawsheen and Powwow River samples (2.39 wet and 2.51 mg/L dry, respectively).

With the exception of the spikes in concentration noted above, the nitrogen concentration trends were comparable to those observed during prior Phase III events.

The highest mainstem concentration of total nitrogen was observed in the wet weather sample collected downstream of Methuen, 4.16 mg/L. The highest tributary concentration was observed in the wet weather sample collected from the Concord River, 5.15 mg/L, which has historically had the highest nitrogen concentrations of all the tributaries during both wet and dry conditions. There was no observable trend of the tributaries showing higher or lower nitrogen concentrations than the nearby mainstem locations. There is no numeric MA or NH surface water quality standard for total nitrogen; however, there is a NH Class B Fresh Surface Water Criteria for Human Health of 10 mg/L (for water and fish ingestion) for nitrate. Nitrate is one of many components of total nitrogen. All total nitrogen results were below the 10 mg/L NH surface water criteria for nitrate, which indicates that nitrate must also be below that standard.

Total nitrogen observed in WWTP effluent showed no observable trend and ranged from 5.3 mg/L at the Haverhill WWTP to 35.2 mg/L at the Merrimack, NH WWTP.

Table 3-8: Total Nitrogen Concentration Summary for Event #3 (mg/L)

Location Type	Minimum		Maximum		Average	
	Dry	Wet	Dry	Wet	Dry	Wet
Mainstem Freshwater	0.56	0.65	1.91	4.16	1.06	1.70
Mainstem Saltwater (downstream of Powwow River)	0.44	-	1.31	-	0.71	-
Tributary	0.52		2.51		1.27	
WWTPs	5.30		35.20		19.67	

Note: Reporting limit = 0.001 mg/L

Ammonia concentrations in the river (mainstem and tributaries) were generally low, ranging from 0.0009 to 0.39 mg/L NH_3-N (Figure 3-7), with the exception of seven wet weather samples whose ammonia concentrations were elevated when compared to the August 2016 and prior Phase III sampling events. These locations and concentrations are as follows: downstream of the Nashua WWTP (1.23 mg/L); downstream of the Lowell WWTP (0.791 mg/L); at the mouth of the Spicket River (0.612 mg/L); downstream of the GLSD WWTP (1.03 mg/L); downstream of the city of Methuen (2.59 mg/L); and upstream and downstream of the stormwater outfall in Methuen (1.35 and 0.562 mg/L, respectively).

By comparison, the 2013 published EPA[14] ammonia limits for toxicity to aquatic life, at pH 7 and 20 degrees Celsius, are 17 mg/L acute and 1.9 mg/L chronic. The highest concentration in the Merrimack River was less than one-fifth of the EPA acute exposure criterion; however, one wet weather location, (downstream of Methuen) was greater than the EPA chronic exposure criterion at 2.59 mg/L. It is important to note that the concentration at that location during the August 2016 sampling event was elevated when compared to all prior events and is more representative of acute rather than chronic conditions. Ammonia concentrations in the WWTP effluent samples ranged from 0.173 mg/L to 9.58 mg/L; however, the EPA ammonia aquatic life toxicity limits are not applicable.

3.3.5 Phosphorus

During the August 2016 event, wet weather concentrations of total phosphorus tended to be higher than dry weather concentrations (Figure 3-8). Total phosphorus concentrations in dry weather mainstem samples were generally steady and at or below 100 µg/L, with the exception of four samples results that ranged from 102.15 to 135.88 µg/L. Wet weather sample concentrations exhibited more variability throughout, with concentrations ranging from 59.75 to 175.39 µg/L, with the exception of peak concentrations observed downstream of the Nashua WWTP (200.17 µg/L) and downstream of the Lowell WWTP (350.30 µg/L). There are no numeric water quality standards for total phosphorus in New Hampshire or Massachusetts. However, EPA suggests that total phosphorus concentrations in streams not exceed 100 µg/L. This is a non-enforceable guidance value that is used

[14] U.S. EPA Office of Water, 2013, Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater. EPA-822-R-13-001

in this report for comparison purposes only. Total phosphorus concentrations in the WWTP composite effluent samples ranged from approximately 723 µg/L to 6,483 µg/L, with no discernable trend.

The total phosphorus concentrations in dry and wet weather tributary samples were generally at or below nearby mainstem levels. Concentrations remained below 100 µg/L, with the exception of the following wet weather samples: upstream of the stormdrain outfall on the Nashua River (175.39 µg/L); the mouth of the Spicket River (564.91 µg/L); upstream and downstream of the stormdrain outfall on the Shawsheen River (159.01 and 129.13 µg/L, respectively); and the mouth of the Shawsheen River (384.95 µg/L).

It should be noted that phosphorus concentrations observed in river and tributary stations during the August 2016 event were generally within the ranges observed during prior events, and that higher phosphorus concentrations tended to be observed during both wet weather events than would typically be expected for a wet weather and/or high flow event. While some increases in total phosphorus concentrations were observed in select river stations downstream of WWTPs and in tributary stations, spikes in concentrations may be attributed to other nonpoint sources, which could not be quantified as a part of this scope. Nonpoint sources, including tributaries, will be further evaluated during the modeling phase. **Table 3-9** summarizes the total phosphorus concentrations observed during the August 2016 dry/wet weather event. Statistics on the total phosphorus concentrations are split up based on the designations made in Table 2-18, determining which samples were collected during dry conditions versus wet conditions. For statistics, when results are nondetect, the laboratory reporting limit was used.

Table 3-9: Total Phosphorus Concentration Summary for Event #3 (µg/L)

Location Type	Minimum		Maximum		Average	
	Dry	Wet	Dry	Wet	Dry	Wet
Mainstem Freshwater	18.24	42.40	135.88	320.47	66.23	120.28
Mainstem Saltwater (downstream of Powwow River)	32.77	-	96.37	-	52.04	-
Tributary	15.36	21.20	86.73	564.91	45.98	163.79
WWTPs	722.77		6,483		3,757	

Note: Reporting limit = 3.1 µg/L

Algal growth in the Merrimack River is limited by multiple factors, including nutrient availability, light availability, and water temperature. Either phosphorus or nitrogen is the limiting nutrient depending on which compound is more abundantly available based on the stoichiometry of algal nutrient uptake. The less-available nutrient limits the growth of algae if other factors are favorable for growth. A molar ratio of total nitrogen to total phosphorus of greater than 20 indicates that phosphorus is the limiting nutrient[15]. The molar TN:TP ratio in the Merrimack River during this sampling event ranged from 13.8

[15] Borchardt, M. A. (1996). Nutrients. In: Stevenson, R.J., Bothwell, Max L. and Lowe, Rex L. (Eds) Algal Ecology: Freshwater Benthic Ecosystems. Academic Press, San Diego, USA. pp 184-228.

to 160, with a mean of 40.4 and median of 36.1. These values indicate that the majority of the system is phosphorus-limited, as has been observed throughout Phase III.

Orthophosphates

Measuring orthophosphates along with total phosphorus in the river indicates how much of the nutrient is bioavailable for algal growth (Figure 3-9). Orthophosphate is the inorganic, dissolved portion of phosphorus, and is bioavailable. Typically, the fraction of total phosphorus that is orthophosphate in rivers is 0.5, but it can vary depending on the sources of phosphorus and the algal activity.

Both dry and wet weather orthophosphate concentrations demonstrated some variability throughout the study area. Dry and wet weather concentrations were comparable, ranging from 4.97-163.95 µg/L (dry) and 15.27 to 215.64 µg/L (wet). Orthophosphates observed in the river during the August 2016 event were generally the highest observed during all Phase III events, and generally higher than would be expected during a wet weather event. This may be attributed to the near 7Q10 flows coupled with the first flush conditions. The drop in orthophosphate concentrations in locations downstream of the Lawrence area may be attributed to saltwater impacts. Orthophosphate concentrations in WWTPs followed a similar pattern as the total phosphorus concentrations.

The ratio of orthophosphates to total phosphorus (Figure 3-10) in the mainstem river and tributaries was generally the highest observed during all Phase III events. Dry and wet weather ratios were comparable, and ranged from 0.08 to 0.79 (average 0.42), with the exception of the dry weather ratio observed downstream of the Essex Dam (1.60). Since this ratio should not be greater than 1, this may represent some variability between the sample volume collected for the total phosphorus and orthophosphate analysis at this location. The ratio is generally increasing slightly from upstream to downstream in the study area. These results indicate that phosphorus is the limiting nutrient, but not the limiting factor in algal growth. Other potential limiting factors include water temperature, residence time, and light penetration. The ratio of orthophosphates to total phosphorus in the WWTP effluent was greater than 0.5 during the sampling event (average of 0.88 for all sites).

3.3.6 pH

Field readings of pH in the mainstem river were generally above neutral (7 standard units), and consistent with readings observed during prior events. Dry and wet weather readings ranged from 6.17 to 8.75 SU, with an average pH of 7.37 SU. The tributary field readings ranged from 6.52 to 7.56 SU, with the average pH of 7.02 SU (Figure 3-11). The lowest pH value of 6.17 SU was observed upstream of the Amesbury WWTP, and the highest pH value of 8.75 SU was observed at upstream of the Essex Dam. Field readings of pH in the WWTP effluent were only available for select WWTPs, and ranged from 5.5 to 7.6 SU. Due to the volume of data and for simplicity and consistency of reporting, the average of the initial and final field readings was used for data plots and in data tables. Individual results are included on the field worksheets. The New Hampshire Class B water quality standards require pH to be between 6.6 and 8.2 SU. There were no readings in New Hampshire greater than 8.2 SU and none less than 6.6 SU. Therefore, the samples collected in New Hampshire were in compliance with Class B water quality standards. The Massachusetts Class B standards require pH to be between 6.5 and 8.3 SU, and the Massachusetts Class SB standards range from 6.5 to 8.5 SU. There were two dry weather readings in Massachusetts greater than 8.3 (downstream of the O006D stormdrain in Lowell and upstream of the Essex Dam), four readings less than 6.5 (upstream and downstream of both the Merrimac, MA and Amesbury, MA WWTPs), and no readings in the shellfish beds greater than 8.5.

3.3.7 Bacteria

New Hampshire Class B water quality standards for bacteria in freshwater, MA Class B water quality standards for bacteria in freshwater, and Massachusetts Class SB water quality standards for bacteria in saltwater were defined in Section 3.1.7. The relevant state standards are summarized in **Table 3-10**, along with a count of relevant sample results above stated criteria. It should be noted that all results are for single samples and any comparisons to means or median standards is for information only. Further, comparisons to shellfishing bed (saltwater only) standards are provided for all saltwater samples regardless of use designation at the location of the sample. As there are no Massachusetts Class saltwater (Class SB) standards for *E. coli*, all Massachusetts station samples, with the exception of two stations designated as shellfishing beds (saltwater only), are compared to Freshwater (Class B) standards for informational purposes only.

Figures 3-12 through 3-14 show the results of the bacteria analyses during the August 2016 hybrid dry/wet weather survey, and **Figure 3-17** presents a graphical representation of locations with bacteria concentrations above relevant state water quality criteria.

Table 3-10: Count of Bacteria Concentrations Above New Hampshire and Massachusetts Water Quality Criteria for Freshwater and Saltwater Relevant Classes for Event #3

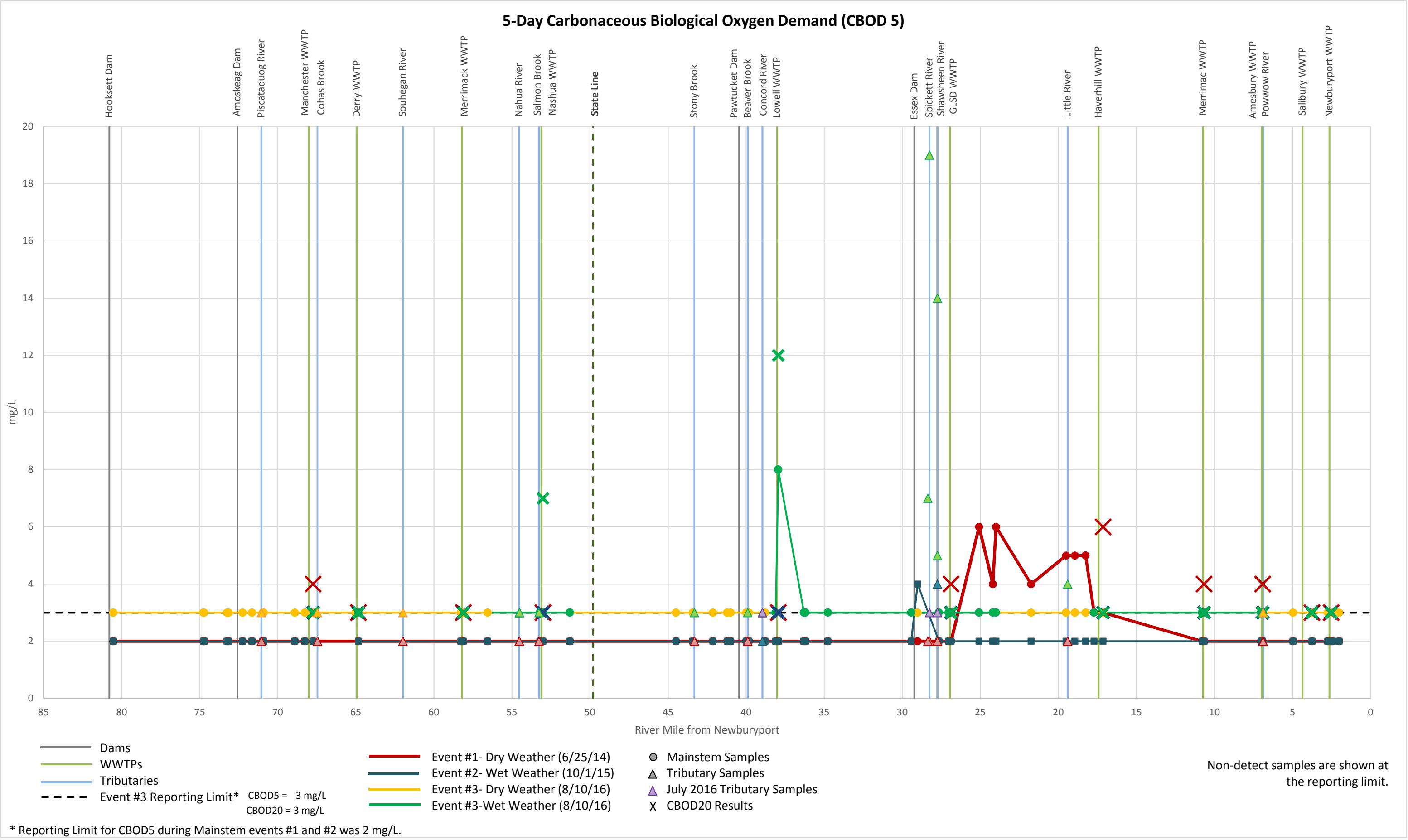
(# above/total samples)	New Hampshire Freshwater Class B	Massachusetts Freshwater Class B	Massachusetts Saltwater	
Station Type	Single Sample, Non-Beach[1]	Single Sample, Bathing Beach & Non-Beach[1]	Median or Mean*, Shellfishing[2]	Single Sample, Class SB Bathing Beach & Non-Beach[1]
	E. coli 406 mpn/100 mL	*E. coli* 235 mpn/100 mL	*Fecal coliform 88 mpn/100 mL*	*Enterococci 104 mpn/100 mL*
Mainstem (overall)	4/20	15/36	3/12	2/12
Dry	2/16	4/19	1/7	1/7
Wet	2/4	11/17	2/5	1/5
Tributary (overall)	6/7	8/9	0/1	0/1
Dry	2/3	0/1	0/1	0/1
Wet	4/4	8/8	-	-

Notes:
1. Water quality standards are for single sample thresholds
2. This standard is for a median or geometric mean, however only one samples was collected. Comparisons for information purposes only.

E. coli and fecal coliform were detected at most dry weather and wet weather mainstem and tributary locations. The highest *E. coli* concentration was reported at the wet weather sample collected upstream of the Haverhill WWTP in Haverhill, MA (24,196 mpn/100 mL). This site also had the highest fecal coliform concentration of >24,146 colonies per 100 mL. Also notable were the dry weather *E. coli* and fecal coliform concentrations downstream of the Haverhill WWTP (11,199 mpn/100 mL and 12,997 mpn/100 mL, respectively). High fecal coliform concentrations (>2420 mpn/100 mL) were reported at the eight mainstem sample stations (five dry/three wet) and ten wet weather tributary stations. *E. coli* was also reported at the same concentration at the same locations, except for one tributary. It is important to note that most *E. coli* and fecal coliform samples were not diluted by the laboratory prior to incubation and analysis, but if a sample was brackish, the lab automatically did a 10x dilution. Thus, 2420 mpn/100 mL was the maximum achievable reporting limit for freshwater samples during the August 2016 event, and 24,196 mpn/100 mL was the maximum achievable reporting limit for brackish water samples. Wet and dry weather enterococci results were comparable, but the highest observed enterococci concentration was 145 mpn/100 mL at the station upstream of the Haverhill WWTP.

The August 2016 wet weather bacteria results are generally significantly higher than those dry weather samples collected on the same day as well as concentrations observed during the June 2014 dry weather event, which may likely be attributed to tributary discharges as well as the CSO discharges from multiples WWTPs during the rainstorm.

Figure 3-1
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)



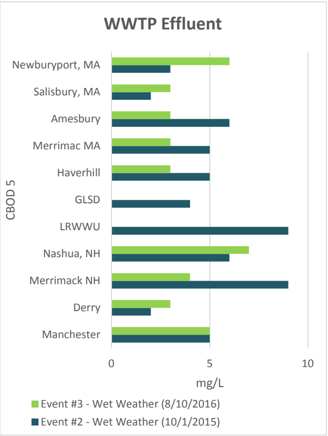


Figure 3-2
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)

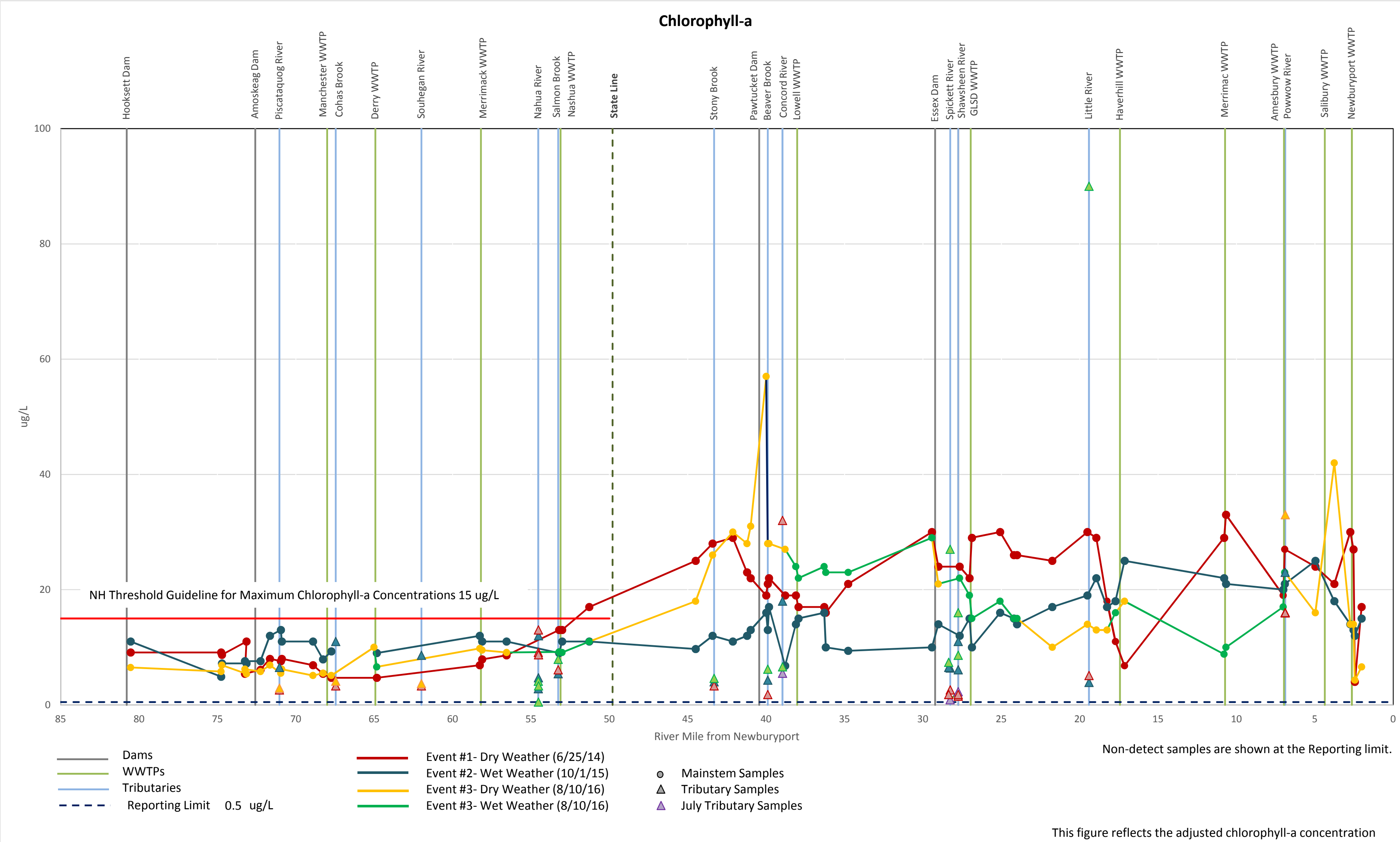
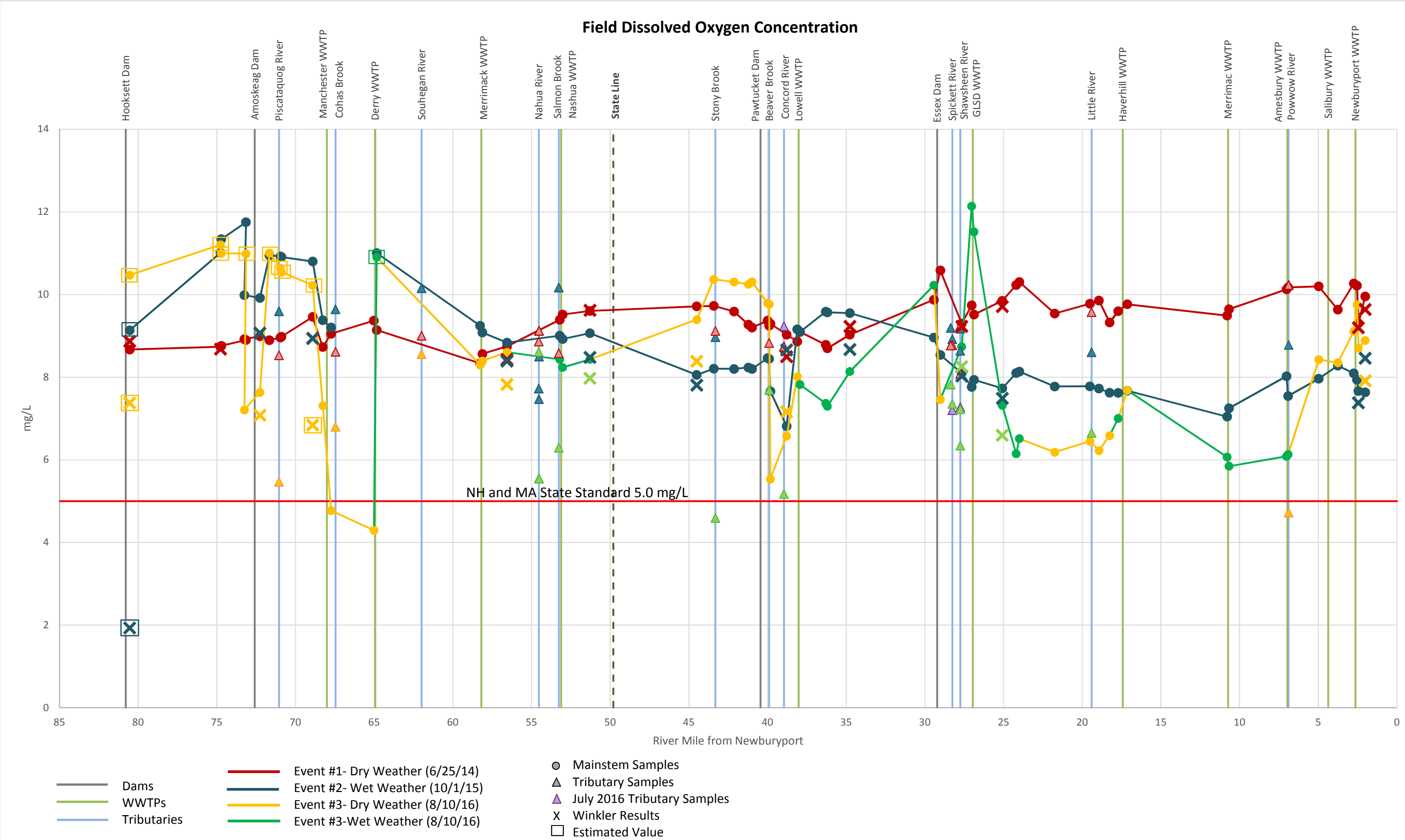


Figure 3-3
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)



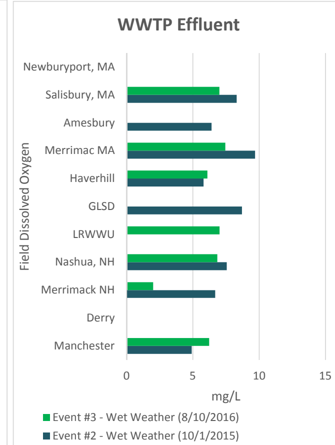
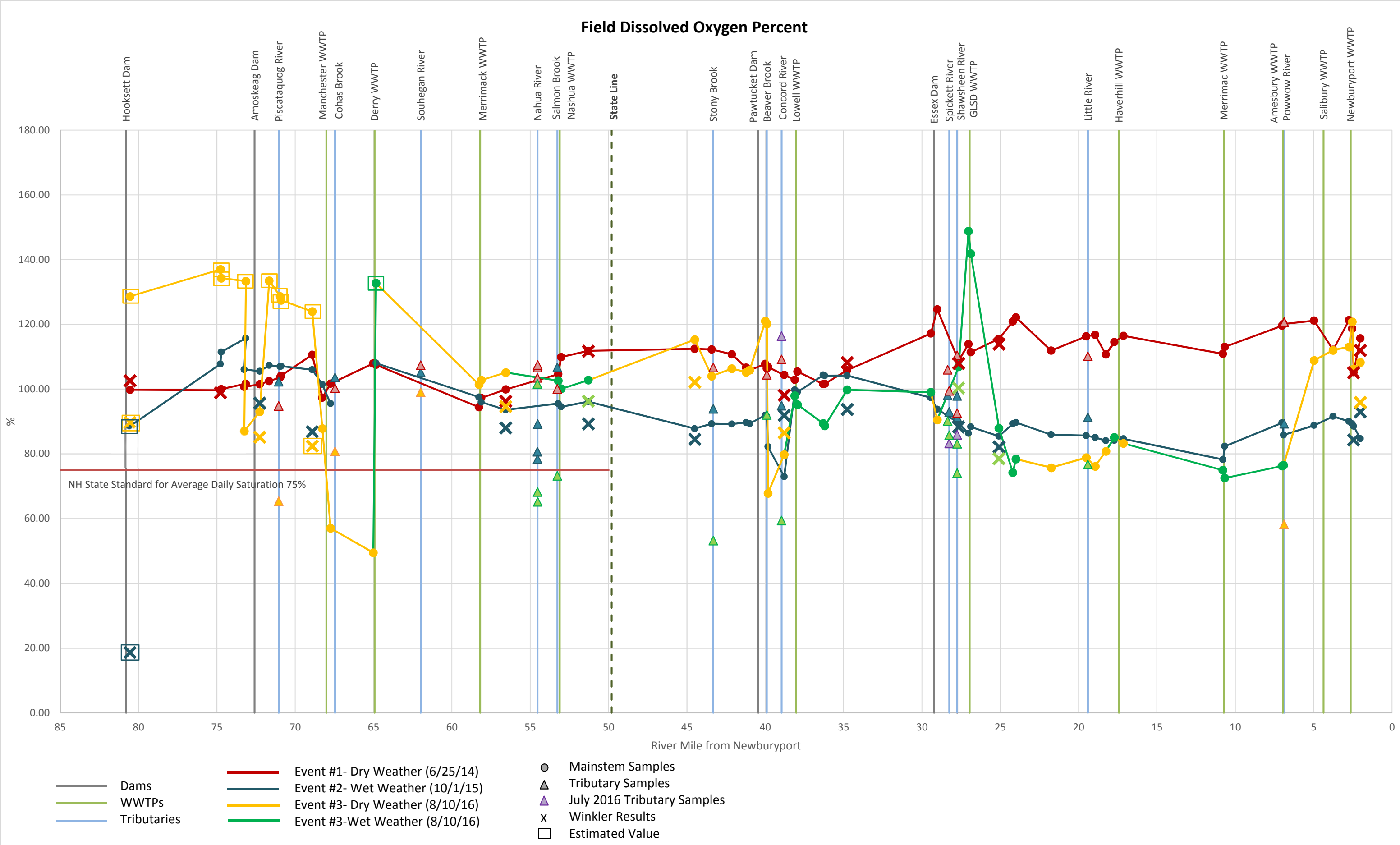


Figure 3-4
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)



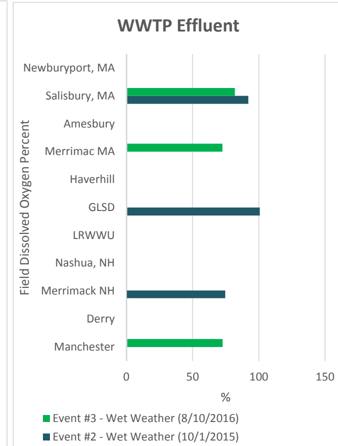
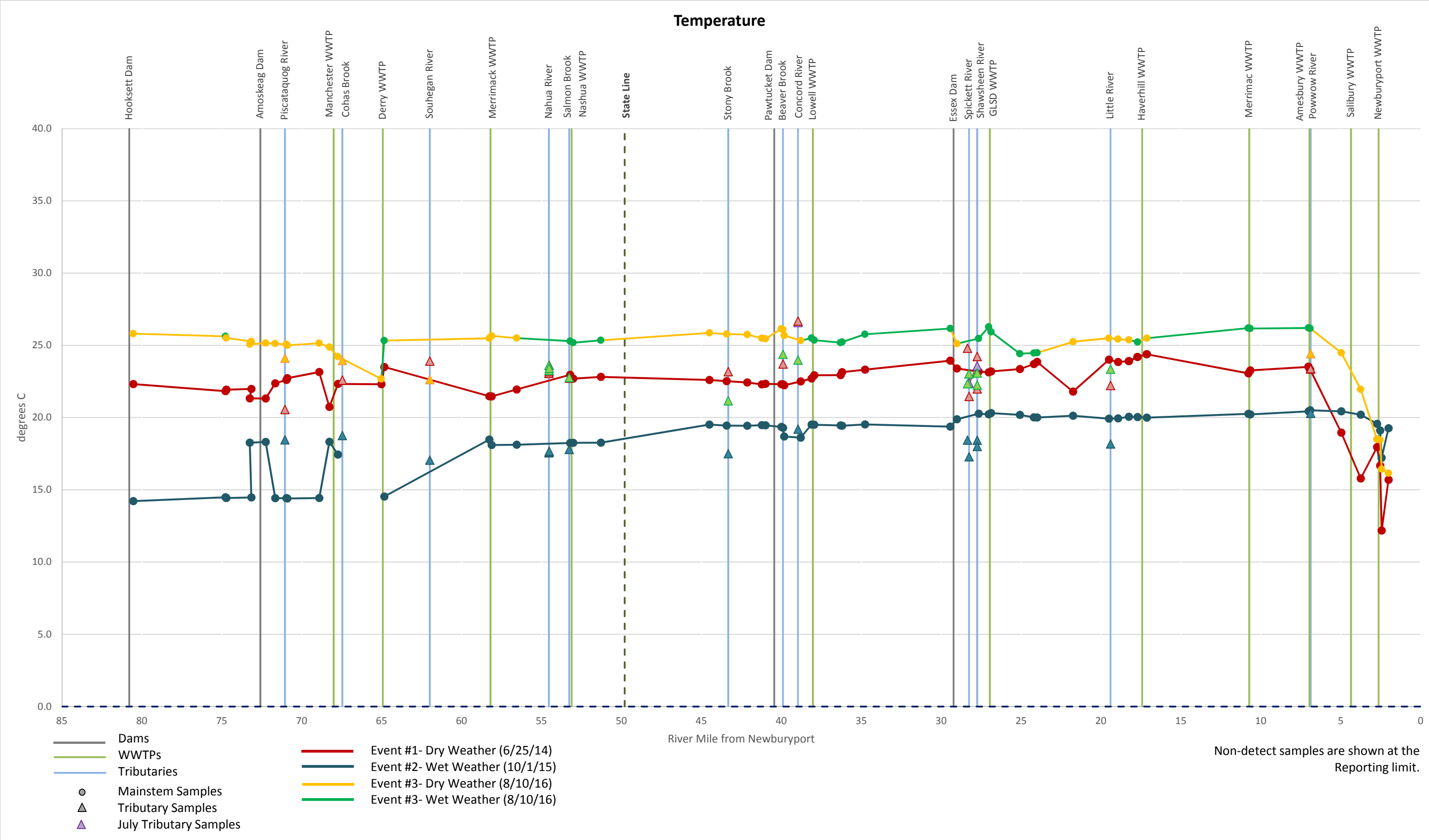


Figure 3-5
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)



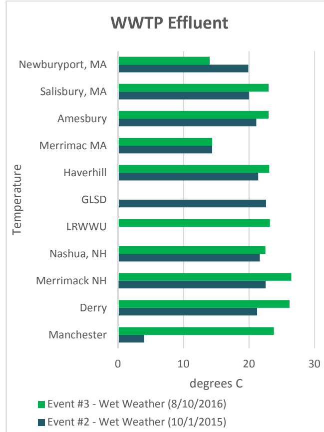
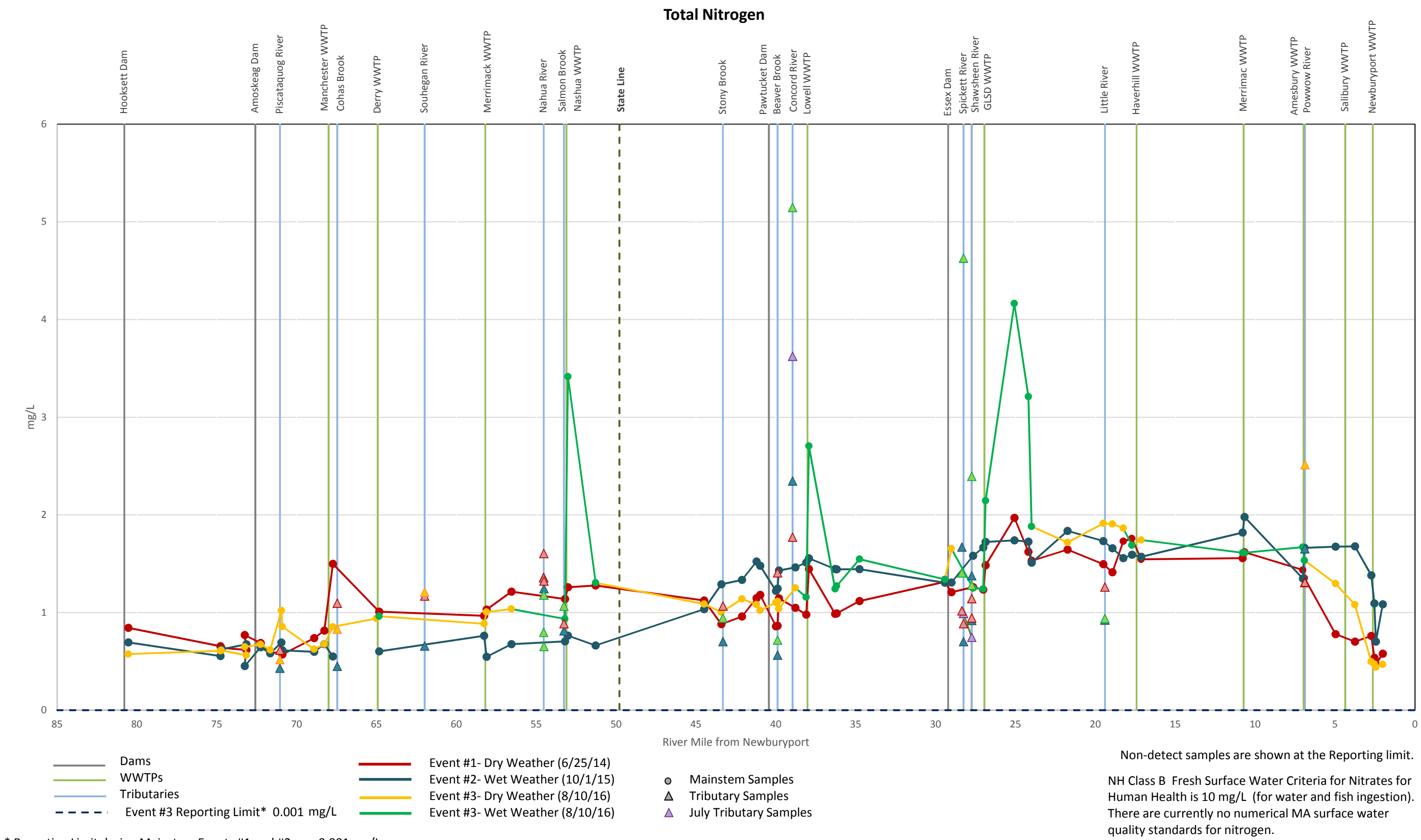


Figure 3-6
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)



* Reporting Limit during Mainstem Events #1 and #2 was 0.001 mg/L.

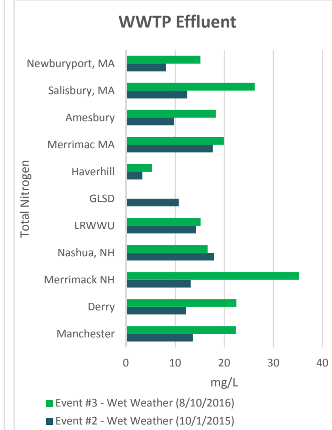


Figure 3-7
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)

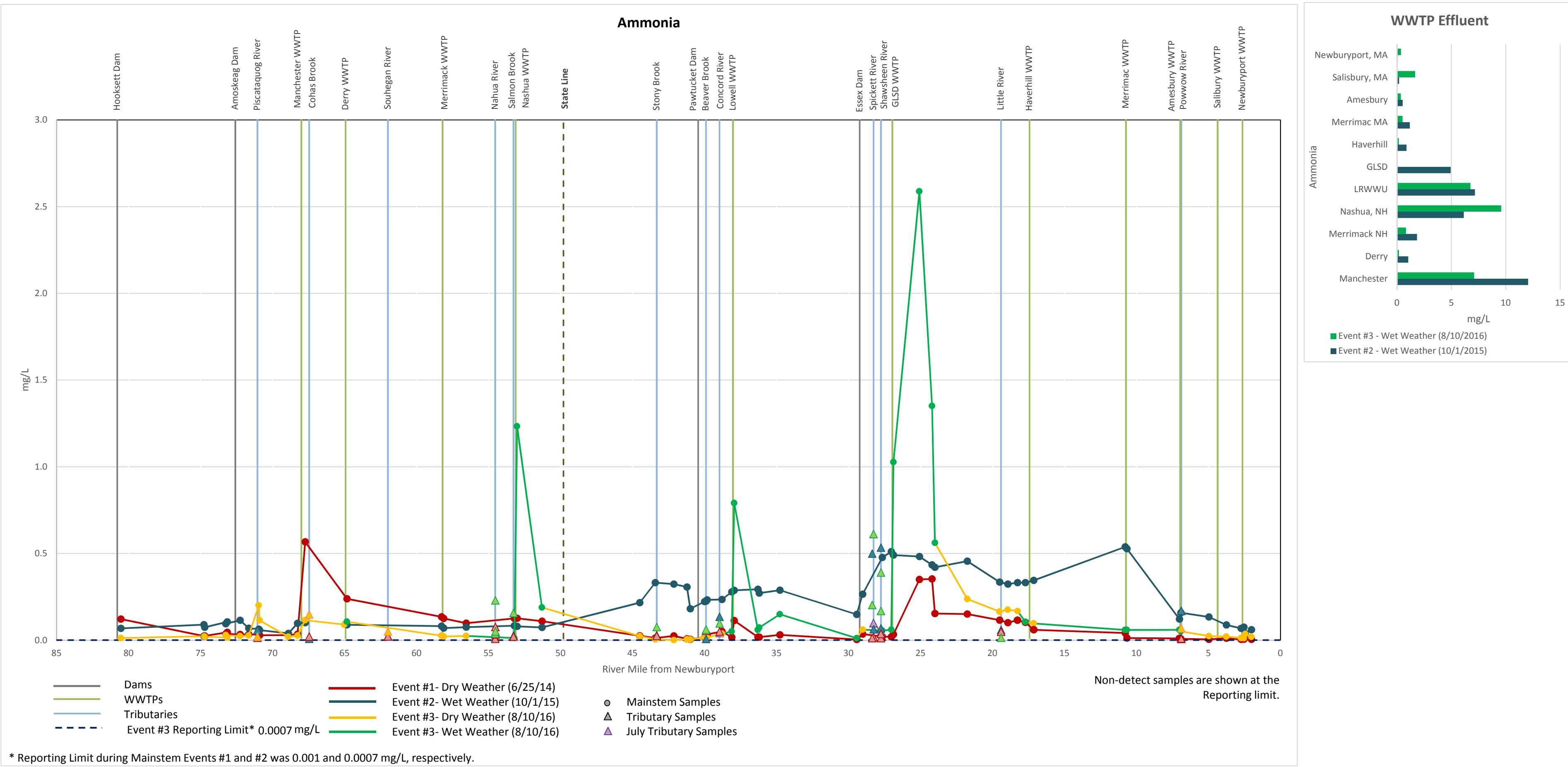
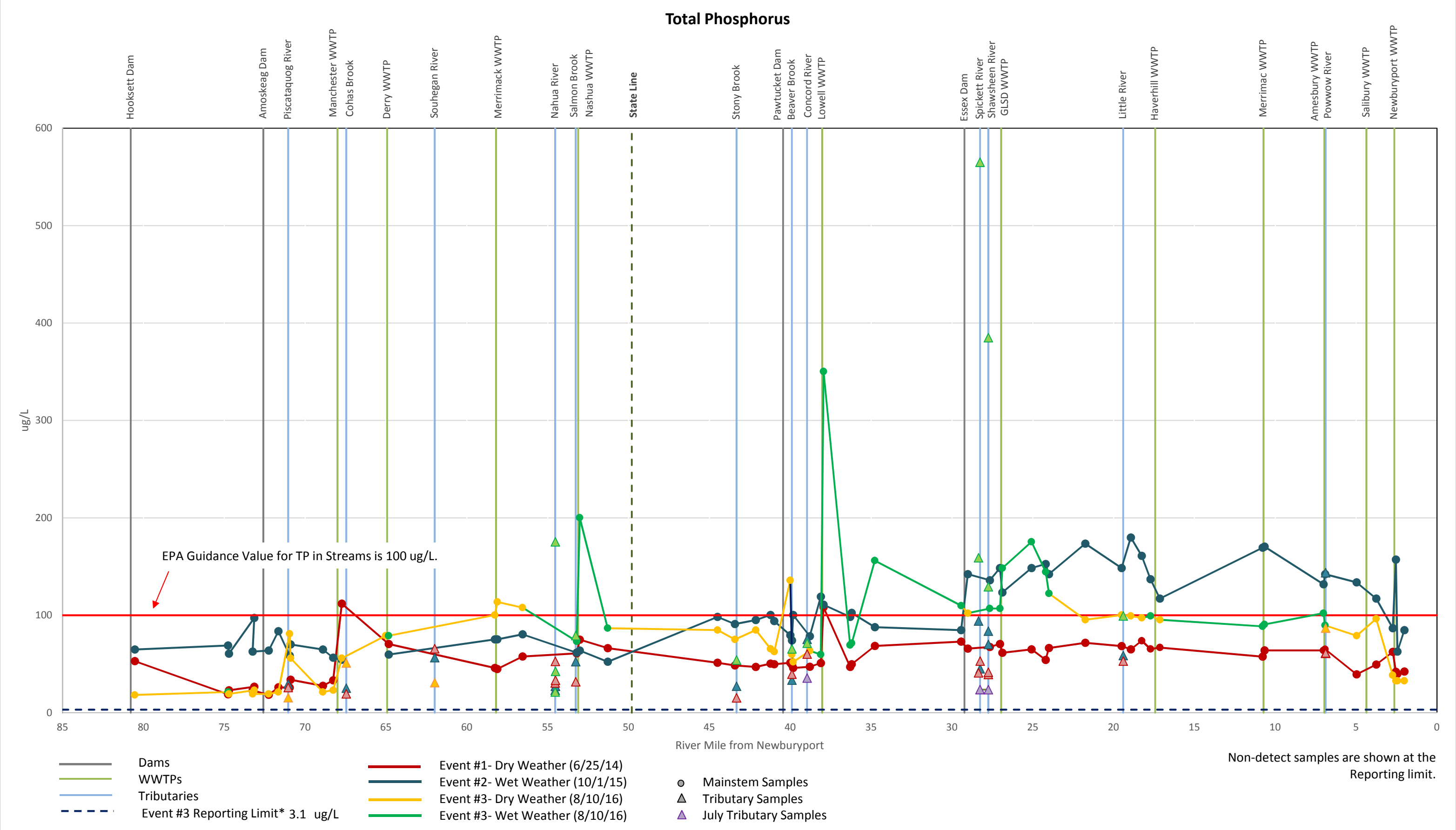
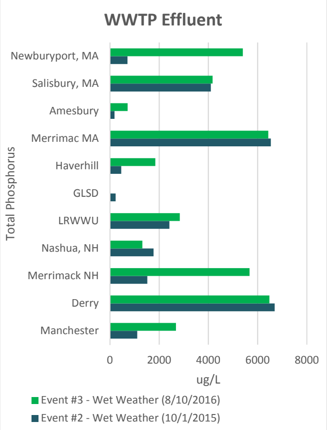


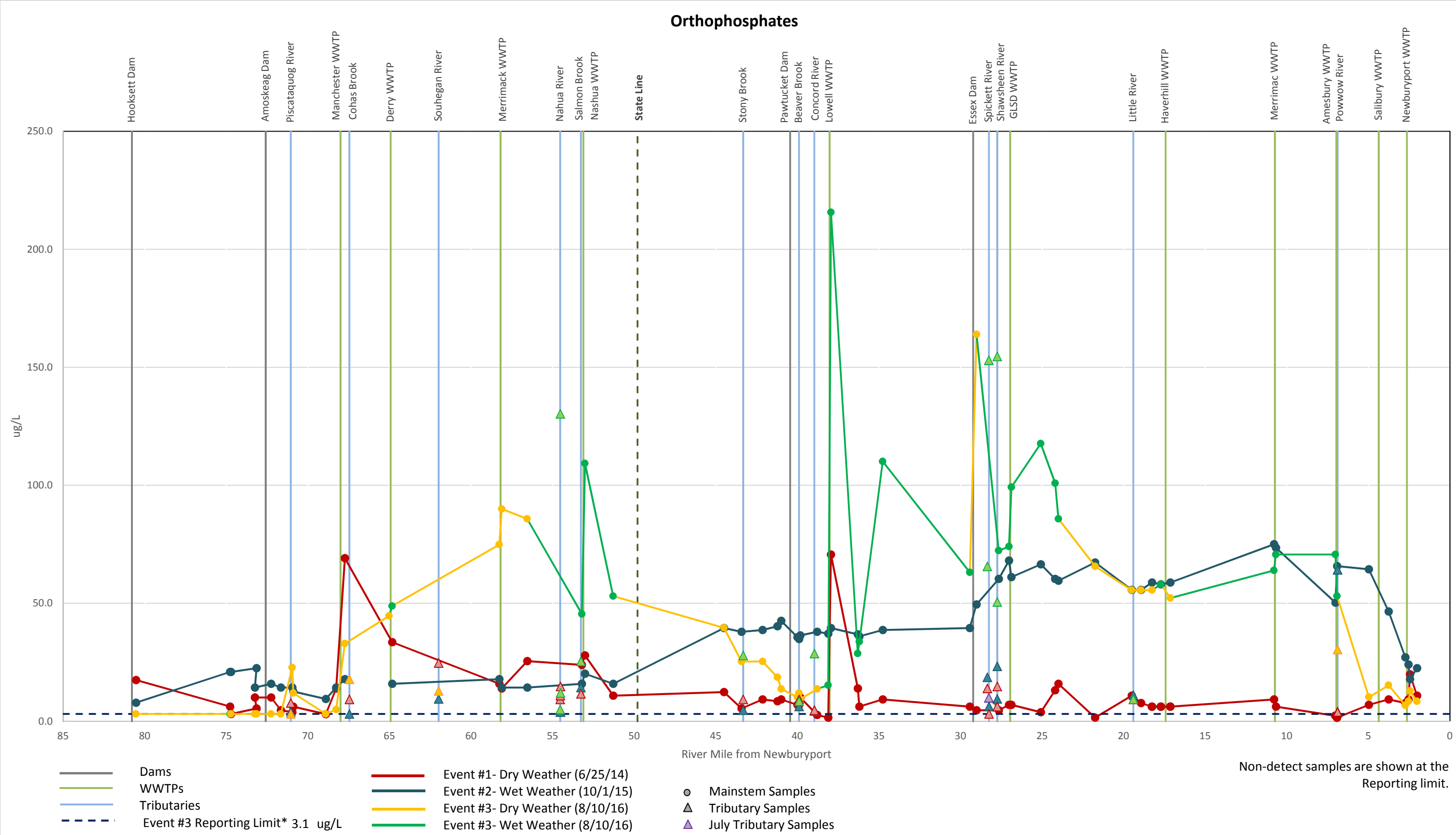
Figure 3-8
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)

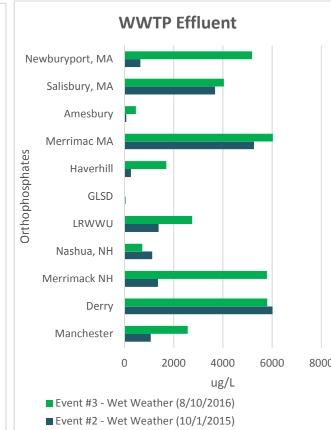




* Reporting Limit during Mainstem Events #1 and #2 was 2 and 3.1 ug/L, respectively.

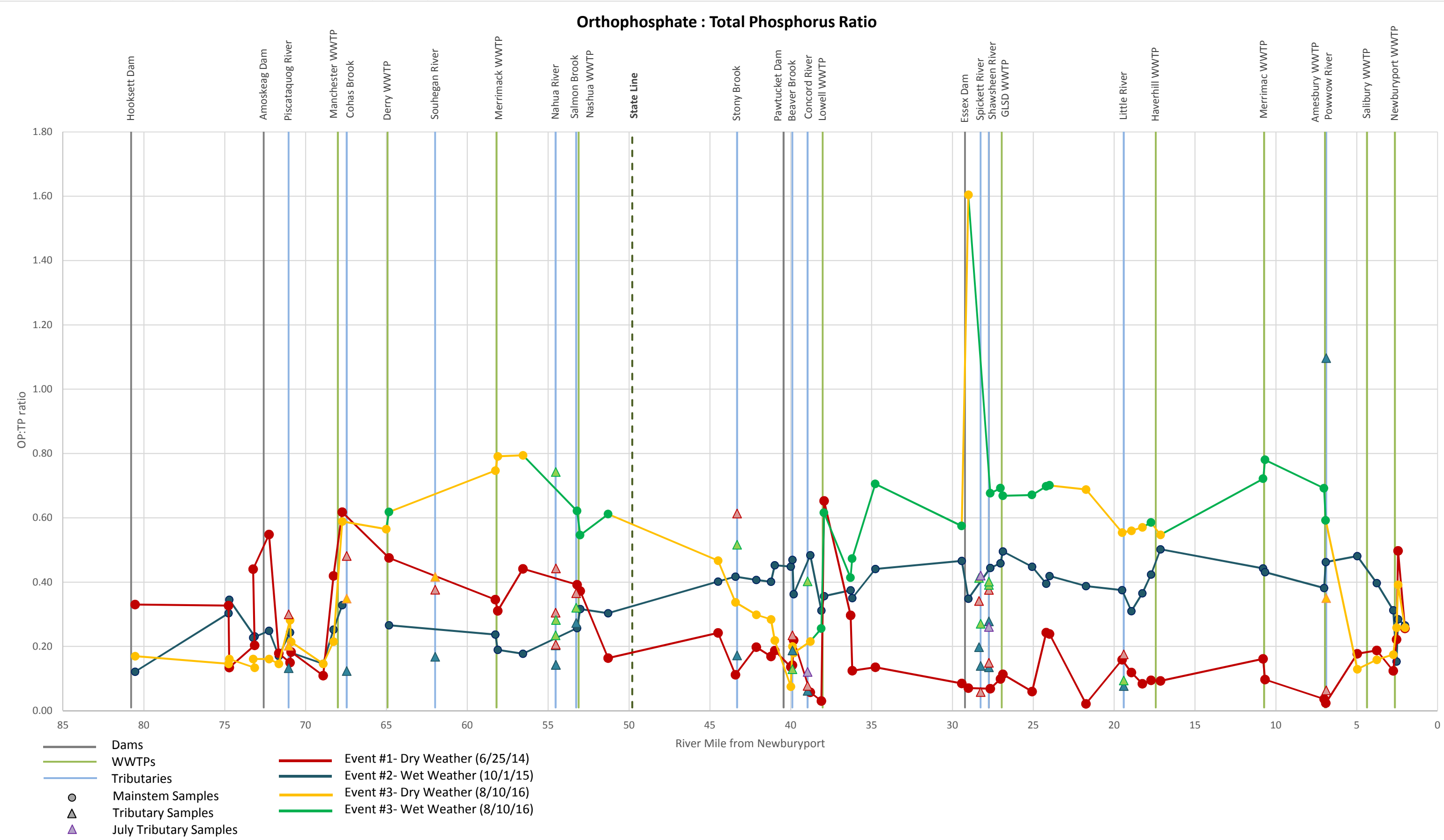
Figure 3-9
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)





* Reporting Limit during Mainstem Events #1 and #2 was 2 and 3.1 ug/L, respectively.

Figure 3-10
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)



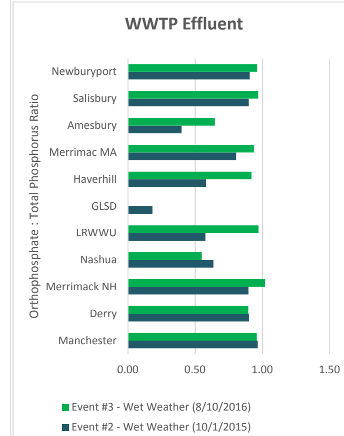
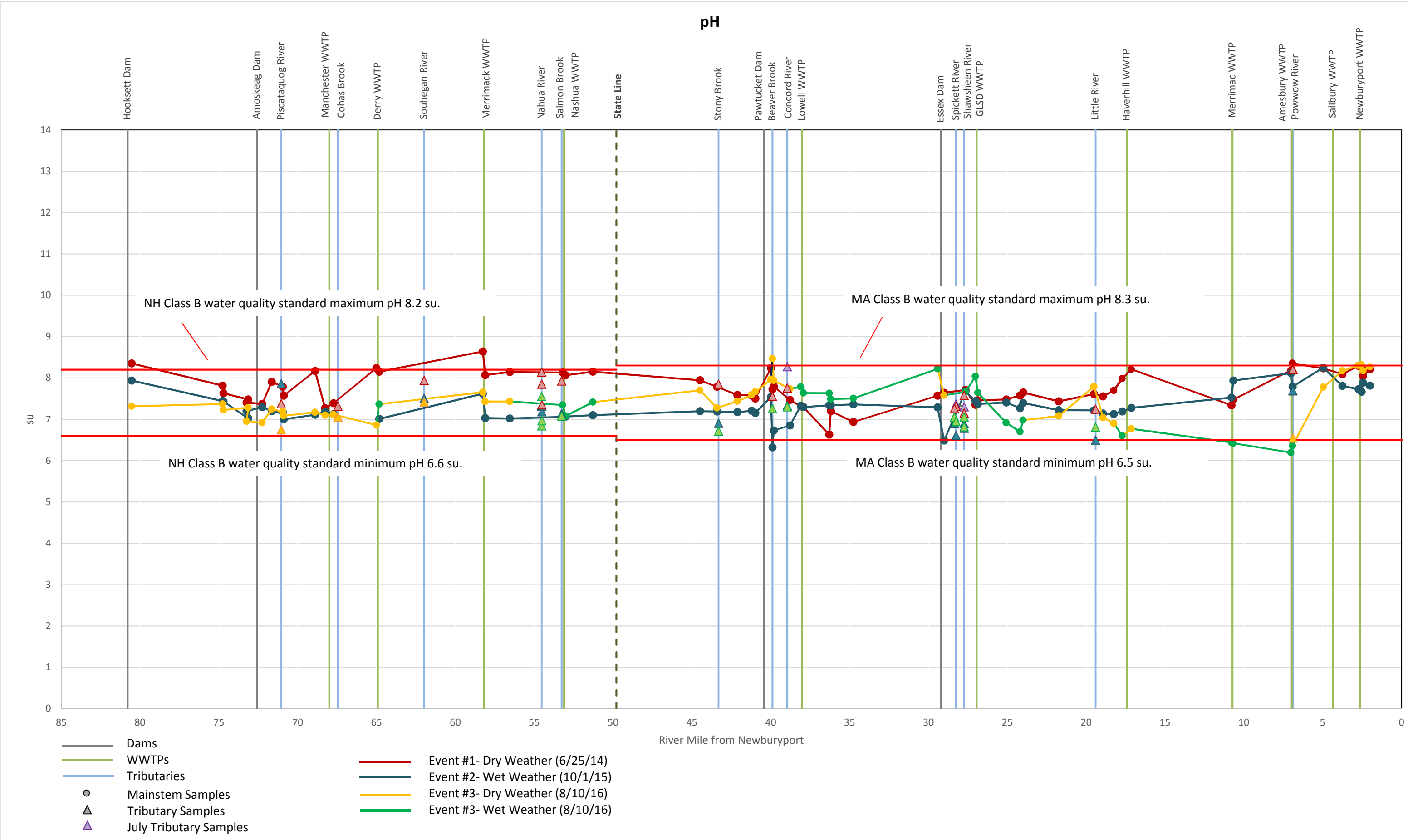


Figure 3-11
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)



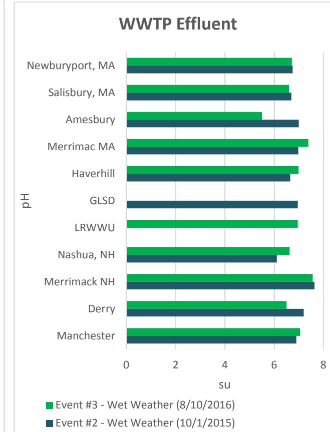


Figure 3-12
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)

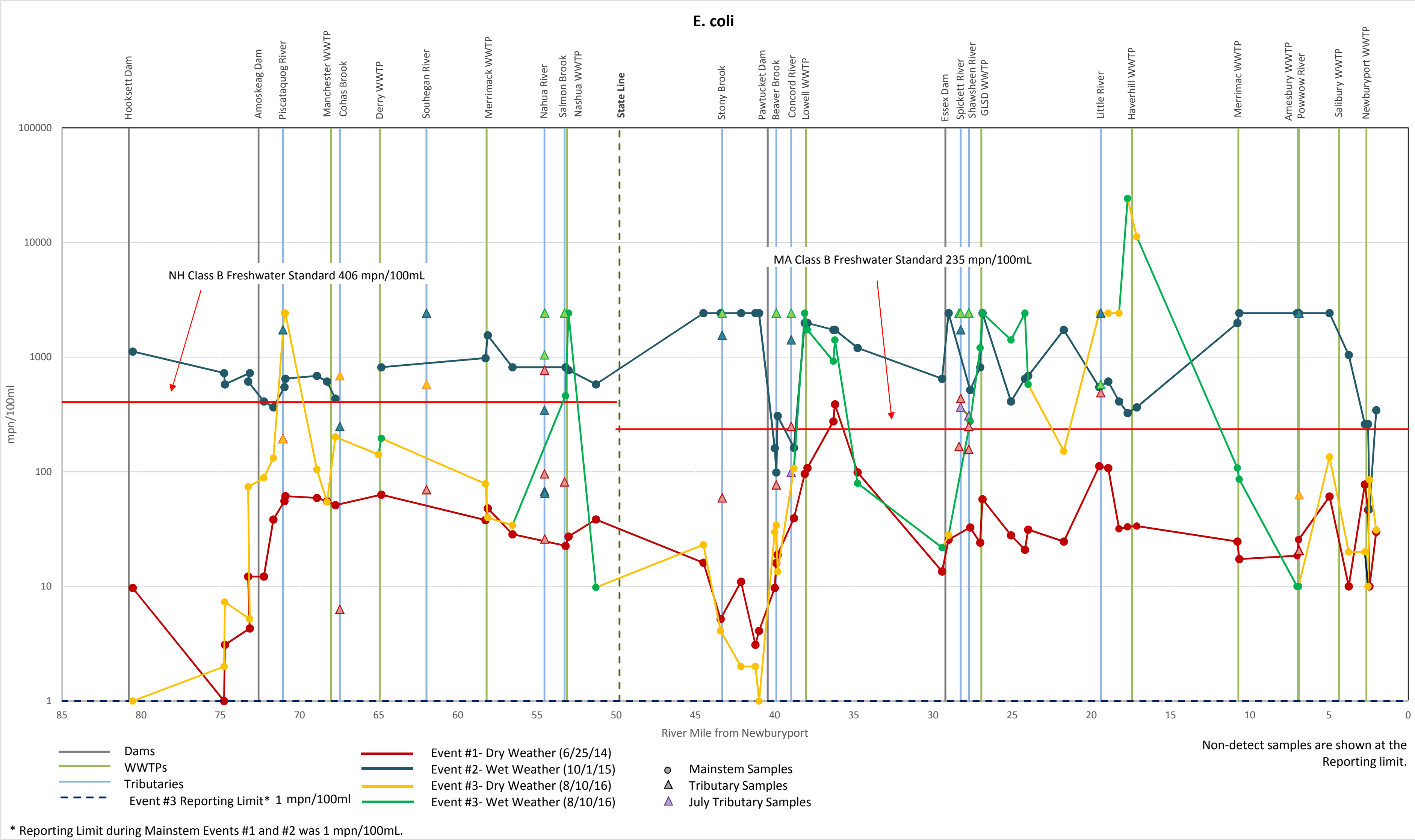


Figure 3-13
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)

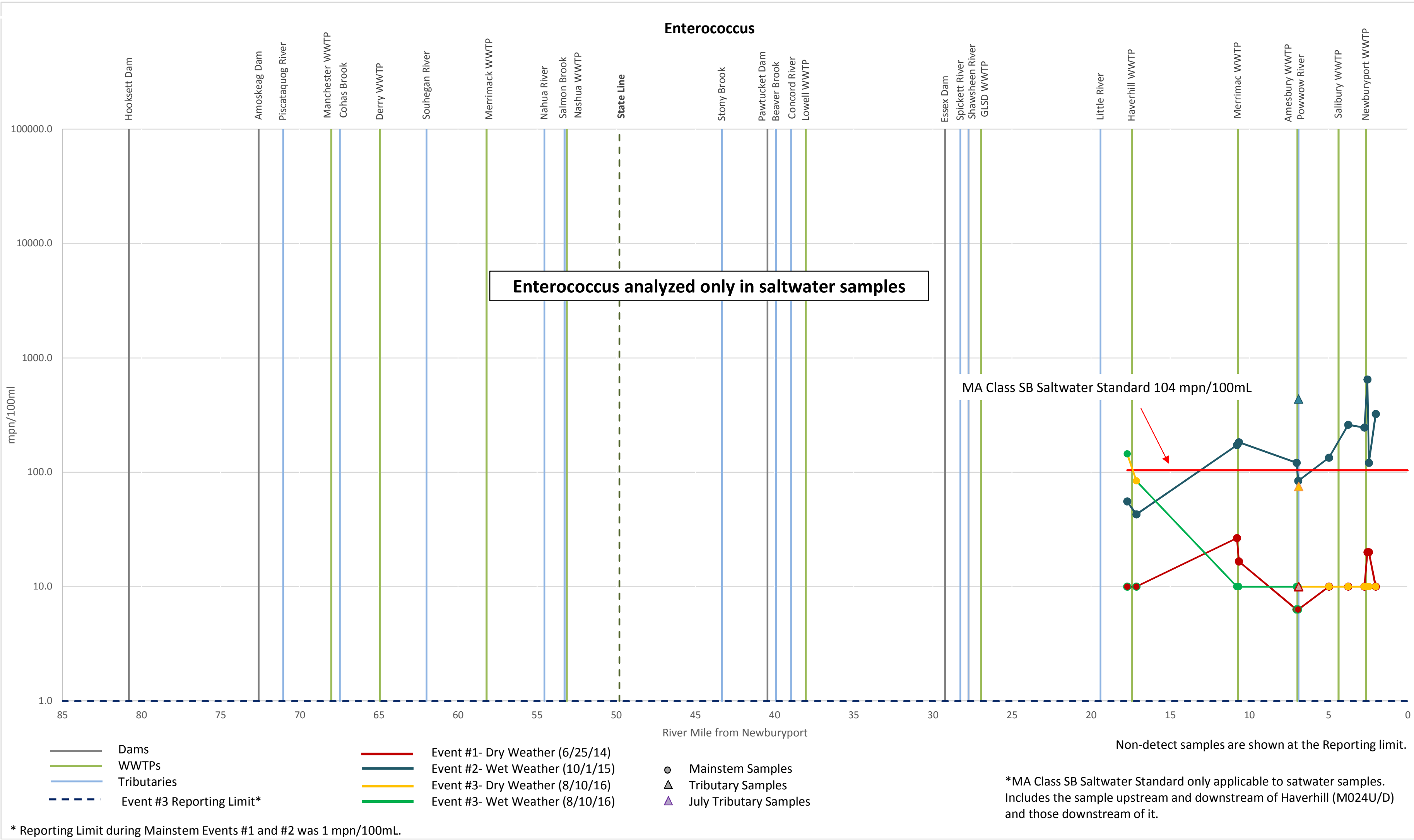
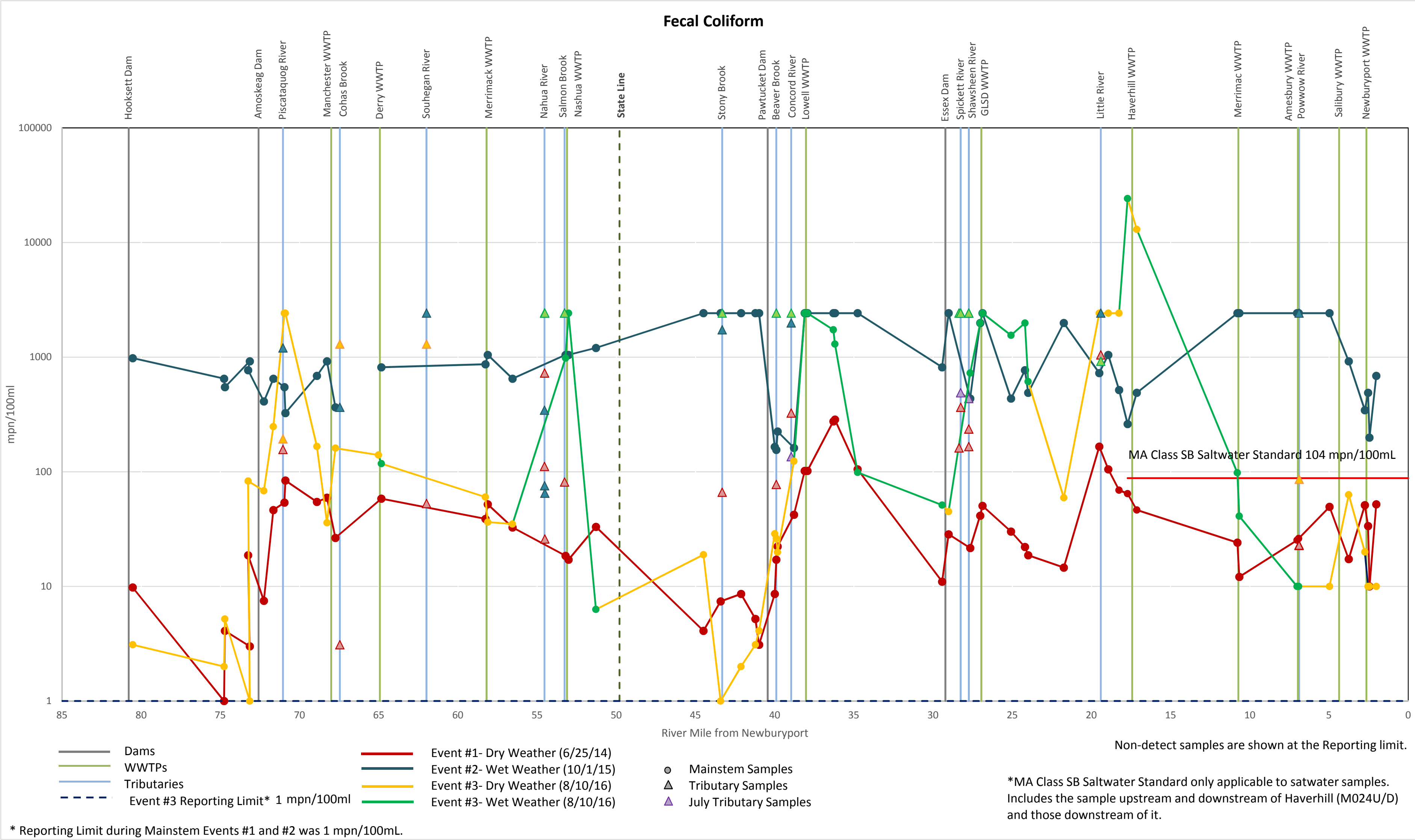


Figure 3-14
Merrimack River Watershed Study
Phase III - Event #1 (6/25/2014), Event #2 (10/1/2015) & Event #3 (8/10/2016)



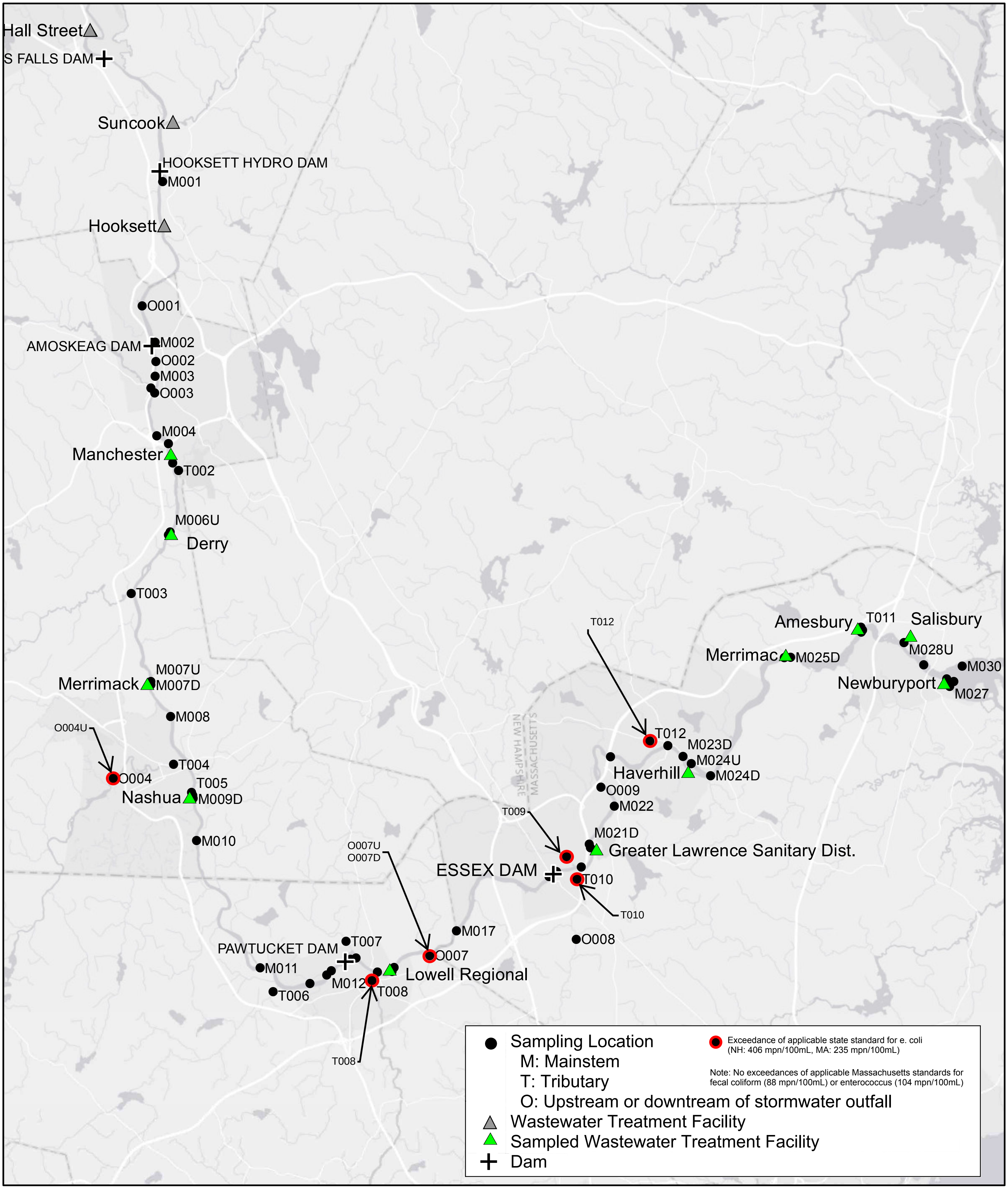


Figure 3-15

Merrimack River Watershed Study
Phase III Lower Merrimack Event #1 Bacteria Results

0 2.5 5 10 Miles

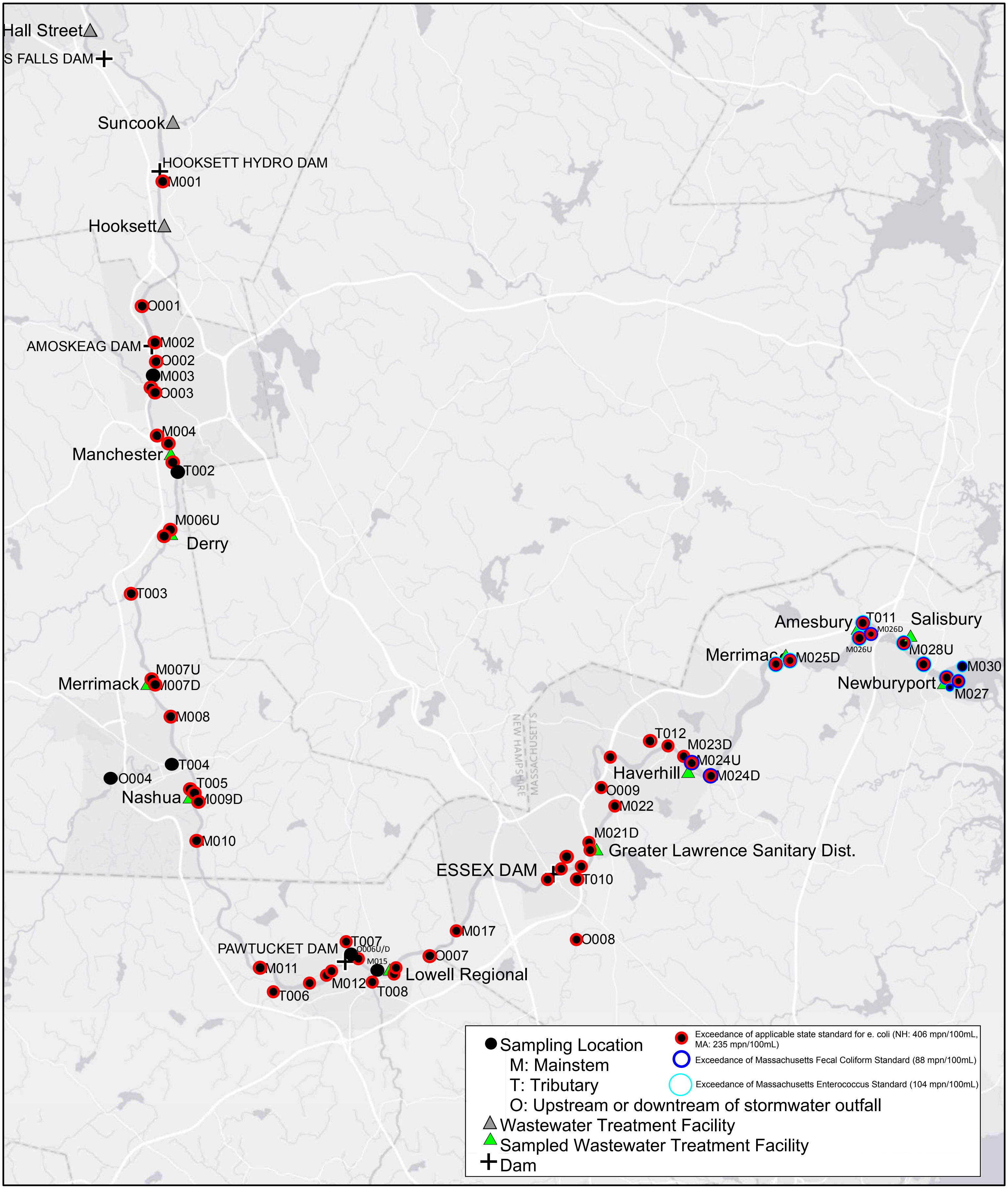


Figure 3-16

Merrimack River Watershed Study
Phase III Lower Merrimack Event #2 Bacteria Results

0 2.5 5 10 Miles

CDM Smith

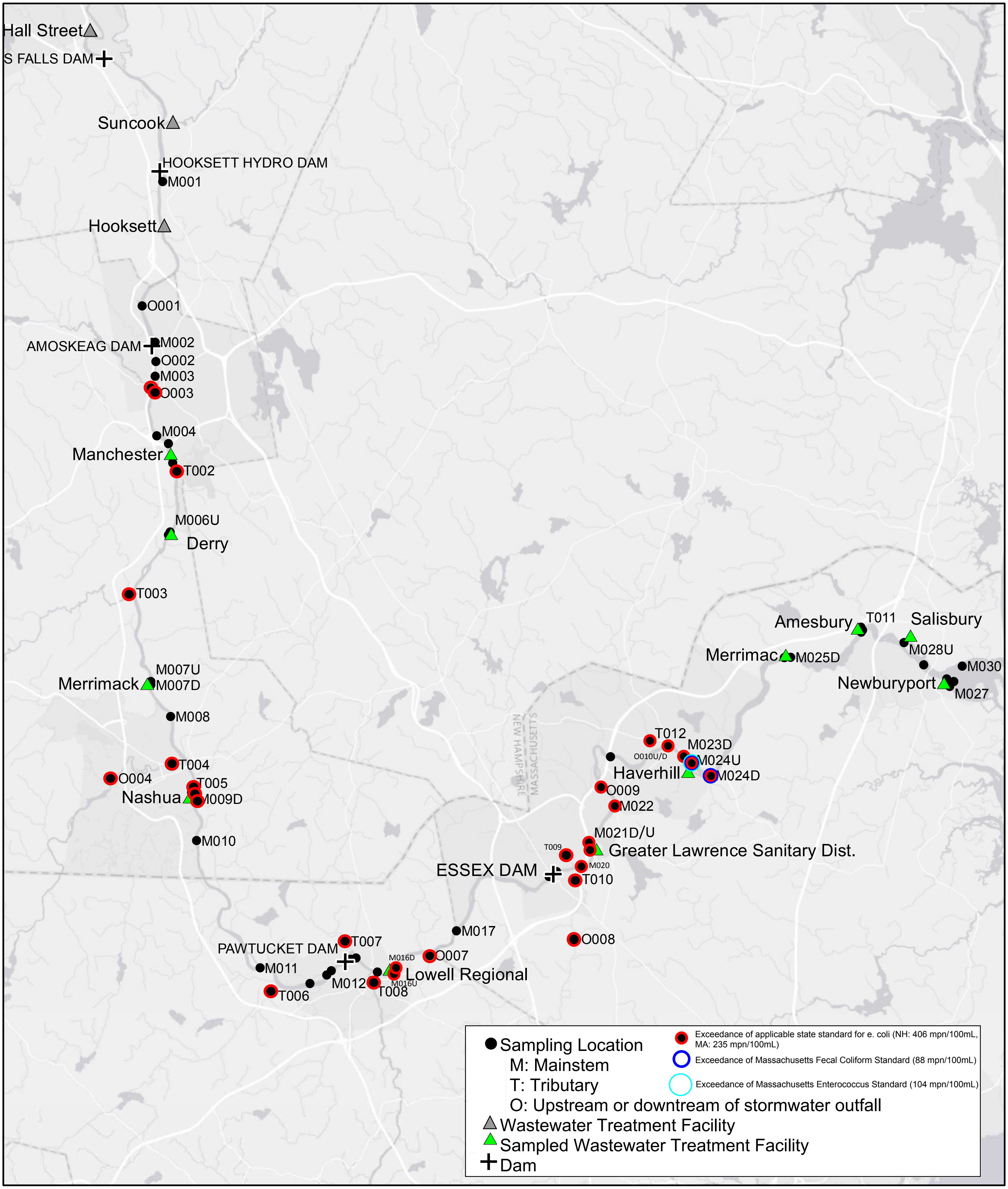


Figure 3-17

Merrimack River Watershed Study
Phase III Lower Merrimack Event #3 Bacteria Results

0 2.5 5 10 Miles

CDM Smith

Section 4

Key Tributary Event (Dry Weather) Water Quality Survey Data Summary and Observations

Section 4 provides the data summary and observations for the 21 July 2016 dry weather tributary water quality survey. The results of the tributary event, which consist of water quality sampling along three key tributaries (Concord, Shawsheen, and Spicket Rivers), are graphed by individual river but are presented on one figure for each parameter for comparative purposes. It should be noted that Section 4 text, tables, and figures focus on the select parameters that were determined to be the most critical and most representative of river health. Refer to the end of this section and Appendix B for fold-out panels containing data plots and Appendix C for complete data tables. Results of the data validation and evaluation, including the assessment of data usability is included in Appendix D. Field data sheets and laboratory results are included in Appendix E and Appendix F, respectively.

For consistency between the mainstem and tributary field programs, the most downstream sampling location on each of the three tributaries corresponds to the three tributary confluence samples collected as part of the mainstem water quality surveys. That is, Concord 11 corresponds to T008, Shawsheen 11 corresponds to T010, and Spicket 8 corresponds to T009. For reference, these select results were included in the Section 3 plots.

Samples collected during the tributary sampling event consisted only of river stations, which included stations upstream and downstream of the two WWTPs on the Concord River (Concord, MA and Billerica, MA WWTPs); however, no effluent samples were collected from these WWTPs. It is important to note that each of the river flows were very low (at or below 7Q10 flows), which is typically indicative of worst case conditions in the river and thus higher in-stream concentrations and lower dissolved oxygen concentrations.

As previously stated in this report, this Study uses Massachusetts and New Hampshire SWQS to assess the likely compliance/non-compliance status of the Lower Merrimack River. It does not make a comparison to the Massachusetts or New Hampshire CALM guidelines nor to the individual WWTP permit limits.

A summary of the field observations for the three mainstem events, as recorded on the field data sheets, is included in **Table 4-1**. These observations include tree coverage, algae, wildlife, and other noteworthy conditions or features observed during the sampling events

Table 4-1: Summary of Tributary Sample Location Field Observations
Merrimack River Watershed Study
Phase III Lower Merrimack River

Sample Location			Observations
Sample ID	**Description**	**River Mile**	**Tributary Event #1 (July 21, 2016)**
Concord River Locations			
Concord 1	Assabet River Contribution	16.43	Algea Coverage: Small groupings Wildlife: Few turtles
Concord 2	Sudbury River contribution	16.40	Algea Coverage: Minimal Wildlife: Insects
Concord 3	Upstream/ Background	16.13	Tree Cover: along river
Concord 4U	Upstream from Concord WWTP	15.39	Algea Coverage: None to slight Tree Cover: along edges of river Wildlife: Birds
Concord 5D	Downstream of Concord WWTP, agricultural fields, and orchards.	14.64	Wildlife: Turtles, Insects Other: People on shore
Concord 6	Downstream of residents and conservation areas.	11.38	Algae Coverage: minimal Other: People on shore
Concord 7	Downstream of residents, conservation land, and Rt 3. Bottom of watershed	8.19	Algae Coverage: Slight on sides Tree Cover: On sides, not at sample location Other: Murky, can't see bottom
Concord 8	Downstream of residents, high school, sports fields, conservation land.Bottom of watershed.	5.99	Algae Coverage: Slight on edges Tree Cover: On edges
Concord 9U	Upstream Billerica WWTP	4.38	Algae Coverage: Slight on edges Tree Cover: On river edges, not at sample location
Concord 10D	Downstream of Billerica WWTP.	3.95	Tree Cover: On river's edge, not at sample location Other: trash
Concord 11	Downstream of city/ residents prior to discharge into Merrimack.	0.54	Algae Coverage: Plants Tree Cover: On river edges, not at sample location Wildlife: Birds/Ducks
Spicket River Locations			
Spicket 1	Upstream/ background location	14.18	Tree Cover: Moderate to heavy Wildlife: Small birds, bugs
Spicket 2	Downstream of Hog Hill Brook and Atkinson Resort & Country Club	13.73	Tree Cover: Moderate Wildlife: Birds, insects and dragon flies Other: Slightly stagnant odor, down at upstream end of bridge. Possibly beavers, a dam of some sort observed.
Spicket 3	Downstream of Residents/ town/ greenspace/ Policy Brook	11.31	Algae Coverage: minimal Tree Cover: moderate, small trees mostly Wildlife: Birds, insects Other: Some river grasses
Spicket 4	Downstream of residents/ prior to commercial area	9.02	Algae Coverage: no algae, some upstream though Tree Cover: moderate, large trees Wildlife: Birds, insects, frog/toad Other: Slight organic sheen on water
Spicket 5	Downstream of residents, Rockingham Park, Rockingham Mall, Commercial area	7.29	Algae Coverage: Some, lots of aquatic grasses Tree Cover: few small trees Wildlife: Aquatic grasses, shrubs, Birds, insects Other: Aquatic grasses
Spicket 6	Downstream from World End Brook and Harris Brook.	5.67	Algae Coverage: minimal, some aquatic grasses Tree Cover: some medium sized trees Wildlife: Birds, insects Other: School field trip, two men walking dogs
Spicket 7	Downstream from 93, bird sanctuary, and Nevins Farm & Equine Center.	2.13	Algae Coverage: minimal Tree Cover: Few small trees Wildlife: Birds, insects Other:Lots of trash, garbage, waste, scrap metal, trash odor

Table 4-1: Summary of Tributary Sample Location Field Observations
Merrimack River Watershed Study
Phase III Lower Merrimack River

Sample Location			**Observations**
Sample ID	**Description**	**River Mile**	**Tributary Event #1 (July 21, 2016)**
Spicket 8	Downstream of city and residents, prior to discharge in Merrimack.	0.62	Algae Coverage: none Tree Cover: Major- shady large trees Wildlife: Birds, insects Other: Stagnant water odor
Shawsheen River Locations			
Shawsheen 1	Upstream/ background location, downstream of Hanscom , bottom of first watershed.	25.75	Tree Cover: Full Other: Very slow to no flow. Mucky
Shawsheen 2	Downstream of residents, commercial area. Bottom of two small watersheds.	24.38	Tree Cover: Partial Wildlife: Fish, Birds Other: Low flow, turbid. Some rearation upstream under culvert
Shawsheen 3	Downstream of golf course. collect upstream of Route 3, at bottom of watershed.	21.86	Algae Coverage: Thick filamentous algae Tree Cover: partial Wildlife: Birds (robin), insects Other: Slow moving water, lots of algae, mucky sediment, no rearation "marshy area"
Shawsheen 4	Downstream of residents and industrial/commercial area, bottom of watershed.	19.98	Algae Coverage: Large clumps at edge, none at sample location Tree Cover: ~ 50% Wildlife: Song birds, insects Other: trash at edge, tass grass growing mid stream
Shawsheen 5	Downstream of Jones Brook/ Billerica Country Club (golf course). Bottom of watershed.	18.48	Algae Coverage: minimal Tree Cover: none Wildlife: Frogs, bugs, rabbit Other: powerlines, cattails
Shawsheen 6	Downstream of residents/ recreational area access point. Bottom of watershed.Collect u/s of 129 bridge.	16.64	Algae Coverage: none, sandy bottom in center of channel Tree Cover: 80% Wildlife: Fish, birds Other: Low flow, trees down in channel
Shawsheen 7	Downstream of residents, Strong Water Brook (Meadow Brook), Tewksbury Country Club (golf course)	13.15	Algae Coverage: Paraphyton Tree Cover: 60% Wildlife: Frogs, fish, insects Other: Rocky
Shawsheen 8	Downstream of residents and 93, bottom of one small and one larger watershed (Access point?)	8.42	Algae Coverage: Not a lot Tree Cover: Many trees hang over river Wildlife: Birds, insects, frogs Other: Log jam upstream
Shawsheen 9	Downstream of Residents and Indian Ridge Golf Club, bottom of watershed	6.35	Algae Coverage: Some Tree Cover: None Wildlife: Damsel fly Other: Oily sheen on water directly below canoe channel
Shawsheen 10	Downstream of Sacred Heart, residents, town, sports fields, dams. Bottom of two small and one larger watershed.	3.28	Algae Coverage: Some, not much Tree Cover: 50% Wildlife: Pigeons Other: Shopping cart in water
Shawsheen 11	Downstream of residents, 495, and sports fields, prior to discharge into Merrimack. Park Access.	0.58	Algae Coverage: A lot attached to rocks Tree Cover: Partial Wildlife: Fish, dragon fly Other: Dead fish, flies eating dead fish, car bumper, lots of broken glass and trash

Notes:
River mile "0" starts at the mouth of each tributary, at its confulence with the Merrimack River

4.1 Carbonaceous Biological Oxygen Demand

Concentrations of CBOD5 in the river were mostly non-detect (new 2016 laboratory reporting limit: 3 mg/L; see **Figure 4-1**). There were two samples detected above the laboratory reporting limit, as follows:

- Concord River - Downstream of the Billerica WWTP (15 mg/L)
- Concord River - In the duplicate sample collected downstream of the Concord WWTP (4 mg/L)

CBOD20 was analyzed downstream of the two WWTPs on the Concord River, and from one mid-reach station on the Spicket and Shawsheen Rivers. CBOD20 was detected at all four stations, and ranged from 5 mg/L to 14 mg/L (indicated with X-markers in Figure 4-1), as follows:

- Concord River - Downstream of the Billerica WWTP (14 mg/L)
- Concord River - Downstream of the Concord WWTP (8 mg/L)
- Shawsheen River - Downstream of residential and recreational areas in Billerica, MA (9 mg/L)
- Spicket River- Downstream of residential and commercial areas, Salem, NH (5 mg/L)

4.2 Chlorophyll-a

Chlorophyll-a was detected at all tributary stations, and concentrations ranged from 0.8 ug/L to 26 µg/L (**Figure 4-2**). Concentrations in the Concord River were the highest when compared to the other two tributaries, and displayed some variability with increases observed after each of the two WWTPs. Concentrations in the Shawsheen and Spicket Rivers were generally stable with some minor fluctuations, and remained below 7 ug/L.

The state of New Hampshire uses 15 µg/L as a guideline threshold for maximum chlorophyll-a concentrations for primary contact recreation. Only the upper portion of the Spicket River is in New Hampshire, and a review of those chlorophyll-a concentrations indicate that the maximum concentration was 6.3 ug/L, below the guideline threshold. Massachusetts does not specify a chlorophyll-a guideline or standard.

4.3 Dissolved Oxygen and Temperature

Dissolved Oxygen

Dissolved oxygen levels in the river were measured in-situ using field water quality meters (initial and final readings) and in the laboratory using Winkler titration. Winkler titration values are typically used to validate the field meters, which can fall out of calibration while being used in the field. The field-measured values and the Winkler titration values of both dissolved oxygen concentration and percent saturation are shown in **Figures 4-3 and 4-4** (Winkler dissolved oxygen values indicated with X-markers).

Average field measured concentrations of dissolved oxygen in the Concord and Shawsheen Rivers were generally stable with minor fluctuations within an acceptable range (ranging from 4.83 mg/L to 10.35 mg/L). Winkler dissolved oxygen samples were collected at select stations, and were consistent with these results. All concentrations remained above the MA Class B minimum standard of 5 mg/L, with the exception of one average reading in the Concord River of 4.83 mg/L. The Spicket River field measured dissolved oxygen concentrations tended to be the lowest of all three tributaries. Almost all stations in NH were below the Class B minimum standard of 5 mg/L, with concentrations in that reach (Salem, NH) ranging from 2.70 to 5.75 mg/L. It is important to note that the Spicket River was below 7Q10 flow conditions on the day of sampling, which may indicate stressed or worst-case conditions in that river. Concentrations in the lower reaches were within the acceptable range, from 5.25 to 9.28 mg/L. Winkler concentrations in the Spicket River were generally consistent with field measurements.

Dissolved oxygen saturations in all three tributaries followed the trends observed for the dissolved oxygen concentrations. That is, saturations in the Concord and Shawsheen Rivers were generally stable with some fluctuations throughout (ranging from 58% to 127%, averaging 88%), while saturations in the Spicket River tended to be lower (ranging from 30% to 109%, averaging 59%). In addition to field readings, Winkler values for percent saturation were calculated using the field measured water temperature and specific conductance according to USGS methods[16]. Calculated Winkler saturations for the Concord and Shawsheen River validated field values. While there was some variability with the field measured and calculated Spicket saturations, both indicated generally lower dissolved oxygen levels. All of the field dissolved and calculated oxygen percent saturation readings in the Salem, NH reach of the Spicket River were below the applicable NH State minimum standard of 75%. There are no MA saturation standards with which to compare results at MA stations.

Temperature

During the July 2016 tributary event, water temperatures were generally consistent throughout the study area between 18 and 27°C (**Figure 4-5**) and typical for mid-summer conditions. A slight increase in temperature was observed upstream to downstream in the Spicket River when comparing the NH and lower MA stations. Temperatures were within the same range in all three rivers, however the Concord River does appear to be slightly warmer than the other two, on average. The average temperature of the Concord River locations was 24.7°C, while the average temperatures of the Shawsheen and Spicket Rivers were 22.9°C and 21.4°C, respectively.

4.4 Nitrogen

Total nitrogen concentrations were typically steady in the Shawsheen and Spicket Rivers, and ranged from 0.47 to 0.99 mg/L. Total nitrogen concentrations in the upper reaches of the Concord River were stable and ranged from 0.84 to 1.64 mg/L. An increase was observed downstream of the Billerica WWTP, where concentrations ranged from 3.62 to 4.65 mg/L. It should be noted that mainstem sampling has historically indicated that the Concord River has the highest nitrogen concentrations of all the tributaries during both wet and dry weather conditions. The range of observed total nitrogen concentrations in tributary samples is shown on **Figure 4-6**, and presented in **Table 4-2**.

[16] U.S. Geological Survey, 2011, Change to solubility equations for oxygen in water: Office of Water Quality Technical Memorandum 2011.03, accessed March 30, 2016, at http://water.usgs.gov/admin/memo/QW/qw11.03.pdf.

Table 4-2: Total Nitrogen Concentration Summary for Tributary Event #1 (mg/L)

Location Type	Minimum	Maximum	Average
Concord River	0.61	4.65	1.58
Shawsheen River	0.47	0.94	0.65
Spicket River	0.55	0.99	0.69

Note: Reporting limit = 0.001 mg/L

Ammonia concentrations in the tributaries demonstrated some fluctuations throughout, but were generally low and ranged from: 0.0059 to 0.056 mg/L in the Concord River; 0.012 mg/L to 0.13 mg/L in the Shawsheen River; and 0.031 mg/L to 0.115 mg/L in the Spicket River (**Figure 4-7**). By comparison, the 2013 published EPA[17] ammonia limits for toxicity to aquatic life, at pH 7 and 20°C, are 17 mg/L acute and 1.9 mg/L chronic. The highest concentration in all tributary samples was 0.13 mg/L, which is an order of magnitude lower than the EPA chronic exposure criterion.

4.5 Phosphorus

Total phosphorus concentrations in all three tributaries were generally consistent, and remained less than 50 µg/L throughout (**Figure 4-8**). There are no numeric water quality standards for total phosphorus in New Hampshire or Massachusetts; however, EPA suggests that total phosphorus concentrations in streams not exceed 100 µg/L[18]. All concentrations remained below this guidance value.

Table 4-3 summarizes the total phosphorus concentrations observed during the July 2016 dry weather event. As shown, the Concord River samples were generally greater than those observed in the Shawsheen or Spicket Rivers.

Table 4-3: Total Phosphorus Concentration Summary for Tributary Event #1 (µg/L)

Location Type	Minimum	Maximum	Average
Concord River	20.93	49.14	33.22
Shawsheen River	13.76	41.86	20.29
Spicket River	13.76	23.66	21.15

Note: Reporting limit = 3.1 µg/L

Algal growth in the rivers is limited by multiple factors, including nutrient availability, light availability, and water temperature. Either phosphorus or nitrogen can be the limiting nutrient depending on which compound is more abundantly available based on the stoichiometry of algal nutrient uptake. The less-available nutrient limits the growth of algae if other factors are favorable for growth. A molar

[17] U.S. EPA Office of Water, 2013, Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater. EPA-822-R-13-001

[18] US EPA, 1986. Quality Criteria for Water. US-EPA 440/5-86-001. Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D.C.

ratio of total nitrogen to total phosphorus of greater than 20 indicates that phosphorus is the limiting nutrient[19]. The molar TN:TP ratios were as follows:

- Concord River: Range 37.7-258, mean 106, median 78.5;
- Shawsheen River: Range 47.6-115, mean 69.9, median 74.0; and
- Spicket River: Range 56.2-105, mean 73.7, median 69.5.

These values indicate that the majority of the system is phosphorus-limited.

Orthophosphates

Measuring orthophosphates along with total phosphorus in the rivers indicates how much of the nutrient is bioavailable for algal growth (**Figure 4-9**). Orthophosphate is the inorganic, dissolved portion of phosphorus, and is bioavailable. Typically, the fraction of total phosphorus that is orthophosphate in rivers is 0.5, but it can vary depending on the sources of phosphorus and the algal activity.

Orthophosphate concentrations in each of the rivers displayed various trends, but for all rivers the concentrations were highest in the most downstream reaches. Concentrations in the Concord River were consistently nondetect (reporting limit 3.1 µg/L) in the upper reaches of the river, but increased slightly to between 3.34 and 4.29 µg/L beginning upstream of the Billerica WWTP. Concentrations in the Shawsheen River remained between nondetect (reporting limit 3.1 µg/L) and 7.11 µg/L, but exhibited fluctuations throughout. Concentrations in the Spicket River increased from upstream to downstream, with concentrations ranging from nondetect (reporting limit 3.1 µg/L) to 23.66 µg/L.

The ratio of orthophosphates to total phosphorus **(Figure 4-10)** in all tributaries was less than 0.5 during the July 2016 sampling event (average of 0.18 for all sites). Concentrations in the Concord and Shawsheen Rivers were generally stable, but a peak was observed in Spicket River ratios in the Massachusetts stations. These results indicate that phosphorus is the limiting nutrient, but not the limiting factor in algal growth. Other potential limiting factors include water temperature, residence time, and light penetration.

4.6 pH

Field readings of pH in all three tributaries were generally stable and at or above neutral (7 SU), with observed (average of initial and final readings) and average values as shown on **Figure 4-11** and summarized as follows:

- Concord River: 7.41-8.27 SU, average 7.80 SU
- Shawsheen River: 7.01-7.69 SU average 7.29 SU

[19] Borchardt, M. A. (1996). Nutrients. In: Stevenson, R.J., Bothwell, Max L. and Lowe, Rex L. (Eds) Algal Ecology: Freshwater Benthic Ecosystems. Academic Press, San Diego, USA. pp 184-228.

- Spicket River: 6.84-7.45 SU, average 7.03 SU.

The NH Class B water quality standards require pH to be between 6.6 and 8.2 SU, and readings at all NH stations were within this range. The MA Class B standards require pH to be between 6.5 to 8.3 SU, and readings at all MA stations were within this range.

4.7 Bacteria

NH and MA Class B water quality standards for bacteria in freshwater were defined in Section 3.1.7. The relevant state standards are summarized in **Table 4-4**, along with a count of relevant sample results above stated criteria.

Figures 4-12 through 4-13 show the results of the bacteria analyses during the July 2016 dry weather event, and **Figures 4-14 through 4-16** presents a graphical representation of locations with bacteria concentrations above relevant state surface water quality criteria. Concentrations in each river were generally low and consistent with those observed during Phase III dry weather mainstem events; however, elevated concentrations above applicable standards were observed. *E. coli* and fecal coliform detections followed similar trends in each river, and typically locations with *E. coli* concentrations above applicable standards also reported elevated fecal coliform concentrations.

Table 4-4: Count of Bacteria Concentrations Above New Hampshire and Massachusetts Water Quality Criteria for Freshwater Relevant Classes for Tributary Event #1

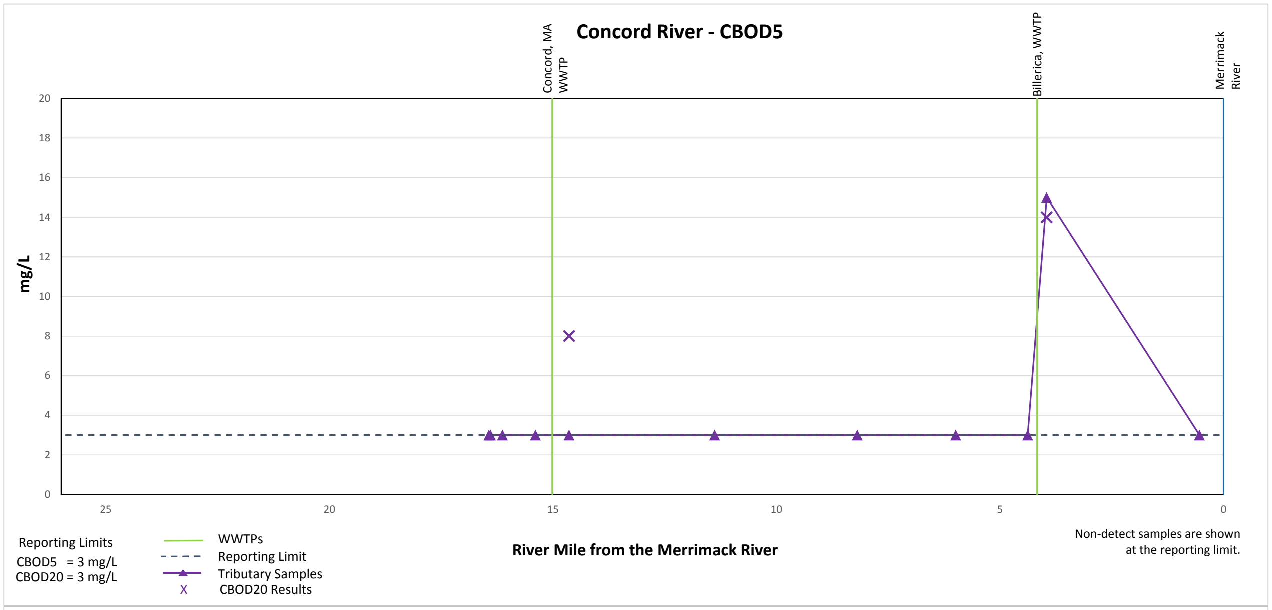
(# above/total samples)	New Hampshire Freshwater Class B	Massachusetts Freshwater Class B
Station Type	**Single Sample, Non-Beach[1]**	**Single Sample, Bathing Beach & Non-Beach[1]**
	E. coli 406 mpn/100 mL	*E. coli* 235 mpn/100 mL
Concord River	-	3/11
Shawsheen River	-	4/11
Spicket River	0/5	2/3

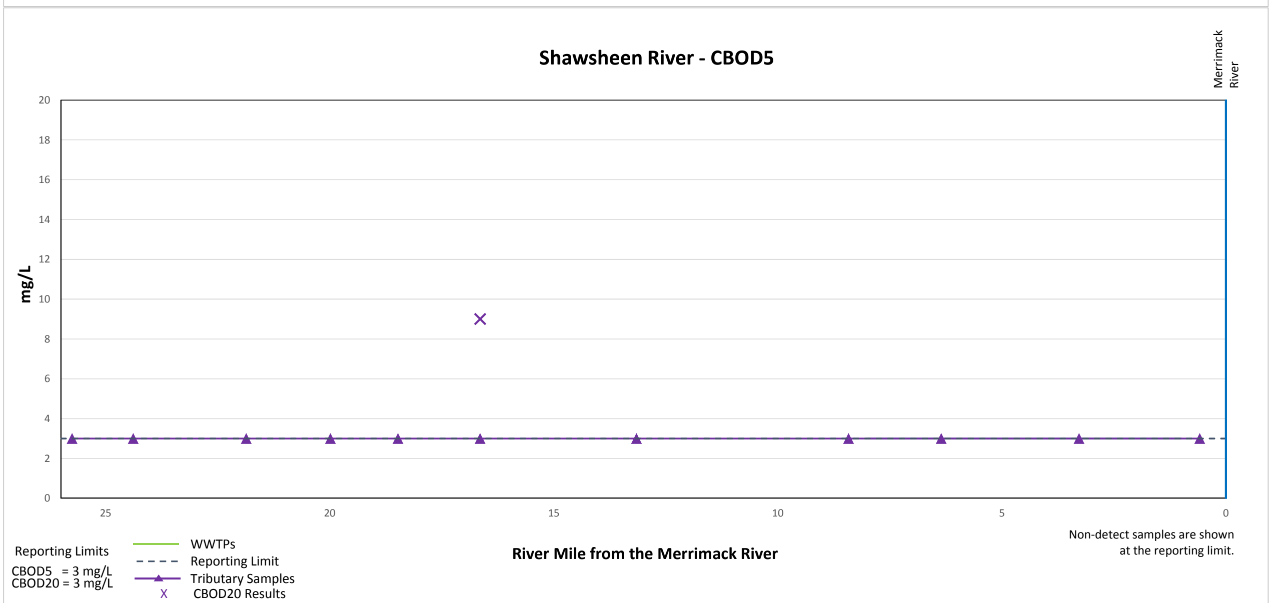
Notes:

1. All water quality standards are for single sample thresholds

The highest *E. coli* and fecal coliform concentrations, 2420 mpn and > 2420 mpn/100 mL, respectively, were observed in the upstream Concord River sample that represented background conditions. It is important to note that *E. coli* and fecal coliform samples were not diluted by the laboratory prior to incubation and analysis, thus 2420 mpn/100 mL was the maximum achievable reporting limit during the July 2016 event.

Figure 4-1
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





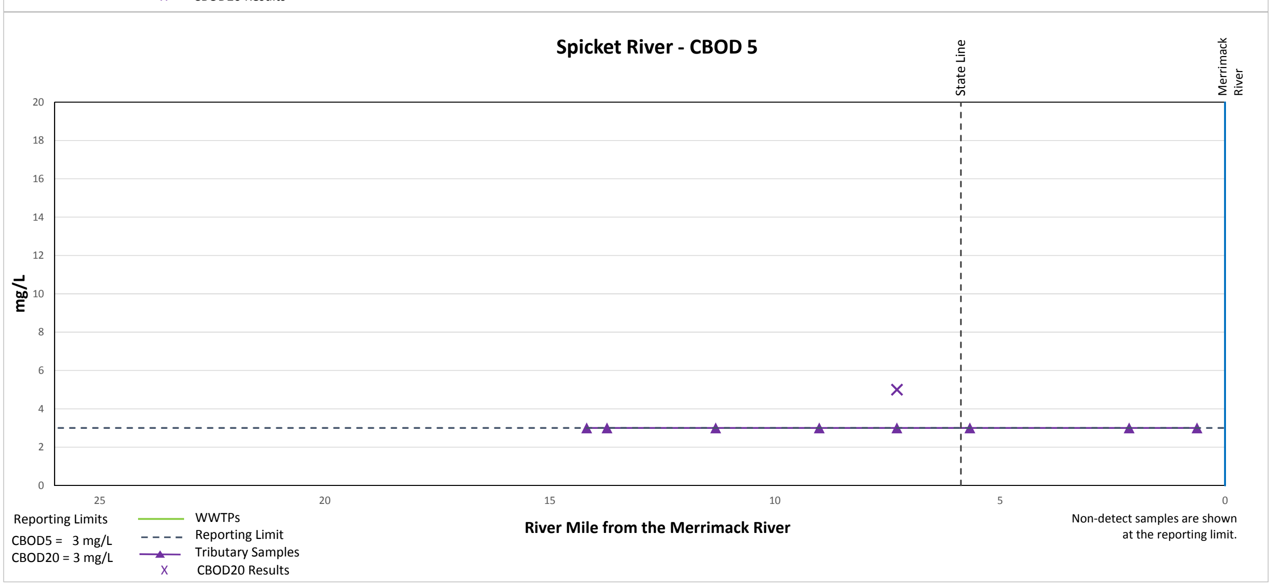
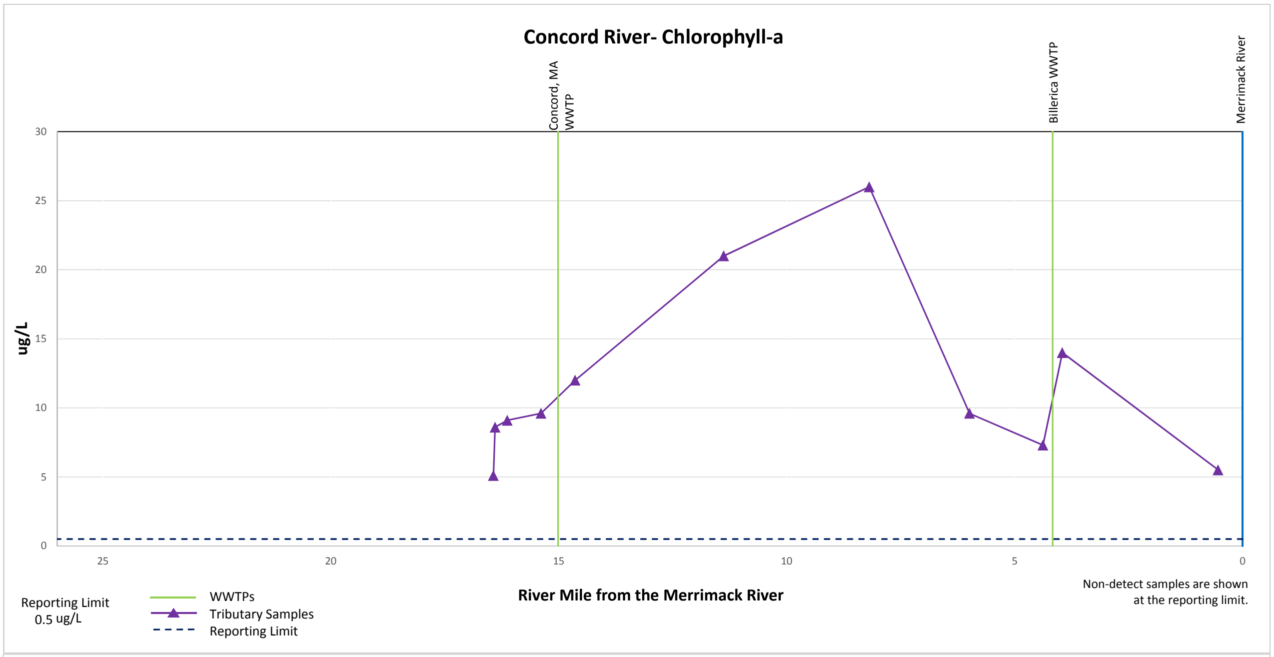
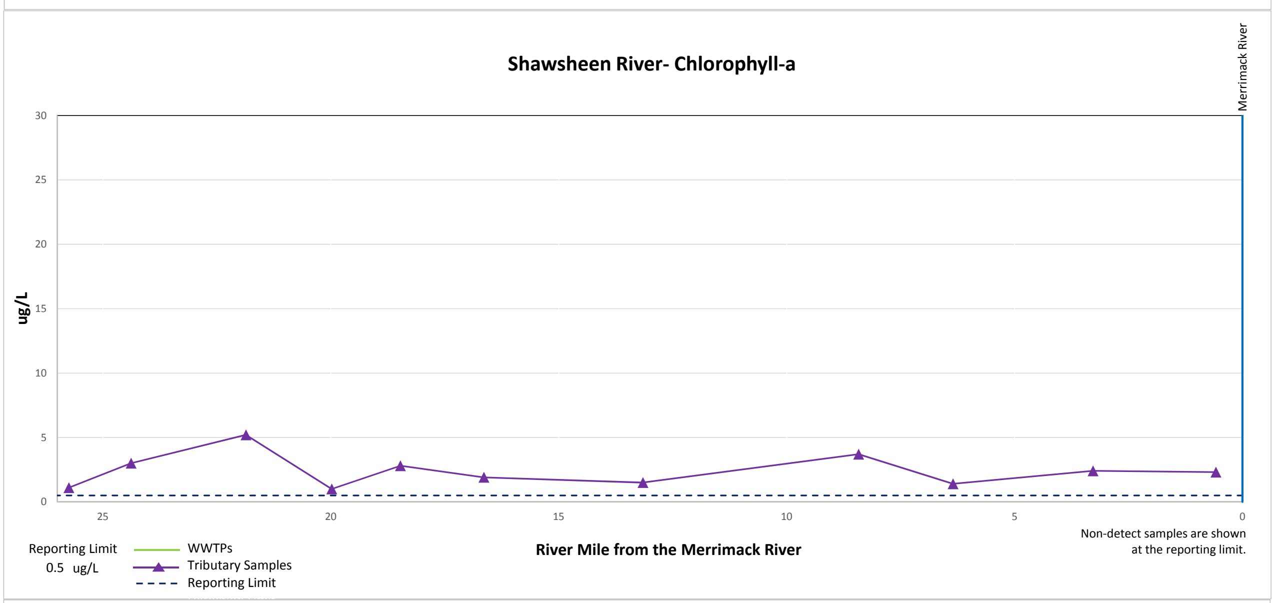


Figure 4-2
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





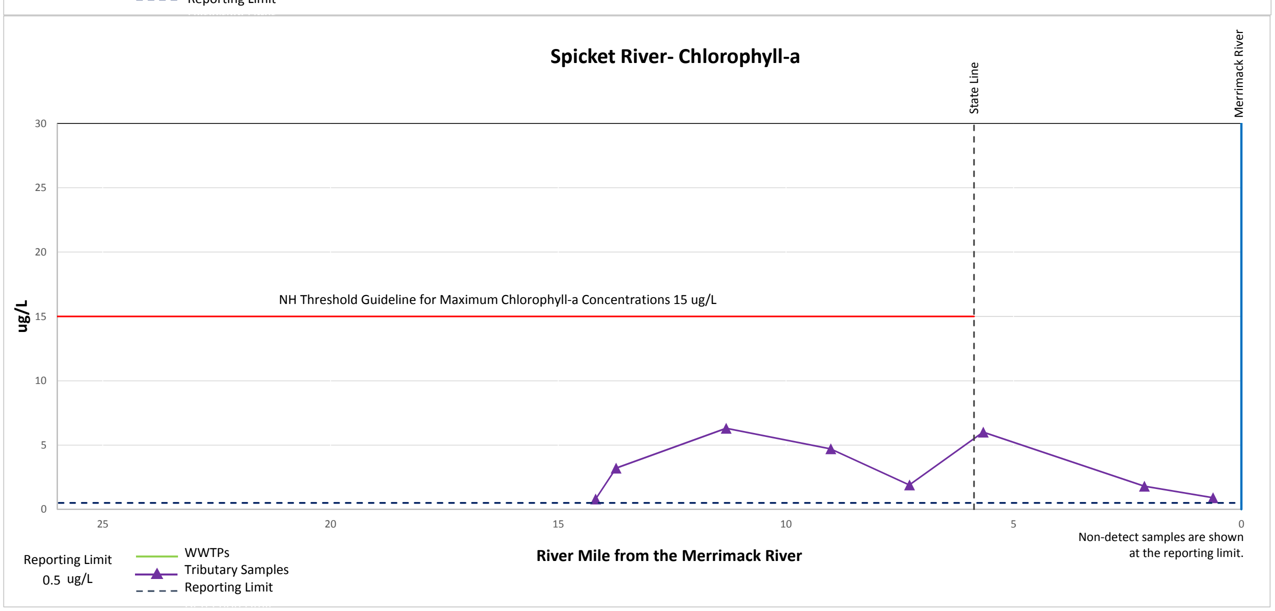
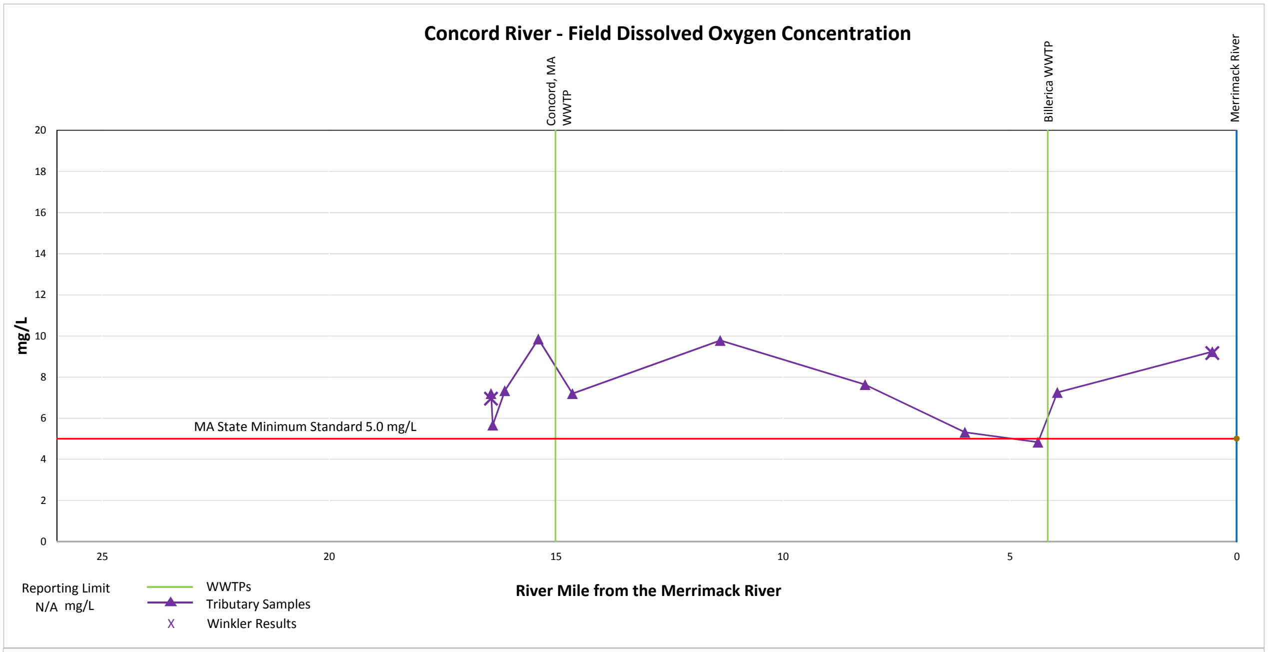
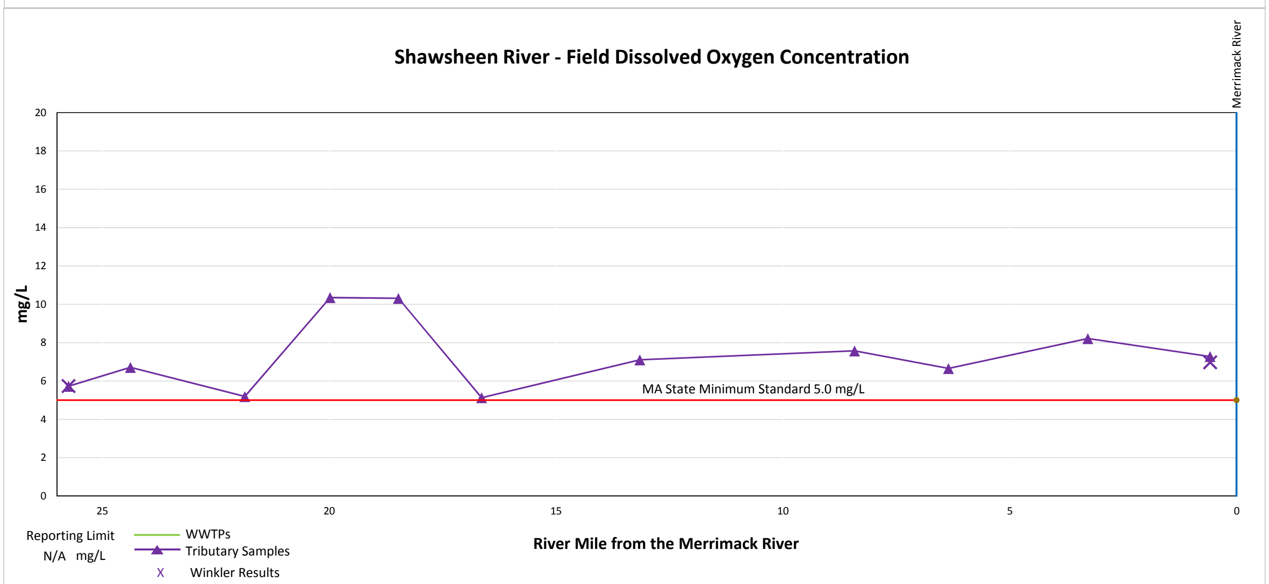


Figure 4-3
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





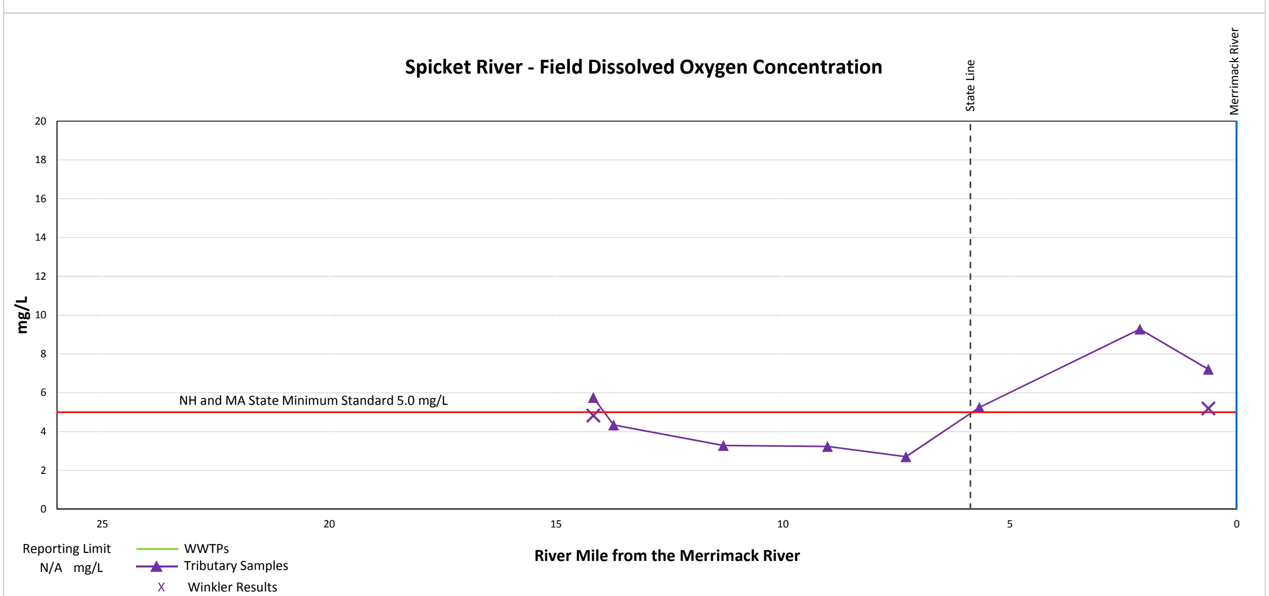
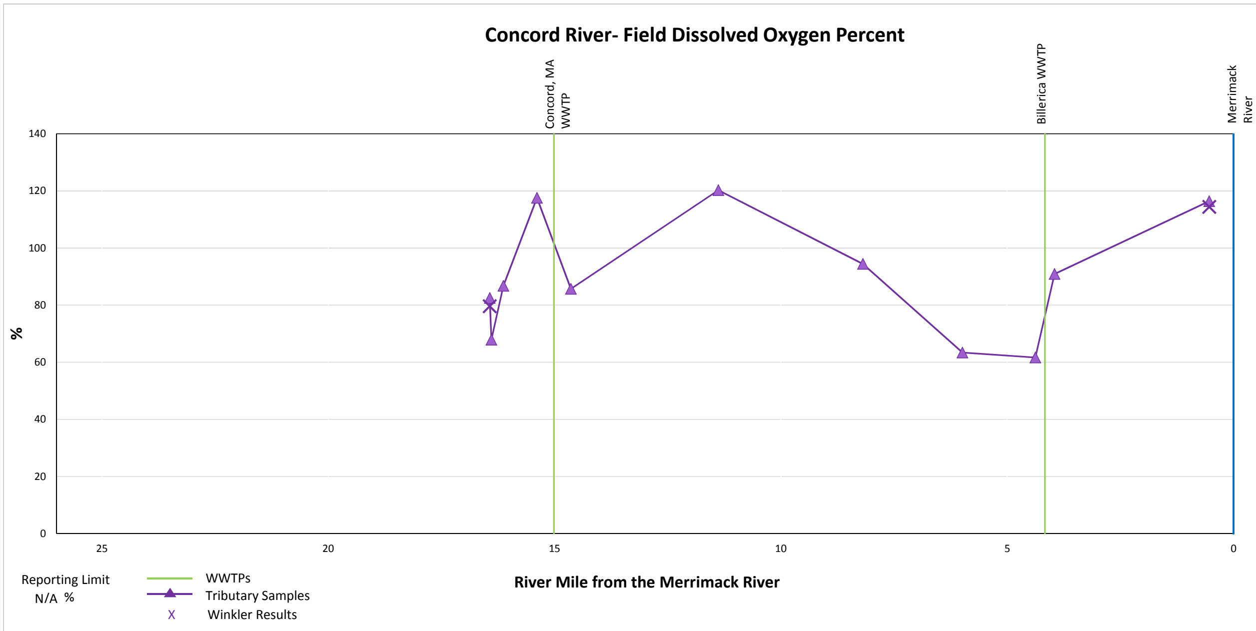
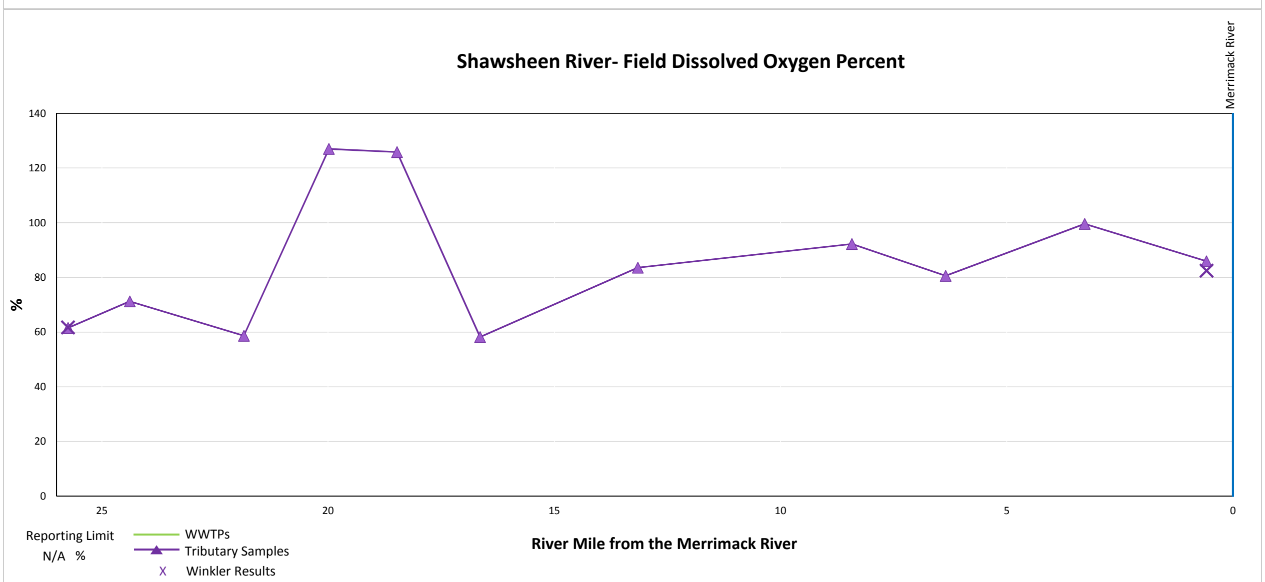


Figure 4-4
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





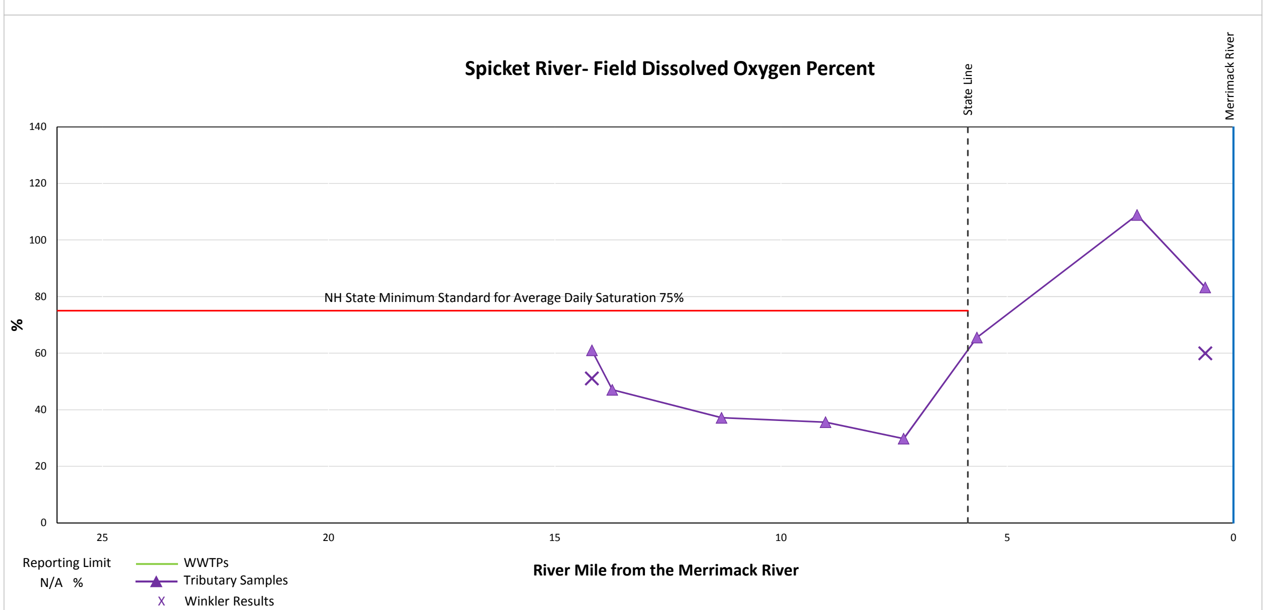
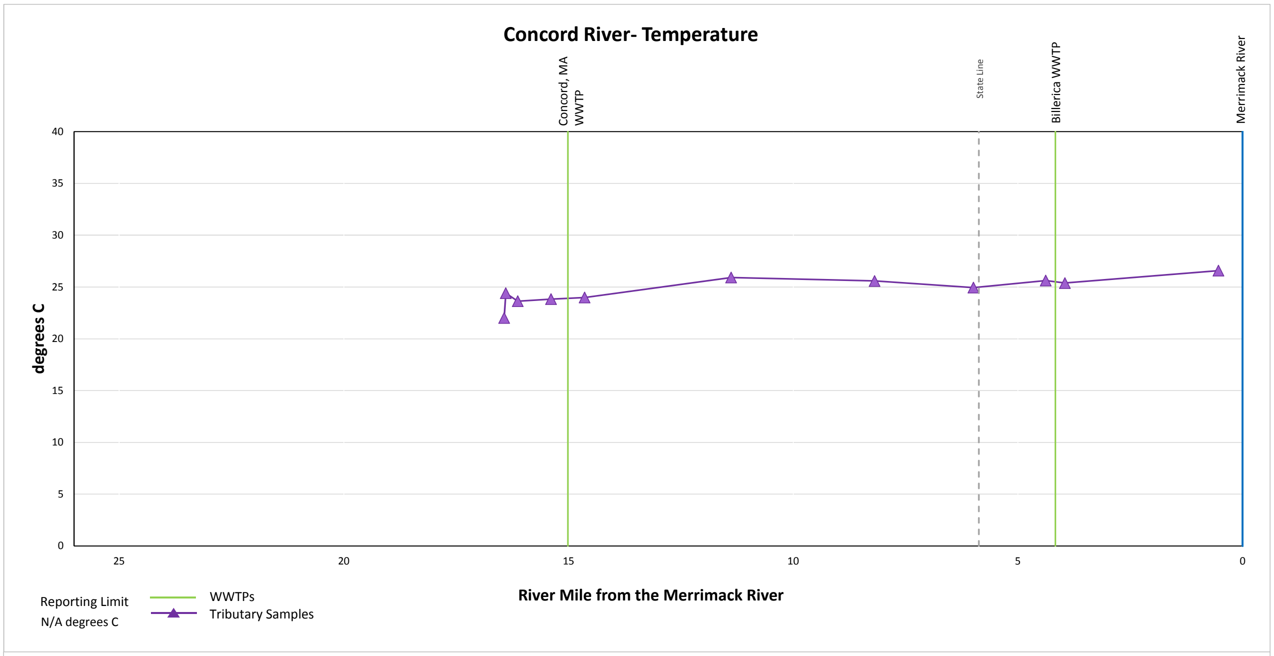
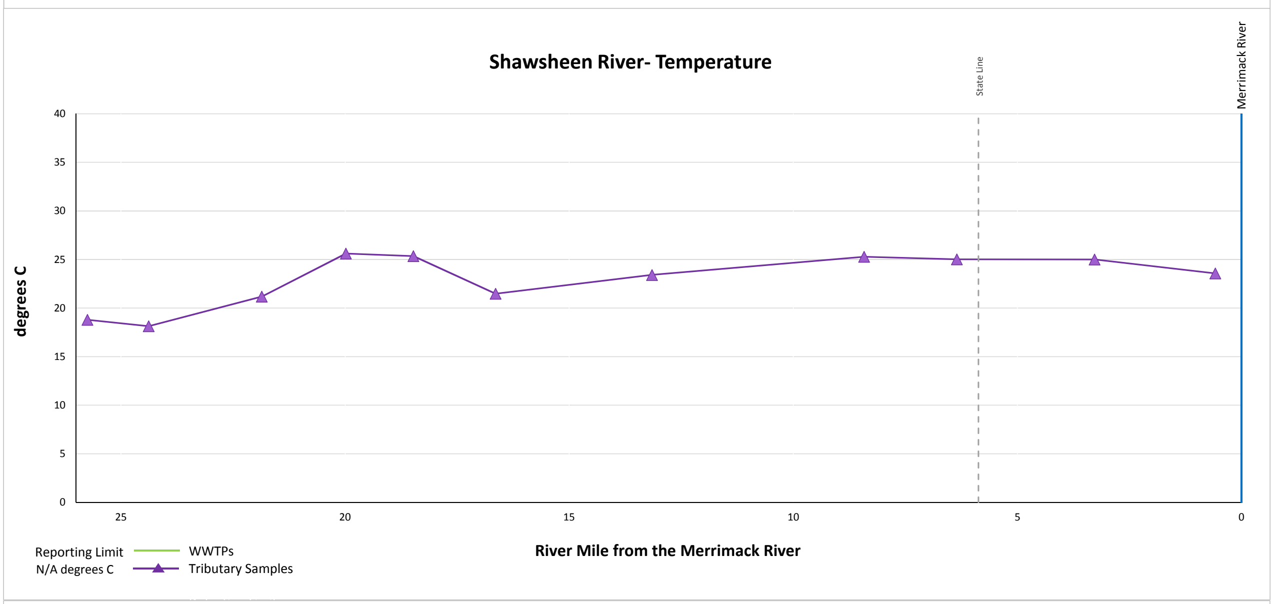


Figure 4-5
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





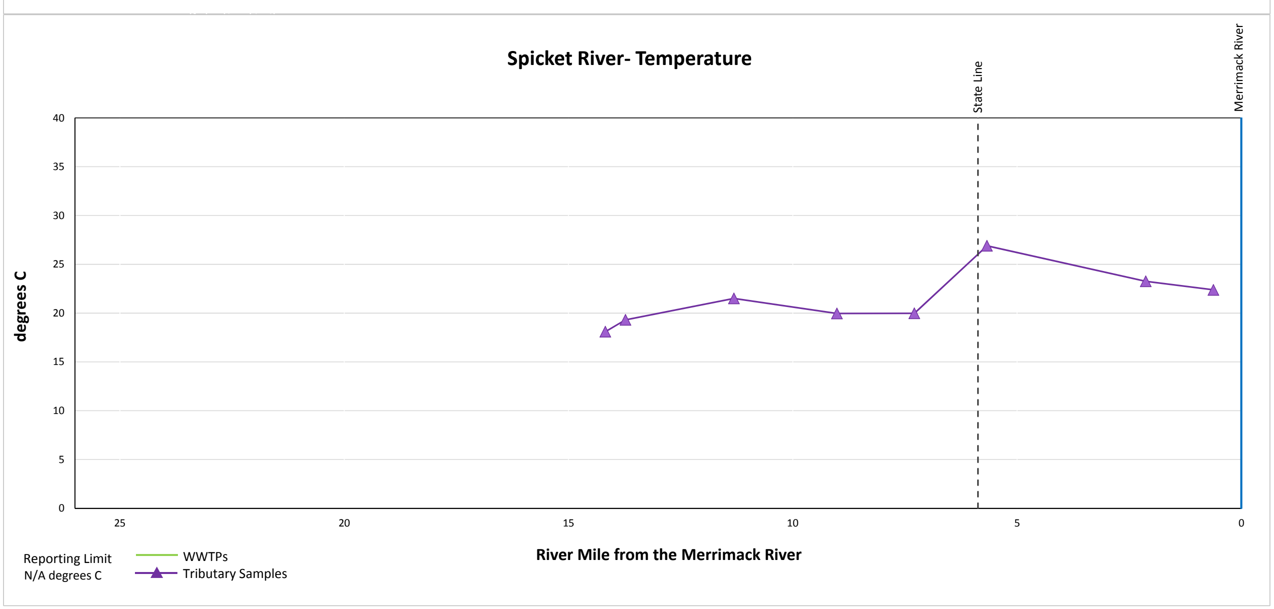
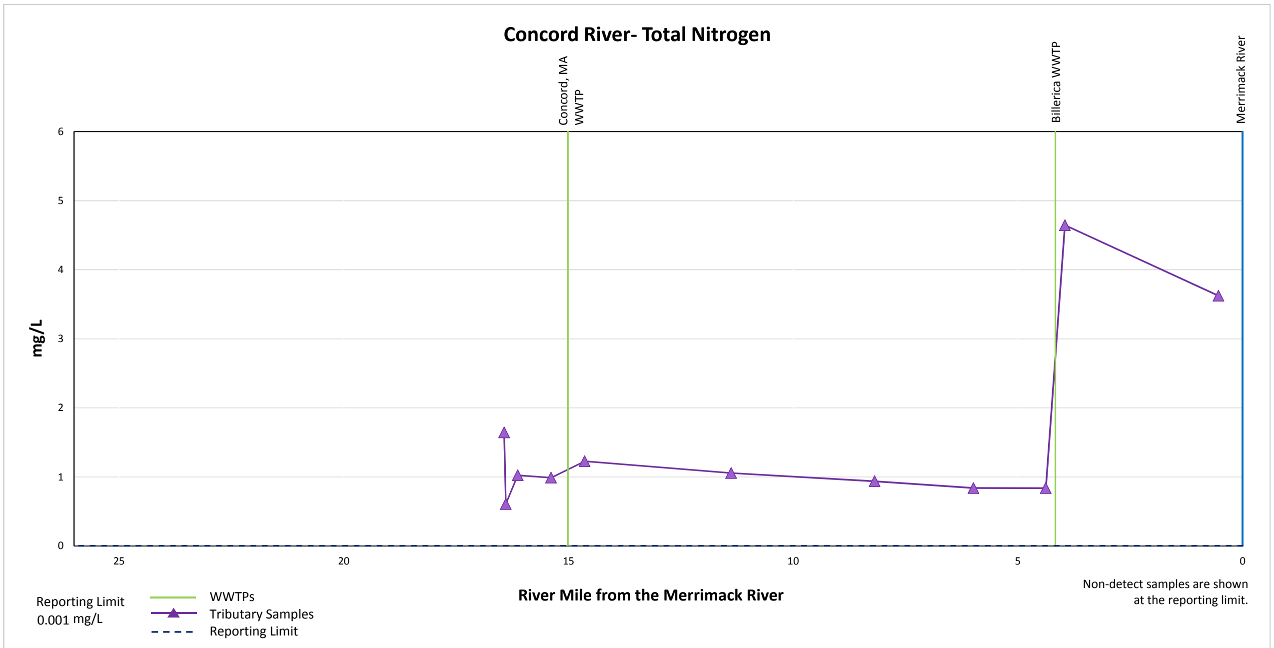
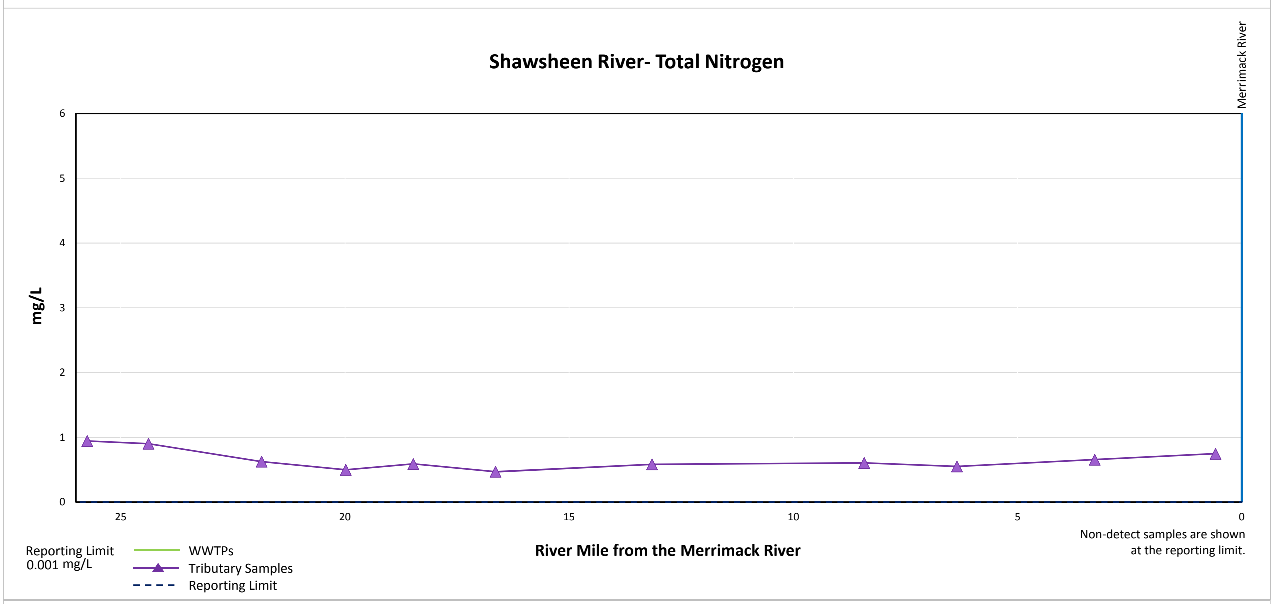


Figure 4-6
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





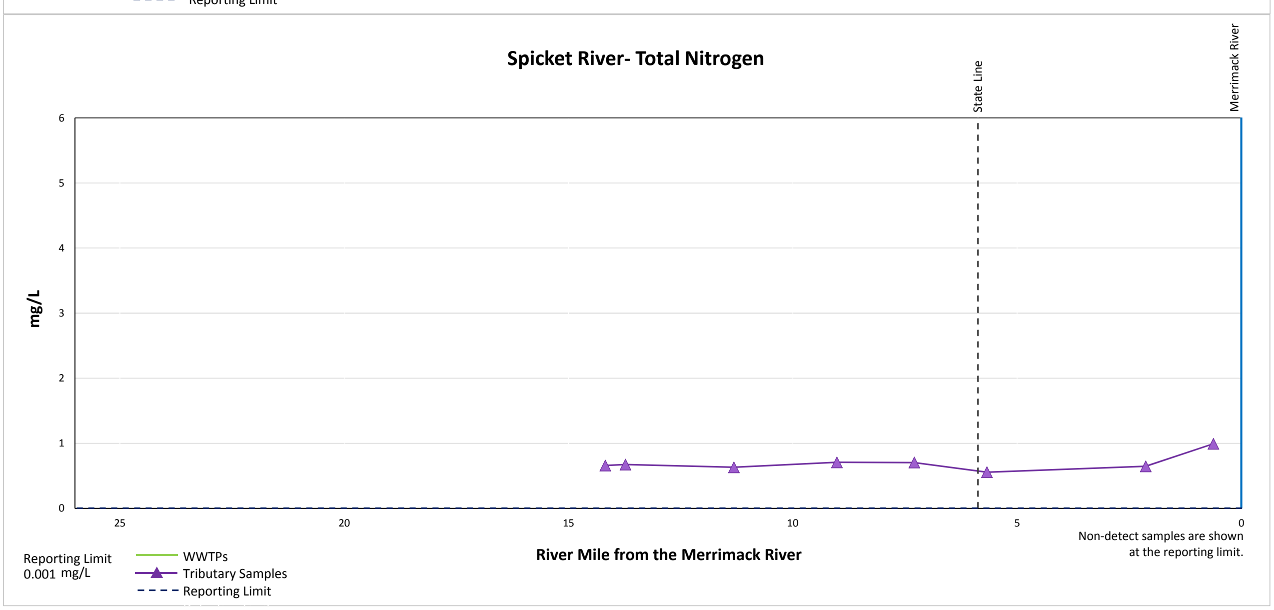
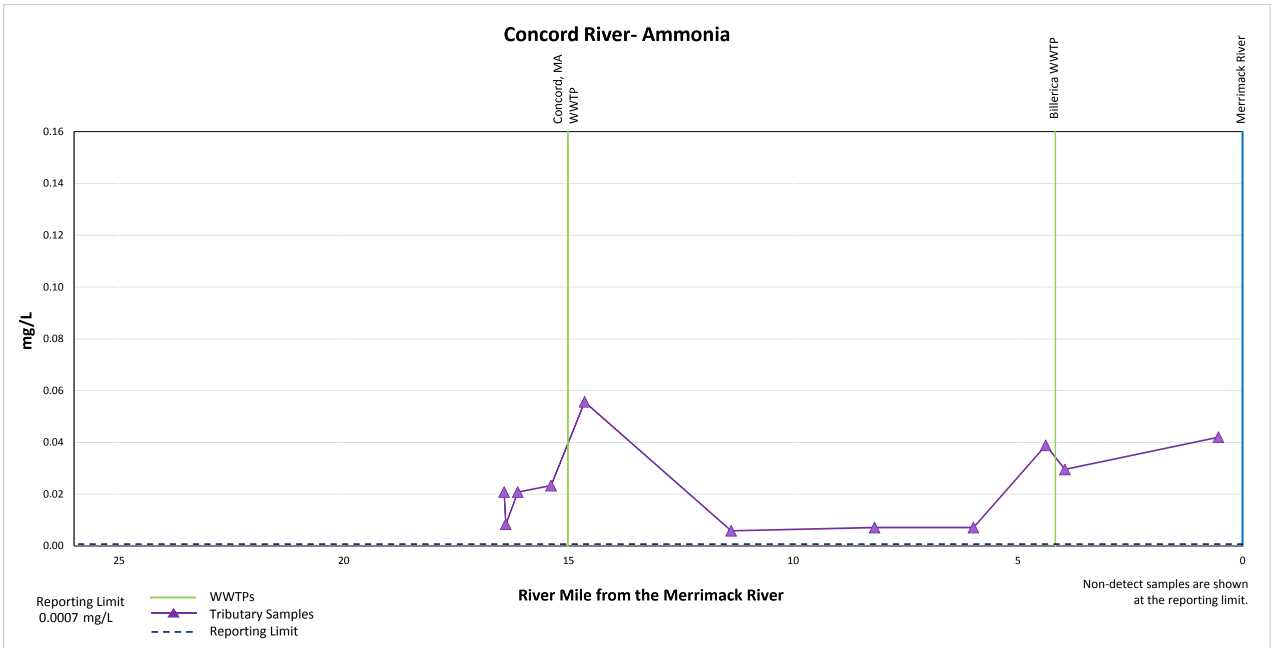
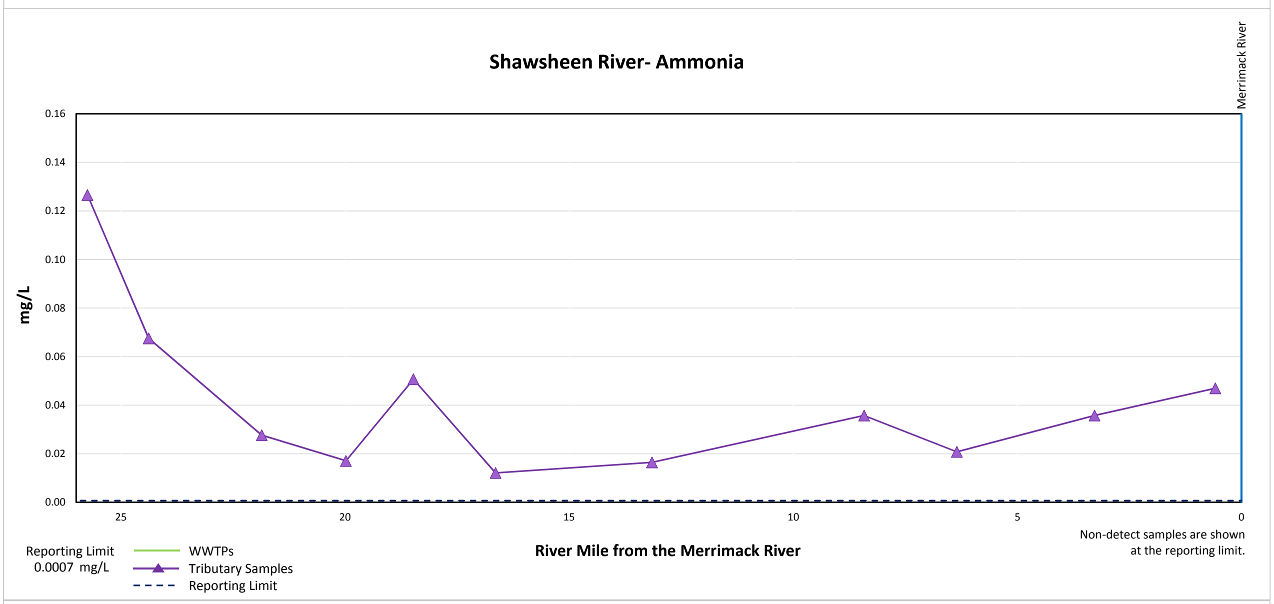


Figure 4-7
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





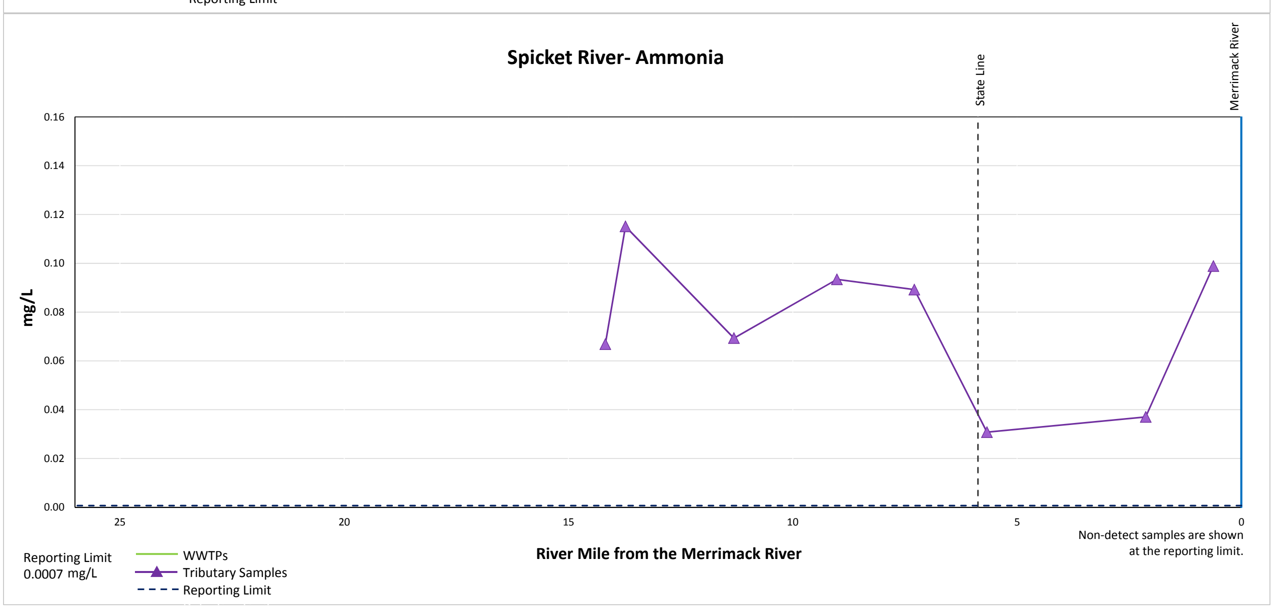
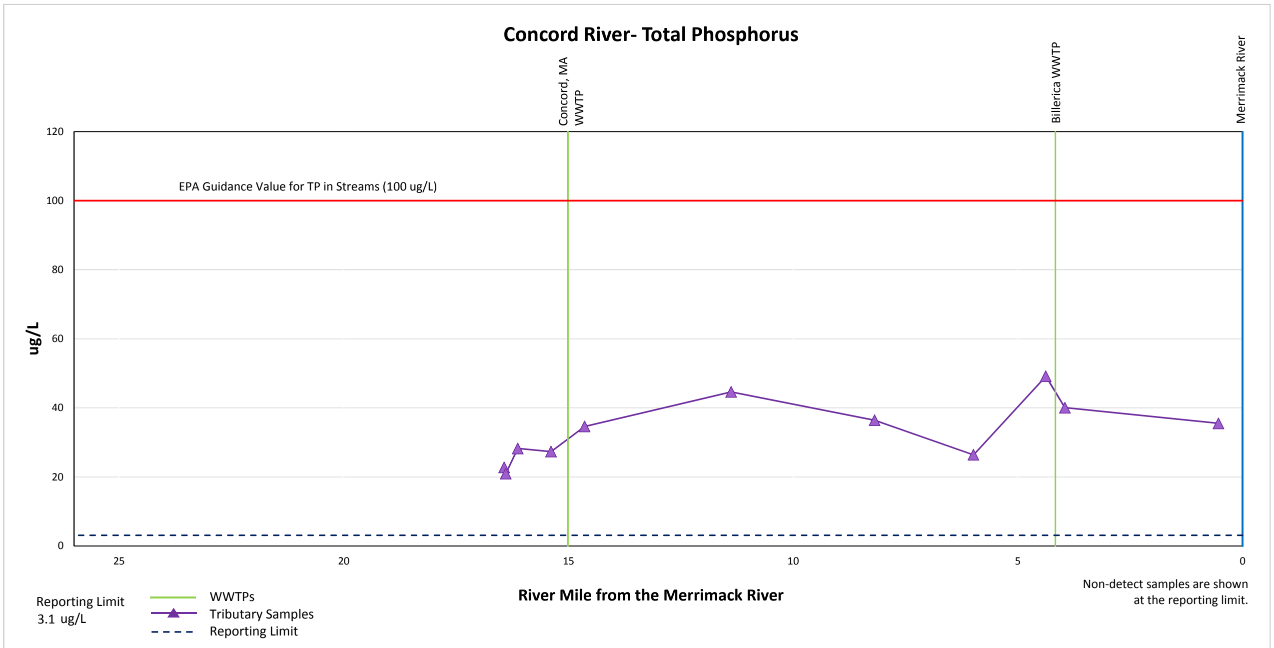
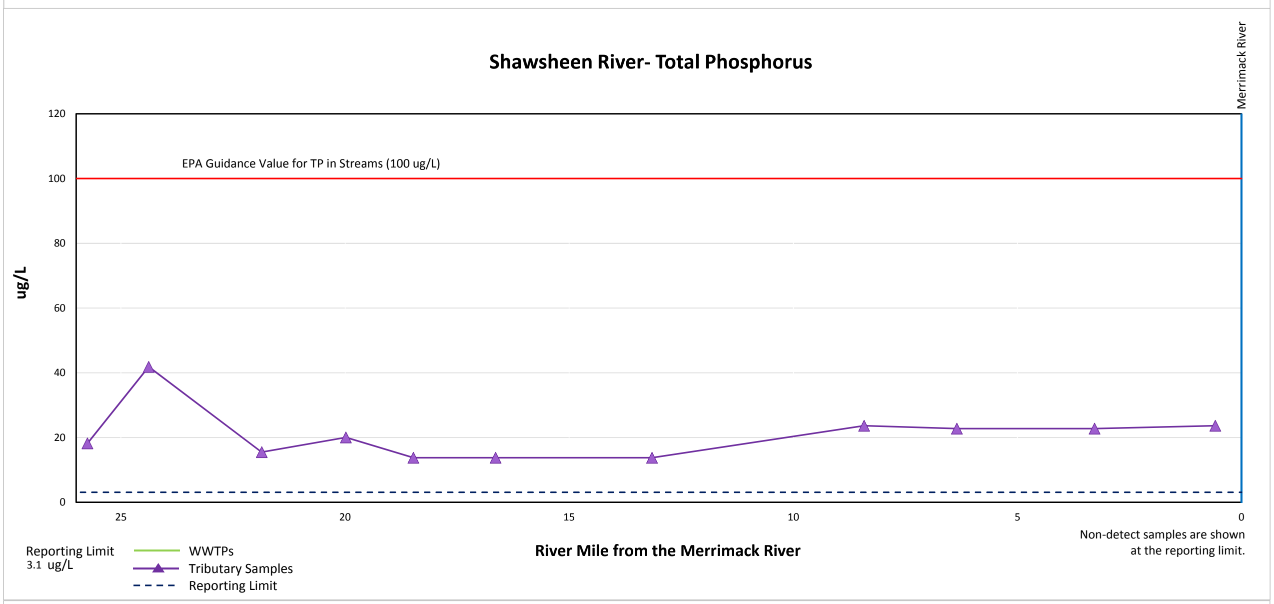


Figure 4-8
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





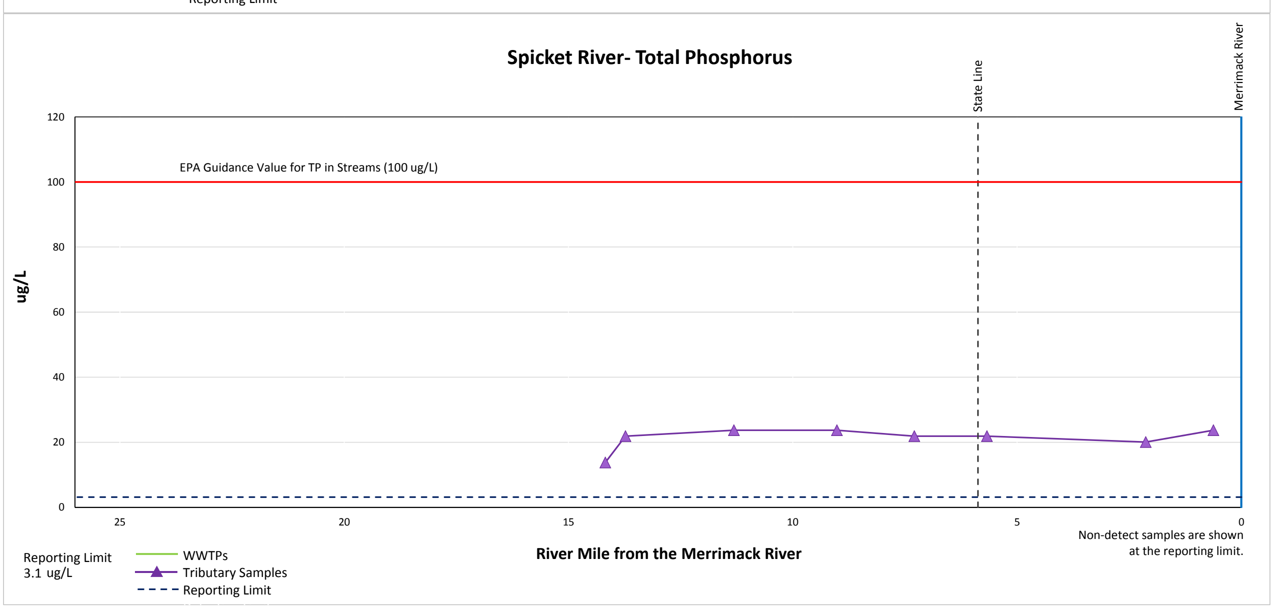
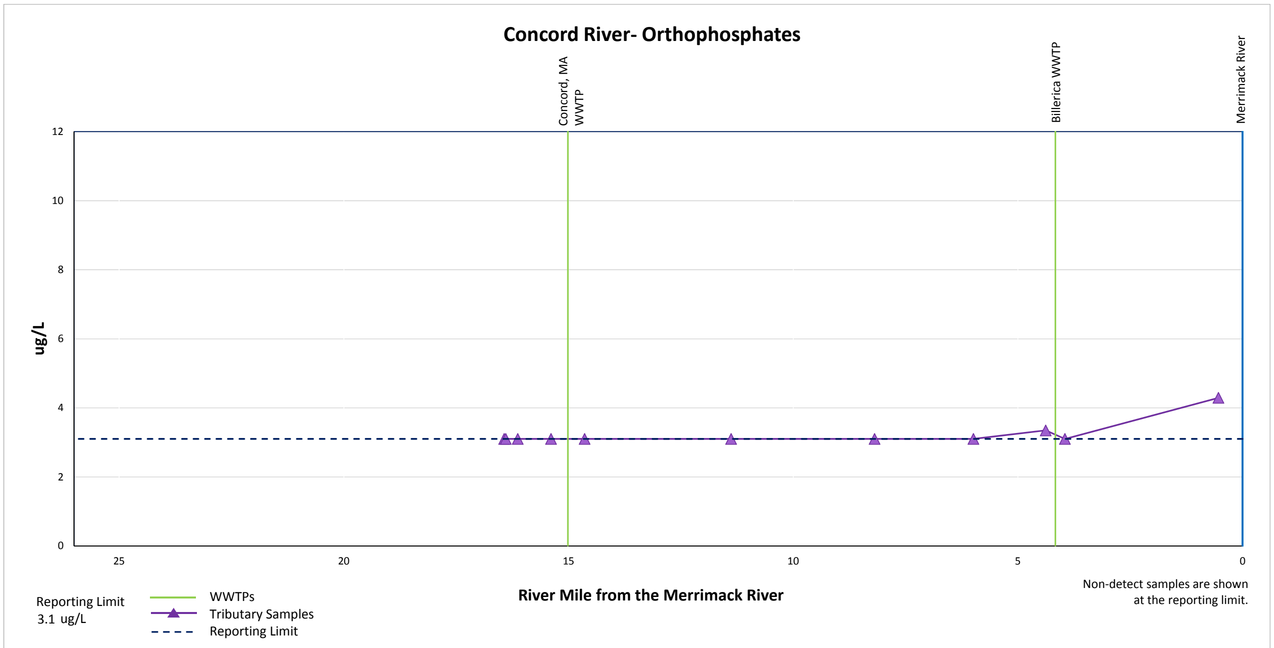
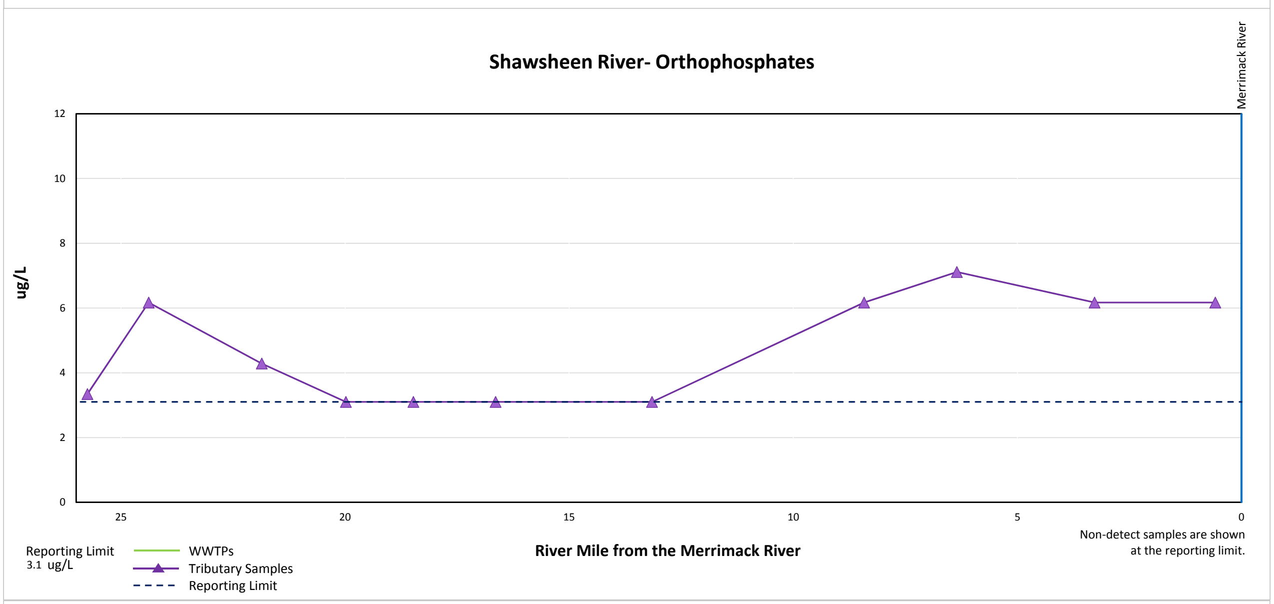


Figure 4-9
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





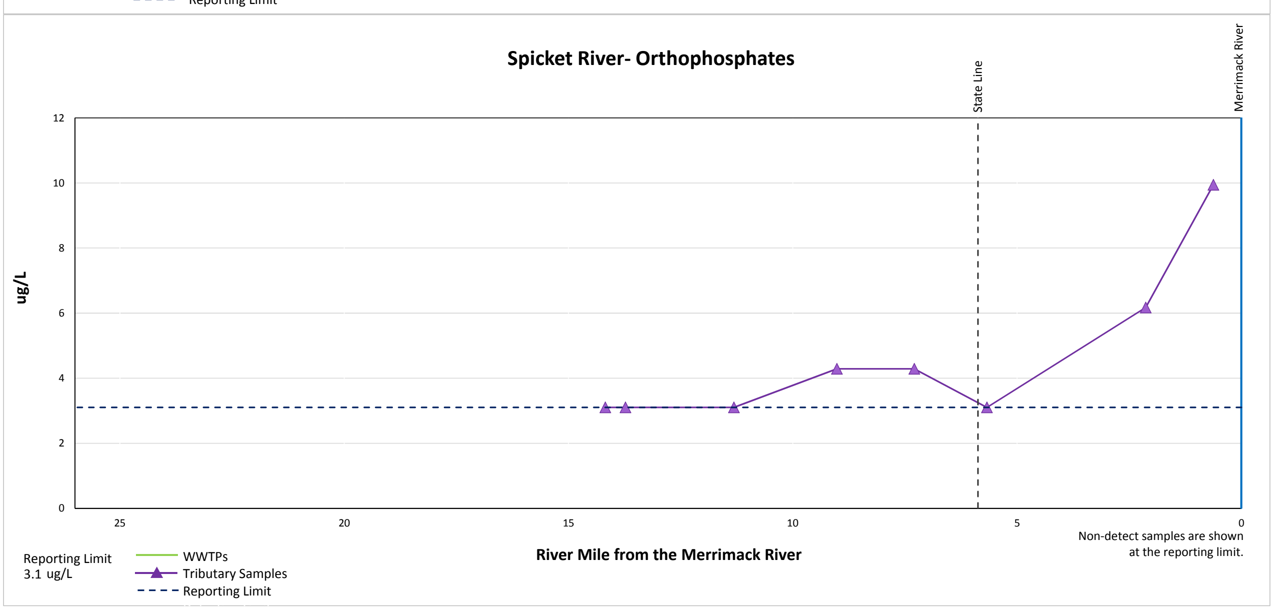
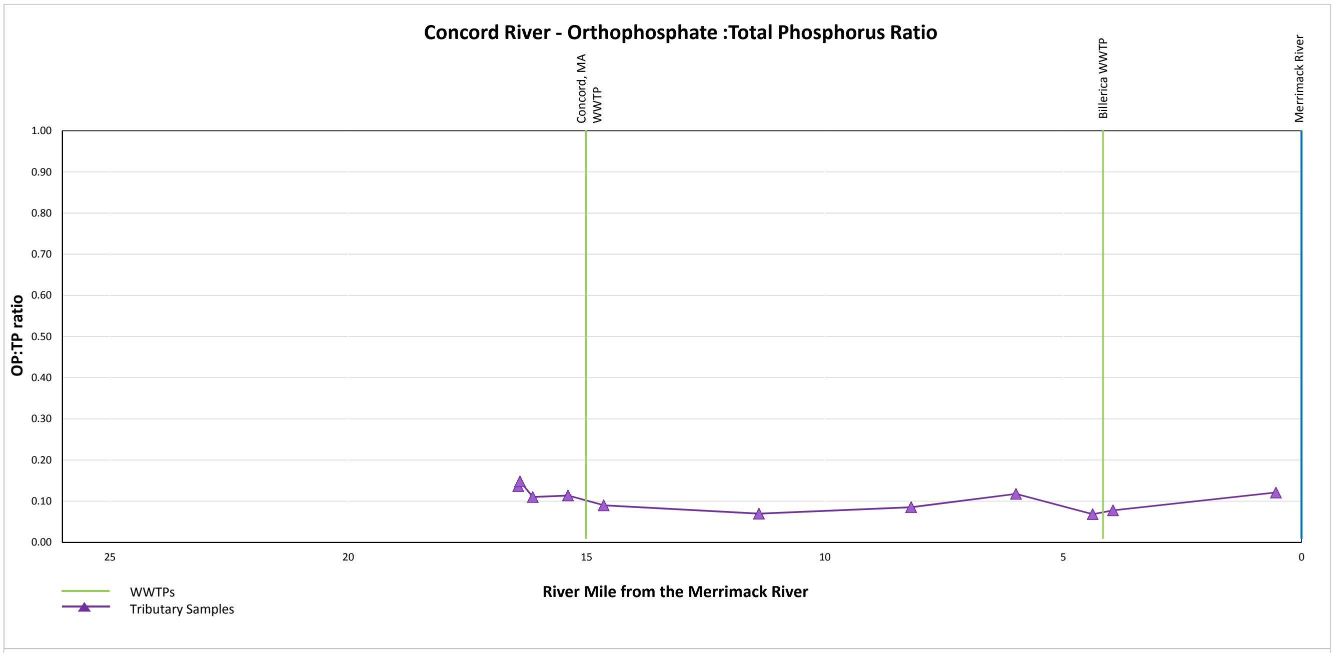
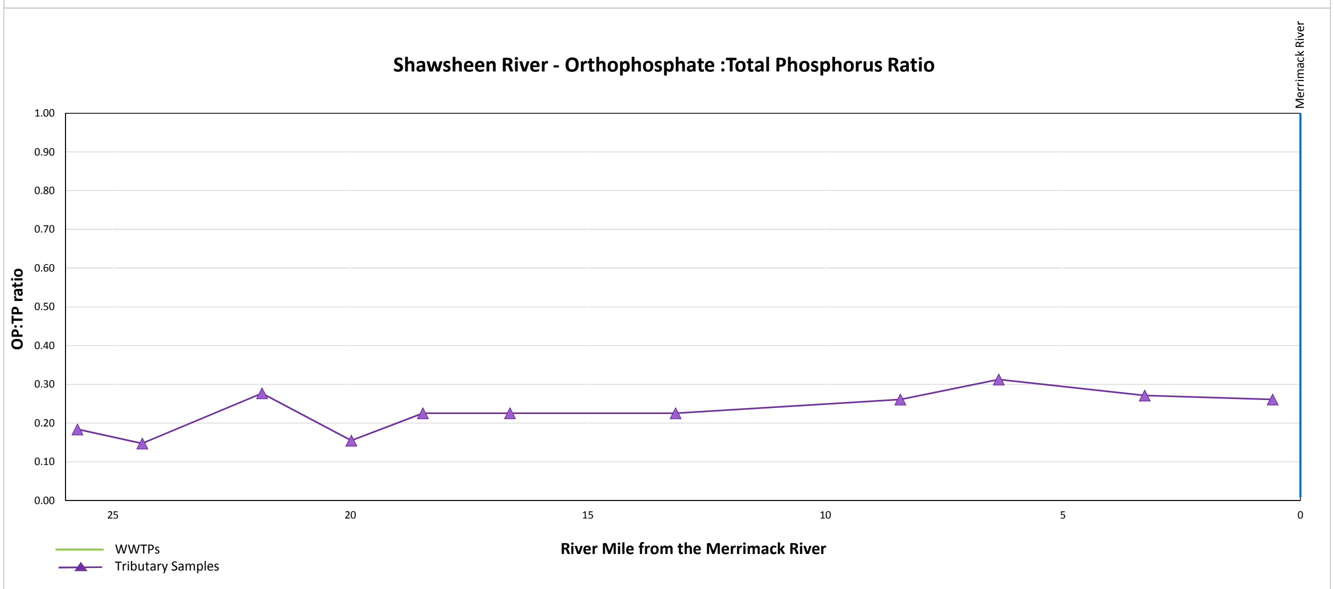


Figure 4-10
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





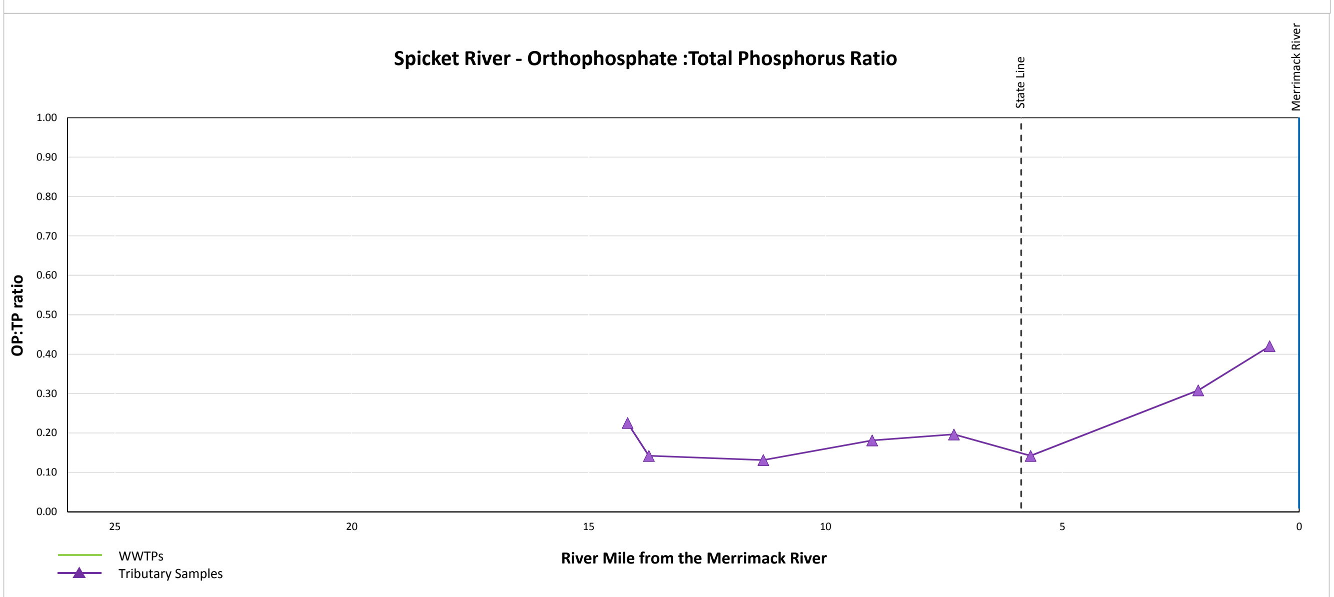
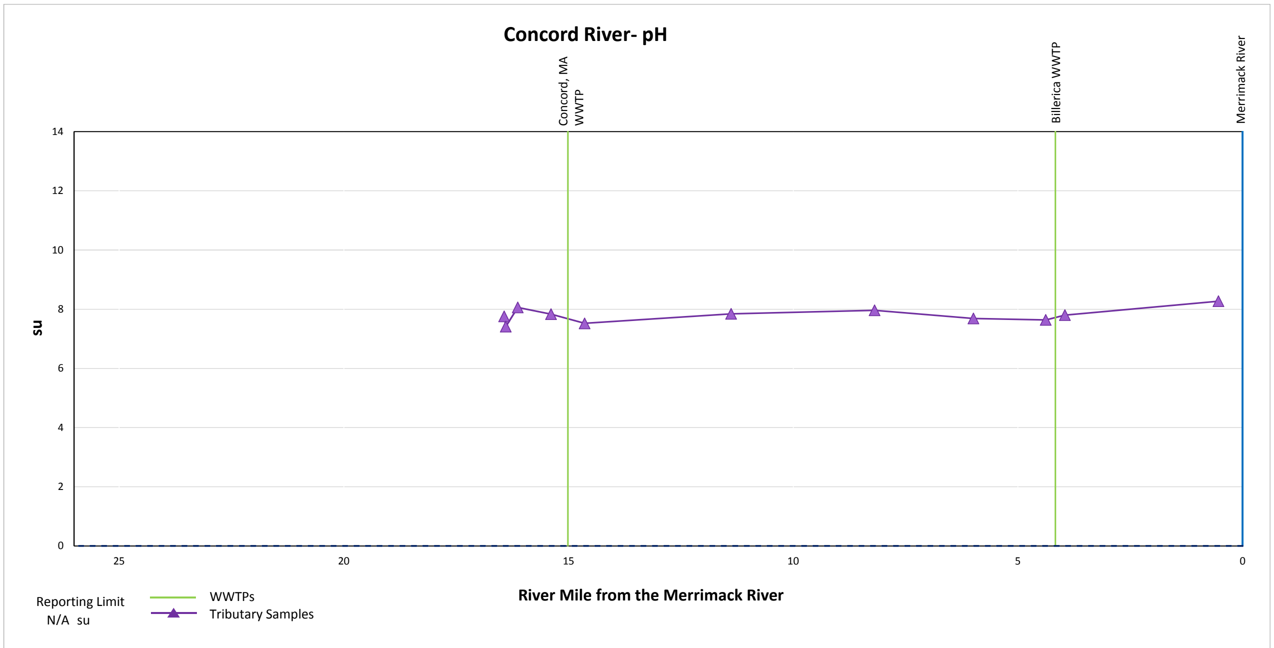
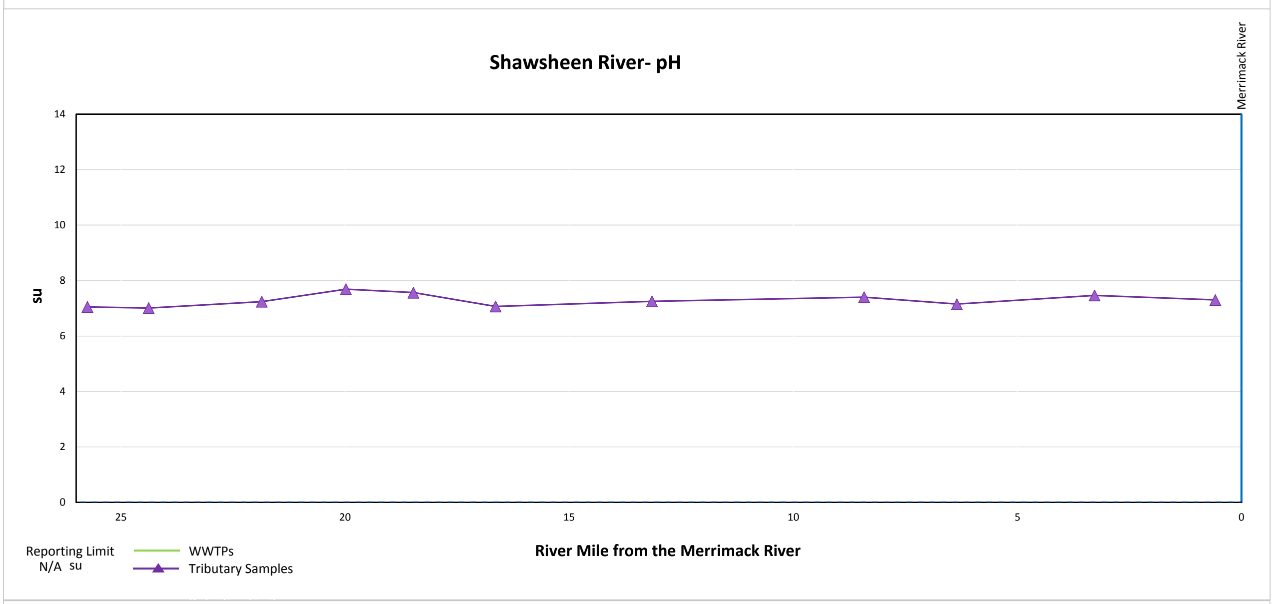


Figure 4-11
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





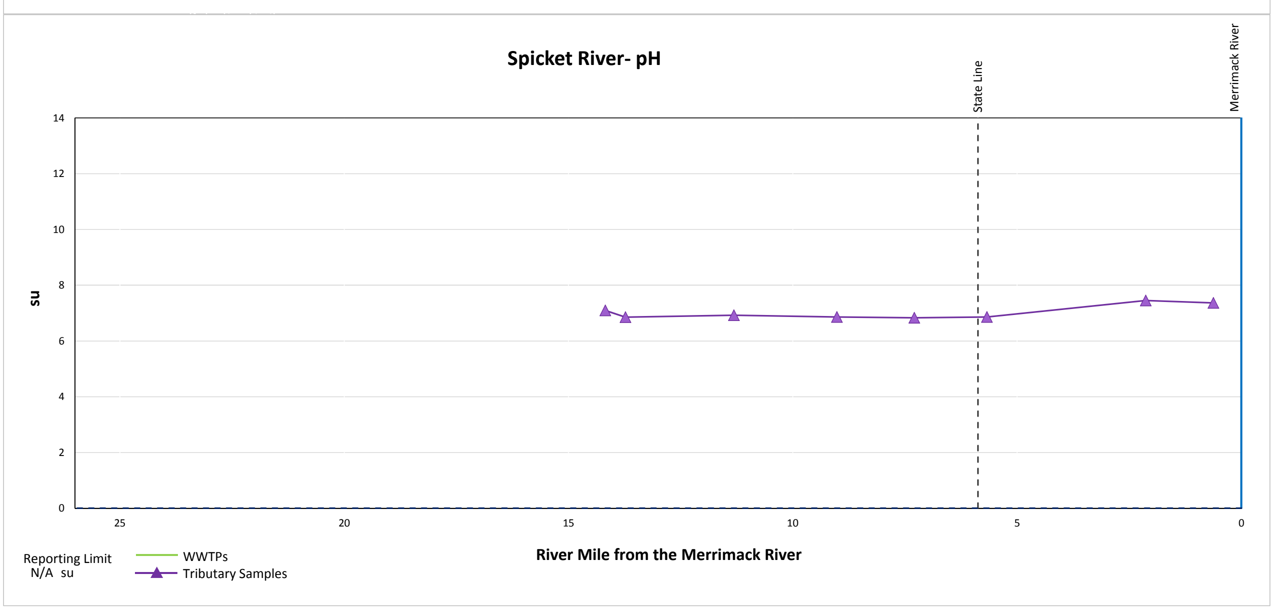
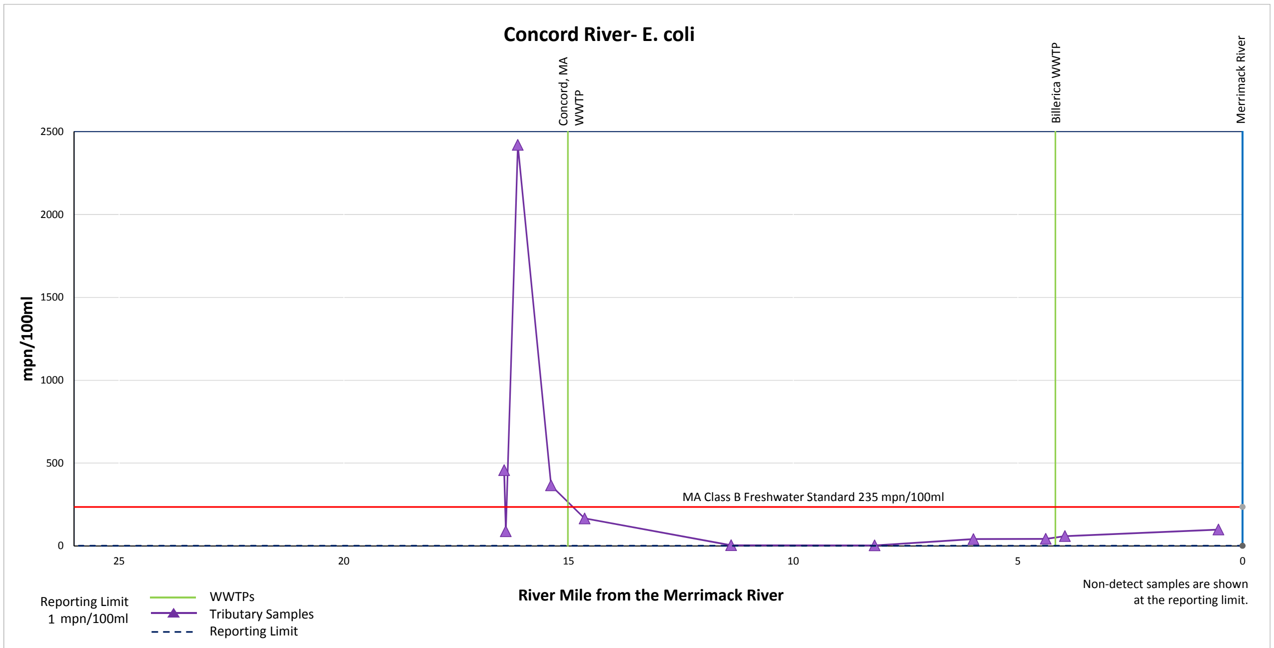
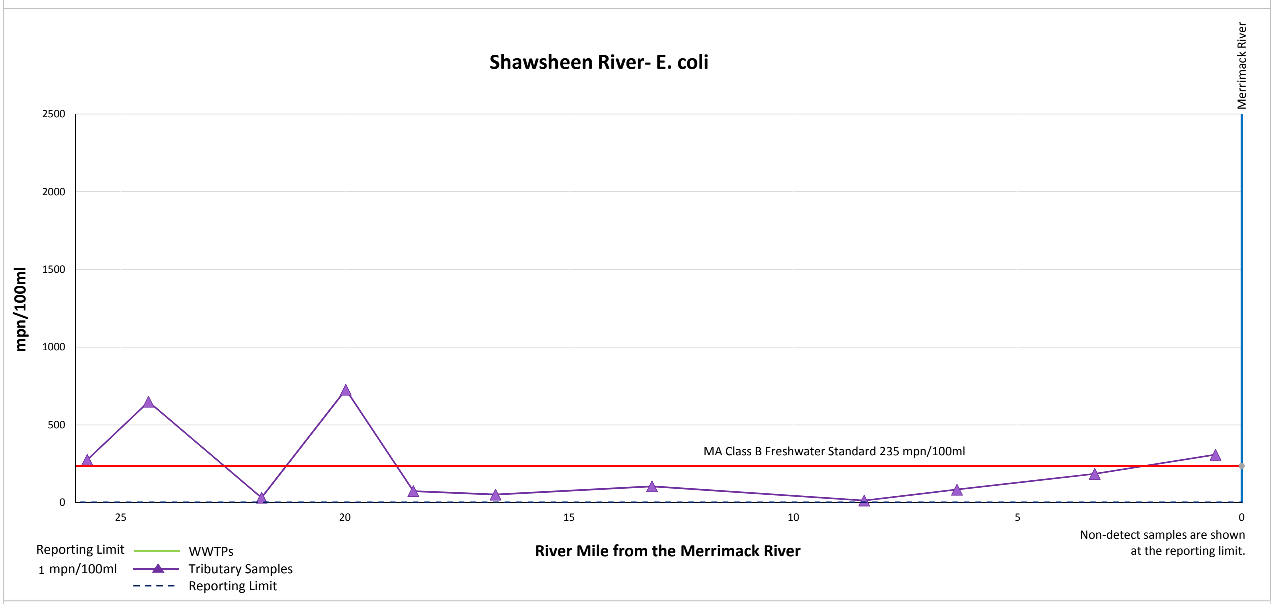


Figure 4-12
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)





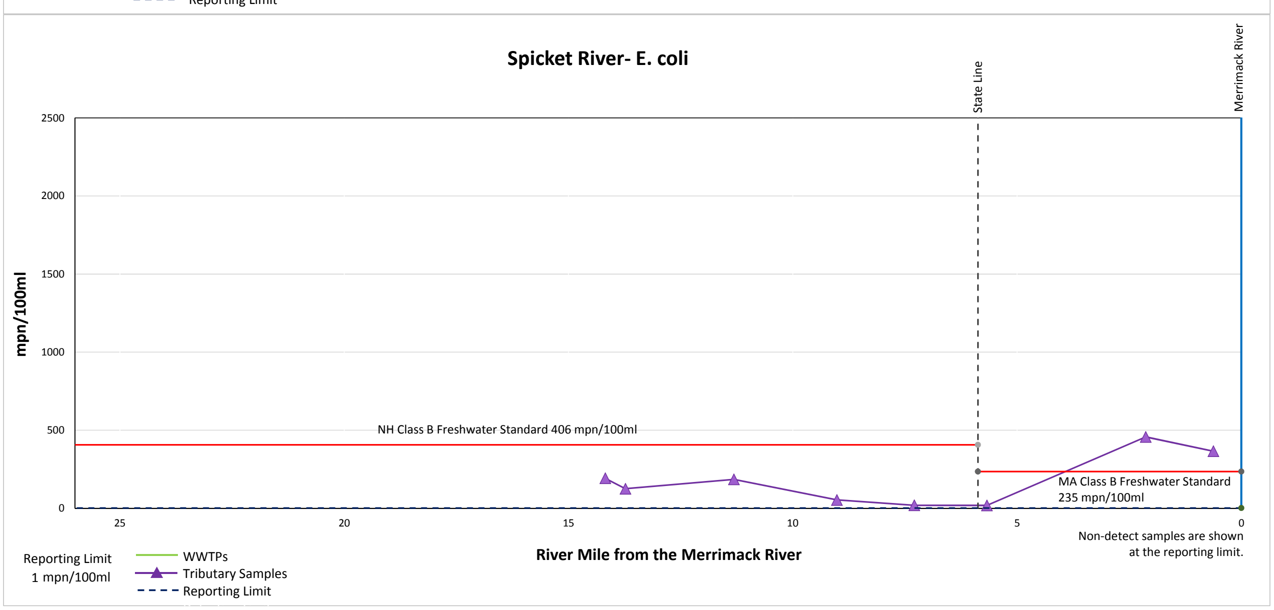
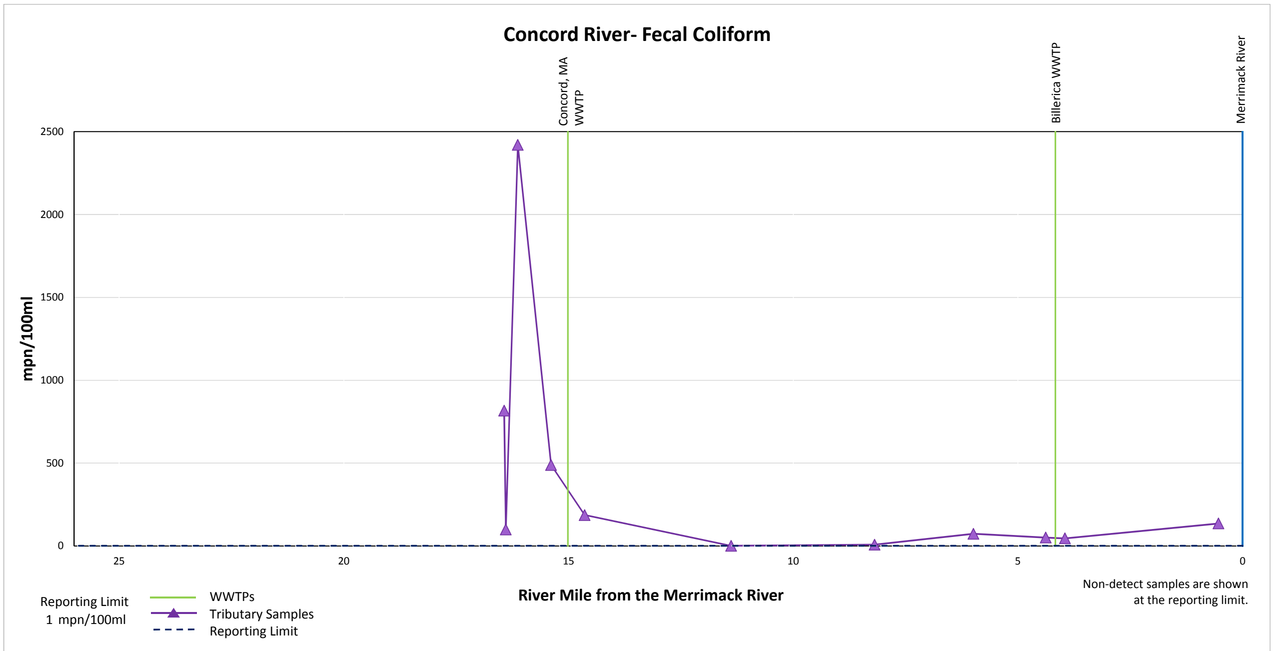
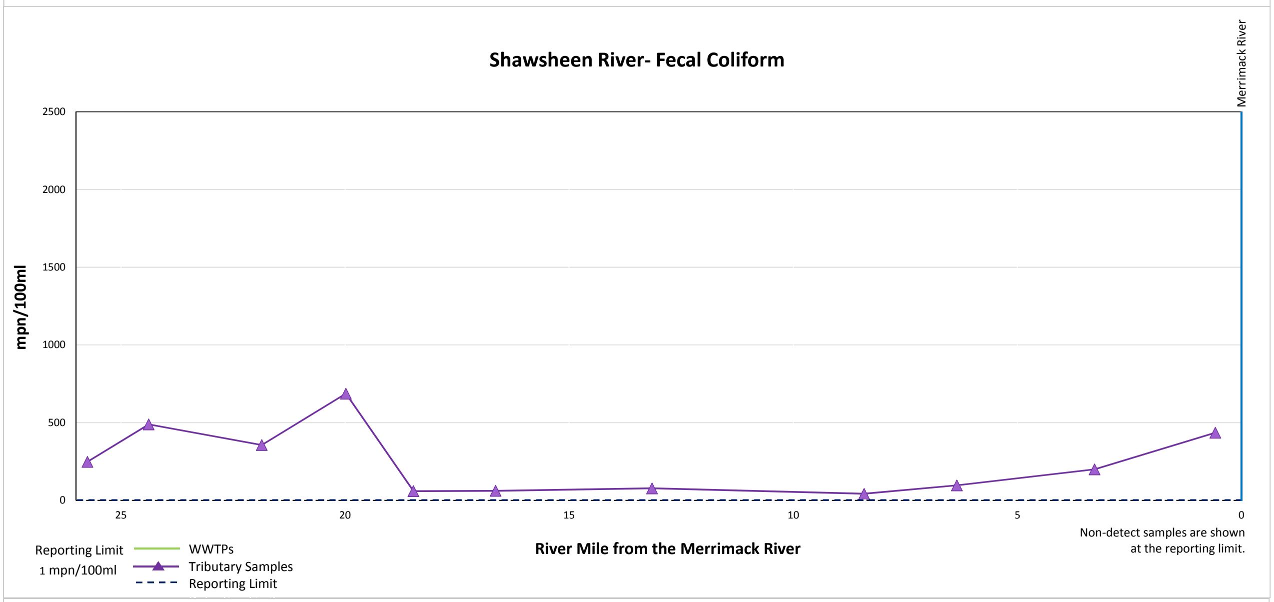
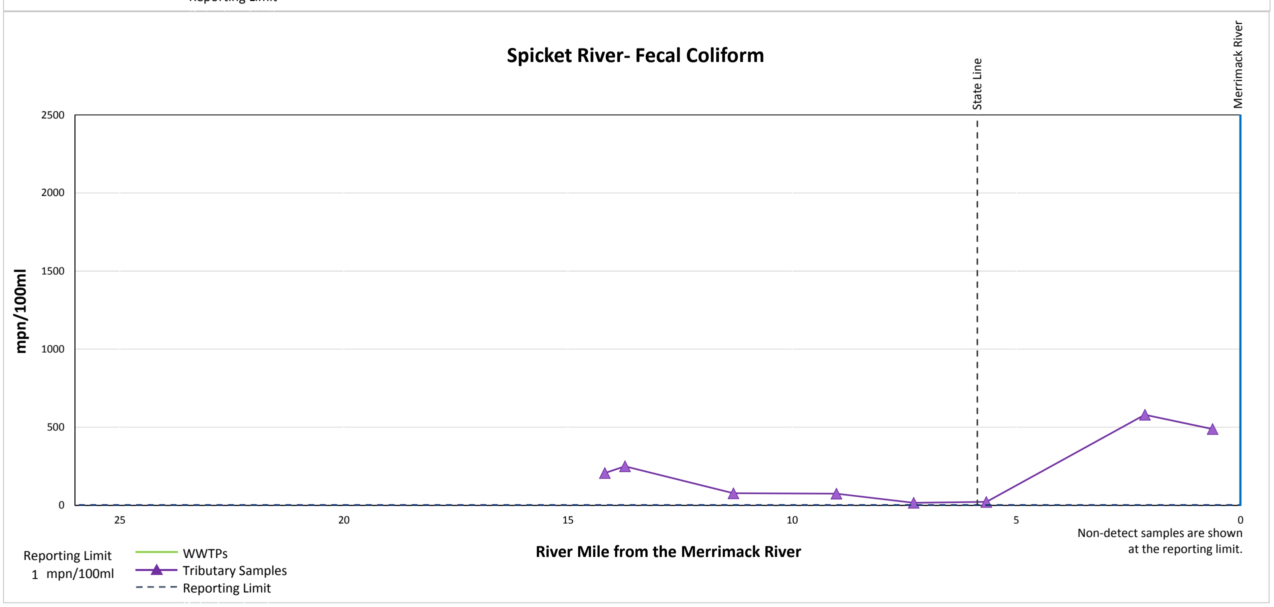
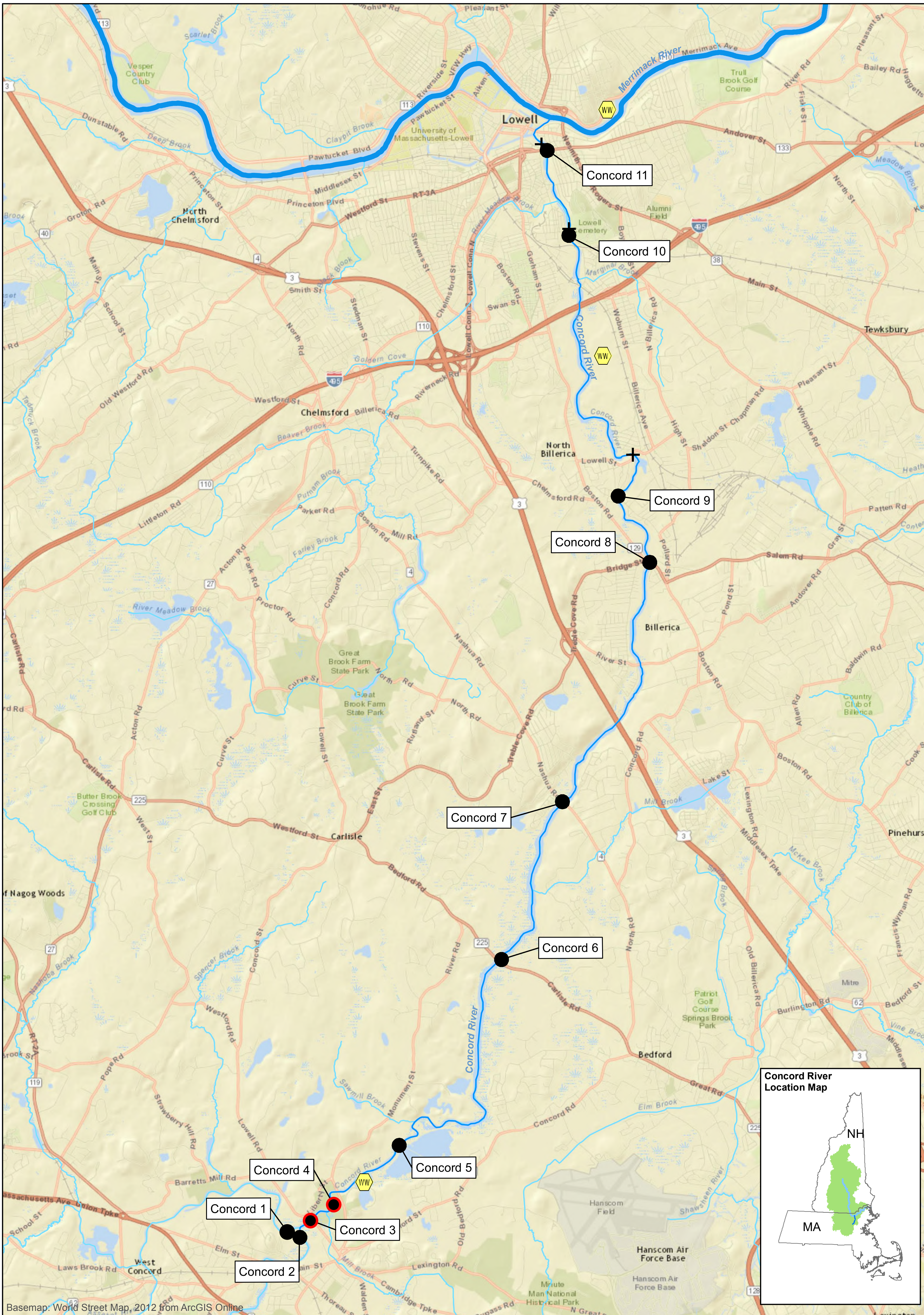


Figure 4-13
Merrimack River Watershed Study
Phase III - Tributary Event #1 (7/21/2016)









Legend

- ● Sampling Locations
- Merrimack River
- Concord River
- + Dams
- WW Wastewater Treatment Plant (WWTP)
- Exceedance of applicable state standard for e.coli (NH 406 mpn/100 mL, MA 235 mpn/100 mL)

Merrimack River Watershed Study
Phase III - Lower Merrimack

0 0.5 1 2 Miles

Figure 4-14

Tributary Event #1
Bacteria Results
Concord River

CDM Smith

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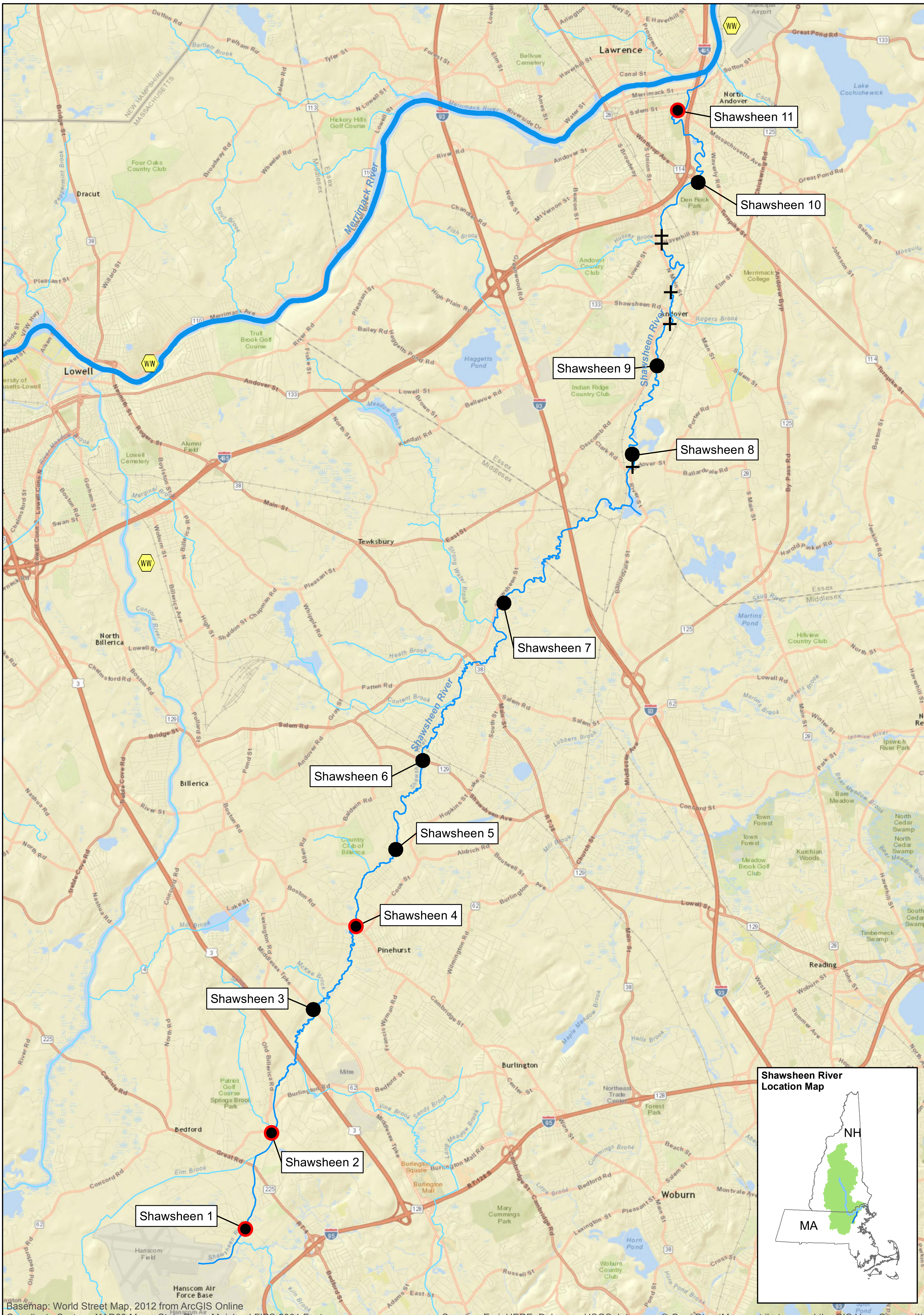

Legend

- Sampling Locations
- Exceedance of applicable state standard for e.coli (NH 406 mpn/100 mL, MA 235 mpn/100 mL)
- Merrimack River
- Shawsheen River
- Dams
- Wastewater Treatment Plant (WWTP)

Merrimack River Watershed Study
Phase III - Lower Merrimack

N S E W

0 0.5 1 2 Miles

Figure 4-15
Tributary Event #1
Bacteria Results
Shawsheen River

CDM Smith

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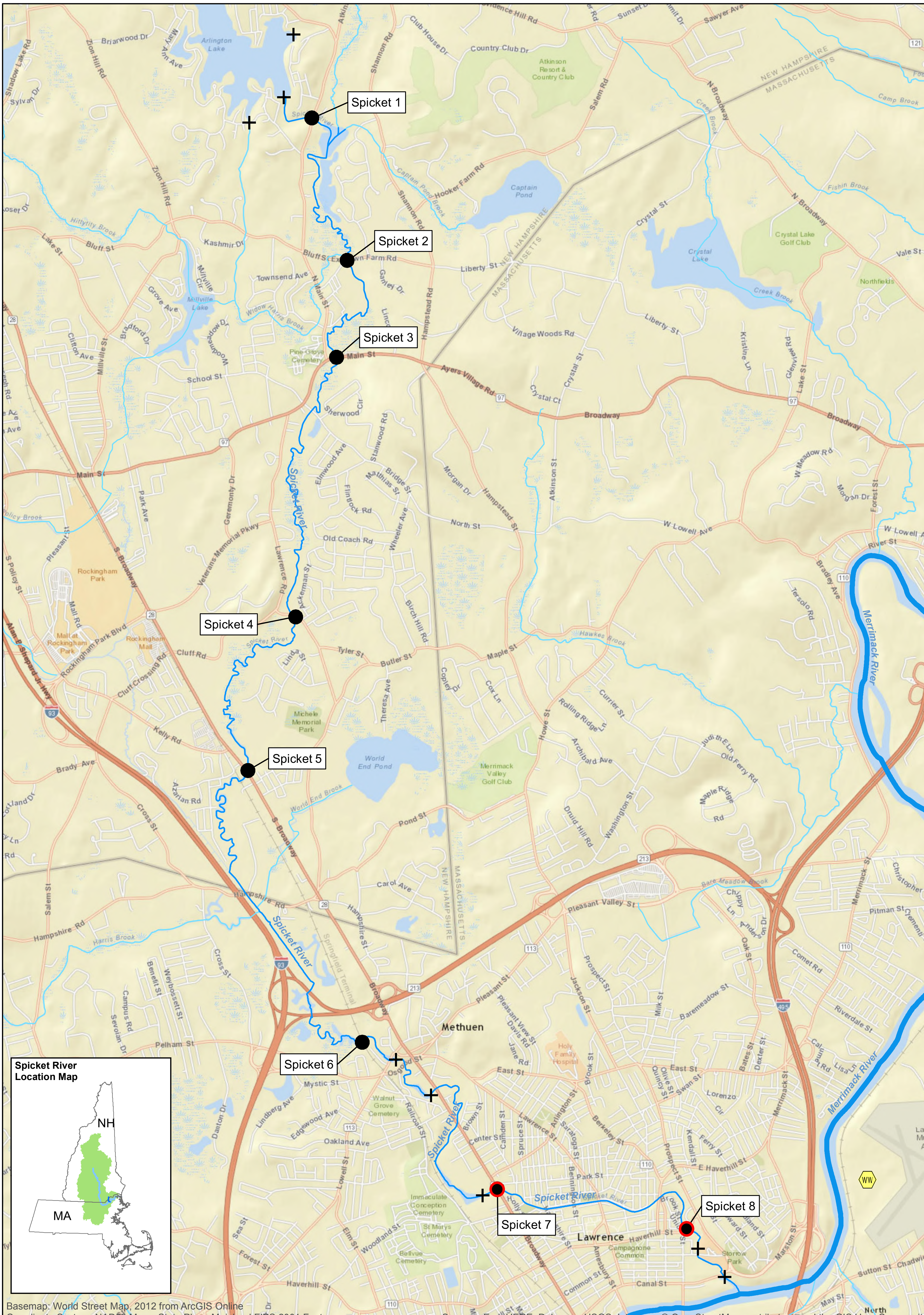

Legend

- ● Sampling Locations
- Exceedance of applicable state standard for e.coli (NH 406 mpn/100 mL, MA 235 mpn/100 mL)
- Merrimack River
- Spicket River
- + Dams
- WW Wastewater Treatment Plant (WWTP)

Merrimack River Watershed Study
Phase III - Lower Merrimack

0 0.25 0.5 1 Miles

Figure 4-16

Tributary Event #1
Bacteria Results
Spicket River

CDM Smith

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Section 5

Remaining Study Tasks

This report presents a summary of the water quality data collected in Phase III of the Merrimack River Watershed Assessment Study. This includes the results of:

- the June 2014 mainstem dry weather event (Mainstem Event #1 – 25 June 2014)
- the October 2015 mainstem wet weather event (Mainstem Event #2- 1 October 2015),
- the August 2016 mainstem hybrid (dry/wet) weather event (Mainstem Event #3- 10 August 2016), and
- the July 2016 dry weather tributary event (Tributary Event #1- 21 July 2016).

With the completion of the data collection presented in this report, the next steps for the Merrimack River Watershed Assessment Study will be the modeling tasks. The general scope of this modeling work includes the following:

- Use of data described in this report along with data collected in Phase I to model changes in water quality.
- Validation of the watershed/water quality model against the new water quality data to confirm that the model representation captures the watershed dynamics.
- Working with project stakeholders to develop and run the model scenarios.

A watershed report will be prepared by the USACE, that incorporates the results of Phases I, II, and III of the Study.

Section 6

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