FINAL

Phase III Lower Merrimack Summary Report

February 2019

Prepared for

by

Table of Contents

Executive Summary

The Merrimack River is formed by the confluence of the Pemigewasset and Winnipesaukee Rivers in Franklin, New Hampshire. The river flows southward for approximately 78 miles in New Hampshire before crossing the New Hampshire/Massachusetts border and flowing in a northeasterly direction for approximately another 50 miles before discharging to the Atlantic Ocean at Newburyport, Massachusetts. The final 22 miles of the river, downstream of Haverhill, Massachusetts, are tidally influenced. The Lower Merrimack River study area is a subset of this drainage area, beginning approximately 35 miles downstream of the confluence of the Pemigewasset and Winnipesaukee Rivers at the Hooksett Dam and ending at the ocean in Newburyport, Massachusetts.

The study was designed to develop a comprehensive understanding of the existing water quality conditions of the river, the pollution sources impairing designated uses along the river, and the water quality benefits of different water quality management scenarios. The overall goal of the study is to develop a comprehensive watershed assessment to guide water quality related investments in the basin. The study was conducted across three phases, summarized on **Figure ES-1**:

- Phase I, with a focus on the Lower Merrimack River from the Hooksett Dam to the confluence with the Atlantic Ocean in Newburyport, MA. The principal focus of this phase was bacteria impairments and the tradeoff between combined sewer overflow (CSO) abatement and nonpoint source reduction.
- Phase II, with a focus on the Upper Merrimack and Pemigewasset Rivers from Lincoln, NH to the New Hampshire/Massachusetts state line. The principal focus of this phase was sensitivities related to nutrients and primary contact recreation impairments in New Hampshire. Bacteria sensitivities were not assessed in this phase.
- Phase III (subject of this report), with a focus on the Lower Merrimack study reach but accounting for updated CSO, stormwater, and wastewater treatment plant (WWTP) conditions since the original Phase I study. The focus of this study was on both nutrient- and bacteria-related sensitivities as well as sensitivities to climactic (temperature) conditions.

The study consisted of water quality monitoring, simulation modeling, and a comprehensive stakeholder-driven assessment of existing and potential future river conditions.

Historical Water Quality

Water quality in the Merrimack River prior to the construction of WWTPs in the 1970s was generally poor and did not support aquatic life or recreation uses. In 1966, the U.S. Department of the Interior (USDOI), through the Merrimack River Project, published a series of reports on water quality in the Merrimack River and its principal tributaries in Massachusetts and New Hampshire, including the Pemigewasset River, a major tributary to the Merrimack River in New Hampshire (USDOI 1966a, 1966b). As of 1966, there were over 20 different industrial or municipal facilities discharging waste to the New Hampshire portions of the Pemigewasset and Merrimack Rivers with no treatment. Across the entire watershed, these sources discharged the equivalent biochemical oxygen demand (BOD) load contained in the raw sewage of nearly 700,000 persons.

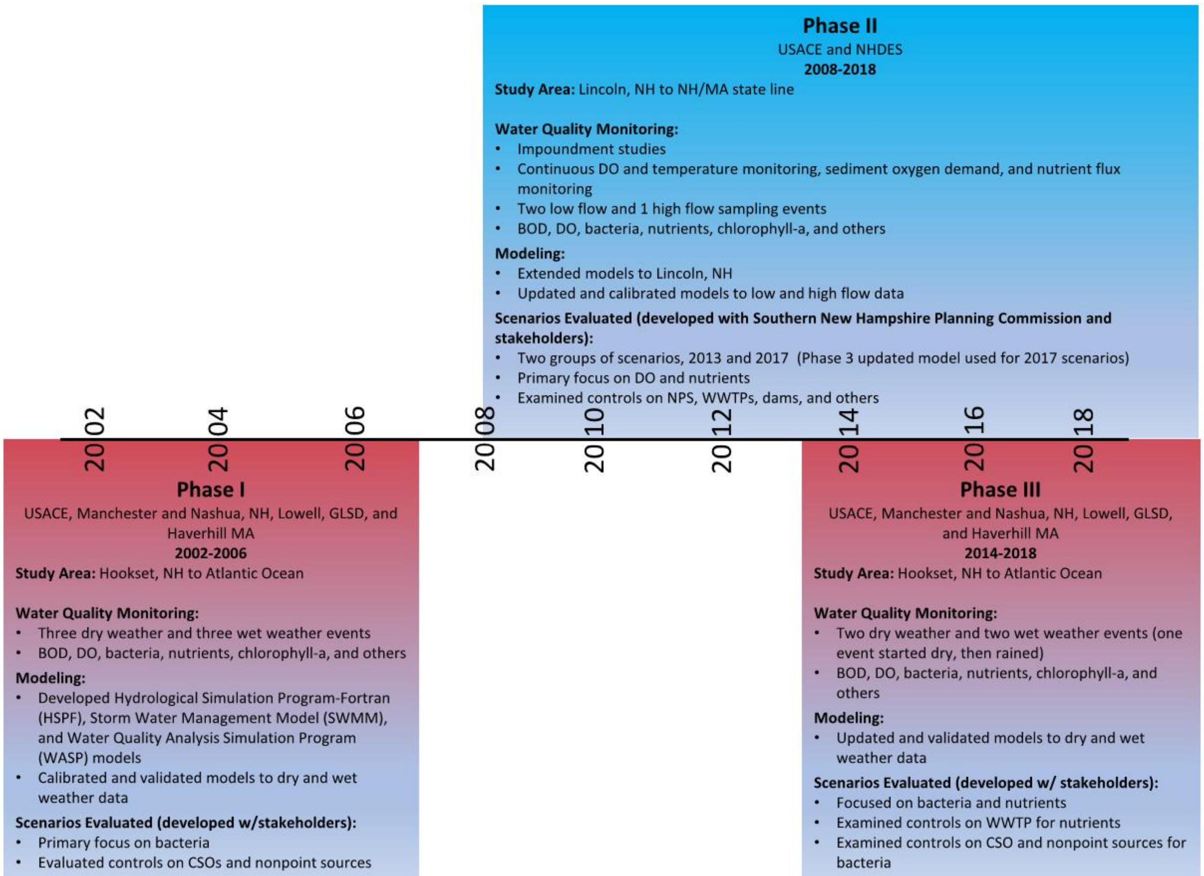

Figure ES-1. Merrimack River Watershed Assessment Study Timeline

The Pemigewasset River was characterized by exceptionally poor water quality and designated by the New Hampshire Legislature in 1958 as Class D, "devoted to transportation of sewage or industrial waste without nuisance [… and…] not acceptable for fishing, boating, swimming, or municipal or industrial water supplies, even with water treatment." Dissolved oxygen (DO) from the East Branch of the Pemigewasset River to Franklin, NH averaged about 2.7 milligrams per liter (mg/L), with values below 1 mg/L common. The minimum DO value based on sampling conducted in 1960, 1961, and 1962 was always less than 5 mg/L (USDOI 1966b). For reference, the state water quality criteria in both New Hampshire and Massachusetts portions of the Merrimack River is currently 5 mg/L.

Farther downstream, in the Merrimack River, low DO concentrations were reported, around 4 to 5 mg/L, between the headwaters of the Merrimack River and Manchester, New Hampshire, and DO concentrations well below 5 mg/L were reported between Manchester, New Hampshire and the New Hampshire/Massachusetts state line. The minimum observed DO was less than 2 mg/L at every monitoring location between Manchester, New Hampshire and Newburyport, Massachusetts. Sensitive organisms could not survive in the lower 57 miles of the river from Nashua, New Hampshire to Newburyport, Massachusetts and only 15 out of the total 116 miles from Winnipesaukee, New Hampshire to Newburyport, Massachusetts could support such sensitive organisms (USDOI 1966a).

Bacteria concentrations were a serious problem at the time of the 1966 DOI study, which concluded the bacteria contribution to the river from industrial and municipal sources was equivalent to the raw sewage from 416,000 persons, 66% of which originated in Massachusetts; an estimated 99% of the New Hampshire bacteria pollution originated south of Manchester, New Hampshire. The large amount of untreated sewage discharge to the river led to elevated bacteria levels as high as 1,859 times the recommended maximum level in 1960.

Current Water Quality

Water quality in the Merrimack River has been greatly improved since the 1966 USDOI study. Today, every waste discharge to the rivers receives at least secondary treatment and disinfection, and Manchester and Nashua, New Hampshire and Lowell, Lawrence, and Haverhill, Massachusetts are making progress on reducing wet weather CSO discharges to the river through their approved long-term control plans. The Merrimack River is now classified as a Class B or SB waterway in New Hampshire and Massachusetts, suitable for fishing, swimming, and other recreational purposes and, after adequate treatment, for use as water supplies.

Phase III of the Merrimack River Watershed Assessment Study

Phase III of the Merrimack River Study represents the culmination of over fifteen years of water quality monitoring, modeling, and evaluation conducted across the three phases of study. The monitoring and assessment conducted in Phase III was focused on the Lower Merrimack River from the Hooksett Dam in Hooksett, New Hampshire to the Atlantic Ocean in Newburyport, Massachusetts, shown in **Figure ES-2**. This phase of the study was undertaken to assess sensitivities to water quality for both nutrients and bacteria for both existing conditions and potential future conditions.

Initial model development was conducted during Phase I for the Lower Merrimack study area. Over the three phases of the study, CDM Smith completed a comprehensive field monitoring program and used the data collected during the field monitoring program to develop, calibrate, and validate a watershed hydrology, riverine hydraulic, and receiving water quality model. The model was applied to understand basin-scale nutrient and bacteria water quality dynamics.

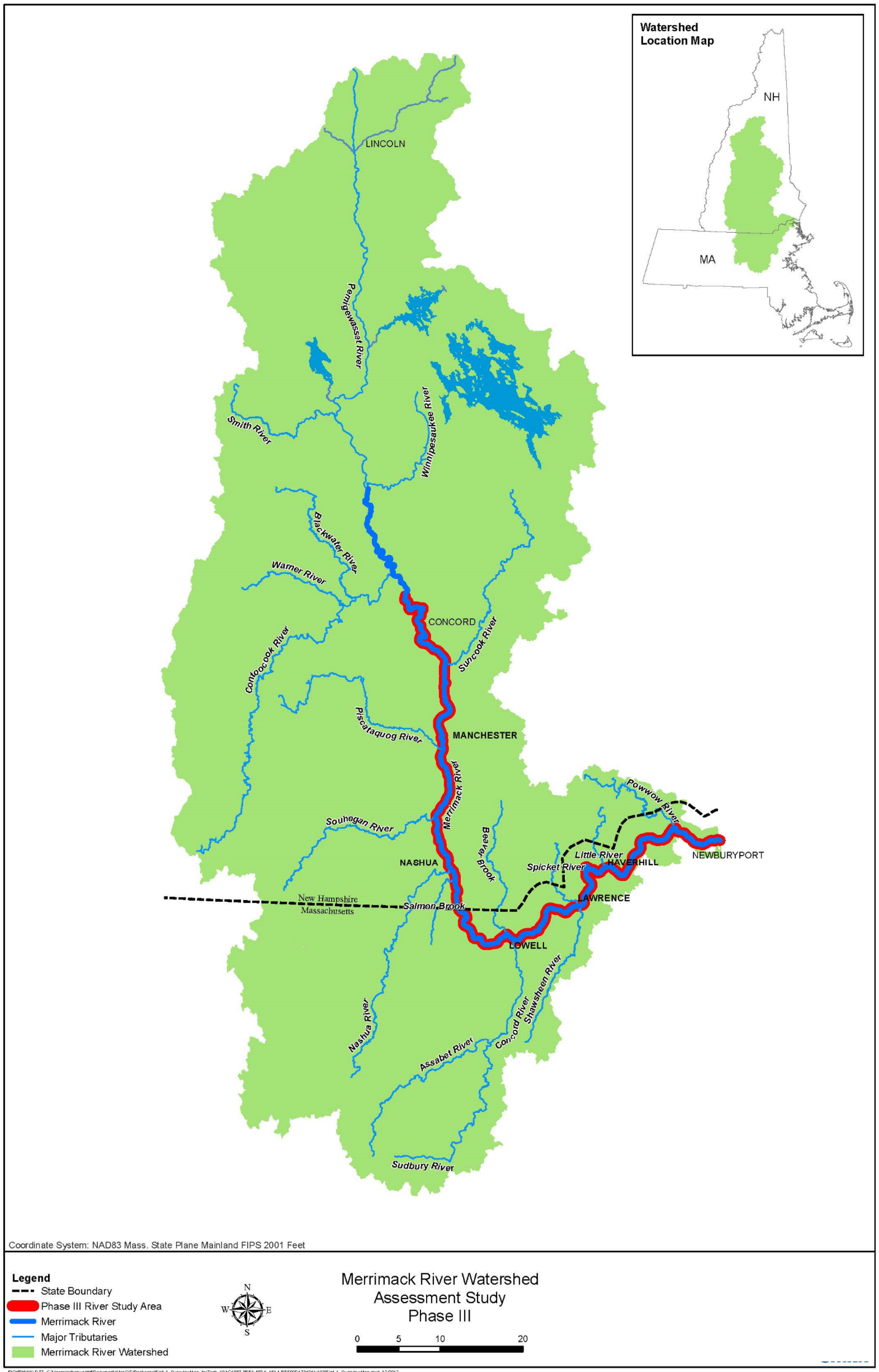

Figure ES-2. Phase III Lower Merrimack Watershed Study Area

Field Monitoring

A principal component of all three phases of the Merrimack River Watershed Assessment Study was to collect a spatially and temporally comprehensive water quality dataset describing nutrients, DO, chlorophyll-*a*, and bacteria concentrations along the entire Merrimack and Pemigewasset River system. The primary objective of the field sampling program was to provide an accurate and representative picture of the current water quality conditions at specific sampling stations along the mainstem, with emphasis on impounded reaches (behind dams), as well as the mouths of major tributaries. Data collected were used to understand current river water quality and to calibrate and validate the water quality model.

The field sampling program consisted of the following components:

- Impoundment studies (Phase II only) to understand water quality dynamics in the riverine impoundments in New Hampshire.
- Continuous dissolved oxygen and temperature monitoring (Phase II only) to understand the diurnal variation in DO concentrations.
- Low flow water quality surveys, implemented as a single-day, longitudinal sampling program, to understand baseline water quality during low flow conditions without stormwater or CSO impacts.
- High flow water quality survey, also implemented as a single-day, longitudinal sampling program, to understand water quality during high flows that are influenced by stormwater and CSOs.
- Sediment oxygen demand and nutrient flux monitoring (Phase II only) to understand the impact that sediment has on lowering DO concentrations and the relative impact of phosphorus release from sediments into the river.

Nine monitoring events were conducted between 2009 and 2016 as part of Phases II and III of the Merrimack River Watershed Assessment Study. Nutrient, dissolved oxygen, and chlorophyll-*a* data presented in Phases II and III demonstrate a slight improvement compared with Phase I, with slightly lower instream TP, chlorophyll-a, and BOD concentrations. The monitoring data collected across Phases I, II, and III collectively do not indicate DO impairment to the aquatic life uses in New Hampshire, representing a significant improvement over the legacy impairments documented in the USDOI (1966a and 1966b) report. Specifically, no exceedances of the current New Hampshire or Massachusetts minimum DO criteria were found in any of the low or high flow water quality surveys, the detailed impoundment surveys, or in the continuous DO monitoring data.

The bacteria data presented in this study demonstrate improvements over the historical conditions presented in Phase I of this study and over the conditions discussed in the USDOI (1966a and 1966b) report. The significant progress made by communities throughout the Merrimack River watershed on their illicit discharge detection and elimination (IDDE) programs and CSO reduction is evident in the monitoring and modeling results. During dry weather – with rare exceptions –measured bacteria levels in the river are below the New Hampshire and

Massachusetts bacteria criteria. Wet weather sampling shows consistent exceedances of water quality criteria in both states, which are likely caused by a combination of stormwater and CSO pollution. The model results confirm this observation, with no modeled exceedances of state bacteria criteria during dry weather and exceedances of criteria during wet weather events.

Computer Model Development and Assessment Modeling

The assessment modeling component of the Merrimack River Watershed Study applied the data and information derived from the field monitoring program to develop a comprehensive hydrologic, hydraulic, and receiving water quality model. Three linked models were used to simulate the watershed runoff and pollutant loads, the river hydraulic routing, and the instream water quality processes.

The modeling objectives of the study are to:

1. Represent pollutant sources and river processes affecting nutrients, chlorophyll-*a*, DO levels, and bacteria concentrations in the mainstem of the Merrimack River.
2. Understand the relative impacts of point sources and nonpoint sources on river water quality.
3. Evaluate sensitivities to changes in pollution sources relative to water quality standards.
4. Understand potential impacts of future conditions in the watershed, including the sensitivities to climate changes and increased development.

The water quality model was used to evaluate river health and system sensitivities to pollutant sources and potential future conditions for the watershed through a series of scenarios, which are simulations used to explore the impact of water quality changes on river health. Twenty-one scenarios were developed in a collaborative effort between CDM Smith, USACE, NHDES, and key watershed stakeholders. These scenarios consist of 16 nutrient-related scenarios and five bacteria-related scenarios. The 16 nutrient scenarios are summarized in **Table ES-1**, and the five bacteria scenarios are summarized in **Table ES-2**.

Table ES-1. Summary of Nutrient Scenarios

Scenario	Basis	Question/Purpose
Scenario 1	Historical (2000-2002) loads and flows	Demonstrate the historical water quality conditions
Scenario 2	Baseline Current Conditions	Existing Condition: Demonstrate the current water quality conditions
Scenario 3	Summer Max Flows	Worst-case Condition: Evaluate worst case effluent flow rates for current development
Scenario 4	Current WWTP Effluent Flows at 1 mg/L Total Phosphorus (TP) (or current concentrations if lower)	Experimental scenario isolating impacts of adjusted maximum WWTP TP effluent concentrations: Evaluate river sensitivity to effluent phosphorus control
Scenario 5	80% design Flow at permitted TP loads (current concentrations if no permit)	Worst-case Condition: Evaluate river sensitivity to permitted effluent phosphorus control at the worst-case effluent flow rate for the current development

Scenario	Basis	Question/Purpose
Scenario 6	Design Flow at 1 mg/L TP (or current concentrations if lower)	Potential Future Condition: Evaluate river sensitivity to effluent phosphorus control for effluent flow rates at permit limits
Scenario 7	Increased water withdrawals from the river at baseline WWTP conditions	Potential Future Condition: Evaluate the impact of increasing water withdrawals on current water quality
Scenario 8	Temperature and tidal boundary sensitivity with WWTPs at design flow with 1 mg/L TP (or current concentrations if lower)	Potential Future Condition: Evaluate the impact of temperature and tidal boundary changes on water quality
Scenario 9	Zero Discharge in Massachusetts with Permitted TP Loads in New Hampshire	Experimental scenario isolating the impact of New Hampshire maximum WWTP effluent TP loads: Evaluate impact of imposing New Hampshire permitted phosphorus mass limits as concentrations on water quality responses in downstream Massachusetts river segments
Scenario 10	Effluent Nitrogen Controlled at 7 mg/L Maximum	Experimental scenario isolating the impacts of reduced nitrogen WWTP effluent: Evaluate river sensitivity to effluent nitrogen control
Scenario 11	Current WWTP Effluent Flows at 2 mg/L TP (or current concentrations if lower)	Experimental scenario isolating the impacts of adjusted WWTP TP effluent: Evaluate river sensitivity to effluent phosphorus control to 2 mg/L
Scenario 12	Temperature sensitivity with existing effluent flows and concentrations	Potential Future Condition: Evaluate the impact of temperature changes on water quality
Scenario 13	Baseline (dry, average, and wet) conditions with CSO flows contributing to instream nutrients (Long Term Control Plan [LTCP] Phase 1 + Minimum Control Measures [MCMs][1] in Municipal Separate Storm Sewer Systems [MS4s])	Current Condition: Demonstrate the current water quality conditions considering the effect of CSO on nutrient concentrations
Scenario 14	Additional CSO Control (Largest four overflow events per year with reduced volume)	Experimental scenario isolating the impacts of increased CSO controls: Evaluate water quality improvement from additional CSO control with current stormwater program implementation
Scenario 15	Stormwater practices to comply with new MS4 permit	Experimental scenario isolating the impacts of increased green infrastructure controls: Evaluate water quality improvement from pilot-scale MS4 green infrastructure stormwater practices with current LTCP implementation
Scenario 16	Additional (3-month) CSO control with MS4 stormwater practices	Experimental scenario evaluating the impacts of CSO and pilot-scale green infrastructure MS4 stormwater practices

[1] Phase I CSO permits require the permittee to implement the nine minimum controls, to document that this requirement has been met, and to prepare a LTCP to control CSOs. The nine minimum controls are: monitoring to characterize CSO impacts and the efficacy of CSO controls; proper operation and regular maintenance programs for the sewer system and the CSOs; maximum use of the collection system for storage; review and modification of pretreatment requirements to minimize CSO impacts; maximize flow to the WWTP for treatment; prohibition of dry-weather CSOs; control of solid and floatable materials in CSOs; pollution prevention programs; and public notification of CSO occurrences/impacts (EPA 1995).

Table ES-2. Summary of Bacteria Scenarios

Scenario	Basis	Question/Purpose
Scenario 1	Historical Bacteria	Historical Condition: Demonstrate the historical water quality conditions
Scenario 2	Baseline Current Conditions (with LTCP Phase 1 + MCMs in MS4s)	Current Condition: Demonstrate the current water quality conditions
Scenario 3	Additional CSO Control (Largest four overflow events per year with reduced volume)	Experimental scenario isolating the impacts of increased CSO controls: Evaluate water quality improvement from additional CSO control with current stormwater program implementation
Scenario 4	Stormwater Practices to comply with new MS4 permit	Experimental scenario isolating the impacts of increased Green Infrastructure controls: Evaluate water quality improvement from MS4 stormwater practices with current LTCP implementation
Scenario 5	Additional (3-month) CSO Control with MS4 stormwater practices	Experimental scenario evaluating the impacts of CSO and green infrastructure MS4 stormwater practices

Each scenario is evaluated through manipulation of one or more variables to assess the sensitivity of model results to changes in these variables. Only the specified variables change across simulations; all other variables are not changed. Hydrology (rainfall, runoff, and river flow) and atmospheric conditions (temperature, evapotranspiration, solar radiation) in each simulation are drawn or modeled from observed data from May through October for the years 2002 through 2016 (for Nutrient Scenarios 1 through 12) or 1993, 1994, and 1998 (for Nutrient Scenarios 13 through 16 and all Bacteria Scenarios). This provides a consistent, multi-year set of observed conditions over which the simulation results are assessed.

Findings and Recommendations

Nutrients

The river exhibits no aquatic health risks due to low DO levels, and available data suggest nutrients do not prevent the river from meeting aquatic life or recreational uses. The ability of the Merrimack to support both ecological and human health is notable for a post-industrial river in a highly urbanized basin. Indicators of water quality risks, such as levels of phosphorus and chlorophyll-*a* could suggest, when taken out of context, that the river is at risk of use impairment because these values sometimes exceed guidance levels that are used to assess river health state-wide. However, the monitoring and modeling in this study over the past 15 years have shown that the unique hydrology and hydraulics of this river flush it rapidly, re-oxygenate it frequently, and absorb the byproducts of urbanization that might render other smaller rivers in this region impaired.

Other key findings include:

- Reducing WWTP phosphorus concentrations to 1 mg/L or 2 mg/L would result in a reduction in total phosphorus levels. This results in a lower likelihood of conditions that could cause simulated levels of chlorophyll-*a* above the primary contact recreation-based chlorophyll-*a* threshold in New Hampshire and the 16 µg/L chlorophyll-*a* threshold in Massachusetts. However, the fact that no low dissolved oxygen concentrations were details of these adjustments can be found in the *Lower Merrimack Assessment Report* (CDM Smith 2018a)

The dry hydrologic May through October simulation may have fewer than four overflows per year, and the wet hydrologic May through October simulation may have greater than four overflows per year. The input dataset for representing 3-month CSO controls was based on an adjustment to current CSO datasets, without identifying specific projects or interventions required to achieve this level of control.

5.1.2 Stormwater Practices Scenario Development

Simulated in nutrient Scenarios 15 and 16 and bacteria Scenarios 4 and 5, stormwater practices were developed to approximate the water quality impact of a pilot implementation of the recently issued Massachusetts and New Hampshire Small MS4 General Permit (Massachusetts NPDES Permits MAR041000, MAR0402000, and MAR043000 and New Hampshire NPDES Permits NHR041000, NHR042000, and NHR043000). The measures considered in these scenarios are improved stormwater controls implemented through increased green infrastructure and low impact development and the implementation of minimum control measures basin-wide.

Improved stormwater controls were modeled conceptually as pilot-scale green infrastructure installations in HSPF by assuming an increase in impervious interception storage within a subset of the MS4 areas in each subbasin. For this assessment, 5% of the impervious area contained within the MS4 boundaries is treated as a pilot. While modest in area, this improvement still presents a substantial capital expense for municipalities.

Nonpoint sources, including stormwater, can be a significant source of nutrients and bacteria to the Merrimack River and its tributaries. **Figure 5-1** shows the relative average simulation period *E. coli* and total phosphorus load to the Merrimack River from point (CSOs discharging *E. coli* and phosphorus, and WWTPs discharging phosphorus) and nonpoint (stormwater rainfall runoff, MS4s, septic systems, animal contributions, etc.) sources as a percentage of the watershed-wide total in the baseline simulation period. *E. coli* distributions are based on the wet, dry, and average baseline simulation and the total phosphorous distributions are based on the 2002 through 2016 baseline simulation. These loads show that point sources dominate both bacteria and nutrient loads to the river, but that nearly half of the modeled *E. coli* load and over one quarter of the modeled total phosphorus load is nonpoint source in origin. Contributions of *E. coli* from CSOs are based on the frequency and volume of CSOs triggered during the simulation period which are triggered by precipitation patterns. Furthermore, the stormwater bacteria load reported here represents the load to the mainstem Merrimack River. Significant bacteria die-off occurs upstream in each tributary prior to discharging to the Merrimack River. While the nonpoint source contribution is lower overall, there are likely cost-effective nonpoint source controls that can be implemented to reduce nonpoint source impacts on the river. These nonpoint source controls will also likely have a significant impact on tributary water quality even if the relative impact on Merrimack River water quality is lower.

when the model predicts that high phytoplankton growth rates are a possibility, no exceedances of the aquatic life use criteria for DO are predicted, which supports the results of the of the monitoring study.

The bacteria data presented in this study demonstrate improvements over the historical data presented in Phase I of this study. The significant progress made by communities throughout the Merrimack River watershed on their IDDE programs and CSO reduction is evident in the monitoring and modeling results. During dry weather—with rare exceptions—instream measured bacteria concentrations are below the New Hampshire and Massachusetts single sample maximum criteria. Wet weather sampling shows consistent exceedances of water quality criteria in both states, which is likely caused by a combination of stormwater and CSO inputs. The baseline model results confirm this observation, with no modeled exceedances of state bacteria criteria during dry weather and exceedances of both the geometric mean and single sample maximum/statistical threshold value criteria during wet weather events. This finding is true for both the existing and proposed Massachusetts bacteria criteria.

7.2 Review of Model Scenarios

The calibrated and validated water quality model was applied to understand the overall sensitivity of the Merrimack River to point and nonpoint sources.

7.2.1 Nutrient Scenarios

The scenario runs completed under Phase III (covering the Merrimack River from Hooksett Dam to the estuary at Newburyport, Massachusetts) uniformly found no predicted exceedances of the DO 5 mg/L or 75% daily average saturation criteria (New Hampshire only), suggesting that the river is meeting aquatic life uses despite the occasional exceedance of TP or chlorophyll-*a* guidance values. Scenarios for current WWTP flows show that reducing WWTP loads to the equivalent of a 1 mg/L TP effluent limit would result in a reduction in instream total phosphorus concentrations corresponding to a lower likelihood of conditions that could cause exceedances of the primary contact recreation-based chlorophyll-*a* threshold in New Hampshire and the 16 µg/L chlorophyll-*a* threshold in Massachusetts.

Modeled conditions for future flows can be used to prepare for potential management actions to maintain the current Merrimack River water quality. The alternatives analysis found that increasing the WWTP flows to 80% of design flows or to full design flows does not correspond to a significant change in the likelihood of exceedances of the chlorophyll-*a* threshold.

The opposite finding is true for the climate sensitivity scenario. In this scenario, phytoplankton growth is expected to increase significantly. The increased growth rate is based on the calibrated chlorophyll-*a* rate constant in which increased temperature corresponds to increased phytoplankton growth. This relationship is well studied, and it is certain that growth for any given phytoplankton species will increase with higher temperatures. However, there is uncertainty in the future phytoplankton population under different climatic and hydrologic conditions. This could lead to a different growth rate divergent from the calibrated rate constants and parameters. Therefore, the results of this scenario should be interpreted as potential climate sensitivities but not as a certainty, which should be considered before requiring any action now to prevent these impacts from occurring.