Merrimack River Watershed Assessment Study

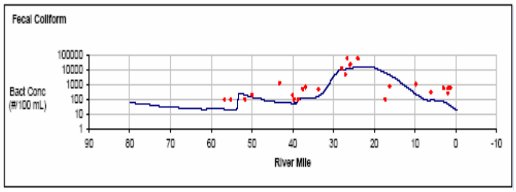
Final Phase I Report

Prepared for:

New England District
U.S. Army Corps of Engineers

Sponsor Communities:

Manchester, NH
Nashua, NH
Lowell, MA
Greater Lawrence Sanitary District, MA
Haverhill, MA



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Executive Summary

This report summarizes Phase I of the Merrimack River Watershed Assessment Study, whose overall purpose is to develop a comprehensive Watershed Management Plan for the Merrimack River watershed. The plan will be used to guide investments in local environmental resources and infrastructure, with the goal of achieving water quality and flow conditions to support uses such as drinking water supply, recreation, fisheries, and aquatic life support.

Work conducted during Phase I quantitatively compared alternative management strategies for the watershed designed to reduce the impact of pollutants such as bacteria and nutrients. Further, opportunities are evaluated for ecological improvements in the watershed.

Phase I of the Merrimack River Watershed Assessment Study was a jointly-funded effort between the Federal government, through the United States Army Corps of Engineers (USACE) New England District, and the five local-community sponsors of Manchester and Nashua, New Hampshire; Lowell and Haverhill, Massachusetts; and the Greater Lawrence Sanitary District (GLSD), Massachusetts. Collectively, these communities formed the Merrimack River Basin Community Coalition (MRBC). The Merrimack watershed and the sponsor communities are shown in Figure ES–1.

The study was divided into numerous tasks that were structured around the six-step USACE planning process, as outlined in Table ES–1. While many of the tasks were aggregated into larger task orders, the reference numbers below represent the original task designations in the Project Study Plan (PSP).

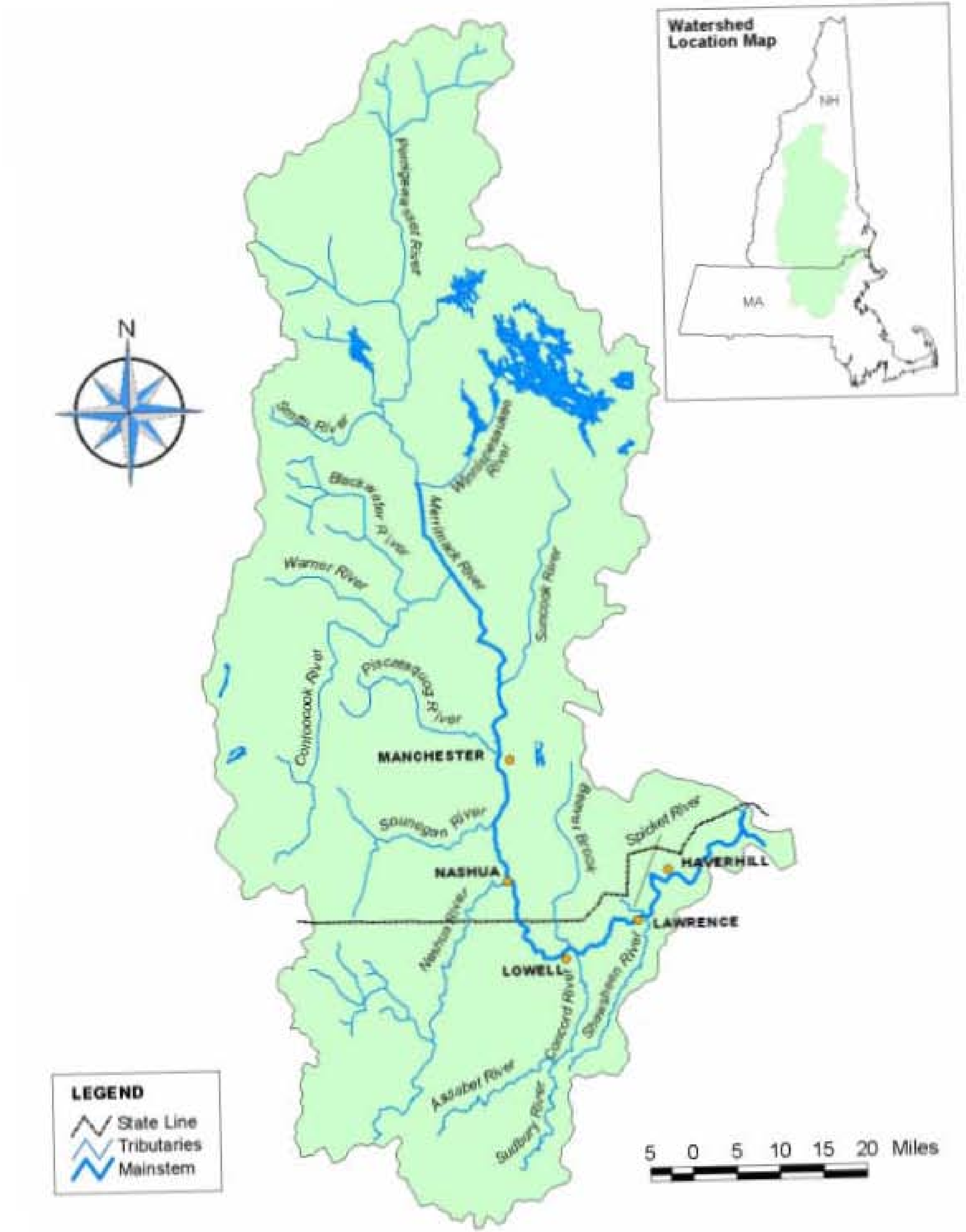


Figure ES–1: Merrimack River Watershed

Table ES-1: Implementing the Study with the Corps Six-Step Planning Process

Corps Planning Step	Task ID # per PSP	Task Description	Deliverables*	Utility of Study Output
Step 1: Problem Identification and Opportunities	1	Summarize Existing Conditions (hydrology, climate, water quality, land uses, regulations)	*Summary of Existing Conditions (CDM, 2003)*	Identified baseline causes and impacts of pollution throughout watershed
	2	Summarize Current Water Uses	Included in Existing Conditions Report	
	3	Summarize Pollution Sources (point and nonpoint) throughout the watershed	*Summary of Pollution Sources Report (CDM, 2003)*	
Step 2a: Inventory	7	Hydrology and Hydraulics Survey of the Mainstem Merrimack River	*Hydrology and Hydraulics Report (CDM, 2003)*	Established a high-quality and targeted database of water quality and flow information throughout the watershed
	8	Develop Water Quality Sampling Program – Bacteria, Nutrients, and Nutrient Impacts	Approved *Field Sampling Plan (CDM, 2003)*	
	9	Develop Quality Assurance Project Plan (QAPP)	Approved *Quality Assurance Project Plan* (CDM, 2003)	
	10	Water Quality Sampling and Flow Monitoring – 6 surveys of the river and its key tributaries during dry and wet weather	*Field Monitoring Report (CDM, 2006)* *Electronic Database of Field Data*	
Step 2b: Forecast	6	Screening Level Model – Low resolution screening tool to estimate relative annual pollutant loads	*Screening Model Report (CDM, 2003)*	Provided predictive tools for identifying key pollution sources and evaluating alternatives for abatement quantitatively
	4	Develop a detailed modeling plan	*Modeling Methodology Report (CDM, 2003)*	
	11	Develop dynamic simulation models: Hydrology, watershed loads, hydraulic routing, and instream water quality	*Simulation Model Development Report (CDM, 2005)*	
Step 3: Formulation	13	Plan Formulation: Develop a comprehensive list of planned abatement projects, including future alternatives.	Memorandum dated June 28, 2005	Identify planned improvements and develop metrics for river improvements
	Integrated	Stakeholder Workshop to identify planning objectives and key performance measures	Summary memorandum dated June 17, 2004	
Step 4: Evaluation	12	River Analysis with Simulation Models: Simulate incremental pollutant reductions for point sources and nonpoint sources and planned abatement projects.	Results included in Phase I Report (this report)	Associate pollution abatement plans with quantitative improvements in the river.
Step 5: Comparison	14	Alternatives Analysis: Associate costs with abatement plans and their simulated river improvements.	Results included in Phase I Report (this report)	Understand the value of dollars spent on pollution abatement in terms of quantitative river improvements.
Step 6: Select Recommended Plan	19	A recommended plan for the Merrimack River Watershed is the responsibility of local, state, and federal agencies responsible for the uses and regulation of the Merrimack River and its tributaries. A recommended plan is not included in this report.		

In Step 1, the *Summary of Existing Conditions* reviews and discusses existing documentation on the Merrimack River watershed, including water quality, water quantity, dams and impoundments, sediment quality, biological resources and habitat, designated water uses and attainment, and limited discussion of pollution sources within the watershed. The report includes no new findings, but summarizes other documents issued primarily within the past ten years.

Several conclusions emerged from this review: Previous studies indicated that the four largest causes of non-support of designated uses in the basin are pollution from (1) urban runoff, (2) natural sources, (3) municipal point sources, and (4) combined sewer overflow (CSO) discharges.

This study also identified elevated bacteria levels as the primary cause of non-supporting use in the basin, followed by low dissolved oxygen concentrations and high nutrient levels. Other issues of concern include low-flow conditions, water supply, flooding, contamination of shellfishing beds, and fish and wildlife habitat and contamination issues.

The *Summary of Pollutant Sources* identified many of the current and potential pollutant sources in the watershed. This interim report did not attempt to quantify or rank their impact, but to summarize existing data, and to identify data needs. Much of the data collected in this task was collected via literature review, contact with communities, or from state and national sources (e.g. NPDES database, US Census). Other information was collected via field work; e.g. river bank erosion and storm drain locations. This interim report described the following pollutant sources:

- Combined Sewer Overflows (CSOs) in the five sponsor communities of Manchester and Nashua, New Hampshire; Lowell and Haverhill, Massachusetts; and the Greater Lawrence Sanitary District (GLSD), Massachusetts
- Stormdrain outfalls in 22 communities along the mainstem Merrimack River downstream of Hooksett, New Hampshire
- Quantity and quality of discharges from municipal and privately-owned treatment plants and industrial point sources along the Merrimack River
- Other sources of pollutants, including sediments, air deposition, groundwater plumes from landfills, erosion along streambanks, areas with failing septic systems, pump station overflows, and illicit wastewater discharges to stormdrains
- Tributary sources, including storm drains, point sources, septic systems etc.

Work under Step 2a, Inventory, began the collection of watershed data that was used for analysis and decision-making, including an extensive water quality sampling/monitoring program.

Water quality and streamflow data collected under this task were instrumental in the calibration and validation of water quality and hydrologic/hydraulic models. The field data also helped to determine whether segments of the mainstem Merrimack River are likely meeting state water quality standards.

The monitoring area encompassed the mainstem of the Merrimack River from Concord, New Hampshire to its estuary in Newburyport, Massachusetts, and also included the mouths of eleven major tributaries adjoining the mainstem. Forty-two sampling locations were strategically located in-stream to measure streamflow and concentration of pollutants such as bacteria and nutrients. Additionally, numerous stormdrain outfalls and combined sewer overflow (CSO) outfalls were sampled during wet-weather events to monitor contributing pollutant loads from urbanized areas.

From 2003–2005, three dry-weather surveys and four wet-weather surveys were conducted. Additionally, a continuous survey of dissolved oxygen and temperature was conducted at two locations for a one-month period during low-flow conditions in August and September 2003.

The monitoring work was conducted in accordance with a Q*uality Assurance Project Plan* (QAPP) developed in conjunction with Massachusetts DEP and New Hampshire DES, and approved by the USACE and USEPA.

The following conclusions were drawn from the water-quality surveys:

- The mainstem of the river from Manchester to the Atlantic Ocean is impaired with respect to bacteria standards, although many reaches exhibit satisfactory bacteria levels during dry weather.

- Many of the tributaries are impaired with respect to bacteria standards, as measured upstream of combined sewer outfalls.

- The mainstem of the river from Manchester to the Atlantic Ocean is not impaired with respect to dissolved oxygen standards. Measured and simulated concentrations of dissolved oxygen were always well above the regulatory threshold of 5 mg/l.

- While currently there are no regulatory requirements for nutrient levels in riverine waters, 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. Mainstem concentrations of nitrogen and phosphorus exhibited a wide range that is generally thought to be acceptable.

- Levels of chlorophyll-a, another indicator of organic productivity in the water, were generally not excessive in the New Hampshire reaches of the river. Levels in the mainstem downstream of Lowell ranged as high as 42 µg/L under 7Q10 conditions. Despite these high levels of Chlorophyll-a, no impairment of dissolved oxygen were found, indicating that the river can support high levels of algae growth.

Modeling

In Step 2b, Plan Formulation, a suite of hydrologic, hydraulic, and water quality models were developed as tools to assist in evaluating and comparing watershed management strategies and in prioritizing potential improvements in the watershed. The goals of the modeling effort were to:

- Simulate the generation of pollutant loads (primarily bacteria and nutrients) throughout the watershed, both from point sources and nonpoint sources.
- Simulate the water quality and flow regimes in the mainstem Merrimack River under dry weather and wet weather conditions.
- Simulate the dynamic nature of storm events as well as seasonal patterns and their effect on water quality and hydraulic conditions in the mainstem Merrimack River.
- Calibrate the models to observed measurements from the comprehensive field monitoring program executed under Task 4 of this Watershed Assessment Study, and to USGS flow records. Figure ES-2 illustrates examples of model calibration graphs. Full sets of calibration results are included in the Interim Report for Task 6: *Simulation Model Development.*

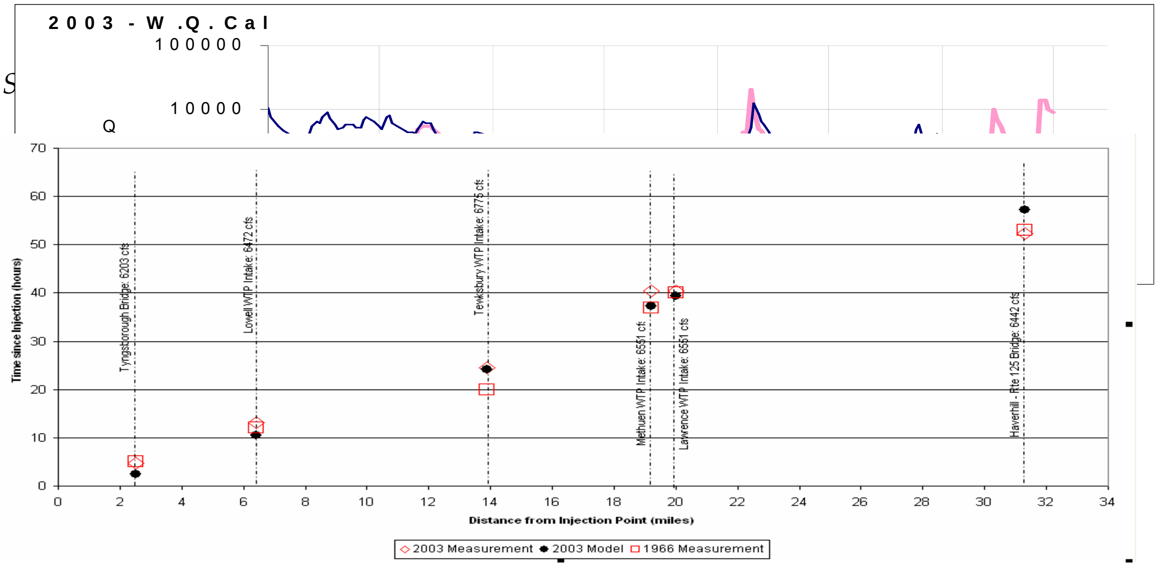
These goals were achieved by combining the strengths of several different public domain models. Existing models of combined sewer systems developed in USEPA Storm-Water Management Model (SWMM) and MOUSE for each of the five major CSO communities in the basin were incorporated.

The Hydrologic Simulation Program – Fortran (HSPF) was used to model the remainder of the watershed hydrology, including all major tributaries, as well as non-point source loads for the basin. The CSO and HSPF flow inputs were entered into the EXTRAN block of the SWMM model, which simulated the hydraulic routing and dynamics of the mainstem Merrimack River.

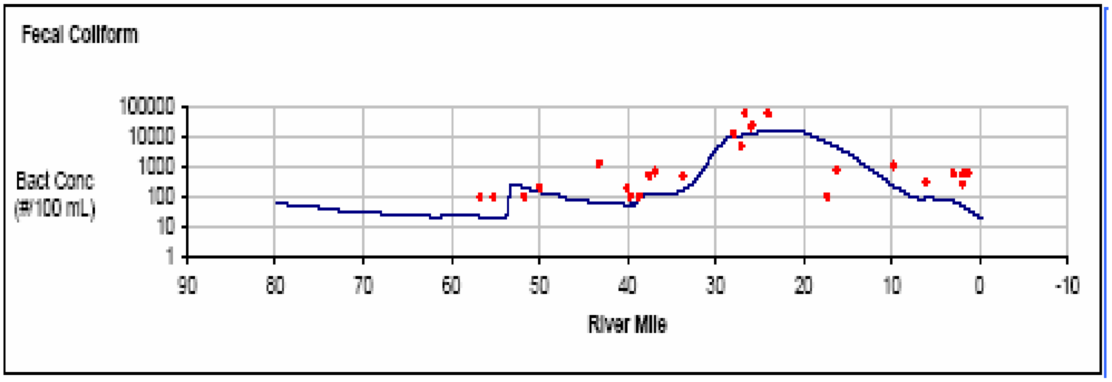
The Water Quality Simulation Program (WASP) was used to simulate dynamic concentrations of bacteria, nutrients, dissolved oxygen, chlorophyll-a, and BOD in the river.

Prior to being used in a predictive mode, the models were compared to measured data to first calibrate and then verify that they were accurately simulating real conditions in the river. Hydrologic flow from the HSPF model was calibrated to USGS flow records throughout the basin. Watershed loads, predominantly evidenced as mass loading into the mainstem via the tributaries, were calibrated to observed tributary loads from the dry and wet weather monitoring conducted under Task 4 of this watershed assessment study.

Hydraulic routing characteristics in the mainstem were compared to travel time measurements obtained under Task 3 of this watershed assessment study, and to additional measurements conducted by the USGS in Massachusetts and New Hampshire, and federal measurements of travel times in the river from earlier studies. Finally, instream water quality responses were calibrated to observed concentrations of pollutants obtained from the dry and wet weather monitoring conducted under Task 4 of this watershed assessment study.



Sample verification plot of travel times in the mainstem Merrimack River (See Section 4.0)



Sample calibration plot of bacteria concentrations in the Merrimack River

Figure ES–2: Sample Watershed Simulation Model Calibration Plots

In Step 4, a series of abatement strategies in Step 3, were evaluated in terms of their ability to bring about improvements to the river. Potential projects were identified in consultation with stakeholders in Step 3. The stakeholders included representatives from the following agencies:

- United States Army Corps of Engineers, New England District
- Sponsor Communities
- United States Environmental Protection Agency
- Massachusetts Department of Environmental Protection
- New Hampshire Department of Environmental Services
- United States Geological Survey
- Merrimack Valley Planning Commission
- Merrimack River Watershed Council

Furthermore, metrics by which "river improvements" are to be judged were determined with stakeholder input in Step 3.

The four key metrics of potential river improvements were: (1) River segments & duration below state thresholds or EPA guidance limits for bacterial indicators in the context of recreational uses of the river; (2) River segments/duration above state thresholds for dissolved oxygen in the context of aquatic habitat as a beneficial use; (3) Flux of bacteria into the estuary; and (4) Flux of nitrogen into the estuary.

Table ES–2 lists the alternatives selected for modeling and evaluation, briefly discusses the reason that each alternative was included in this study, and why certain alternatives were combined:

Table ES–2: Scenarios simulated with the Merrimack watershed model

Scenario Code	Scenario Description	Details	Reason for Selection
6A	Phase I CSO Control Plan: **Manchester**	• WWTP upgraded to 70 mgd • Elimination of CSOs discharging to Piscataquog • Elimination of CSOs at Victoria St, Crescent Rd, Poor St, and Schiller Rd.	Ongoing programs in accordance with EPA consent agreements – selected in order to understand quantitative benefits to be expected. These alternatives are combined into #6F because all communities are expected to complete Phase I programs.
6B	Phase I CSO Control Plan: **Nashua**	• WWTP upgraded to 110 mgd • Upgraded and/or separated CSOs 001, 002, 003, 004, 005	
6C	Phase I CSO Control Plan: **Lowell**	• WWTP upgraded to 110 mgd • Improved grit and diversion facilities • Partial sewer separation: Sixth/ Emory Ave, Gorham St, Warren St.	
6D	Phase I CSO Control Plan: **GLSD**	• Improved grit removal and screening • Increased secondary treatment capacity • Secondary bypass/disinfection facilities • 10-acre disconnecton at Honeywell site • Separation along Broadway	
6E	Phase I CSO Control Plan: **Haverhill**	• Improved primary treatment • Improved grit removal • WWTP upgraded to 60 mgd • Numerous overflow weirs raised • Essex and Lafayette CSOs closed • Siphon gates remain open during storms	
6F	All Phase I CSO Control Plans	All 5 communities simulated with Phase I CSO improvements listed in 6A – 6E	
7A1	Long-Term CSO Control Alternatives: **Manchester**	• Screening/Disinfection of remaining CSOs to 4 OF/year level (Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge.) • Use 3-month design storms for sizing	Alternatives for Manchester subsequent to Phase I CSO Control
7A2		• Full separation of remaining CSOs	
7A3		• Storage to 3-month level at Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge. • Use design storms for sizing	
7A4		• Storage to 6-month level at Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge. • Use design storms for sizing	
7B1	Long-Term CSO Control Alternatives: **Nashua**	• Full Separation	Alternatives for Nashua subsequent to Phase I CSO Control
7B2		• Screening/Disinfection at E. Hollis/Burke St (49.4 MGD peak capacity) • 40,000 Gallon storage at Farmington Road CSO • 10,000 Gallon storage at Burke Street CSO	
7C1	Long-Term CSO Control Alternatives: **Lowell**	• Separation of Warren Street (Area A, ~757 ac) • WWTP upgrade (to 150 MGD) • Beaver Brook – Pipeline storage • Tilden Street – $6 million partial storage • Merrimack – Separate 110 acres	Alternatives for Lowell subsequent to Phase I CSO Control
7C2		• Storage of remaining Warren St area (Area B- ~727 ac and Area C- ~542 ac) • WWTP upgrade (to 150 MGD)	

Scenario Code	Scenario Description	Details	Reason for Selection
		• Beaver Brook – Pipeline storage • Tilden Street – $6 million partial storage • Merrimack – Separate 110 acres	
7D1	Long-Term CSO Control Alternatives: **GLSD**	• Do Nothing	Alternatives for GLSD subsequent to Phase I CSO Control
7D2		• Expand WWTP to 165 MGD	
7D3		• Partial separation to 3-month level of control	
7D4		• Satellite storage facilities, 0.245 mg at CSO 002 and 3.39 mg at CSO 004 (Table 7-10, LTCP)	
7E1	Long-Term CSO Control Alternatives: **Haverhill**	• Do Nothing	Alternatives for Haverhill subsequent to Phase I CSO Control
7E2		• 7.8 MGD (0.2 acre) Treatment facility at Bradford Ave (3 Month Control Level) • 9.1 MGD (0.45 acre) treatment facility at Little River (3 Month Control Level)	
7F	All Communities: Representative Long-Term CSO Alternatives	Combination of Scenarios 7A3, 7B2, 7C2, 7D2, 7E2, implemented together	Combination of most likely long-term control plans
8	Full CSO Separation	All combined sewer systems simulated as fully separated	Basis of comparison to specific options
9A	NPS Reduction Only	Bacteria concentrations in stormwater throughout watershed reduced by approximately 20%. Also, background concentrations of fecal coliform in extremely polluted tributaries (Salmon Brook, Spickett River, Shawsheen River) reduced to 5,000 counts per 100 ml.	Understand the quantitative impacts of nonpoint source pollution abatement by itself and in conjunction with CSO abatement to see if a balanced approach is warranted

The following conclusions were drawn from the analysis of alternative scenarios:

- Phase I and Long-Term CSO improvements, including partial separation, storage, increased treatment capacity, etc. will reduce the frequency, magnitude, and duration of overflows, but will not significantly improve compliance with bacterial water quality standards. This is because overflow events taken as a whole occur for a very small percentage of the time in any given year. The remainder of the time, the river system is dominated by stormwater and background concentrations that often exceed bacteria standards. The river would still be significantly impaired after all the Long-Term CSO plans are implemented.

- Full Separation of combined sewers would offer very little improvement in river water quality for the same reasons as stated above.

- Reasonable levels of nonpoint source control, as defined by approximately 20% reduction in all runoff concentrations and reduction of background concentrations in highly polluted tributaries to 5,000 org/100ml (still well above standard), will offer significant improvements in compliance with bacteria standards.

- Nonpoint Source (NPS) controls coupled with Phase I CSO controls may be sufficient to achieve compliance. In fact, the implementation of the nonpoint source reductions described above would actually increase the effectiveness of Phase I CSO controls by bringing the river closer to compliance and closing the gap that CSO abatement would need to bridge. Model results suggest that under normal hydrologic conditions, the river would be fully compliant with bacteria standards with the suggested nonpoint source reductions and Phase I CSO abatement. During abnormally dry and wet years, there may still be small isolated reaches that do not fully comply.

- Long-Term CSO abatement offers very little additional improvement in compliance when compared to either Phase I abatement alone or to Phase I abatement AND nonpoint source reductions. There are very few appreciable instream benefits of Long-Term CSO control plans beyond the Phase I programs already in progress, whether or not such plans are coupled with nonpoint source abatement. However, the long-term alternatives will reduce the occurrence of very high bacteria levels in the river, though these occur during a total of just a few days during each year.

- By far, the greatest value in abatement dollars can be realized with nonpoint source abatement and Phase I CSO controls. Phase II CSO offers much lower value. In this case, value is measured in terms of river miles or days of compliance that can be achieved for every million dollars spent. Results suggest that a balanced watershed management plan that includes modest CSO abatement coupled with reasonable levels of nonpoint source reduction should form the basis of watershed management decisions in the Merrimack Basin. A balanced approach includes:

    - Phase I CSO plans,

    - 20% reduction in bacteria concentrations in runoff, and

    - Reducing background levels of bacteria in highly polluted tributaries to 5,000 org/100ml

  Using the metric of miles of river brought into compliance per million dollars spent, this approach is approximately 4 times more cost-effective than Long-Term CSO control plans. Results also suggest that such a balanced strategy would be 8 times more cost-effective than full CSO separation using this same metric. In addition to being more cost-effective, the balanced approach would offer significantly more benefits than CSO abatement alone, and would result in a river that would likely comply with water quality standards under most conditions.

Ecological Opportunities

Ecological restoration opportunities have been organized into six categories. These are: fisheries/aquatic species, water quality, soils/erosion control, terrestrial rare species and wetlands, marine/estuarine, and riparian resources. A survey of published plans and local contacts revealed many projects in each of the categories. Section 5 lists many specific examples, a summary of which is included below.

- Fisheries/aquatic species—Opportunities exist to enhance the health of fish and other aquatic species by improving their habitat. This include activities such as streambed enhancement or naturalization, riparian habitat improvement, upstream and downstream fish passage improvement, provision of adequate stream flow, and mitigation of temperature changes.

- Water quality—Nonpoint source water quality problems exist throughout the watershed and contribute to degraded water quality on the mainstem of the Merrimack and the major tributaries. These watershed-wide water-quality issues are primarily the result of a combination of increased development and agricultural practices.

  Implementation of best management practices (BMPs) for the control of nonpoint source pollution throughout the watershed (both urban and agricultural) as well as maintenance of existing BMPs is critical to the ultimate success of nonpoint source control. Development using low impact development (LID) techniques also has the potential to minimize development impacts on water quality.

  In addition, wetlands are important buffers against upland non-point pollutant sources by filtering and cleansing runoff before it reaches a surface water body. Wetland protection, creation or restoration can also improve water quality in the river.

- Soils/erosion control— Erosion in the Merrimack watershed can be split into two general categories: (1) Loss of topsoil in the watershed due to disturbances such as site development and transportation projects; and (2) river shoreline or bank erosion. Both types of erosion can significantly alter the water quality and ecology of receiving waters by adding nutrients, covering critical aquatic habitat, filling wetlands and impounded areas and reducing water clarity.

  The restoration of riverbanks to reduce the contribution of sediment and their associated nutrients to the Merrimack River could be accomplished using a phased approach. Section 5.The first phase, identification of eroding banks, has been partly completed and is summarized in

  The second phase would be to prioritize the riverbanks based on the risk posed to important infrastructure (bridges, roads, houses and utilities) and aquatic/riparian habitat. In the third phase the sites identified as being high priority would be surveyed in more detail so that conceptual restoration designs could be prepared. The advantages of bioengineering techniques are discussed, and should be given consideration during conceptual design.

- Terrestrial rare species and wetlands—Protection/enhancement of rare or declining non-game species and communities can best be achieved through enhancement, restoration and protection of targeted habitats. These include habitat for the New England cottontail rabbit (*Sylvilagus transitionalis*), brook floater mussel (*Alasmidonta varicosa*), eastern hognose snake (*Heterodon platyrhinos*), and Blanding's turtle (*Emydoidea blandingii*), as well as pine barrens and forested floodplain communities.

- Marine/estuarine—The estuary may be among the most vulnerable resources in the Merrimack; its downstream location means it receives the cumulative impact of all activities in the watershed. Impacts to the estuary result from nutrient and bacteria loading, sedimentation, shoreline erosion. These effects have resulted in changes in populations of anadromous and catadromous fish species. Marine and estuarine opportunities include restoration of critical habitats such as eelgrass and salt marsh, as well as restoration of soft-shell clam harvesting areas.

- Riparian resources—The riparian zone provides habitat for a number of plant and animal species, and provides a critical buffer which can minimize the impact of activities on the land. Development near the river is often desirable; the challenge is to do it in a manner that showcases the river while preserving natural functions of the riparian zone and supporting the species that depend upon it. Potential projects include converting old rail lines to greenway trails, reducing paved area in the riparian zone, and providing buffer zones and conservation easements.

Section 1
Study Authority

1.1 Background

The cities of Manchester and Nashua, New Hampshire, the Cities of Lowell and Haverhill, Massachusetts, and the Greater Lawrence Sanitary District (GLSD), Massachusetts, are currently working separately to develop and implement long-term Combined Sewer Overflow (CSO) control plans in compliance with the Federal Clean Water Act. The collective cost of these potential CSO improvements may exceed 500 million dollars over the next 20 years. Given this sizable investment, the communities are concerned that decisions regarding the potential mitigation measures are being made without adequate understanding of the existing conditions in the Merrimack River, the pollution sources to the River, and the potential benefits of the proposed CSO improvements.

1.2 Study Authority

The Federal government, through the United States Army Corps of Engineers (USACE), is providing 50 percent of the cost share for the Merrimack River Watershed Assessment Study (hereafter referred to as the "Study"), as well as technical assistance. Involvement of the USACE is authorized under Section 729 of the Water Resources Development Act (WRDA) of 1986 entitled "Study of Water Resources Needs of River Basins and Regions" as amended by Section 202 of WRDA 2000. This report was prepared in response to specific language contained in Section 437 of WRDA 2000 that directed the USACE to conduct a comprehensive study of the water resource needs of the Merrimack River basin in Massachusetts (MA) and New Hampshire (NH).

Directed funds for this effort were provided to the USACE by Congress in the fiscal year 2001 and 2002 Energy and Water Development Appropriation. The City of Lowell, Massachusetts, serving as the local sponsor of this project, entered into a Memorandum of Understanding with the four other communities in the watershed (Haverhill and GLSD, Massachusetts; Manchester and Nashua, New Hampshire) to provide the remaining financial support for the Study.

1.3 Consultant Project Team

The primary consultant for this study was CDM. Numerous subconsultants and firms assisted during the course of the study:

- Normandeau Associates, Incorporated: Conducted hydraulic surveys of the river, conducted an erosions survey of the river, helped orchestrate and conduct the water quality surveys of the river, and conducted an assessment of ecological restoration opportunities in the watershed.

- Northern Ecological Associates, Inc.: Helped orchestrate and conduct the water quality surveys of the river.

- AMRO Environmental Laboratories Corporation: Conducted laboratory analysis of non-biological water quality constituents.

- Aquatec Biological Sciences: Conducted laboratory analysis of biological water quality constituents.

Section 2
Study Purpose and Scope

2.1 Background

The Merrimack River Watershed encompasses approximately 14,000 square kilometers (approximately 5,000 square miles), originating in Northern New Hampshire and discharging into the Atlantic Ocean in Newburyport, Massachusetts. The river and its associated canals and tributaries helped fuel the industrial revolution in the 1800s, and today the river system supports a variety of designated uses, including water supply, recreation, aquatic habitat, and hydropower. Although the watershed is heavily forested (approximately 75% of the land area is covered with forest), its southern region is characterized by five major urban/industrial cities along the river: Manchester NH, Nashua NH, Lowell MA, Lawrence MA (Greater Lawrence Sanitary District, GLSD), and Haverhill MA.

Many reaches of the river are listed on NH and MA 303(d) lists for violations of bacterial water quality standards. The five communities, each of which are serviced by aging combined sewer systems, have signed individual consent agreements with the United States Environmental Protection Agency and their respective states to commit large sums of money to the abatement of combined sewer overflows (CSOs), in accordance with the federal Clean Water Act. In accordance with the consent agreements, each community is in various stages of development and implementation of CSO Long-Term Control Plans (LTCPs). Since enforcement protocols are specific to individual communities, these plans are being developed in isolation from the rest of the watershed, and from the other CSO communities along the mainstem. Collectively, these communities may need to spend up to $500 million on CSO control alone to comply with EPA mandates, and there is insufficient information regarding the benefits to be achieved.

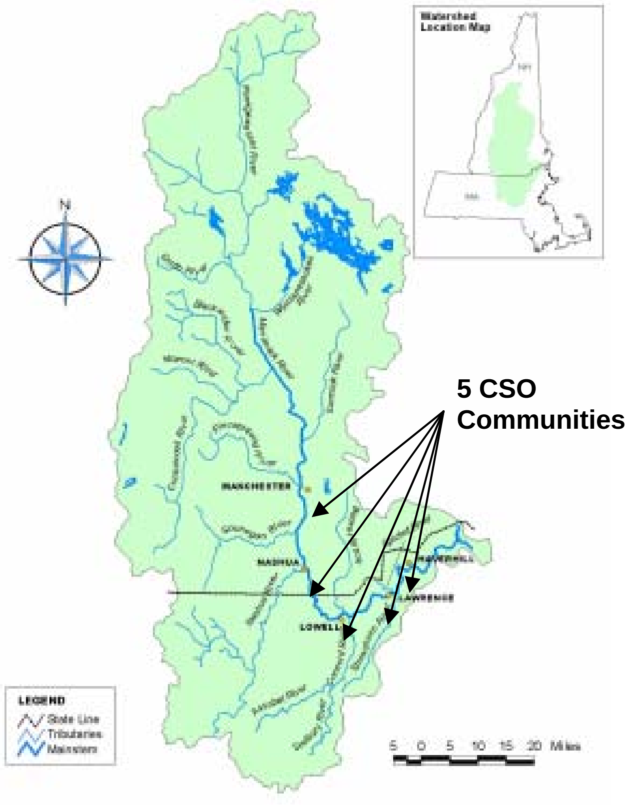


Figure 2-1: Merrimack Watershed

This study was initiated in order to add clarity to the expected benefits that could be achieved from various watershed management strategies (including CSO abatement plans, nonpoint source abatement plans, and blended plans), as measured by improvements in river conditions. The underlying principle is that such information is necessary in order to evaluate and compare the value of dollars spent on both point source and nonpoint source abatement.

2.2 Purpose

The overall purpose of the Merrimack River Watershed Assessment Study is to develop a comprehensive Watershed Management Plan. The Plan will be used to guide investments in the environmental resources and infrastructure of the basin and will be aimed at achieving water quality and flow conditions that support beneficial uses, including water supply, recreation, hydropower, fisheries, and other ecological habitat. The Plan will encompass the diverse interests and goals of the various partners and stakeholders throughout the Merrimack River watershed, including state, local, and Federal governments, industry, and environmental groups.

2.3 Watershed Overview

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; it turns abruptly across the New Hampshire - Massachusetts border and flows 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 Merrimack River watershed covers an area of approximately 5,000 square miles in New Hampshire (76-percent of the drainage area) and the northeastern portion of Massachusetts (24-percent of the drainage area), making it the fourth largest watershed in New England. It encompasses a variety of terrain and climate conditions, from the mountainous White Mountain region in northern New Hampshire to the estuarine coastal basin of northeastern Massachusetts. Precipitation in the watershed is fairly evenly distributed throughout the year. There are, however, large inter-basin variations in the amount and type of precipitation (*i.e.* rain versus snow) primarily as a result of the effects of terrain, elevation, latitude, and proximity to the ocean (Flanagan *et al.* 1999). Temperatures in the basin generally vary widely on an annual basis. Based on a review of climate data, July is typically found to be the warmest month and January is generally the coldest.

A mix of deciduous and evergreen forest, covering approximately 77 percent of the watershed area, dominates the land use in the basin. Urban areas, including residential, industrial, commercial and commercial land uses, make up the second largest land use category, covering approximately 10 percent of the total watershed area.

The U.S. Geological Survey (USGS) currently operates two gaging stations on the mainstem Merrimack River at (1) Merrimack River near Goffs Falls, below Manchester, New Hampshire and (2) Merrimack River below Concord River at Lowell, Massachusetts. Numerous other gaging stations currently exist on major tributaries to the Merrimack River. A review of the monthly discharge statistics on the mainstem reveals that the highest average and most variable flows generally occur during the month of April; the lowest and least variable flows generally occur during the late summer (August and September).

Numerous hydropower dams on the mainstem Merrimack River and its major tributaries significantly impact the daily, weekly, and monthly streamflow conditions. During high flow conditions, the hydropower facilities generally operate under "run of the river" conditions, with substantial spillage. During periods of low flow, the dams are required to pass a minimum flow, while still operating to meet peak demands. This often results in short-term water level fluctuations during summer months.

2.4 Scope of Watershed Assessment and Focus of Phase I Study

The assessment includes a water resources and ecosystem restoration investigation of the Merrimack River and can be used to answer the following questions:

1. What are the existing and potential future beneficial uses of the Merrimack River?

2. What are the impacts of pollutants on the Merrimack River mainstem with respect to state water quality standard and therefore the designated uses of water supply, recreation, and aquatic habitat?

3. What is the relative contribution of pollutants from various sources?

4. What watershed management strategies will provide the most significant return on investment?

The assessment study is divided into two phases, the current Phase I which has been completed and future phases to be completed at a later date. The general purpose of each phase is discussed below.

Phase I (Funded and Complete): The primary purpose of Phase I was to identify the relative causes and impacts of pollution problems in the Merrimack River basin, and to understand the expected instream improvements associated with various abatement strategies. This was accomplished through characterization, field surveys, laboratory analysis, dynamic simulation modeling, and planning-level cost comparisons of abatement strategies. Scenarios providing the most significant return on investments were identified. The output from Phase I, summarized in this report, should help decision-makers to understand the relative contributions of pollutants from various sources and the basin-wide impacts of these pollutants. This information can be used to guide decisions about how best to direct funding to yield the greatest overall benefits with respect to the designated uses of the river.

Future Phases: Future phases will build on the results from Phase I, and may potentially include further investigation of specific tributaries or the northern reaches of the Mainstem Merrimack. Additionally, it is expected that a detailed cost-benefit analysis will be conducted during these future phases to evaluate a wide array of possible abatement, control, and restoration initiatives, building upon the scenarios identified during Phase I. The simulation modeling and planning-level alternatives analysis performed during Phase I may serve as the basis for the development of optimization models during later phases of the project. The optimization models may help to identify potential alternatives that are both economically and environmentally preferable. Section 5 of this report includes discussion of ecosystem restoration opportunities that may also be included in future work. Ultimately, the output from subsequent phases will be a prioritized list of recommended investments throughout the Merrimack River watershed aimed at improving beneficial uses and restoring ecosystems.

2.5 Establishment of Watershed Partnership (Federal, State, Local Interest)

The communities and sanitary district formed the Merrimack River Basin Community Coalition to promote a concerted, watershed-wide assessment to help ensure that the money spent on pollution abatement and restoration would be targeted at *all* major contributing sources and that investments would yield scientifically defensible and economically efficient environmental benefits. These communities advocate an interpretation of the CWA that is based on achieving the greatest improvement in water quality and beneficial use attainment throughout the watershed (as outlined in a white paper published by Costa, *et al*, 1999, which is available through the New England District of the Corps of Engineers).

Through the legislative process, the communities were able to enlist the help of the U.S. Army Corps of Engineers for watershed planning efforts. In the Water Resources Development Act (WRDA) of 2000, Section 437 directed the Corps to conduct a study of the comprehensive water resources needs of the Merrimack River Basin in Massachusetts and New Hampshire in accordance with Corps Section 729 watershed study authority per WRDA of 1986. This watershed authority allows the Corps to conduct progressive multi-objective planning, driven primarily by the need to restore ecosystems.

The study, as discussed below, is structured around the concept that a holistic approach is needed for water resources management and restoration. The following three basic tenets were developed:

1. Pollution abatement should not be limited to local enforcement, as this results in only partial accounting of pollution sources and the causal mechanisms within a watershed.
2. Pollution abatement investments should only be made when expected environmental benefits can be well defined, measurable, and prioritized.
3. Pollution abatement should be a cooperative process, with local, state, and federal authorities working to ensure the best allocation of financial resources to protect the nation's natural resources.

This watershed assessment, therefore, was aimed at determining the *relative* instream impacts attributable to CSOs and to other sources, and how watershed restoration can be balanced such that investments in CSOs, WWTP technology, septic system rehabilitation, illicit connection detection and abatement, stormwater controls, and general nonpoint source reduction are commensurate with expected improvements.

Section 3
Overview of Prior Studies and Reports

Numerous studies and reports have been completed regarding the water quantity and quality in the Merrimack River to date. The reports listed below were useful in establishing and understanding baseline conditions in the Merrimack Watershed. However, review of these reports confirmed that while many agencies had studied specific areas of water quality, there was a lack of a comprehensive water quality and abatement study for the Merrimack Watershed. This study was initiated to help fill that void.

<u>A Massachusetts Merrimack River Water Supply Protection Initiative. Publication #16,325</u>. Prepared by: Executive Office of Environmental Affairs (EOEA), Massachusetts Department of Environmental Protection (MADEP), Division of Water Pollution Control (DWPC). April 1990.

<u>A Study of the Marine Resources of the Merrimack River Estuary. Monograph Series Number 1. Publication #3000-6-65-940885</u>. Prepared by: Massachusetts Department of Natural Resources, Division of Marine Fisheries. June 1965.

<u>Assessment of Unassessed Waters in the Merrimack Basin Using Rapid Biological Monitoring. Publication #16,907-92-25-7-91-C.R</u>. Prepared by: Massachusetts Department of Environmental Protection (MADEP), Division of Water Pollution Control, Technical Services Branch. November 1990.

<u>Commonwealth of Massachusetts Summary of Water Quality - 2000</u>. Prepared by: Executive Office of Environmental Affairs (EOEA), Massachusetts Department of Environmental Protection (MADEP), Bureau of Resource Protection, Division of Watershed Management. July 2000.

<u>Commonwealth of Massachusetts Summary of Water Quality - 1992. Appendix I – Basin/Segment Information</u>. Prepared by: Massachusetts Department of Environmental Protection (MADEP), Division of Water Pollution Control. February 1993.

<u>Merrimack River Corridor Management Plan for the Communities of Hudson, Litchfield, Merrimack and Nashua</u>. Prepared by: Nashua Regional Planning Commission. September 1989.

<u>Merrimack River Initiative – Watershed Connections. A Preliminary Water Quality Assessment for the Merrimack River Watershed</u>. Prepared by: Merrimack River Watershed Council, Clean Waters Program. December 1994.

<u>Merrimack River Initiative – Watershed Connections. Merrimack River Bi-State Biomonitoring Report. Part Two</u>. Prepared by: NH Department of

Environmental Services, MA Department of Environmental Protection, and the US Environmental Protection Agency. November 1996.

Merrimack River Wastewater Management: Key to a Clean River, Summary Report. Prepared by: New England Division of US Army Corps of Engineers. November 1974.

Merrimack River Watershed – 2000 Assessment Report. Prepared for: Merrimack Watershed Team. Prepared by: Michelle Carley. June 2001.

The Merrimack River 1990: Water Quality Data, Wastewater Discharge Data, Drinking Water Treatment Plant Data, and Water Quality Analysis. Prepared by: Executive Office of Environmental Affairs (EOEA), Massachusetts Department of Environmental Protection (MADEP), Division of Water Pollution Control. March 1991.

Northeastern United States Water Supply Study: Merrimack River Basin Water Supply Study. Prepared by: US Army Corps of Engineers. January 1977.

Region I EPA-New England, Compendium of Quality Assurance Project Plan Requirements and Guidance. Prepared by: USEPA- New England, Region I. October 1999.

Report on Pollution of the Merrimack River and Certain Tributaries. Prepared by: Federal Water Pollution Control Administration. 1966.

State of New Hampshire 2000 Section 305(b) Water Quality Report. Prepared by: New Hampshire Department of Environmental Services (NHDES). 2000.

State of New Hampshire Methodology for 1998 – 303(d) List. Prepared by: New Hampshire Department of Environmental Services (NHDES). 1998.

Strategic Plan & Status Review: Anadromous Fish Restoration Program, Merrimack River. Prepared by: Technical Committee for Anadromous Fishery Management of the Merrimack River Basin & Advisors to the Technical Committee. October 1997.

Travel Times and Dispersion of Soluble Dye in Thirteen New Hampshire Rivers. Prepared by the United States Geological Survey in cooperation with the New Hampshire Department of Environmental Services. USGS Open File Report 02-226. 2002.

Water Demand Analysis on the Merrimack River Watershed, Final Report. Prepared by: Merrimack River Watershed Council. October 2002.

Section 4
Study Methodology

4.1 Implementing the Corps Six-Step Planning Process

The study was divided into numerous tasks and task orders that were generally structured around the six-step Corps planning process, as outlined in Table 4-1. While many of the tasks were aggregated into larger task orders, the reference numbers below represent the original task designations in the Project Study Plan (PSP). Some of the original tasks in the PSP were omitted from the eventual project due to funding limitations. Others that do not appear in Table 4-1 were reserved for management, reporting, and oversight of the project.

Table 4-1: Implementing the Study with the Corps Six-Step Planning Process

Corps Planning Step	Task ID # per PSP	Task Description	Deliverables*	Utility of Study Output
Step 1: Problem Identification and Opportunities	1	Summarize Existing Conditions (hydrology, climate, water quality, land uses, regulations)	*Summary of Existing Conditions (CDM, 2003)*	Identified baseline causes and impacts of pollution throughout watershed
	2	Summarize Current Water Uses	Included in Existing Conditions Report	
	3	Summarize Pollution Sources (point and nonpoint) throughout the watershed	*Summary of Pollution Sources Report (CDM, 2003)*	
Step 2a: Inventory	7	Hydrology and Hydraulics Survey of the Mainstem Merrimack River	*Hydrology and Hydraulics Report (CDM, 2003)*	Established a high-quality and targeted database of water quality and flow information throughout the watershed
	8	Develop Water Quality Sampling Program – Bacteria, Nutrients, and Nutrient Impacts	Approved *Field Sampling Plan (CDM, 2003)*	
	9	Develop Quality Assurance Project Plan (QAPP)	Approved *Quality Assurance Project Plan* (CDM, 2003)	
	10	Water Quality Sampling and Flow Monitoring – 6 surveys of the river and its key tributaries during dry and wet weather	• *Field Monitoring Report (CDM, 2006)* • *Electronic Database of Field Data*	
Step 2b: Forecast	6	Screening Level Model – Low resolution screening tool to estimate relative annual pollutant loads	*Screening Model Report (CDM, 2003)*	Provided predictive tools for identifying key pollution sources and evaluating alternatives for abatement quantitatively
	4	Develop a detailed modeling plan	*Modeling Methodology Report (CDM, 2003)*	
	11	Develop dynamic simulation models: Hydrology, watershed loads, hydraulic routing, and instream water quality	*Simulation Model Development Report (CDM, 2005)*	

Corps Planning Step	Task ID # per PSP	Task Description	Deliverables*	Utility of Study Output
Step 3: Formulation	13	Plan Formulation: Develop a comprehensive list of planned abatement projects, including future alternatives.	Memorandum dated June 28, 2005	Identify planned improvements and develop metrics for river improvements
	Integrated	Stakeholder Workshop to identify planning objectives and key performance measures	Summary memorandum dated June 17, 2004	
Step 4: Evaluation	12	River Analysis with Simulation Models: Simulate incremental pollutant reductions for point sources and nonpoint sources and planned abatement projects.	Results will be included in Final Report.	Associate pollution abatement plans with quantitative improvements in the river.
Step 5: Comparison	14	Alternatives Analysis: Associate costs with abatement plans and their simulated river improvements.	Results will be included in Final Report	Understand the value of dollars spent on pollution abatement in terms of quantitative river improvements.
Step 6: Select Recommended Plan	19	A recommended plan for the Merrimack River Watershed is the responsibility of local, state, and federal agencies responsible for the uses and regulation of the Merrimack River and its tributaries. A recommended plan is not included in this report.		

**See Section 9 for details on referenced reports.*

4.2 River Monitoring

In the last few decades, a number of agencies have collected water quality data from the Merrimack River; however, these efforts have generally been limited in scope or geographic extent. To date, no comprehensive database had been developed for the watershed that bounded specific pollution sources, included tributaries, and included bacteria, nutrients, and nutrient impacts. This type of database, comprehensive in its spatial extent, temporal variability, specificity of pollution sources, and broad inclusion of pollutants, is necessary to make confident decisions about watershed abatement. To fill this data void, a comprehensive monitoring program was developed to measure key water quality constituents in the river during wet weather and dry weather.

Key pollutants, including bacteria and nutrients, as well as their impacts (dissolved oxygen, chlorophyll-a) were measured at numerous locations during six surveys of the mainstem river and its major tributaries. Results were analyzed to help determine the source of pollutant loads from throughout the watershed as well as their impacts on the mainstem Merrimack River.

Three surveys were conducted in dry-weather conditions, and three were conducted during wet-weather conditions, during which the combined sewer systems in the basin were overflowing.

This section provides a brief summary of the goals, monitoring activities, and results. Detailed information on the monitoring program, its rationale, and its results are summarized in the following interim task reports (see Section 9 for further description of these reports):

- Summary of Information on Pollution Sources, January 2004
- Field Sampling Plan, May 2003
- Quality Assurance Project Plan (QAPP), May 2003
- Merrimack River Monitoring Report, May 2006

For the purposes of the field sampling program, the Study Area was identified as the mainstem Merrimack River south of Hooksett, New Hampshire to the estuary at the Atlantic Ocean (see Figure 4-1). This area includes the sponsor communities of Manchester and Nashua, New Hampshire, Lowell and Haverhill, Massachusetts, and the Greater Lawrence Sanitary District, Massachusetts. The final 22 miles of the mainstem Merrimack River in the Study Area downstream of Haverhill, Massachusetts are tidally influenced.

Four dams are located on the mainstem Merrimack River in the Study Area:

- Hooksett Dam in Hooksett, New Hampshire
- Amoskeag Dam in Manchester, New Hampshire
- Pawtucket Dam in Lowell, Massachusetts
- Essex Dam in Lawrence, Massachusetts

The Study Area also includes the confluence of the 11 major tributaries with the mainstem (Table 4-2 and Figure 4-1), many of which contribute to the pollutant load in the Merrimack River.

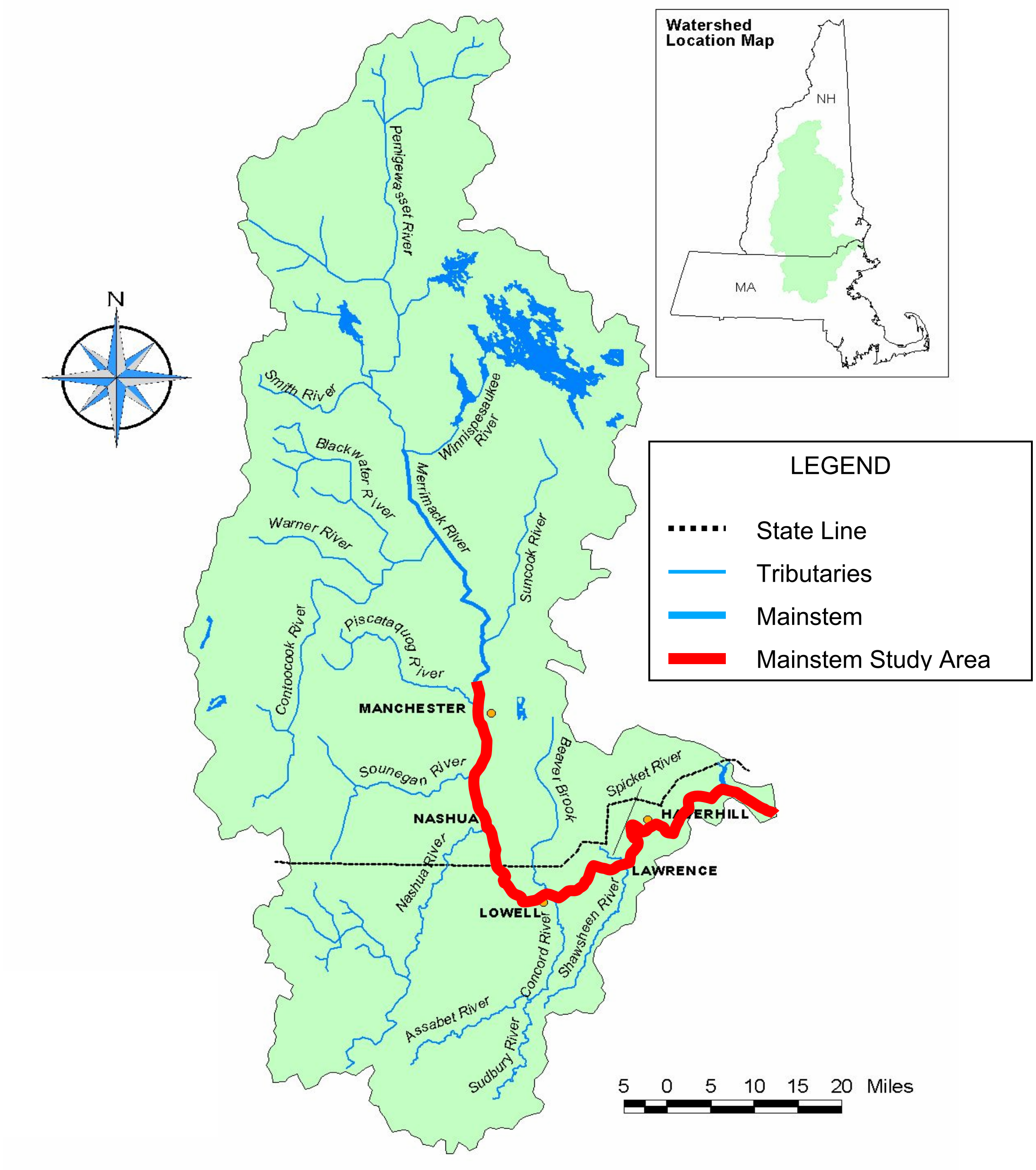


Figure 4-1: Major Tributaries to the Merrimack River

Table 4-2: Major tributaries to the mainstem Merrimack River downstream of Hooksett, New Hampshire

Location of Confluence	Major Tributary
Manchester, NH	Piscataquog River Cohas Brook
Merrimack, NH	Souhegan River
Nashua, NH	Nashua River Salmon River
Lowell, MA	Stony Brook Beaver Brook Concord River
Lawrence, MA	Shawsheen River Spicket River
Amesbury, MA	Powwow River

4.2.1 Goals of Monitoring Program

The following Data Quality Objectives were established for the sampling program:

- Collect water quality data to determine the relative likelihood that segments of the mainstem Merrimack River meet state water quality standards
- Collect water quality and streamflow data sufficient for the calibration and validation of water quality and hydrologic/hydraulic models to be developed under subsequent tasks of this study

Both of these goals were satisfied.

4.2.2 Development of Monitoring Plan with Sponsors and Regulatory Agencies

The monitoring program was developed cooperatively with the following organizations:

- US Army Corps of Engineers, New England District
- Merrimack River Basin Community Coalition
- United States Environmental Protection Agency – Region 1
- Massachusetts Department of Environmental Protection
- New Hampshire Department of Environmental Services

Collectively, these organizations functioned as a steering committee for the development of the monitoring program. Each organization attended planning meetings to formulate objectives for the monitoring program and to help develop a comprehensive logistics program, including locations of monitoring stations, analytes, sampling methods, and sampling frequency. The final versions of the Field Sampling Plan and Quality Assurance Project Plan were approved by the US Army Corps of Engineers, New England District and USEPA, and were also reviewed and signed by the other organizations.

One example of a key recommendation from this group was to composite multiple water samples for analysis of bacteria. At several river locations, composite samples were taken along the width of a river cross-section and compared to individual grab samples. Comparison of results indicated two key findings:

1) The river appears to be well mixed laterally.

2) Composite bacteria sampling produces reasonable estimates of average concentrations at individual sampling locations provided proper equipment and handling procedures are followed in the field.

These early findings helped streamline the sampling program, and were representative of the effective cooperation of the sponsors and regulatory agencies throughout this study.

4.2.3 Summary of Monitoring Activities

Monitoring sites were located along 80 miles of the Merrimack mainstem and at the confluences of 11 major tributaries. Sites were located strategically throughout the river system to bracket known sources of pollution:

- Upstream and downstream of the five CSO communities
- Upstream and downstream of wastewater treatment plants on the mainstem
- In designated recreational areas
- In potentially viable shellfish beds
- At representative CSO outfalls (end-of-pipe)
- At representative stormdrain outfalls (end-of-pipe)
- At the confluence of 11 major tributaries (upstream of all CSO outfalls)

Table 4-3 and Figure 4-3 through Figure 4-9 list and identify the locations of monitoring stations. Table 4-4 lists the analytes that were collected at each type of monitoring station. Brief descriptions of the weather conditions for each event are included in Section 4.2.3.1 and 4.2.3.2, and a summary of results follows in Section 4.2.4.

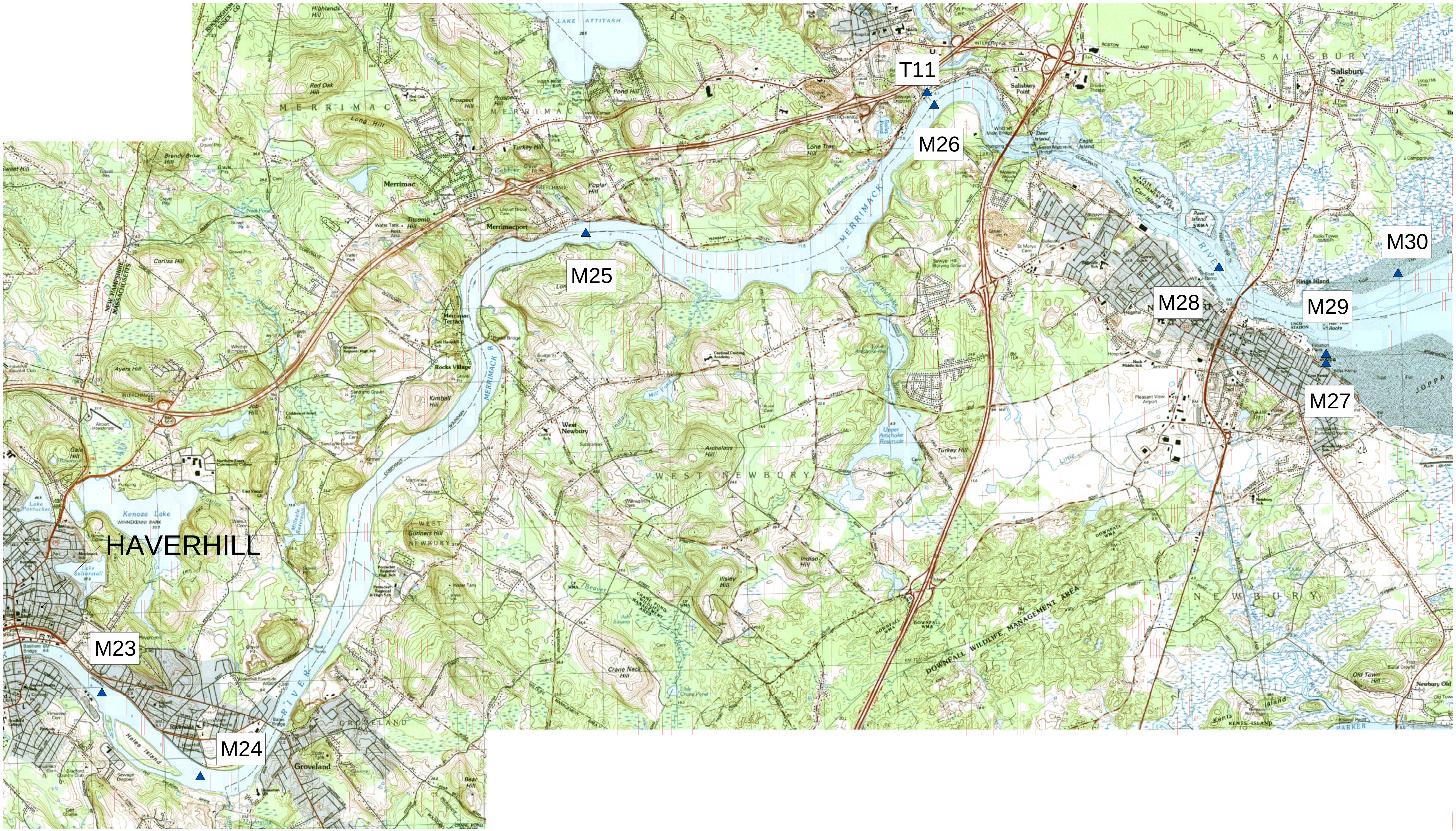
Table 4-3: Sampling Stations

Station No.			**Description**	**Type**		**Location**	**Access**		**GPS Coordinates**	
Main	***Trib***	***Pipe***		***Wet***	***Dry***		***Boat***	***Land***	***Latitude***	***Longitude***
C001			U/S Concord, NH	●	●	D/S of I-93 Pedistrian Bridge		●	43° 13' 45"	71° 32' 10"
C002			D/S Concord, NH	●	●	Manchester Street Bridge		●	43° 11' 35"	71° 31' 25"
M001			D/S Hooksett Dam	●	●	D/S of power plant at railroad bridge crossing	●		43° 05' 45"	71° 27' 50"
M002			U/S Amoskeag Dam	●	●	Float line U/S of Amoskeag Dam	●		43° 00' 16"	71° 28' 11"
M003			D/S Amoskeag Dam	●	●	Granite Street Bridge		●	42° 59' 07"	71° 28' 11"
	T001		Piscataquog River	●	●	Off Electric St. on U/S side of Pinard St. bridge pier		●	42° 59' 37"	71° 29' 43"
M004			D/S Manchester	●		USGS Gaging station at Goffs Falls	●		42° 56' 53"	71° 27' 50"
M005			Manchester WWTP	●	●	Railroad bridge at end of Depot Road		●	42° 56' 10"	71° 27' 23"
	T002		Cohas Brook	●	●	Rte 3A Bridge (U/S side)		●	42° 55' 19"	71° 27' 06"
M006			Derry WWTP outfall	●	●	300′ D/S of pipeline outfall	●		42° 53' 42"	71° 27' 35"
	T003		Souhegan River	●	●	200-300′ U/S of confluence	●		42° 51' 44"	71° 29' 18"
M007			Merrimack WWTP	●	●	300′ D/S of Merrimack WWTP outfall	●		42° 48' 35"	71° 28' 23"
M008			U/S Nashua	●		One mile D/S of Litchfield/Nashua Line	●		42° 47' 31"	71° 27' 28"
	T004		Nashua River	●	●	Footbridge at Lincoln Park		●	42° 45' 28"	71° 30' 03"
	T005		Salmon River	●	●	300′ U/S of confluence	●		42° 44' 56"	71° 26' 31"
M009			Nashua WWTP	●	●	300′ D/S of Nashua WWTP outfall	●		42° 44' 43"	71° 26' 26"
M010			D/S Nashua	●		300′ D/S of first bridge north of state line	●		42° 43' 17"	71° 26' 17"
M011			U/S Lowell	●	●	500′ D/S of Tyngs Island	●		42° 38' 56"	71° 23' 16"
	T006		Stony Brook	●	●	Middlesex Road bridge (D/S side)		●	42° 38' 17"	71° 22' 36"
M012			Lowell Public Beach	●	●	Adjacent to beach area	●		42° 38' 42"	71° 20' 16"
M013			U/S Pawtucket Dam	●	●	200 ' U/SFloat line U/S of Pawtucket Dam	●		42° 38' 55"	71° 19' 53"
M014			D/S Pawtucket Dam	●	●	Ouelette Bridge- Aiken Street		●	42° 39' 17"	71° 18' 55"
	T007		Beaver Brook	●	●	Parker Ave bridge (D/S side)		●	42° 40' 06"	71° 19' 35"
	T008		Concord River	●	●	Lawrence Street Bridge		●	42° 37' 40"	71° 17' 54"
M015			D/S Lowell	●	●	USGS Gaging Station at Lowell	●	●	42° 38' 48"	71° 17' 56"
M016			Lowell WWTP	●	●	300′ D/S of Lowell WWTP outfall	●		42° 38' 57"	71° 17' 10"
M017			U/S Lawrence	●	●	County Line	●		42° 40' 12"	71° 14' 16"
M018			U/S Essex Dam	●	●	Float line U/S of Essex Dam	●		42° 42' 21"	71° 08' 34"
M019			D/S Essex Dam	●	●	Casey Bridge		●	42° 42' 12"	71° 09' 38"
	T009		Spicket River	●	●	Haverhill St bridge (D/S side)		●	42° 42' 49"	71° 09' 29"
	T010		Shawsheen River	●	●	U/S side of box culvert		●	42° 42' 12"	71° 08' 27"
M020			D/S Lawrence	●		1000′ D/S of O'Reilly Bridge	●		42° 42' 29"	71° 08' 08"
M021			GLSD WWTP	●	●	300′ D/S of GLSD WWTP outfall	●		42° 43' 08"	71° 08' 07"
M022			U/S Haverhill	●	●	Haverhill/N. Andover Town Line	●		42° 44' 25"	71° 06' 57"
M023			D/S Haverhill	●		200′ U/S of Hales Island	●		42° 46' 06"	71° 03' 47"
M024			Haverhill WWTP	●	●	300′ D/S of Haverhill WWTP outfall	●		42° 45' 29"	71° 02' 48"
M025			Merrimac WWTP	●	●	300′ D/S of Merrimac WWTP outfall	●		42° 49' 28"	70° 58' 55"
M026			Amesbury WWTP	●	●	300′ D/S of Amesbury WWTP outfall	●		42° 50' 23"	70° 55' 26"
	T011		Powwow River	●	●	300′ U/S of confluence	●		42° 50' 29"	70° 55' 30"
M027			Shellfish Bed	●	●	Newburyport Boat Ramp in Joppa Flats	●		42° 48' 28"	70° 51' 32"
M028			Salisbury WWTP	●	●	300′ D/S of Salisbury WWTP	●		42° 49' 11"	70° 52' 36"
M029			Newburyport WWTP	●	●	300′ D/S of Newburyport WWTP	●		42° 48' 32"	70° 51' 32"
M030			Shellfish Bed	●	●	North side of bay	●		42° 49' 07"	70° 50' 49"
		O001	CSO Outfall- Manchester, NH	●		Cemetary Brook CSO		●	42° 58' 53"	71° 28' 03"
		O002	CSO Outfall- Nashua, NH	●		East Hollis Street CSO		●	42° 45' 48"	71° 26' 41"
		O003	CSO Outfall- Lowell, MA	●		Barasford Ave CSO		●	42° 38' 43"	71° 17' 20"
		O004	CSO Outfall- Lawrence, MA	●		Spicket River CSO		●	42° 42' 22"	71° 08' 50"
		O005	CSO Outfall- Haverhill, MA	●		Bradford Ave CSO		●	42° 46' 12"	71° 05' 07"
		O006	Stormwater Outfall	●		Bridges St Stormdrain		●	42° 59' 37"	71° 28' 08"
		O007	Stormwater Outfall	●		Seminole Dr Strormdrain		●	42° 45' 24"	71° 30' 09"
		O008	Stormwater Outfall	●		Lowell Stormdrain		●	42° 38' 26"	71° 21' 07"
		O009	Stormwater Outfall	●		Shawsheen Stormdrain		●	42° 39' 53"	71° 08' 45"
		O010	Stormwater Outfall	●		Water St. Stormdrain		●	42° 46' 28"	71° 04' 26"

Table 4-4: Summary of analytical parameters and field measurements

Analytical Parameters	Field Measurements
Indicator Organisms	In Situ Measurements
Fecal Coliform	Temperature
E. coli	Dissolved Oxygen (DO)
Enterococcus (marine waters only)	Salinity (marine waters only)
	pH
Nutrients & Impacts	Conductivity
Total Phosphorus	Turbidity (select stations only)
Nitrate/Nitrite	
Total Kjeldahl Nitrogen (TKN)	Secchi disk depth (dry-weather only)
Ammonia-N	Vertical Temp/DO profile (Dry Event 2 & 3 only, upstream of dams)
Chlorophyll-a	
Oxygen & Oxygen Demand	Diurnal DO sweeps (Dry Event 2 & 3 only, select stations)
BOD_5	
BOD_{20} (select stations only)[1]	Streamflow (at mouths of each tributary so that measured pollutant concentrations could be converted into mass loads)
DO Winkler titration (select stations only)	
Metals (Dry Event 2 only)	
Lead	Continuous DO/Temperature monitoring at two locations
Zinc	
Copper	
Cadmium	
Iron	
Nickel	
Hardness	

[1] Approximation of ultimate BOD in the Merrimack River



LEGEND

▲ Wet Sampling Locations

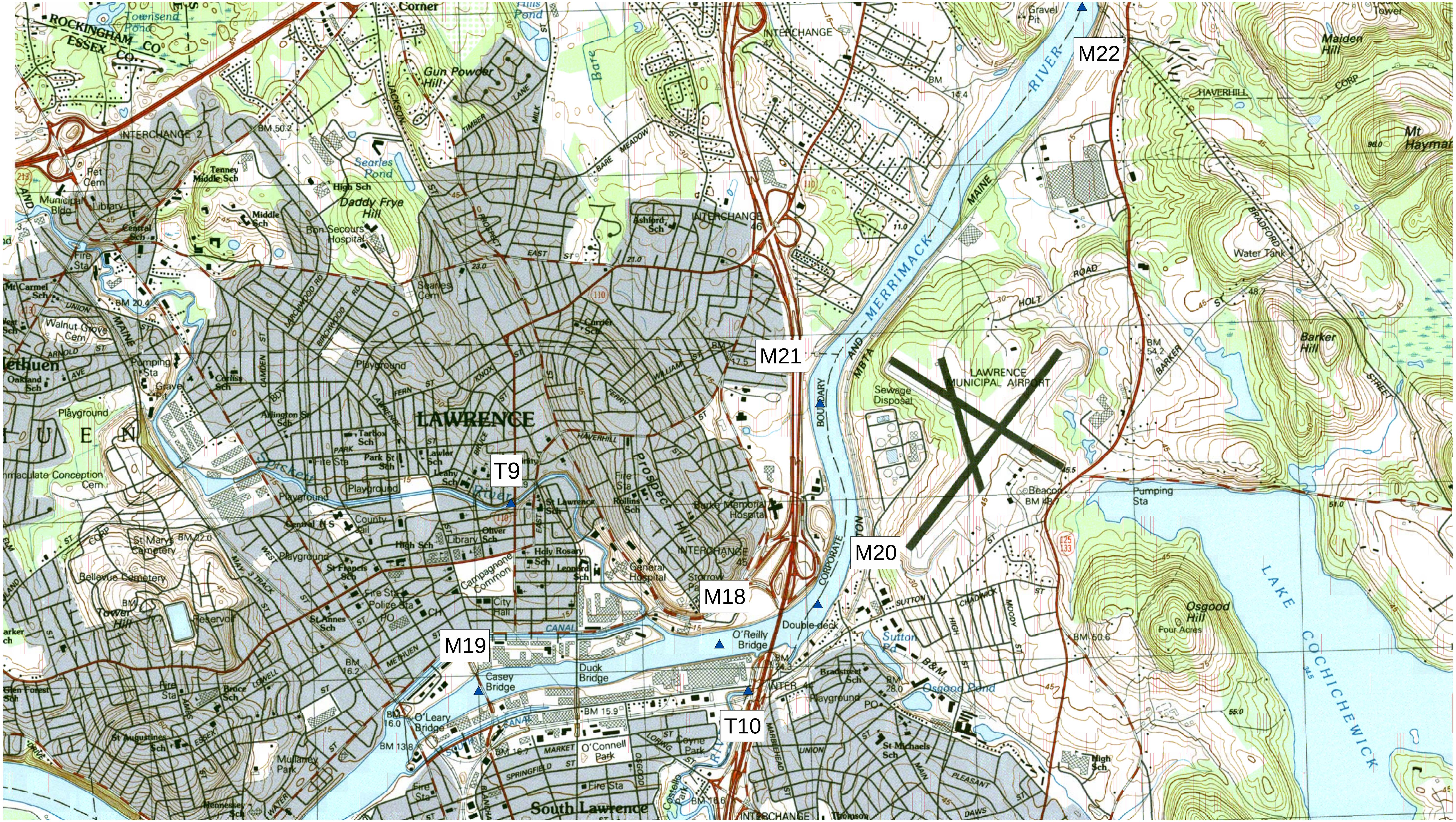
Basemap Source: USGS

5000 2500 0 5000 Feet

N

Merrimack River Watershed
Assessment Study

Figure 4-9: Wet Weather Sampling Locations-Wet Reach 5



LEGEND

▲ Wet Sampling Locations

Basemap Source: USGS

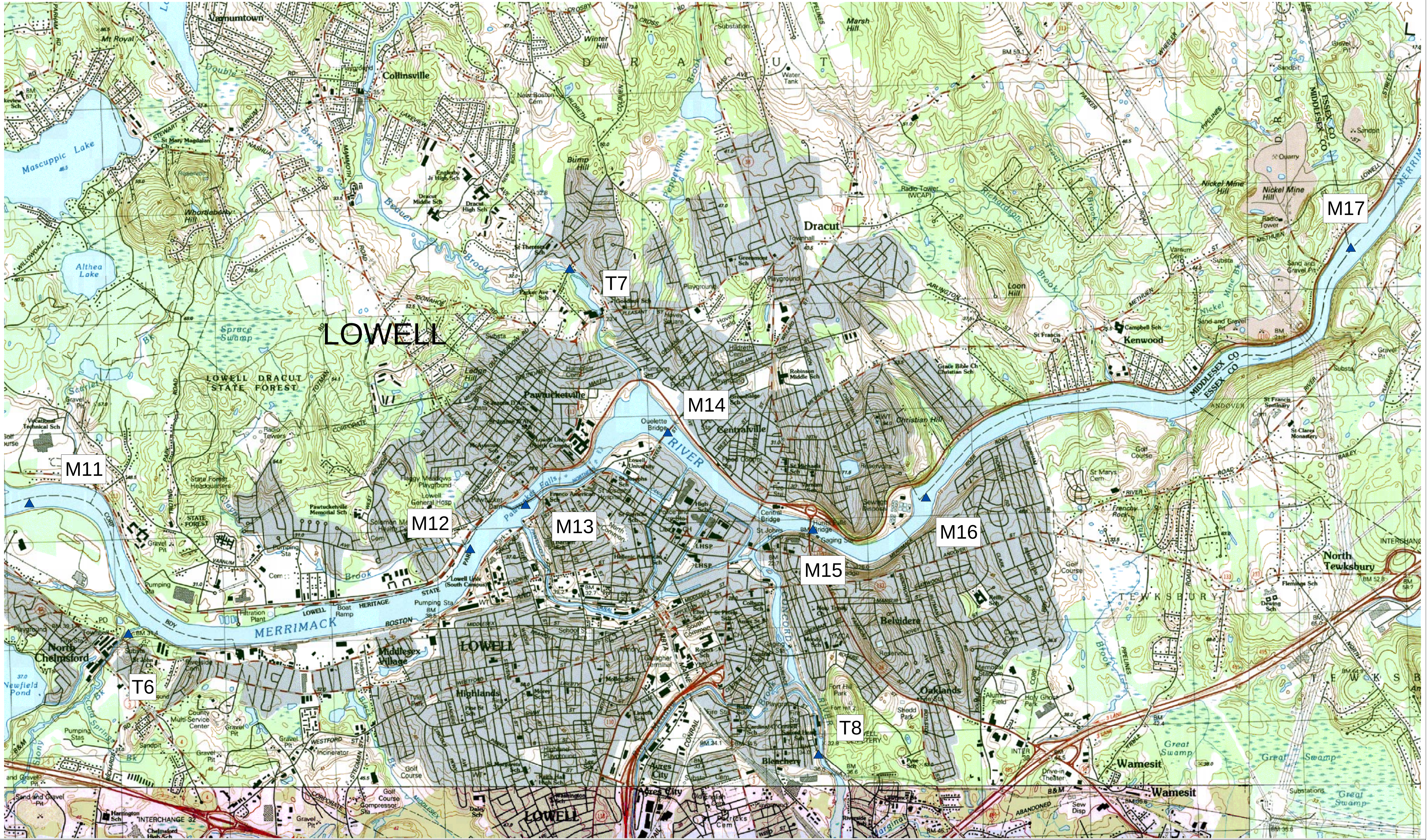
CDM

1000 500 0 1000 Feet

N

Merrimack River Watershed
Assessment Study

Figure 4-8: Wet Weather Sampling Locations-Wet Reach 4



LEGEND

▲ Wet Sampling Locations

Basemap Source: USGS

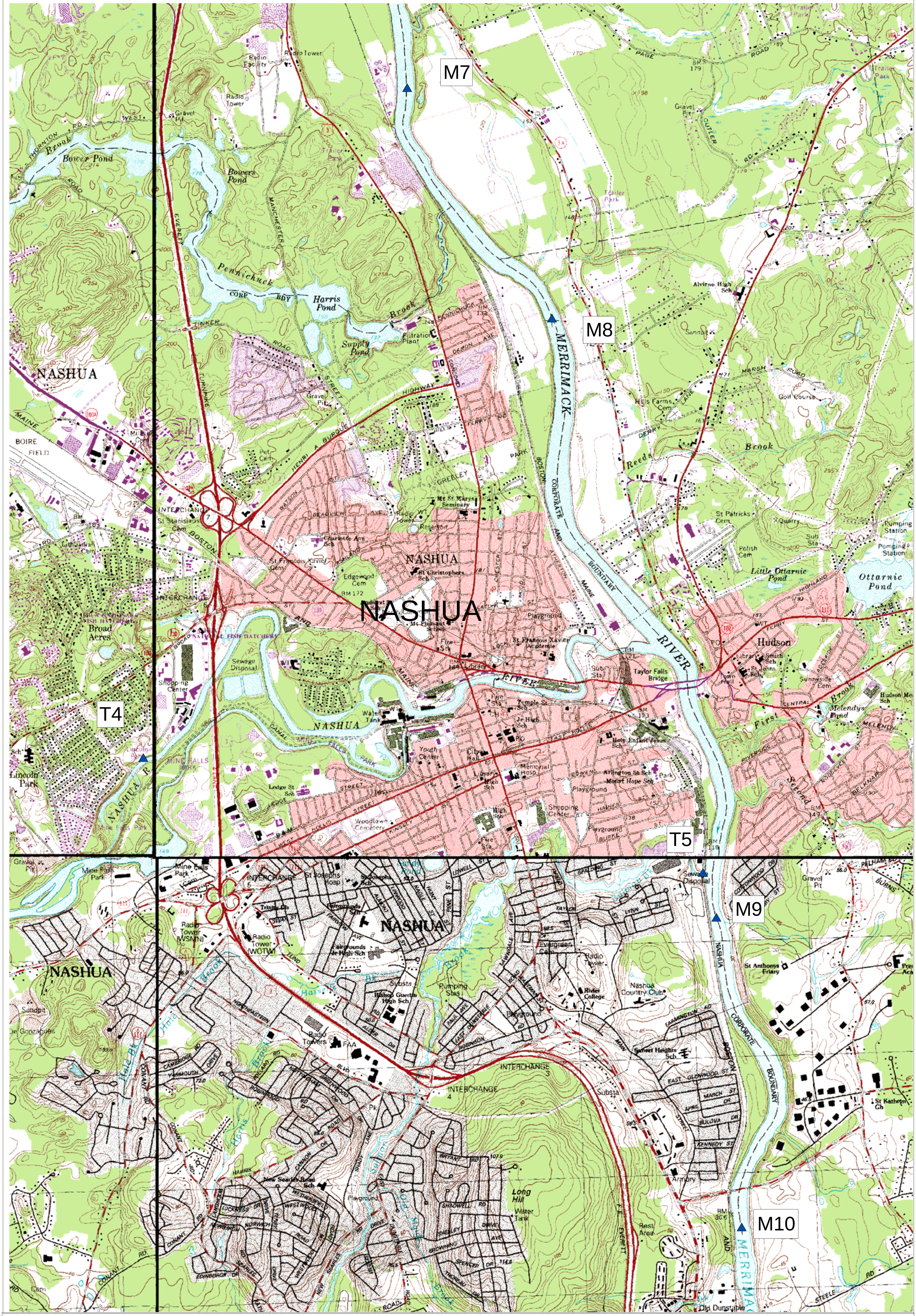
CDM

1500 750 0 1500 Feet

N

Merrimack River Watershed
Assessment Study

Figure 4-7: Wet Weather Sampling Locations-Wet Reach 3



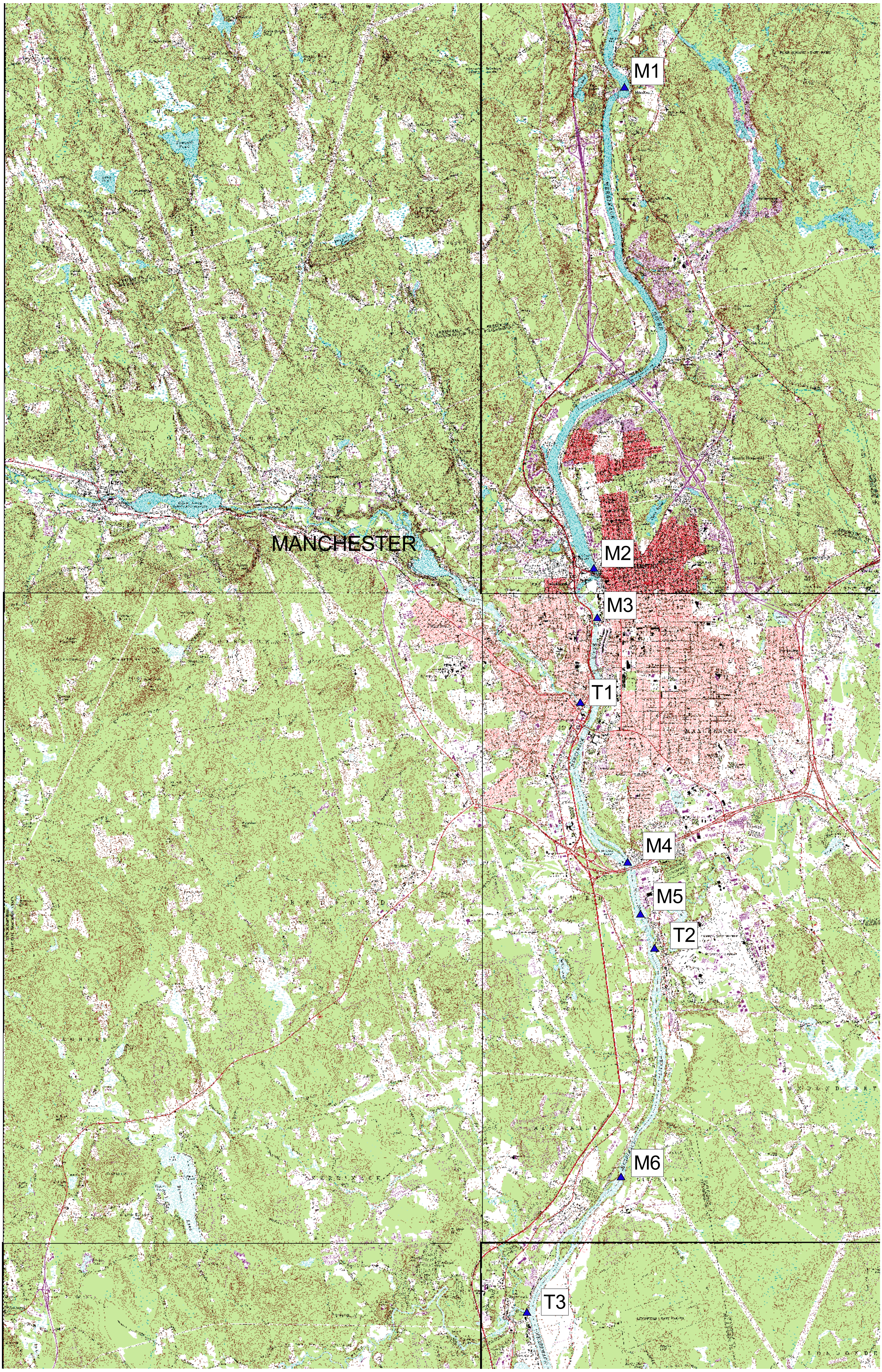
LEGEND

▲ Wet Sampling Locations

Basemap Source: USGS

Merrimack River Watershed
Assessment Study

Figure 4-6: Wet Weather Sampling Locations-Wet Reach 2



LEGEND

▲ Wet Sampling Locations

Basemap Source: USGS

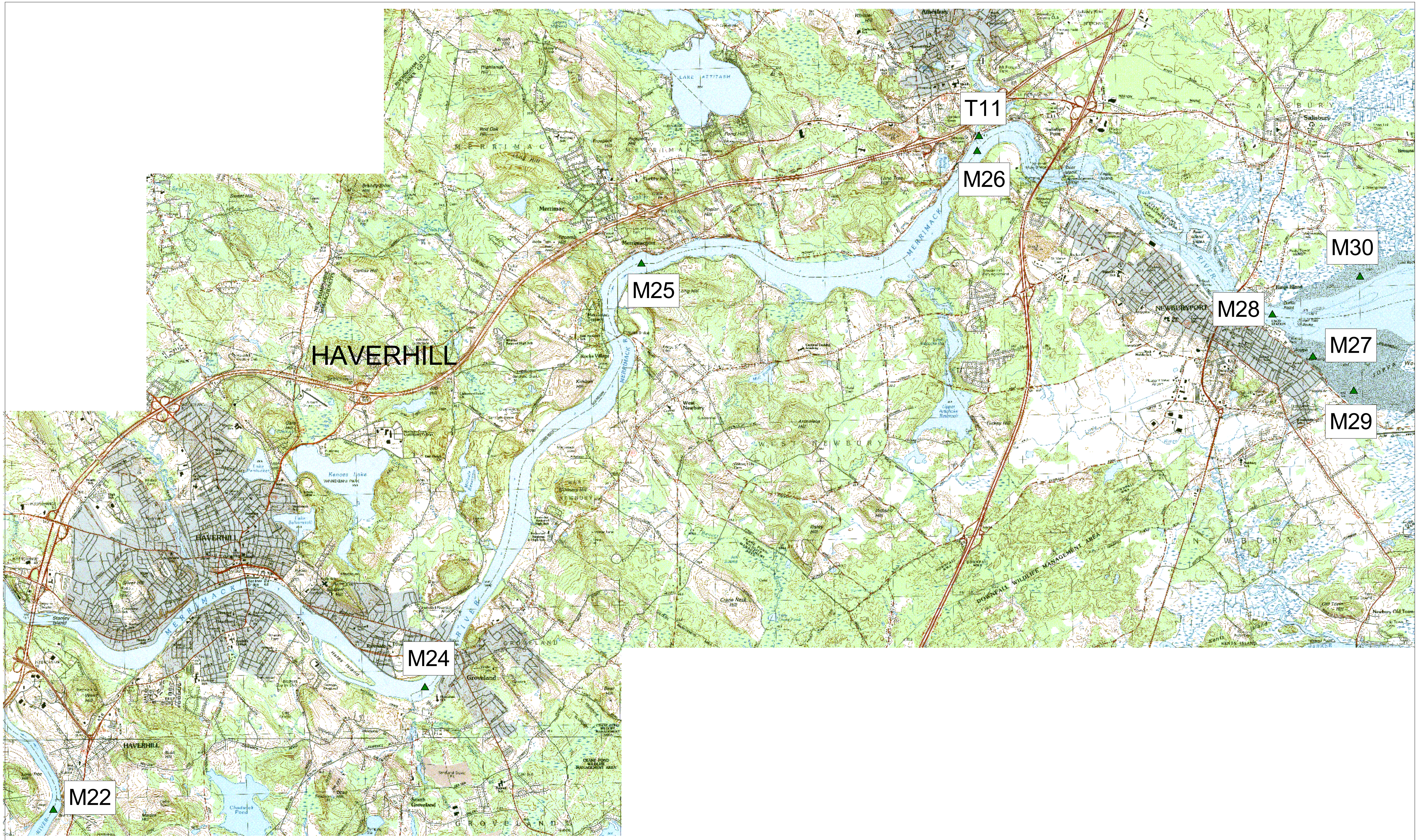
600 0 600 1200 Feet

N

CDM

Merrimack River Watershed
Assessment Study

Figure 4-5: Wet Weather Sampling Locations-Wet Reach 1



LEGEND

▲ Dry Sampling Locations

Basemap Source: USGS

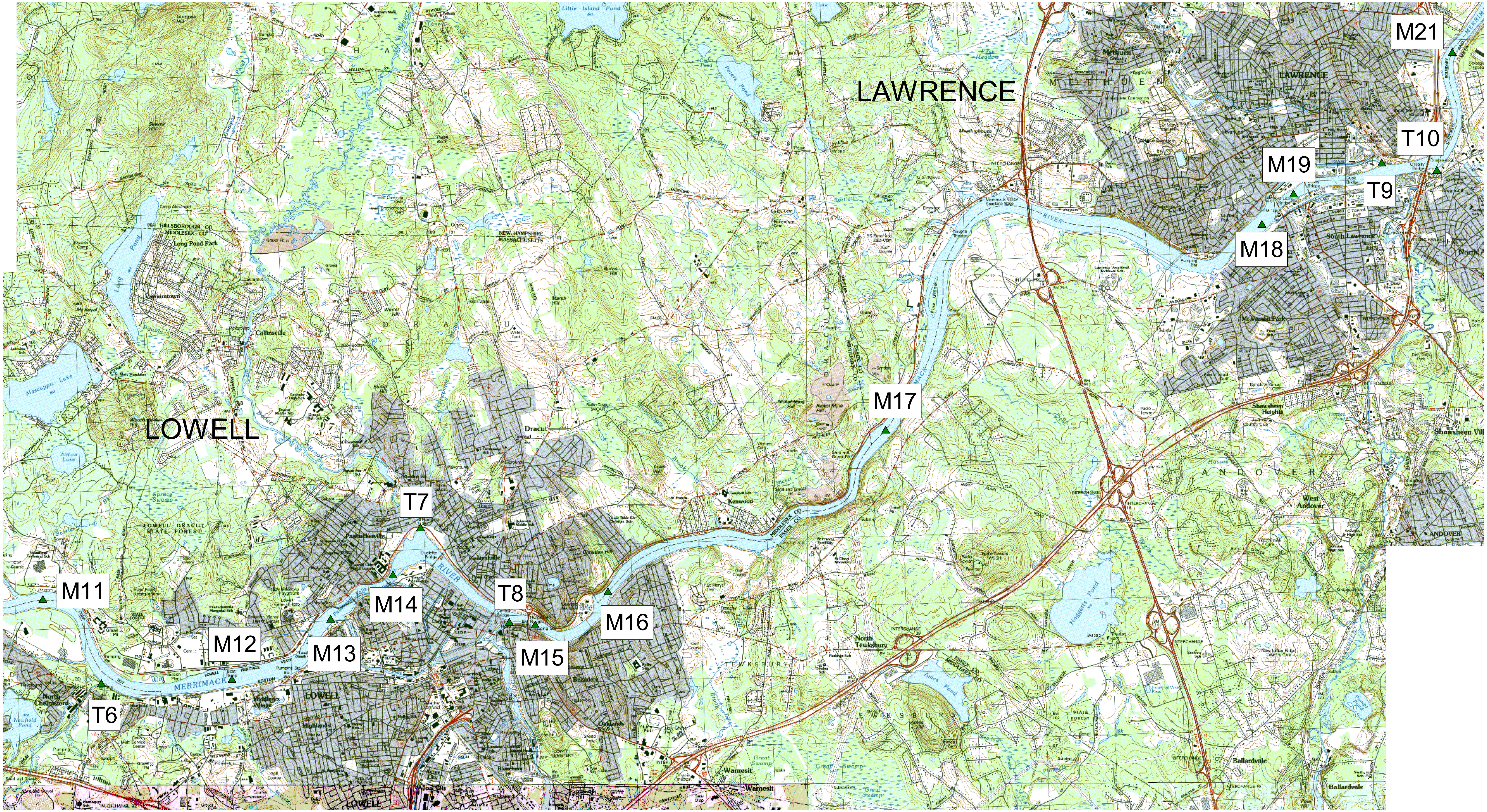
CDM

2000 0 2000 Feet

N

Merrimack River Watershed
Assessment Study

Figure 4-4: Dry Weather Sampling Locations-Dry Reach 3



LEGEND

▲ Dry Sampling Locations

Basemap Source: USGS

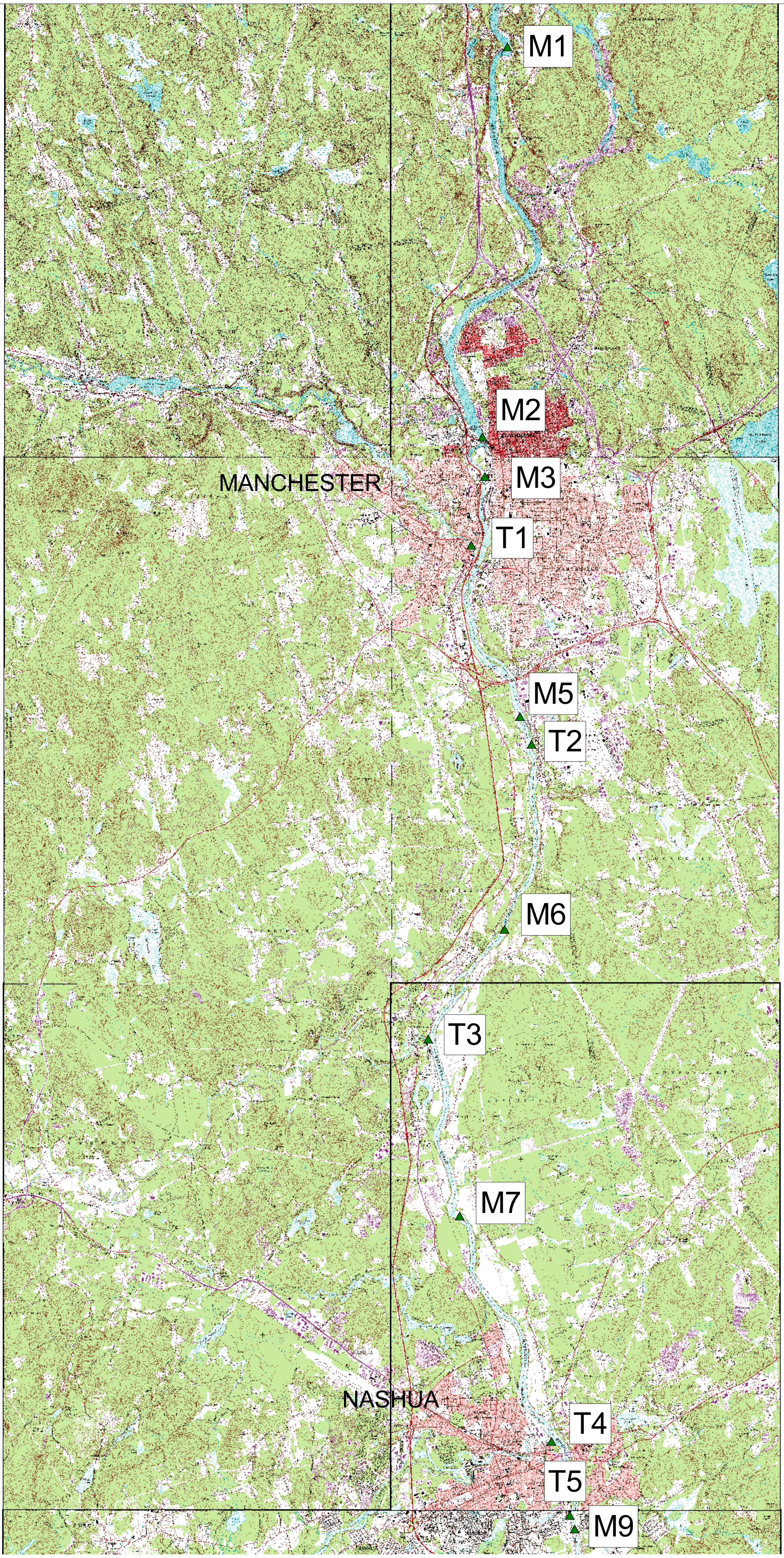
CDM

900 0 900 Feet

N

Merrimack River Watershed
Assessment Study

Figure 4-3: Dry Weather Sampling Locations-Dry Reach 2



LEGEND

▲ Dry Sampling Locations

Basemap Source: USGS

CDM

Merrimack River Watershed
Assessment Study

Figure 4-2: Dry Weather Sampling Locations-Dry Reach 1

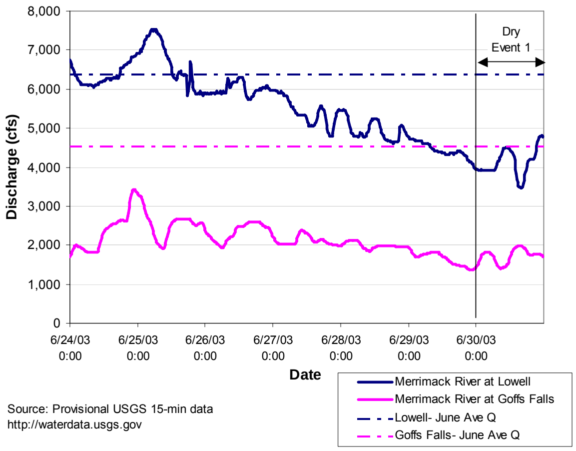
4.2.3.1 Dry-Weather Surveys

Three dry-weather sampling events were conducted as part of the Merrimack River Watershed Assessment Study on the following dates:

- Dry Event 1: June 30, 2003
- Dry Event 2: August 20, 2003
- Dry Event 3: September 12, 2003

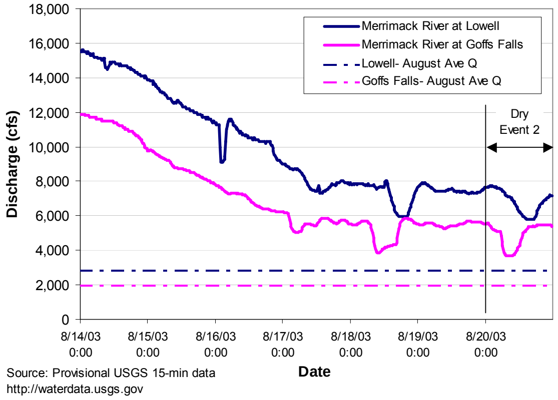
Requirements for dry-weather monitoring included 7 days of antecedent dry conditions in the watershed (no more than 0.1″ of cumulative precipitation), and streamflow conditions as close as possible to the average flow conditions for the current month. Streamflow conditions for each event, including records for the weeks leading up to each events, are illustrated in Figure 4-10. Key results are summarized in Section 4.2.4. Detailed results are included in the *Merrimack River Monitoring Report* (May 2006).

Dry Event #1



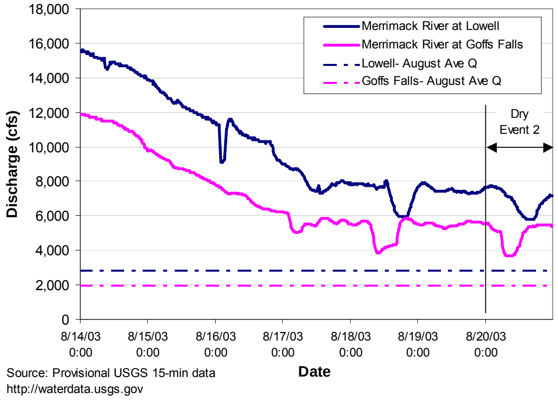
Source: Provisional USGS 15-min data
http://waterdata.usgs.gov

Dry Event #2



Source: Provisional USGS 15-min data
http://waterdata.usgs.gov

Dry Event #3



Source: Provisional USGS 15-min data
http://waterdata.usgs.gov

Figure 4-10: Dry-Weather Flow Conditions

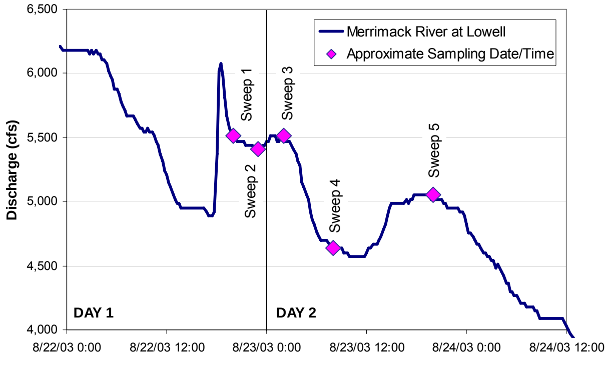
4.2.3.2 Wet-Weather Surveys

Three wet-weather sampling events were conducted as part of the Merrimack River Watershed Assessment Study during the 2003 sampling season, on the following dates:

- Wet Event 1: August 22–23, 2003
- Wet Event 2: September 19–20, 2003 (Remnants of a Hurricane Ivan)
- Wet Event 3: October 15–16, 2004

Streamflow conditions for each event are illustrated in Figure 4-11. Distribution of total rainfall over the study area for each event is shown in the radar images in Figure 4-12 through Figure 4-14.

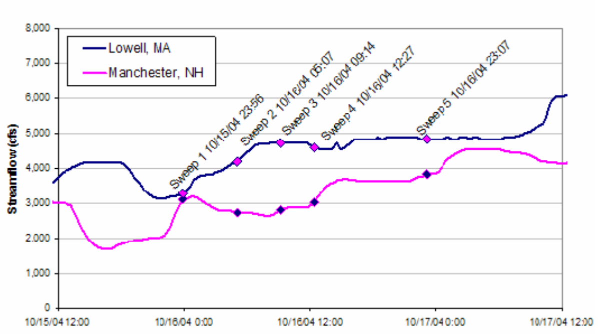
Wet Event #1



Source: Provisional USGS 15-min data
http://waterdata.usgs.gov

Date

Wet Event #2



Wet Event #3

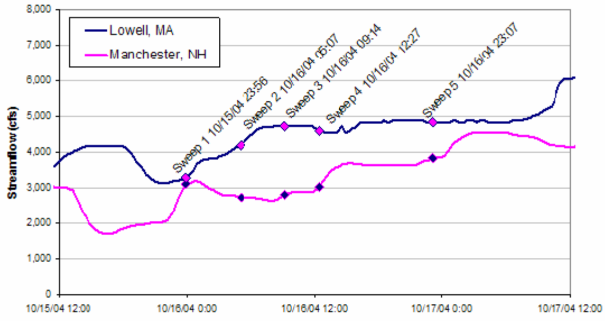
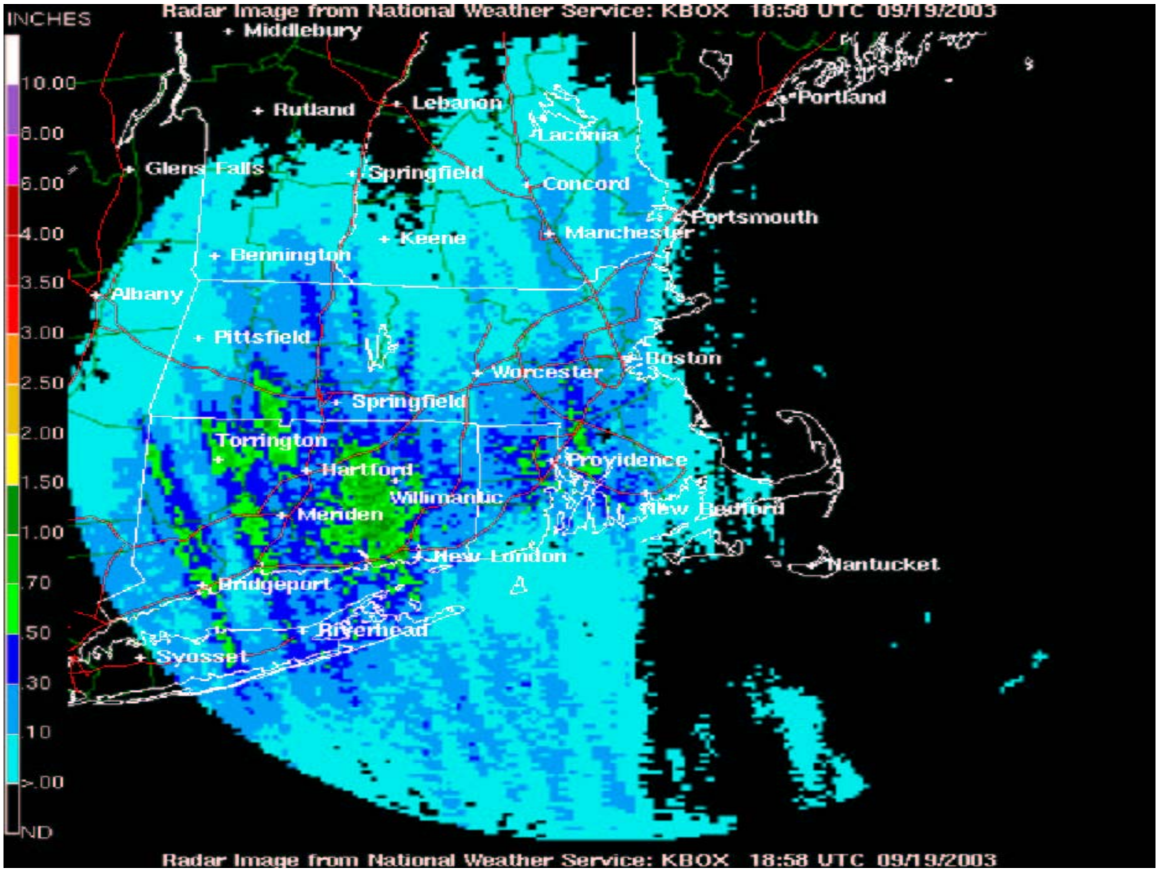


Figure 4-11: Wet-Weather Flow Conditions

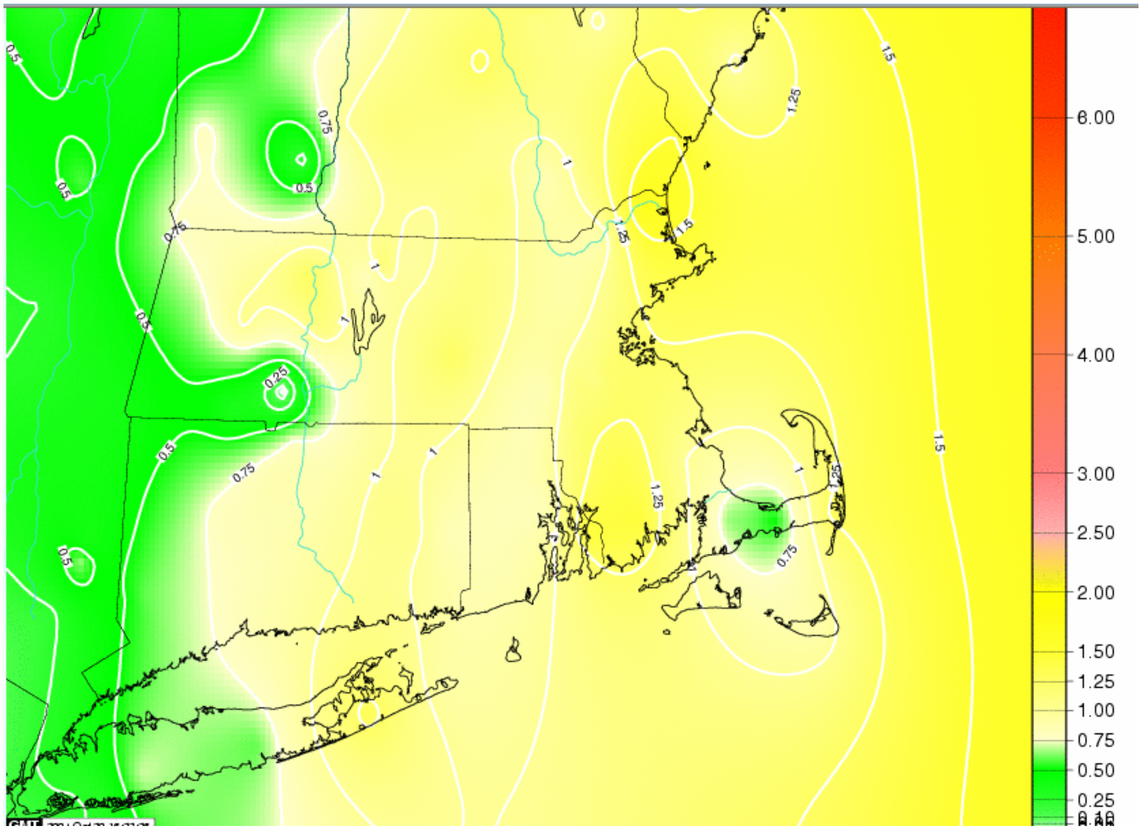


Note: Values in inches Source: www.weather.gov/radar

Figure 4-13: Distribution of Total Rainfall during Wet-Weather Event #2

Rainfall Totals at NCDC Stations for Wet Event #2:

Manchester, NH:	0.45″
Lawrence, MA:	0.35″
Bedford, MA:	0.38″



Note: Values in inches Source: http://www.erh.noaa.gov/box/coopGraphics.html#

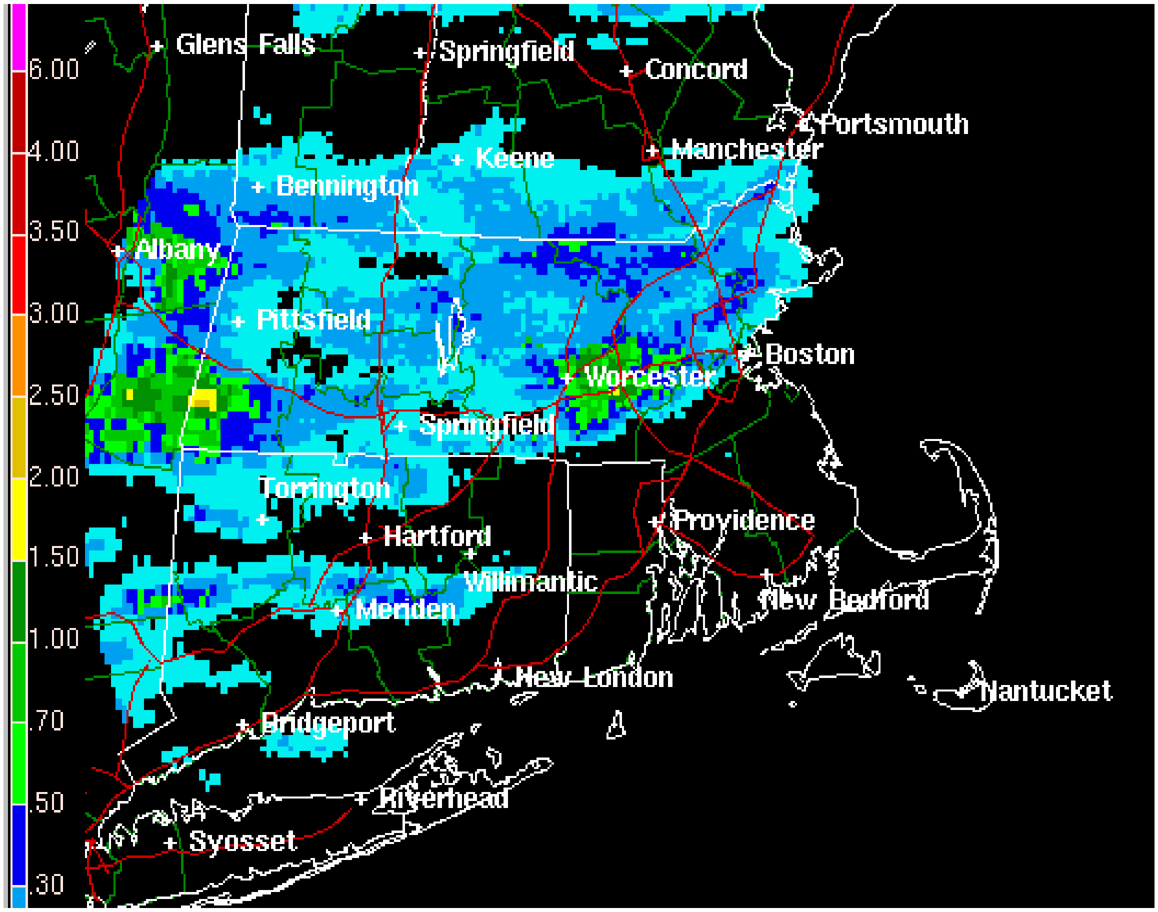
Figure 4-14: Distribution of Total Rainfall during Wet-Weather Event #3

Rainfall Totals at NCDC Stations for Wet Event #3 (Total for 10/15/04 – 10/16/04):

Manchester, NH:	1.09”
Lawrence, MA:	1.01”
Bedford, MA:	0.97”

4.2.3.3 Supplemental Survey in Lawrence, MA

Because the three wet-weather events caused CSO discharges in only four of the five sponsor communities (the GLSD system did not overflow during any of the storms), a supplemental survey was conducted in Lawrence on October 8, 2005 during a heavy storm that caused overflows from the GLSD system. Samples were collected from selected sites upstream and downstream of the primary CSO outfall in Lawrence, as illustrated by the yellow labels in Figure 4-15. Samples were also collected from the Spickett and Shawsheen Rivers (stations T9 and T10 in Figure 4-15).



Note: Scale in inches

Source: www.weather.gov/radar

Figure 4-12: Distribution of Total Rainfall during Wet-Weather Event #1

Rainfall Totals at NCDC Stations for Wet Event #1 (August 22, 2003):

Manchester, NH:	Trace
Lawrence, MA:	0.01”
Haverhill, MA:	0.42”
Groveland, MA:	0.16”
Bedford, MA:	0.27”

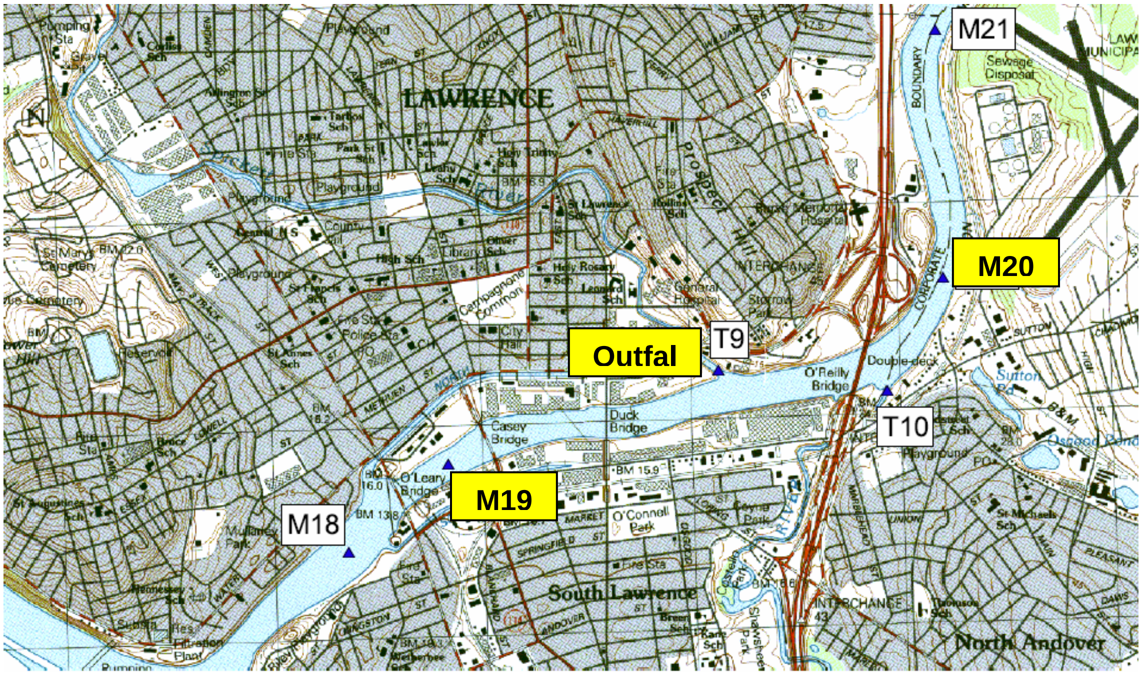


Figure 4-15: Supplemental Sampling Locations in Lawrence

Streamflow at Lowell during this event was approximately 6,000 cfs. The distribution of precipitation is shown in Figure 4-16. The Lawrence area received over 2 inches of precipitation, which caused the combined sewer system to overflow.

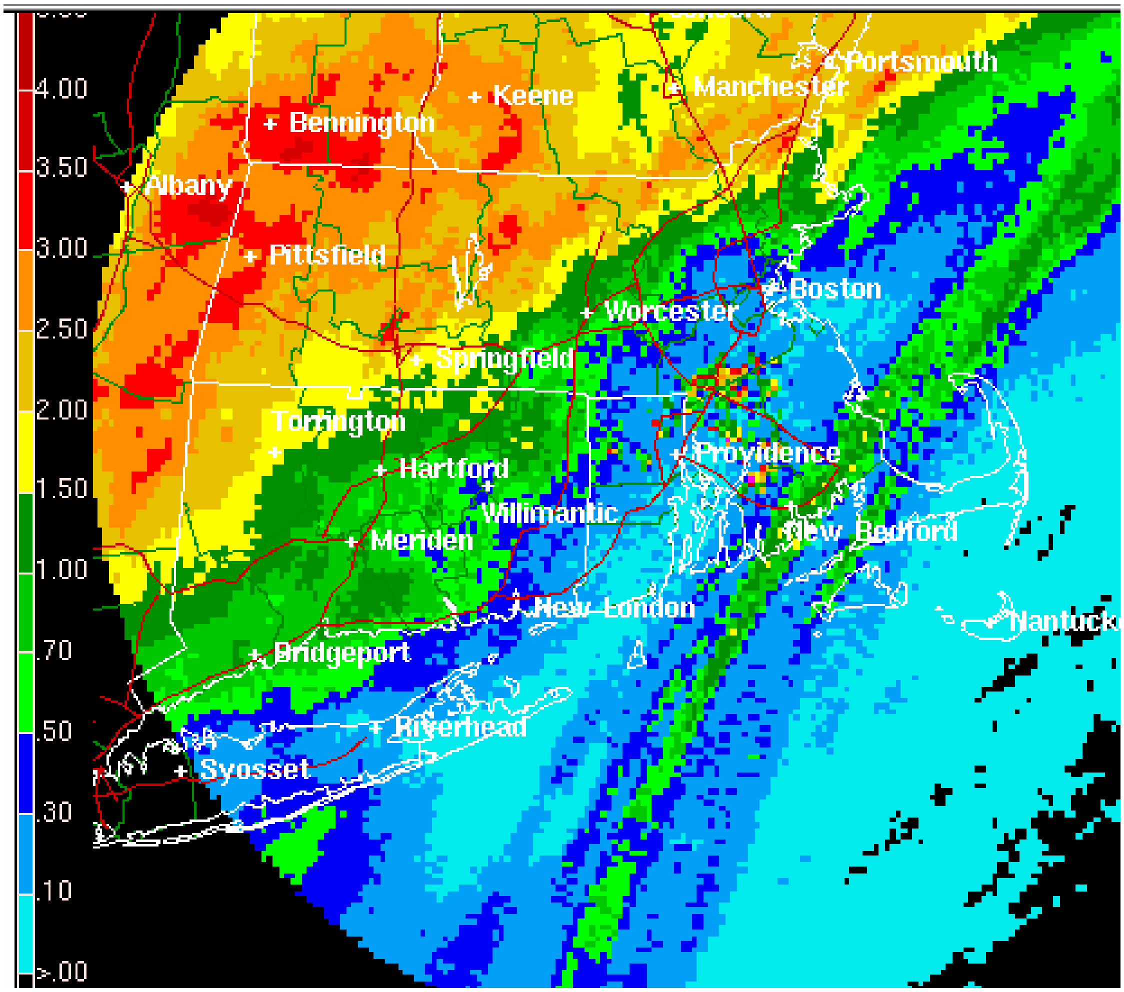


Figure 4-16: Distribution of Total Rainfall during Supplemental Wet-Weather Event in Lawrence

Note: Values in inches
Source: www.weather.gov/radar

4.2.4 Summary of Monitoring Results

Comprehensive results of the monitoring program are available in the *Merrimack River Monitoring Report* (CDM, 2006). Results are also available via an electronic database delivered to the Army Corps of Engineers. A brief summary of key results and findings is included below, and representative tables and figures are included at the end of this section. A description of relevant state water quality standards is included in Section 4.2.4.3, Summary of State Water Quality Standards.

4.2.4.1 Dry-Weather Findings

During dry weather, bacteria concentrations in the mainstem are usually below state standards for recreational use, although isolated and non-recurrent violations were observed. Four of eleven major tributaries consistently exceed bacteria thresholds. This is suggestive of illicit wastewater connections to storm sewers or failing septic systems near these tributaries. This supports the hypothesis that nonpoint source pollutant loads are significant, and suggests that further study is warranted in these tributaries, even though these loads do not necessarily result in dry-weather violations in the mainstem.

During dry weather, the river and its tributaries generally satisfy water quality standards for dissolved oxygen in the study area.

During dry weather, high levels of chlorophyll–a were observed downstream of Lowell, extending to the estuary. This suggests high levels of organic productivity in the river, although no commensurate depletion of oxygen was observed.

4.2.4.2 Wet-Weather Findings

During wet weather, concentrations of bacteria in the Merrimack mainstem violate water-quality standards in both states. Obvious bacterial plumes from CSO communities were observed moving downstream. However, supporting the hypothesis that nonpoint loads are significant, most tributaries also exceeded water quality standards for bacteria during wet weather (upstream of all CSO outfalls). This is an important finding, since it suggests that even full abatement of CSOs, while certainly offering water quality improvements, will still not yield compliance with bacteria standards.

During wet weather, the river and its tributaries generally satisfy water quality standards for dissolved oxygen in both states.

Nutrient levels were not high during wet weather.

4.2.4.3 Summary of State Water Quality Standards

Both Massachusetts and New Hampshire categorize waters according to their use class. Each class is associated with a series of designated uses; the ability of a water body to support these uses is assessed based on its ability to meet the applicable water quality standards. Table 4-5 summarizes of the designated uses for each state.

Table 4-5: New Hampshire and Massachusetts Designated Uses

New Hampshire	Massachusetts
Primary contact recreation (swimming)	Fish consumption
Fish and shellfish consumption	Aquatic life support
Drinking water	Drinking water
Aquatic life support	Shellfishing
	Primary contact recreation (swimming)
	Secondary contact recreation (boating)

Use Classes—New Hampshire

The state of New Hampshire has designated the following two "Use Classes" that govern the baseline water quality required to protect a waterbody's intended uses (per State of New Hampshire Surface Env-Ws 1700: Water Quality Regulations, and

Class A: Highest quality waters considered acceptable for use as public water supply after adequate treatment. Discharge of sewage or waste is prohibited to Class A waters.

Class B: Waters considered acceptable for fishing, swimming, and other recreation purposes; acceptable for use as a public water supply after adequate treatment.

The mainstem Merrimack River within the Study Area is classified as Class B.

Use Classes—Massachusetts

The Massachusetts Surface Water Quality Standards (314 CMR 4.00) designate the most sensitive uses for which the surface waters of the state shall be enhanced, maintained, and protected. The state prescribes the minimum water quality criteria necessary to sustain the designated uses. The following class designations are applicable to the Merrimack River Study Area; the River is classified as Class B from the state line to Haverhill, and Class SB from Haverhill to the Atlantic Ocean due to the tidal influence.

Class B (freshwater): "These waters are designated as habitat for fish, other aquatic life and wildlife, and for primary and secondary contact recreation. Where designated, they shall be suitable as a source of water supply with appropriate treatment. They shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process use. These waters shall have consistently good aesthetic value."

Class SB (marine water): "These waters are designated as habitat for fish, other aquatic life and wildlife, and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting with depuration (Restricted Shellfishing Areas). These waters shall have consistently good aesthetic value".

State Water Quality Standards

Table 4-6 provides a summary of the state water quality standards for Massachusetts and New Hampshire per use class, as they apply to the constituents monitored as part of the Merrimack River Watershed Assessment Study.

In both Massachusetts and New Hampshire, the recreation and shellfish standards are based on human health concerns. E. coli and fecal coliform bacteria are used in New Hampshire and Massachusetts, respectively, as indicators of the possible presence of pathogens in surface waters and the risk of disease, based on epidemiological evidence of gastrointestinal disorders from the ingestion of contaminated waters. Research has shown that contact with contaminated waters may also lead to ear or skin infections, and inhalation of contaminated water may cause respiratory diseases (http://www.epa.gov/OST/beaches/local/sum2.html#intro).

Table 4-6: State Water Quality Standards

Constituent	MA Class B	MA Class SB	NH Class B
Fecal coliform	< 200 org/100 mL (geometric mean in "any representative set of samples") < 10% of samples can exceed 400 org/100 mL (for recreation)	Less than an MPN of 88 org/100 mL < 10% of samples exceeding an MPN of 260 org/100 mL (for shellfish)	N/A
E. coli	N/A	N/A	< 125 org/100 mL (geometric mean[1]) < 406 org/100 mL in any one sample[2] < 1000 org/100 mL at end of CSO pipe
Temperature	<68°F in CWF <83°F in WWF	< 85°F or < daily mean of 80°F	In accordance with RSA 485-A:8, II, & VIII
DO	> 6.0 mg/L in cold-water fisheries > 5.0 mg/L in warm-water fisheries	> 5.0mg/L	Daily average of > 75% saturation Instantaneous > 5.0 mg/L
pH	6.5–8.3 and < 0.5 units outside of the background range	6.5–8.5 and < 0.2 units outside of the normally occurring range	6.5–8.0 except when due to natural causes

[1] Based on geometric mean of at least three samples obtained over a 60-day period

[2] For comparative purposes during the modeling phase of this study, a surrogate standard for peak values in NH was applied due to the extremely high number of data points for each river segment. CDM determined that every segment was likely to experience a peak *E. coli* count in excess of 406 org/100ml for at least one hour during each 180-day simulation, and hence, this standard would not differentiate abatement plans. Similar to the Massachusetts standard, then, a surrogate standard was applied to modeling data such that no more than 10% of all simulated values for each river segment could exceed 200 org/100 ml.

USEPA Water Quality Guidance

In addition to the state water quality criteria, the USEPA provides a series of guidance documents aimed at setting concentration targets for a variety of parameters. Applicable guidance standards are discussed below.

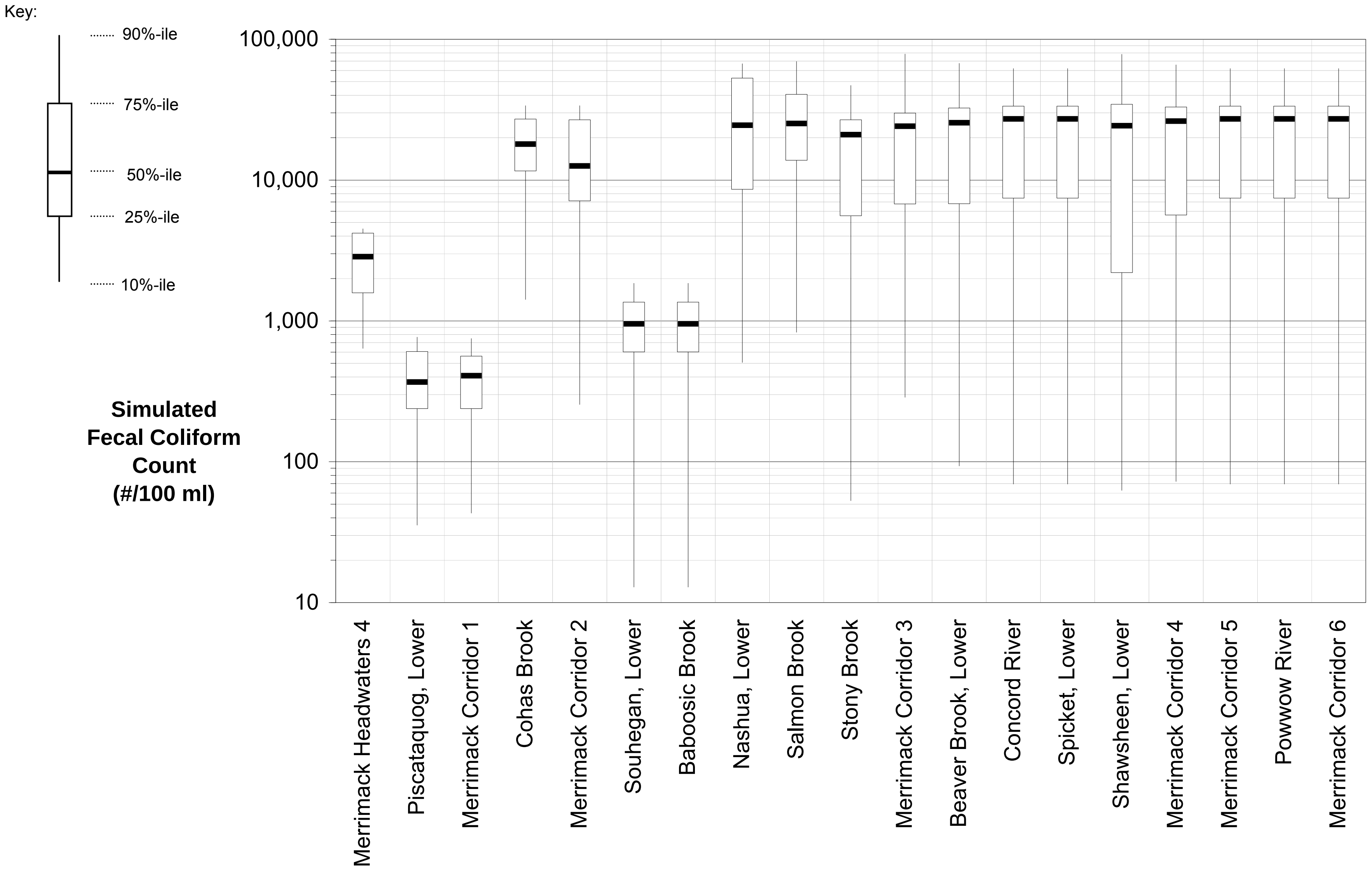


Figure 4-19: Merrimack River watershed simulated fecal coliform counts in impervious surface runoff (stormwater) for Baseline scenario

Enterococcus—Currently, the USEPA recommends the use of an Enterococcus standard in marine waters, as this organism has been found to be a more accurate gage of human health risks associated with recreation usage. The suggested water quality standards for this constituent are as follows:

- 35 org/100mL based on a geometric mean of at least five samples over a 30-day period
- 104 org/100mL based on a single sample

This standard was used to assess the Enterococcus data collected as part of the Merrimack River Watershed Assessment Study

Nutrient Guidance—Between 2000 and 2002, the USEPA published a series of nutrient water quality criteria guidance documents for lakes and reservoirs, and rivers and streams within specific geographic regions (ecoregions) of the United States (http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/). The guidance documents were developed with the aim of reducing and preventing eutrophication on a national scale through the adoption of the criteria by state environmental enforcement agencies. The recommended water quality criteria are suggested baselines, which USEPA suggests that the states use to help identify problem areas.

As noted above, the country was divided into a series of "ecoregions", each with its own associated nutrient criteria. According to the national maps, the Merrimack River watershed falls into the following two ecoregions:

Region VIII—Nutrient-poor, largely glaciated upper Midwest and Northeast

Region XIV—Eastern Coastal Plain

Table 4-7 provides a summary of the applicable nutrient guidance values for lakes and streams in the respective ecoregions.

Table 4-7: USEPA Nutrient Guidance for Rivers and Streams

Parameter	Region VIII	Region XIV
Total Phosphorus (mg/L)	0.01	0.03125
Total Nitrogen (mg/L)	0.38	0.71
Chlorophyll-a (µg/L)	0.63[1]	3.75[2]
Turbidity (FTU/NTU)	1.30	3.04

[1] Measured by Fluorometric method

4.2.4.4 Summary Tables and Figures

The tables and figures in Appendix A are excerpted from the *Merrimack River Monitoring Report* (CDM, 2006). They are intended to serve as a summary of conditions pertaining to bacteria, dissolved oxygen, and nutrients. More comprehensive results can be found in the referenced Monitoring Report, and via the electronic database provided to the Corps of Engineers.

The tables and figures in Appendix A include the following:

- Maps of Peak Bacteria Concentrations
- Matrix diagrams showing exceedance of bacteria standards by location
- Matrix diagrams showing exceedance of dissolved oxygen, temperature, and pH standards by location
- Representative nutrient graphs

4.3 Screening Model

Concurrent with the field monitoring program, a screening model was developed to estimate the annual loads of key pollutants from the primary source types throughout the watershed. The objectives of this preliminary analysis were to help quantify the relative importance of pollutant loads from various sources over time, and to identify watershed behavior that warranted especially detailed attention throughout the field monitoring program and higher-resolution dynamic modeling study to follow.

Using Event Mean Concentration (EMC) loading rates compiled from numerous regional and national studies (presented in the *Screening Level Model,* CDM, 2004), the Watershed Management Model (WMM) was used to provide initial insight into the relative watershed pollutant loads on an annual scale.

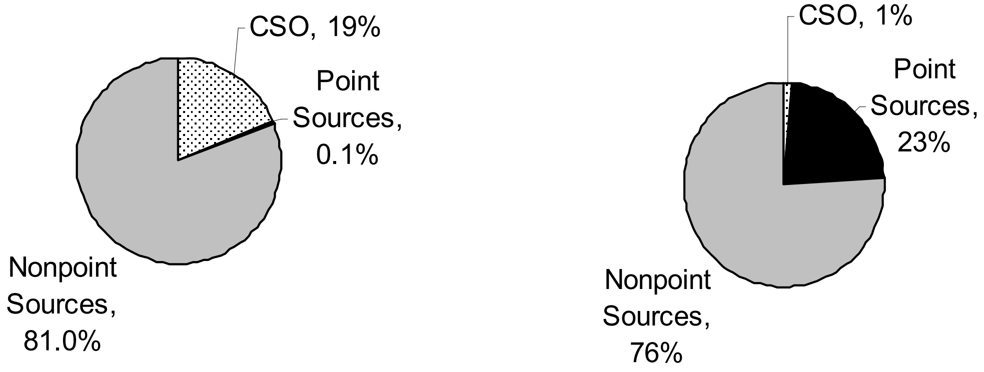
The WMM Model was originally developed to support the Rouge River National Wet-Weather Program in Detroit, Michigan. It blends EMC loading rates with annual water budgets for runoff and baseflow to estimate and compare total loads from a variety of pollution sources. A detailed description of the model and its input is provided in the report entitled *Screening Level Model* (CDM, 2004).

Some of the key results of this preliminary exercise are illustrated in Figure 4-17. The model suggested that on an annual timescale, nonpoint source pollution is the dominant contributor of bacteria throughout the watershed. While the results are annualized, and therefore not representative of dynamic fluctuations and actual causes of water quality exceedances, this preliminary finding triggered two responses for the remainder of the study:

Field monitoring was conducted at the mouth of each major tributary flowing into the mainstem of the Merrimack River (upstream of all CSO outfalls). This monitoring was targeted at measuring, and validating, the hypothesis that nonpoint source pollution may be a dominant factor in receiving water quality. (See Section 4.2 above for a summary of the monitoring program).

The dynamic modeling plan (See Section 4.4 below) was adjusted to consider watershed hydrology and nonpoint source loading with greater accuracy and credibility.

The results of the screening model did not conclusively relegate CSO discharges to a lower priority than nonpoint source pollution in the basin. That is, even though CSOs contribute only an estimated 19% of the total estimated bacterial load into the river according to the screening analysis, the timing and duration of the discharges throughout the year may still lead to instream bacterial levels above state water quality standards. However, the suggested distribution of load origination was disparate enough to warrant very close scrutiny of nonpoint sources as the spatial and temporal resolution of the study was refined.



Fecal Coliform

Copper

Figure 4-17: Annualized Pollutant Load Distribution Estimates from Screening Model

**MA bacterial standards limit Fecal Coliform. NH bacterial standards limit E. coli.*

4.4 Continuous Simulation Modeling

This section describes the computer simulation models that were developed to analyze existing conditions and alternatives for pollution abatement throughout the Merrimack watershed. A detailed discussion of the model development, including software tools, assumptions, parameterization, and calibration results is included in the *Simulation Model Development* report (CDM, 2005).

This section summarizes some of the key model results. The comparison of alternatives using the model results is extended in Section 6 to include costs and environmental improvements associated with various pollution abatement strategies. Detailed model results are included in Appendices B through G.

4.4.1 Modeling Strategy and Tools

This section provides a summary of the modeling objectives and discusses the suite of computer programs selected. The model selection process was presented in more detail in the report entitled *Modeling Methodology* (CDM, 2003), and appendices to the report entitled *Simulation Model Development* (CDM, 2005) list review comments and model revisions during its development. Indications from the screening model (discussed in Section 4.3) that nonpoint source loads could be a significant factor in total watershed loads suggested that the original modeling plan be modified to include a watershed model that could better handle both urban and non-urban hydrology and pollutant load simulation.

4.4.1.1 Modeling Objectives

The underlying objective of the modeling effort was to develop a comprehensive set of models that were capable of:

- Simulating the water quality and hydraulic regimes in the mainstem Merrimack River under normal, low-flow and baseflow conditions
- Simulating the dynamic nature of storm events and their effect on water quality and hydraulic conditions in the mainstem Merrimack River
- Within these overriding goals, the models were developed to address the following sub-objectives:
- Develop water quality and hydrologic/hydraulic models that are technically sound and defensible
- Perform continuous and event-based simulations of bacteria (fecal coliform and E. coli), nutrients, and dissolved oxygen in the mainstem Merrimack River under existing conditions and under various CSO and pollution control abatement strategies with reasonable confidence
- Simulate the relative contribution of pollutants from major sources, including urban and non-urban sources, CSOs, major tributaries, WWTPs, and non-point sources
- Simulate the sensitivity of the mainstem Merrimack River to incremental reductions in various pollutant loads, including CSOs, WWTPs, and non-point source pollution

- Simulate the water quality improvements associated with planned abatement strategies throughout the watershed.
- Simulate the sensitivity of water quality in the Study Area to hydropower dam operating rules

4.4.1.2 Model Selection and Structure

Many models and combinations of models are available for simulating watershed hydrology and its effects on receiving water quality. The *Modeling Methodology* report (CDM, 2003) reviewed a variety of hydrologic, hydraulic, and water quality models in the context of the study objectives. The following questions were posed as guidelines for model selection:

- Is the model capable of simulating continuous and event-based scenarios at very fine timescales (on the order of minutes)?
- Is the model tailored to emphasize urban hydrology and pollutant sources? (See note below – this original question was revisited following the completion of the screening model discussed in Section 4.3.)
- Can the model simulate non-point source pollutant loading?
- Can the model simulate unsteady flow in open channels?
- Can the model simulate in-stream concentrations of bacteria, nutrients, metals, chlorophyll-a, dissolved oxygen, and BOD?
- Can the water quality model simulate unsteady water quality conditions?
- Is the model compatible with existing CSO models?
- Can the output be easily understood and interpreted?
- Is the model compatible with Geographic Information System (GIS)?
- Is the model available through public domain?

An evaluation matrix was compiled comparing a variety of proven hydrologic, hydraulic, and water quality models to the criteria defined above. Based on this analysis, CDM selected the combination of the U.S. Environmental Protection Agency's (USEPA) Stormwater Management Model (SWMM) to simulate the watershed hydrology and the mainstem hydraulics and USEPA's Water Quality Analysis Simulation Program (WASP) to simulate the in-stream water quality. Currently, four of the five sponsor communities have CSO models developed in SWMM; the exception is the city of Nashua, New Hampshire, whose CSO model has been developed in MOUSE.

4.4.1.3 Revisiting the Emphasis on Urban Hydrology

In fall 2003, CDM completed a screening level analysis of the potential pollutant sources in the Merrimack River watershed at the annual time scale; the results were published in the "Screening Level Model" Report, dated March 2004. Based on this analysis, non-point sources from the tributaries were identified as a potentially significant source of pollution at the annual scale for eight of the 10 parameters evaluated using the model, with the exceptions being the two nutrient parameters, total nitrogen and total phosphorus.

Based on this analysis and the overall land use distribution in the watershed which shows that approximately 75-percent of the watershed is forested, CDM reevaluated the use of SWMM to model the watershed hydrology and non-point source loading. In January 2004, CDM held a series of internal workshops to evaluate potential alternative modeling plans. Potential alternative models were ranked based on the following criteria:

- Regulatory acceptance
- Level of effort
- Compatibility with other tools
- Scientific credibility
- Input data parameterization
- Client preference (based on discussions and review of modeling plan)
- Appropriateness for non-urban watershed
- Point source sub-model integration
- Parsimony (detail matches knowledge)

Based on this analysis, CDM selected USEPA's HSPF model as the appropriate tool to simulate the watershed hydrology and the non-point source loads outside of the five CSO communities. A memorandum summarizing the model selection process is included as Appendix A to this report.

4.4.1.4 Model Structure

Figure 4-18 provides a graphical representation of the overall modeling scheme for the Merrimack River Watershed Assessment Study. All models used, with the exception of the pre-existing MOUSE model for the Nashua CSO system, are public domain models). The key functions of each model are provided below:

Existing CSO Models—The five existing CSO models (four in SWMM, one in MOUSE), provide the hydraulic loading of the individual CSO discharges in each community to the mainstem Merrimack River. All hydrologic calculations for the contributing CSO areas are performed internally to the existing models.

HSPF (Hydrologic Simulation Program FORTRAN)—HSPF is used to model the watershed hydrology and non-point source loads for the entire Merrimack River watershed, with the exception of the five CSO areas discussed above. The flows and loads are input to the more detailed hydraulic and in-stream water quality models at the upstream boundary point (Hooksett Dam), at the confluence of 11 major tributaries, and at diffuse points along the mainstem River to account for runoff discharging directly to the channel.

SWMM (Storm Water Management Model)—The EXTRAN block of SWMM is used to perform the hydraulic channel routing in the mainstem Merrimack River downstream of the Hooksett Dam. SWMM accepts hydrologic input from HSPF.

WASP (Water quality Simulation Program)—WASP is used to simulate the in-stream water quality in the mainstem Merrimack River downstream of the Hooksett Dam. The WASP model accepts inputs from the existing CSO models, HSPF, and SWMM.

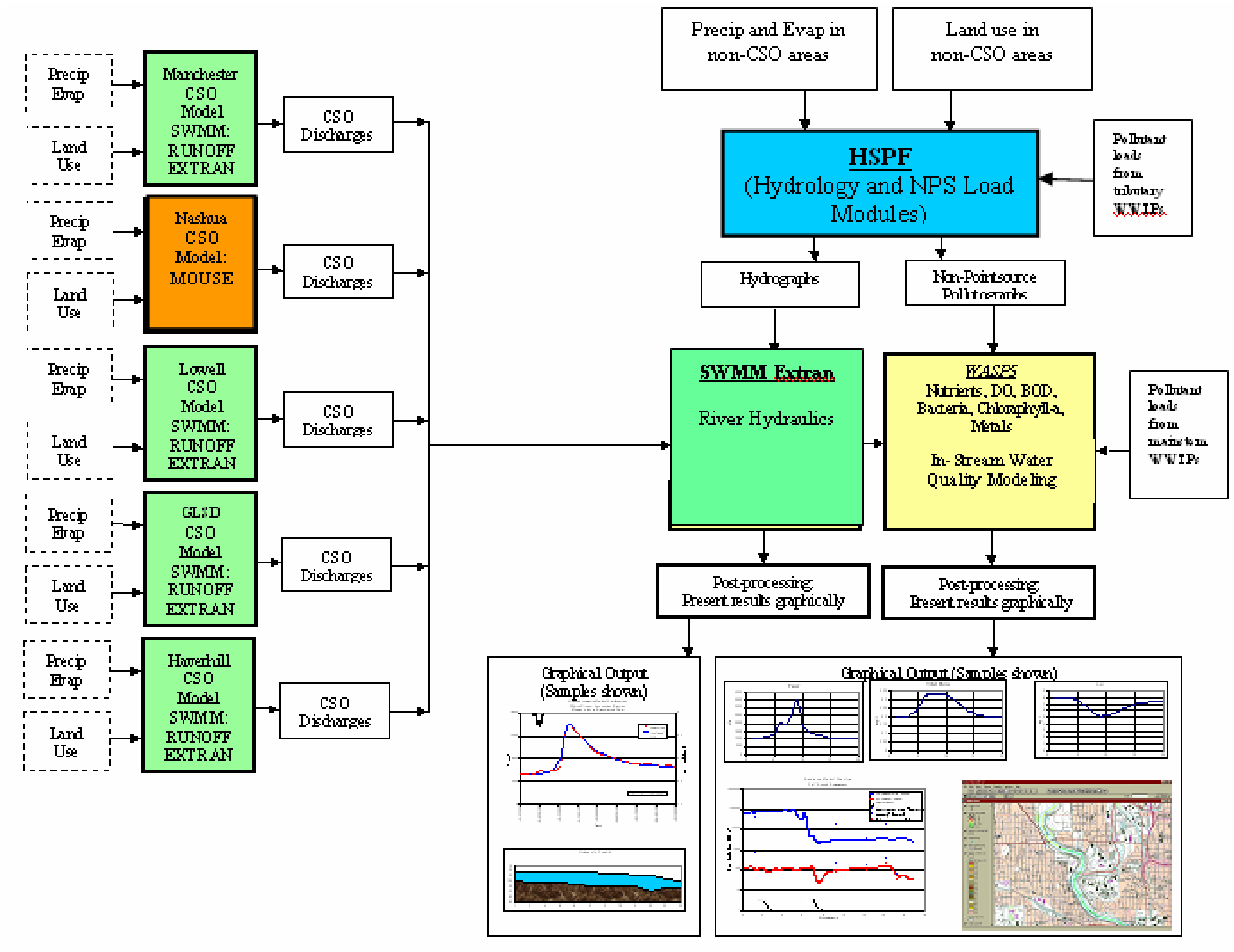


Figure 4-18: Model System Schematic

4.4.2 Calibration of Models

The models used for this study are complex, and some general guidelines for defensibly calibrating the models were established. More detailed descriptions of calibration methods and results are included in the *Simulation Model Development* report (CDM, 2005), but the following general premises applied:

The HSPF and WASP models have many parameters that can influence simulated responses within the model. As such, there are thousands of combinations of parameter values that would reproduce observed physical phenomena. To help ensure that the models were reproducing physical cause-and-effect relationships, and to avoid asserting good performance based solely on mathematical goodness-of-fit statistics, the following guidelines were followed:

- Parameters that could be fixed as constants (based on observed or literature values) were identified, and not adjusted during the calibration process.

- The number of tuning parameters (values that were varied during the calibration process) was minimized per a mandate from Technical Review Committee meeting #1; only parameters which had the greatest influence on model output were varied.

Spatial variability in parameters (without justification) was avoided. Global values, or values that could be directly linked to physical features of the landscape or river, were used to the greatest extent possible.

Accurate hydraulic routing is a necessary precursor to simulation of instream water-quality processes. The instream water quality model was not calibrated until it was demonstrated that the hydraulic model was simulating accurate travel times.

The modeling system is a cascade of information. Each model was calibrated independently to observed data, but the ultimate measure of usefulness is the instream water quality model. Adjustments were made to loading assumptions in the HSPF model based on observations of the WASP simulations.

Known loads as reported from treatment plants or measured from CSO outfalls and urban stormdrains as part of the river monitoring program were used to the greatest practical extent. Measured CSO concentrations were conservatively assumed to be constant during overflow periods.

4.4.2.1 Watershed and CSO Pollutant Loading

The suite of simulation models generated pollutant loads from a number of sources, including “background concentration” in dry-weather flow in tributaries, stormwater, septic systems, wastewater treatment plants, and combined sewer overflows. For nonpoint source pollutant generation from land surfaces, HSPF uses a buildup-washoff simulation model. The buildup process used by HSPF incorporates the idea that pollutants build up on land surfaces over time. After a large rainstorm, land surfaces are ‘swept clean,’ and pollutants begin building up anew.

This approach is significantly different from the *Event-Mean Concentration* (EMC) approach, which assigns a single concentration to runoff. The concentration of bacteria in runoff was found to very significantly by geographic location. Figure 4-19 shows the range of simulated fecal coliform concentrations in surface runoff simulated by the HSPF model.

Bacteria concentrations assigned to computed CSO overflow volume was based on average observed concentrations measured during Wet Events 1 and 2. (Data from the final two wet-weather events had either not yet been collected or had not yet undergone validation). Bacteria concentrations are reported in Table 4-8.

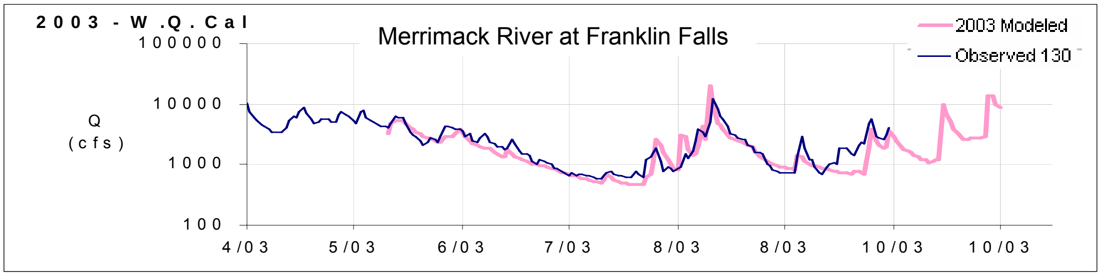
Table 4-8: Bacteria concentration assigned to CSO discharges (Values from the community's Long-Term Control Plan in parentheses)

	Fecal Coliform (cfu/100mL)	E. coli (cfu/100mL)	Enterococcus (cfu/100 mL)
Manchester, NH	990,000	654,000 (40,000)	535,000
Nashua, NH	938,000	859,000 (215,000)	506,000
Lowell, MA	1,890,000 (28,000)	1,540,000 (4,500)	1,020,000
GLSD, MA	1,230,000	979,000	664,000
Haverhill, MA	1,110,000 (165,000)	863,000	729,000

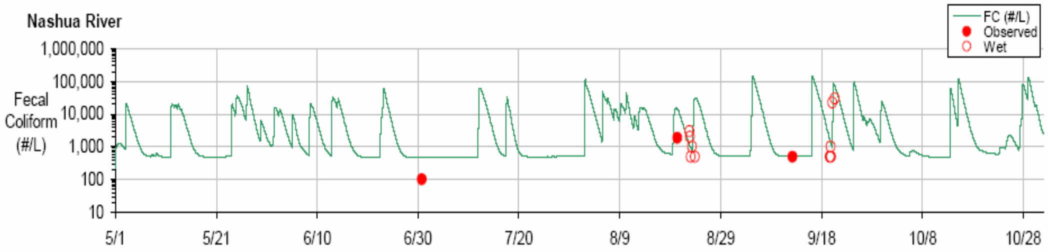
4.4.2.2 Typical Calibration Results

Complete calibration records are included as appendices to the *Simulation Model Development* report (CDM, 2005). Figure 4-20 illustrates typical calibration results for the various types of simulated phenomena.

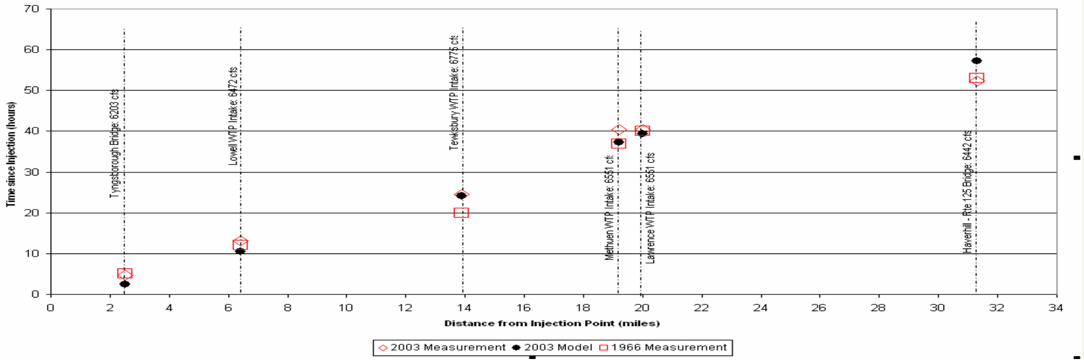
Hydrologic flow in the Merrimack River simulated with HSPF



Pollutant Concentrations in Tributary Runoff simulated with HSPF



Travel time in the mainstem Merrimack simulated with SWMM



Bacteria concentration in the Merrimack River simulated with WASP

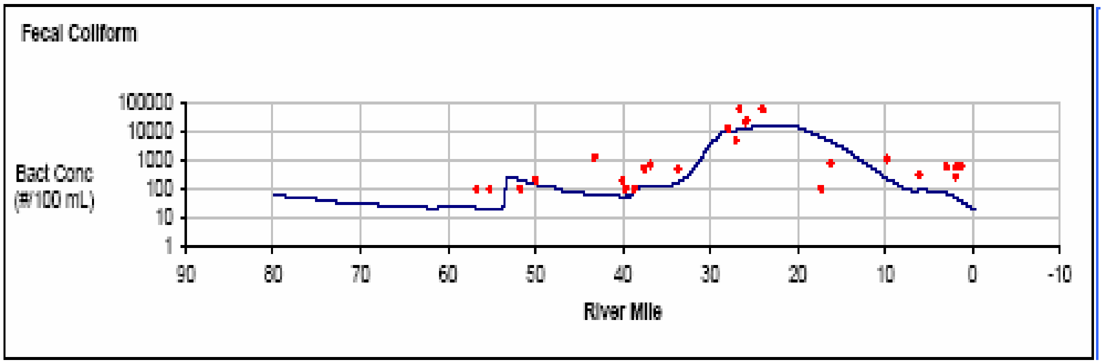


Figure 4-20: Representative Calibration Results

4.4.3 Summary of Model Application

4.4.3.1 Simulation Conditions

The models were developed to simulate continuous periods between May and October. The winter season was excluded because the additional insight afforded by full annual simulation was not commensurate with the necessary additional complexity of reproducing temperature dependency of runoff and infiltration rates, snow accumulation and melting, and icing conditions on the river.

Each scenario outlined in the subsequent sections was analyzed over three varying climatological periods of 6 months (May 1 – October 31); a representative wet period, dry period, and average period. These time periods were selected from the period of 1993 through 2003, the only period for which the full data set of climatological model inputs is available. Criteria for selecting representative years were as follows:

- Dry, Average, and Wet periods are defined to be as near as possible to the 10th, 50th, and 90th percentile, respectively, of daily average streamflow in the mainstem from May – October, and total precipitation from May–October. Percentiles are representative of the full period of record for which streamflow is available (back to the 1920s and 1930s), not just the ten-year record of complete input data availability. The dry year record included low flows in the mainstem river that are representative of 7Q10 conditions, or the lowest flow that can be statistically expected to occur over 7 days in a 10-year period.

- The average and wet periods were not unduly influenced by heavy snowmelt in the spring – that is, the streamflow and precipitation was representative of statistically significant precipitation over the entire period of May–October.

- The frequency and total discharge volume of CSOs were qualitatively commensurate with the total precipitation—that is, the dry period is characterized by fewer CSO impacts than the wet period.

Table 4-9 summarizes the selected periods and key statistics that supported their selection. Figure 4-21 illustrates the key percentiles for the time period from which the representative years were selected.

Table 4-9: Selected Periods for Simulation Analysis[1]

	Climate Condition	*Representative Periods for analysis (May–Oct)*	*Daily Average Streamflow*		*Total Precipitation[3]*		*Percent of total precip in May*	*Total CSO[4]*	
			Cfs at Lowell	*%-ile[2]*	*Inches*	*Inches*		*MG*	*%-ile*
Periods for Analysis	Dry	*1993*	*3,200*	*10*	*16.5*	*18*	*5%*	*250*	*22%*
	Average	*1994*	*4,700*	*41*	*20.0*	*43*	*26%*	*678*	*75%*
	Wet	*1998*	*8,100*	*92*	*25.5*	*83*	*17%*	*1,610*	*96%*
Reference Stats	10%	*–*	*3,200*		*15.0*		*7%*	*130*	
	Average	*–*	*5,200*	*55*	*21.0*	*51*	*14%*	*602*	*62%*
	90%	*–*	*7,900*		*27.3*		*26%*	*1,067*	

1. *All statistics are for the period of May–October only*
2. *Streamflow statistics computed for the period 1924–2002*
3. *Precipitation statistics computed for the period 1855–2003 at Lowell*
4. *CSO statistics based on simplified NetSTORM model of all CSO communities. 1948–2003 simulated using Boston hourly data*

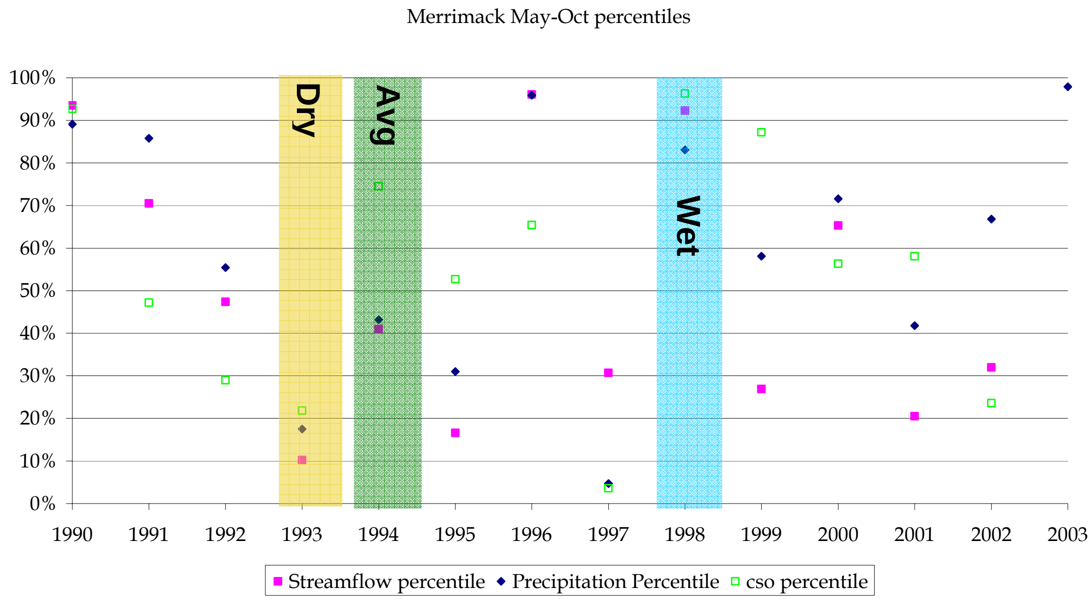


Figure 4-21: Selected Periods for Simulation Analysis

4.4.3.2 Simulation Scenarios

Simulation scenarios were generally divided into three categories:

Existing Conditions:	Baseline conditions before any CSO abatement occurred (infrastructure representative of roughly 1999 – 2000).
Sensitivity Analysis:	Theoretical removal of pollutants by source type to test the sensitivity of water quality in the receiving waters to each source.
Planned Improvements:	Simulation of abatement plans in accordance with consent agreements, and simulation of alternative methods of abatement for point sources and nonpoint sources throughout the basin.

Table 4-10 identifies the scenarios that were analyzed.

Table 4-10: Simulation Scenarios

Type of Analysis	Scenario Code	Scenario Description	Details
Existing Conditions	Baseline	Existing conditions prior to recent system improvements (circa 1999 – 2000)	
Sensitivity: Reduced CSO Load	1D	100% removal of CSO loads	
Sensitivity: Reduced Nonpoint Source Loads	2A	Urban runoff: 100% reduction	All impervious runoff assumed to have no pollutant load
	2B	Septic systems: 100% reduction	
	2C	All other NPS: 100% reduction	Loads from all surface runoff, septic systems, and interflow eliminated
	2D	All surface runoff removed	
	2E	Interflow *and* surface runoff eliminated	
	2F	Lower tributary baseflow concentration	Background levels of bacteria in urbanized basins adjusted to levels in upper Merrimack basin (non-urban)
Sensitivity: Reduced conc. in mainstem WWTP effluent	3D	TP = 0.1 mg/l Nit = 3 mg/L	Baseline Scenario #3D P 2.0 0.1 N-Org 9.0 1.8 NH_3 3.0 0.0 NO_X 3.0 1.2
Sensitivity: Reduced conc. in tributary WWTP effluent	4D	TP = 0.1 mg/l Nit = 3 mg/L	Baseline Scenario #4D P 2.0 0.1 N-Org 9.0 1.8 NH_3 3.0 0.0 NO_X 3.0 1.2

Type of Analysis	Scenario Code	Scenario Description	Details
Sensitivity: Alternative Dam Operations (Mainstem)	5A	Full Run of River	All four dams in the mainstem study area were simulated with run-of-river operations
Planned Improvements: Phase I CSO Control Plans	6A	Manchester	• WWTP upgraded to 70 mgd • Elimination of CSOs discharging to Piscataquog • Elimination of CSOs at Victoria St, Crescent Rd, Poor St, and Schiller Rd.
	6B	Nashua	• WWTP upgraded to 110 mgd • Upgraded and/or separated CSOs 001, 002, 003, 004, 005
	6C	Lowell	• WWTP upgraded to 110 mgd • Improved grit and diversion facilities • Partial sewer separation: Sixth/ Emory Ave, Gorham St, Warren St.
	6D	Greater Lawrence Sanitary District	• Improved grit removal and screening • Increased secondary treatment capacity • Secondary bypass/disinfection facilities • 10-acre disconnection at Honeywell site • Separation along Broadway
	6E	Haverhill	• Improved primary treatment • Improved grit removal • WWTP upgraded to 60 mgd • Numerous overflow weirs raised • Essex and Lafayette CSOs closed • Siphon gates remain open during storms
	6F	ALL 5 Communities	All 5 communities simulated with Phase I CSO improvements listed in 6A – 6E
Planned Improvements: CSO Phase II Control Plan Alternatives	7A1	Manchester	• Screening/Disinfection of remaining CSOs to 4 OF/year level (Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge.) • Use 3-month design storms for sizing
	7A2	Manchester	• Full separation of remaining CSOs
	7A3	Manchester	• Storage to 3-month level at Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge. • Use design storms for sizing
	7A4	Manchester	• Storage to 6-month level at Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge. • Use design storms for sizing
	7B1	Nashua	• Full Separation
	7B2	Nashua	• Screening/Disinfection at E. Hollis/Burke St (49.4 MGD peak capacity) • 40,000 Gallon storage at Farmington Road CSO • 10,000 Gallon storage at Burke Street CSO
	7C1	Lowell	• Separation of Warren Street (Area A, ~757 ac) • WWTP upgrade (to 150 MGD) • Beaver Brook – Pipeline storage • Tilden Street – $6 million partial storage • Merrimack – Separate 110 acres
	7C2	Lowell	• Storage of remaining Warren St area (Area B- ~727 ac and Area C- ~542 ac) • WWTP upgrade (to 150 MGD)

Type of Analysis	Scenario Code	Scenario Description	Details
			• Beaver Brook – Pipeline storage • Tilden Street – $6 million partial storage • Merrimack – Separate 110 acres
	7D1	GLSD	• Do Nothing
	7D2	GLSD	• Expand WWTP to 165 MGD
	7D3	GLSD	• Partial separation to 3-month level of control
	7D4	GLSD	• Satellite storage facilities, 0.245 mg at CSO 002 and 3.39 mg at CSO 004 (Table 7-10, LTCP)
	7E1	Haverhill	• Do Nothing
	7E2	Haverhill	• 7.8 MGD (0.2 acre) Treatment facility at Bradford Ave (3 Month Control Level) • 9.1 MGD (0.45 acre) treatment facility at Little River (3 Month Control Level)
	7F	ALL 5 Communities	Combination of Scenarios 7A3, 7B2, 7C2, 7D2, 7E2, implemented together
Full CSO Separation	8	ALL 5 Communities	All combined sewer systems simulated as fully separated
Possible Improvements: Nonpoint Source Reductions	9A	With Baseline CSO Loading	Bacteria concentrations in stormwater throughout watershed reduced by approximately 20%. Also, background concentrations of fecal coliform in extremely polluted tributaries (Salmon Brook, Spickett River, Shawsheen River) reduced to 5,000 counts per 100 ml.
	9B	With Phase I CSO Plans	
	9C	With Phase II CSO Plans	
	9D	With Full CSO Separation	

4.4.3.3 Simulation Results

Model results are summarized in Section 6.3. Detailed model results for all scenarios are included in Appendices B–G. Appendix B is comprised of results for watershed-wide evaluation, and the accompanying compact disc includes comprehensive results for all river segments, all days, all pollutants, and each of the three representative climate conditions. Appendices C–G include city-specific results for Manchester, Nashua, Lowell, GLSD, and Haverhill. Additionally, Section 6.4 of this report expands on the discussion of results by including costs of alternatives and an evaluation of tradeoffs.

4.4.4 Modeling Technical Review Committees

Two Technical Review Committees (TRCs) were convened during the model development and calibration process. The TRC served as the peer review group for the modeling work.

The purpose of the first TRC, held on July 9, 2004, was to review the model development and initial calibration plans so that any modifications could be made to the models prior to calibration. The following people participated in the meeting:

Study Sponsors:

- Barbara Blumeris, USACE Study Manager
- Townsend Barker, USACE H&H Specialist
- Bob Ward, City of Haverhill
- Paul Jessel, City of Haverhill

Technical Review Committee:

- Billy Johnson, USACE Engineering Research and Development Center (ERDC)
- Dr. Linfield Brown, Tufts University
- Dr. Steven Chapra, Tufts University
- Dr. Brendan Harley, CDM Water Resources Group Manager
- Mike Schmidt, CDM Technical Reviewer
- Mike Savage, CDM Technical Reviewer
- Rich Wagner, CDM Modeling Expert

CDM Modeling Team:

- Gary Mercer, P.E., Project Manager
- Kirk Westphal, P.E., Project Manager
- Beth Rudolph, P.E., Engineer
- Matt Long, Engineer
- Matt Heberger, E.I.T., CFM, Engineer

The meeting minutes and responses from the first technical review are provided as an appendix to the *Simulation Model Development* report (CDM, 2005).

The purpose of the second TRC, held on March 9, 2005, was to review the model calibration and overall performance so that any adjustments could be made prior to using the models for predictive analysis. The following people participated in the meeting:

Study Sponsors:

- Barbara Blumeris, USACE Study Manager
- Townsend Barker, USACE H&H Specialist
- Chris Hatfield, USACE Project Advisor
- Richard Hogan, Greater Lawrence Sanitary District
- Bob Ward, City of Haverhill

- Mario LeClerc, City of Nashua

Technical Review Committee:

- Billy Johnson, USACE Engineering Research and Development Center (ERDC)
- Dr. Linfield Brown, Tufts University
- Dr. Steven Chapra, Tufts University
- Dr. Brendan Harley, CDM Water Resources Group Manager
- Mike Schmidt, CDM Technical Reviewer

CDM Modeling Team:

- Gary Mercer
- Kirk Westphal
- Matt Heberger
- Mitch Heineman
- Richard Wagner

The meeting minutes, responses, and summary of model revisions from the second technical review are provided as Appendices to the *Simulation Model Development* report (CDM, 2005). The committee agreed that the models were suitable for predictive modeling of abatement strategies, with the following general caveats:

- The models are probably slightly less responsive to pollutant loads than the actual river system.
- The downstream boundary conditions for bacteria may not be fully representative of variable conditions in the estuary and ocean.

Based on these two technical reviews, the models were applied to simulate abatement strategies in the watershed, and to generate information to help guide decision-making by relating abatement strategies to instream improvements.

Section 5
Problems and Opportunities

This section presents both a summary of existing conditions and an overview of the potential water quality and ecological restoration opportunities, to be further evaluated in future project phases.

Ecological restoration throughout the watershed may help improve water quality in the mainstem of the Merrimack and its tributaries as well as enhance the communities and populations of organisms that depend on the Merrimack.

Section 5.1 briefly discusses existing conditions in the river basin. Section 5.2 previews opportunities for water quality improvements, and Section 5.3 discusses the opportunities for ecological restoration in the Merrimack Watershed.

5.1 Existing Conditions Summary

In fulfillment of Task Order 1A of Contract number DACW33-02-D-0005: *"Evaluation of Existing Conditions"* a report entitled *Description of Existing Conditions* was submitted to the Corps New England District and the five sponsor communities in January 2003. The purpose of the report was to:

- Communicate the current state of the watershed to project participants, sponsors, and interested stakeholders.

- Serve as a reference during subsequent evaluations and comparisons, especially the sections on designated use attainment and water quality.

A summary of the information found in this report is presented in the following sections.

5.1.1 Water Quality

Historically, the water quality of the Merrimack River was severely degraded by industrial and domestic wastes. In the 1960s, the River was listed as one of the nation's ten most polluted waterways, primarily as a result of raw sewage, paper and textile mill wastes, and tannery sludge (USEPA, 1987).

The passage of the Federal Clean Water Act in 1972 ushered in a period of rebirth for the River. An infusion of large amounts of state and Federal funding for water resources infrastructure, such as wastewater treatment plants (WWTPs), helped restore the river as a significant natural and economic resource for the New England region.

Despite the significant improvements, further work to improve water quality is required. For example, a 1997 study conducted as part of the Merrimack River Initiative (MRI) indicated that the four largest causes of non-support of designated uses in the basin are pollution from (1) urban runoff, (2) natural sources, (3) municipal point sources, and (4) combined sewer overflow (CSO) discharges.

This study also identified elevated bacteria counts as the primary cause of non-supporting use in the basin, followed distantly by low dissolved oxygen concentrations and high nutrient levels (Donovan and Diers, 1997). Other issues of concern include low-flow conditions, water supply, flooding, contamination of shellfishing beds, and fish and wildlife habitat and contamination issues.

The primary water quality data collection agencies in the watershed have been state and federal agencies, including the New Hampshire Department of Environmental Services (NHDES), the Massachusetts Department of Environmental Protection (MADEP), and the USGS. Recently, several volunteer monitoring programs have also begun collecting data within the watershed with the help of these state agencies and the Merrimack River Watershed Council.

The majority of the water quality data that exists in the basin from MADEP was collected prior to 1990. NHDES also collected water quality and biomonitoring data in the watershed throughout the 1990s. Before the sampling done for this project, the most recent comprehensive analysis of the river's quality was performed under the Merrimack River Initiative (MRI) during the 1990's.

This project was a collaborative effort between the USEPA, NHDES, MADEP, and the New England Interstate Water Pollution Control Commission. The MRI collected water quality samples throughout the basin during one wet-weather and one dry-weather event; benthic macroinvertebrate sampling was also performed.

Both Massachusetts and New Hampshire categorize waters according to their use class. Each class is associated with a series of designated uses; the ability of a waterbody to support these uses is assessed based on its ability to meet the applicable water quality standards.

In New Hampshire, designated use categories include swimming (or primary contact recreation), fish and shellfish consumption, drinking water, and aquatic life support. In Massachusetts, these uses include fish consumption, aquatic life support, drinking water, shellfishing, primary contact recreation (swimming), and secondary contact recreation (boating).

In general, the most recent statewide surface water assessments published by Massachusetts and New Hampshire in 2002 show that elevated bacteria counts (*E. coli* and fecal coliform) are the largest cause of water quality violations in the Merrimack River mainstem. This translates into non-attainment of the primary and secondary contact recreation use in the majority of the River downstream of Manchester, New Hampshire, as well as a closure of the shellfishing beds in the tidally influence portion of the River.

The New Hampshire assessment report lists CSOs as the primary cause of these violations; Massachusetts does not provide a similar listing. The Massachusetts assessment report also lists metals, nutrients, and priority organics as significant problems along the mainstem, resulting in a non-attainment of the aquatic life use.

Additionally, the recent MRI study also discovered exceedances of water quality standards for lead and zinc in the lower portion of the River during wet and dry-weather conditions, affecting aquatic life in the river. Table 5-1 summarizes the major causes of non-supporting use in the Merrimack River mainstem based on the states' 2002 assessment reports.

Table 5-1: Causes of Non-support in the Merrimack River Mainstem

Pollutant	**Listed Miles/Area[1]**			**Non-supporting Use**
	NH	*MA*	*Total*	
Pathogens	19.82 mi	27.9 mi, 7.14 mi^2	47.72 mi, 7.14 mi^2	Primary and secondary contact recreation (MA and NH), shellfishing (MA only)
Metals	–	20.8 mi	20.8 mi	Not listed
Nutrients[2]	–	18.7 mi	18.7 mi	Not listed
Priority Organics	–	15.9 mi, 6.97 mi^2	15.9 mi, 6.97 mi^2	Not Listed
pH	4.88 mi	–	4.88 mi	Aquatic Life
Unionized Ammonia	–	4.37mi^2	4.37mi^2	Not Listed
Flow Alteration	0.59 mi	–	0.59 mi	Aquatic Life

[1] Area (in mi^2) is provided for the tidally influenced portion of the basin in Massachusetts
[2] Massachusetts does not specify which nutrients are a problem; however, phosphorus is generally the limiting nutrient in freshwater and nitrogen the limiting nutrient in marine waters.
Source: MADEP 2002, NHDES 2002

Elevated bacteria counts were also identified as a major problem on many of the tributaries to the Merrimack River, particularly in the Massachusetts portion of the basin. This means that the primary and secondary contract recreation use is not supported in listed areas.

Additionally, violations of the pH criteria for aquatic life support were identified in a majority of the New Hampshire tributaries.

The Massachusetts assessment report listed metals, nutrients, and organic enrichment/ low dissolved oxygen as the other top causes of designated use non-attainment. The MRI study also discovered elevated concentrations of lead during wet and dry-weather in the Sudbury/Assabet/Concord (SuAsCo) and Nashua River watersheds, as well as elevated copper concentrations in the SuAsCo watershed.

5.1.2 Resource Summary

The Merrimack River watershed is a high value resource area that supports a range of biological, recreation, and other resources, such as hydropower and public drinking water supplies. The watershed also supports a range of important habitats, as follows:

- **Aquatic Habitat**—These habitats include quickwaters in the northern portion of the watershed, cold and warm water fisheries throughout the watershed, and an estuarine environment in the River's lower reaches.

- **Riparian Habitat**—The diversity of river riparian habitat provides a valuable resource for wildlife. One of the riparian habitats found along the mainstem Merrimack River, the pitch pine/scrub oak barrens, is considered globally rare and supports the only identified New England population of Karner blue butterfly, a federally-listed endangered species. The river corridor is also a significant breeding and wintering area for bald eagles, and the lower river and coastal area support breeding and migrating piping plovers.

- **Freshwater Wetland Habitat**—Freshwater wetlands play an integral role in the ecology of the Merrimack River corridor. The combination of high nutrient levels and primary productivity found in these habitats is ideal for the development of organisms forming the base of the food chain.

- **Tidal Wetland Habitat**—The vulnerable freshwater/saltwater habitat in the lower 22 miles of the mainstem River supports a wide range of aquatic species, including extensive shellfishing beds (which are currently closed due to elevated bacteria counts).

Biological resources in the watershed include shellfish populations in the tidally influenced portions of the mainstem Merrimack River, various resident and anadromous fish populations, and numerous threatened and endangered species. In the past 20 years an extensive anadromous fish restoration program has been implemented on the Merrimack River designed to bring back extirpated stocks of the endangered Atlantic salmon, American shad, alewife, and blueback herring. The largest threats to the fish populations currently include mercury and polychlorinated biphenyl (PCB) contamination, hydromodification, thermal pollution, and flow regulation resulting in insufficient in-stream flow.

The Merrimack River watershed also supports a range of primary and secondary contact recreation activities, including a Class II and III rapids and slalom kayaking course in Manchester, New Hampshire, a public beach at the Lowell Heritage State Park, and numerous marinas and private boat docks. In addition, hiking, camping, cross-country skiing and picnicking are popular activities associated with the River and adjacent back areas. The portion of the mainstem River from its origin at

Franklin, New Hampshire to the backwater impoundment at Hooksett Dam is under Congressional study for designation to the Wild and Scenic River System.

In additional to the biological and recreational resources, the watershed supports a variety of economic uses, including seven hydroelectric dams, which currently operate on the mainstem Merrimack River and the Pemigewasset River. The mainstem River also supports numerous public and industrial water users along its length.

5.1.3 Pollution Source Summary

Water quality in the Merrimack River mainstem is affected by both point and non-point source pollution. Municipal wastewater treatment plants, CSOs, stormdrain discharges, and industrial dischargers are considered to be the largest cause of point source pollution in the watershed. These sources contribute significantly to the non-attainment of designated uses throughout the basin. Both CSO and stormdrain pollution are generally a wet-weather problem, whereas municipal and industrial dischargers are a continuous source.

The primary sources of non-point source pollution in the watershed include: urban and non-urban stormwater runoff, atmospheric deposition, natural sources (such as wildlife and waterfowl populations), pet waste, *in situ* contaminants, agricultural runoff, septic systems, illicit connections, and groundwater plumes from sites regulated under the Resource Conservation and Recovery Act (RCRA) and from landfills. Unlike point source discharges, pollution from non-point sources is very difficult to quantify and remediate. However, these sources may contribute significantly to the non-attainment of designated uses in the Merrimack River watershed.

5.2 Overview of Water Quality Opportunities

The *Merrimack River Monitoring Report*, submitted in May 2006, summarizes two activities:

- Collection of water quality data to determine the relative likelihood that segments of the mainstem Merrimack River meet state water quality standards.
- Collection of water quality and streamflow data sufficient for the calibration and validation of water quality and hydrologic/hydraulic models being developed under this study.

The first activity directly supports the intent of this section: to investigate opportunities to improve the water quality.

In general, the monitoring program results suggested that during dry weather the mainstem Merrimack River was close to meeting regulatory standards for most criteria measured, although some tributaries do not meet standard during dry weather. However, quality in the river during wet weather exhibits noncompliance with state water quality standards in numerous locations.

There are, therefore, more opportunities to make improvements to the mainstem wet weather water quality than dry weather water quality. There are opportunities for both dry and wet weather improvements in many of the tributaries.

5.3 Opportunities for Ecological Restoration

Ecological restoration throughout the watershed may help improve water quality in the mainstem of the Merrimack and its tributaries as well as enhance the communities and populations of organisms that depend on the Merrimack. This section will present the connection between ecological restoration opportunities and water quality.

Opportunities to improve the overall ecological health and condition of the Merrimack River watershed include projects aimed at directly improving water quality and projects focusing on ecological restoration. This latter group includes projects that benefit the watershed and may also indirectly influence water quality in the Merrimack.

As an example, restoration of a wetland within the watershed would allow for increased water quality functions such as sediment/contaminant retention, nutrient uptake and filtering, etc., ultimately having a positive effect on downstream resources including the Merrimack River. Also included in this group of opportunities are projects that can address important ecological issues such as habitat and greenway connectivity, and habitat scarcity of those listed or special status species that exist within the watershed.

5.3.1 Approach

A literature review was conducted to identify the ecological issues of concern within the watershed beyond the water quality impacts. Numerous studies have been conducted on the water quality and ecology of the watershed by a wide variety of organizations, municipal, non-governmental, and private, and many were helpful in identifying issues that need to be addressed. Section 5.4 lists materials that were reviewed.

Once the literature review was completed, the project team contacted stakeholder groups and federal and state agencies with connections to the watershed and compiled existing plans and priority projects designed to improve ecological health. Each of these groups has a geographic region of focus within the watershed and an area of environmental interest that may be narrow or broad.

For example, the Massachusetts Watershed Initiative works within the lower watershed while the SuAsCo Community Watershed Council works only on the Sudbury-Assabet-Concord River Watershed, a subwatershed of the Merrimack. Both of these groups have plans for potential projects that, although differing in location and focus, will improve the health of the Merrimack watershed through ecological restoration. Written plans that were reviewed include:

- Merrimack River 5-year Watershed Action Plan, Massachusetts Watershed Initiative, 2002
- Strategic Plan for Restoration of Anadromous Fish to the Merrimack River, USFWS Central New England Fishery Resources Office, 2002
- New Hampshire's Wildlife Action Plan, NH Fish and Game Department, 2005
- Piscataquog Watershed Association -Watershed Action Plan
- SuAsCo Watershed 5-year Watershed Action Plan, 2005

After the literature review was conducted, the project team contacted many of the agencies or groups working within the watershed in order to gather additional ideas for restoration opportunities. Contact was made with the following organizations:

Massachusetts and New Hampshire Governmental Agencies

- MA Office of Coastal Zone Management (CZM), and its Wetland Restoration Program
- MA Comprehensive Wildlife Conservation Strategy
- MA Division of Marine Fisheries (DMF)
- MA Watershed Initiative
- MA Riverways Program
- MassWildlife
- Natural Heritage Institutes of Massachusetts and New Hampshire
- NH Audubon
- NH Estuary Program
- NH Fish and Game Department (NHF&G) Anadromous Fish Restoration Program
- NH Department of Environmental Services (NHDES) Watershed Assistance Section
- NH F&G Nongame and Endangered Wildlife Program
- NH Coastal Program

- NH Estuaries Project

Federal Agencies

- US Fish and Wildlife Service (FWS) Partners for Fish and Wildlife Program
- Natural Resource Conservation Service (NRCS)
- US Army Corps of Engineers (ACE)
- US Department of Agriculture (USDA) Forest Service

Non-Governmental Agencies

- The Nature Conservancy (TNC)
- Society for the Protection of New Hampshire Forests (SPNHF)
- Piscataquog Watershed Association (PWA)
- Merrimack River Valley Trout Unlimited (TU)
- Corporate Wetlands Restoration Partnerships (CWRP) of Massachusetts and New Hampshire
- University of New Hampshire - Jackson Lab
- Merrimack River Anadromous Fish Committee (MRAFC)
- Nashua River Watershed Association
- Souhegan River Local Advisory Committee (SoRLAC)

In addition to the activities described above, senior project team members with experience working within the watershed were consulted for ecological restoration ideas.

The project opportunities identified fall into six categories, and are discussed either briefly, or in detail where possible. These six categories are:

1. Fisheries/aquatic species
2. Water quality
3. Soils/erosion control
4. Terrestrial rare species and wetlands
5. Marine/estuarine
6. Riparian resources

5.3.2 Fisheries/Aquatic Species

The Merrimack River watershed provides critical habitat for anadromous, catadromous and resident fish species as well as numerous other aquatic species.

Some of these species and their habitat have been impacted by poor water quality, alteration of stream courses, development, and agriculture. Improvement or enhancement of this habitat could enhance the health and populations of these species.

Habitat improvement and enhancement opportunities in the watershed for fish and aquatic species include a wide variety of activities in addition to direct water quality improvement. These activities include streambed enhancement or naturalization, riparian habitat improvement (Section 5.3.7), upstream and downstream fish passage improvement, provision of adequate stream flow and mitigation of temperature changes, among others. Specific examples of projects that could enhance fisheries or aquatic life habitat in the Merrimack watershed are discussed here.

In Massachusetts, anadromous fish, specifically Atlantic salmon (*Salmo salar*), American shad (*Alosa sapidissima*) and river herring (alewife, *A. pseudoharengus*, and blueback herring, *A. aestivalis*), are managed by a Merrimack River Anadromous Fish Committee (MRAFC) comprised of:

- Massachusetts Division of Marine Fisheries (DMF)
- Massachusetts Division of Fisheries and Wildlife
- New Hampshire Fish and Game (NHF&G)
- US Fish and Wildlife Service (FWS)
- National Marine Fisheries Service (NMFS)
- USDA Forest Service

Management strategies are implemented by the mutual consent of these agencies. The first two obstructions on the Merrimack River, the Essex Dam in Lawrence and the Pawtucket Dam in Lowell, have been equipped with fish passage facilities since the mid-19th century (Reback 2004).

Dam projects that contain potential for fish passage restoration, as outlined in *Survey of anadromous fish passage in coastal Massachusetts: Part 4. Boston and North Coastal* (MA DMF Technical Report 18, 2004) include:

- Removal of the Mill Street and Lake Gardiner Dams on the Powwow River in Amesbury, MA;

- Removal of Clarks Pond Dam on the Back River, a tributary to the Powwow River that enters below the Mill Street dam in Amesbury, MA. This relatively low head dam blocks passage into the 6.8 acres of potential habitat provided by Clarks Pond. Small numbers of river herring have been observed in the stream;

- Addition of a fish ladder or partial breach of the Dam at Route 133 on the Shawsheen River; and

- Addition of a fishway at the Talbot Mills Dam in Billerica, MA on the Concord River.

Additionally, FWS evaluated the Boott Station fish lift and fish ladder facility at the Pawtucket Dam in Lowell, MA in 2002 and determined the facility to be ineffective for fish passage beyond this dam (Sprankle, 2005). Video monitoring indicated that from 1989 to 2001, only 17% of the American shad that passed Essex Dam were counted at Pawtucket Dam.

Further studies revealed that a combination of an ineffective fish ladder and the interaction between the tailrace configuration and turbine discharge prevent fish passage. Further study is needed to determine the structural or operational design modifications that could alleviate the problem. Repairing this fishway and effectively passing fish upstream should be a priority to enhance the anadromous fish runs in the Merrimack.

In New Hampshire, NHF&G has listed the following dams as having good potential to increase fish passage if they were removed: Upper IPC Dam in Bristol, Goldman Dam in Milford, Merrimack Village Dam in Merrimack, the Dam at Salmon Brook in Nashua, and the Smith River Dam in Wolfeboro. Also, NHDES has been evaluating dam removal at Black Brook in Manchester, NH and Maxwell Pond Dam. Black Brook is a tributary to the Merrimack and enters the river just upstream of the Amoskeag Dam and Fishways.

The dam at Maxwell Pond was built in 1901 for ice harvesting purposes. Since that time, sedimentation behind the dam has reduced the depth of the pond from 30 feet to 8 feet. The pond is full of emergent wetland plants in the summer months, impairing recreation. The City of Manchester Parks & Recreation Department owns and operates a small park along the shore of the pond and also owns land and trails all along Black Brook upstream of the pond.

This greenway is an impressive corridor in Manchester that affords residents a unique opportunity to access the Brook along recreational trails. The removal of the dam would open up the brook and reconnect it to the Merrimack River and provide about 7 miles of free-flowing stream habitat and remove a barrier to fish.

In addition to the dam removal on Black Brook, the brook itself courses through the Aggregate Industries property off Dunbarton Road. This gravel/cement processing facility has poorly installed culverts that prevent fish passage during the summer months. Debris jams are also common, which creates flooding on the Aggregate property and subsequent erosion and sedimentation into the brook.

Establishment of proper buffers along this reach and the replacement of the culvert crossings with single span, natural stream bottom bridges would improve the connectivity of the brook and restore biological balance to the stream system.

Projects other than dam removal or fish passage enhancements have been identified that could enhance habitat for fish or aquatic species. Both NHF&G and FWS have a list of such potential ecological restoration projects including:

- Assessment, design, and removal of non-dam barriers, such as culverts, to the passage of diadromous (American Shad, river herring, Atlantic Salmon, American eel, rainbow smelt) and resident (trout and other coldwater species) fish;
- Assessment, design, and removal of tidal restrictions to restore degraded salt marsh habitat to appropriate tidal regimes and salinities;
- Support of efforts to restore diadromous fish populations (e.g. American Shad, river herring, Atlantic Salmon, rainbow smelt) to the NH and MA portions of the Merrimack River watershed;
- Other projects targeted at improving riparian habitat for birds and other terrestrial species

Both of these agencies expressed interest in working with the US Army Corps of Engineers (ACOE) and state natural resource agencies and other partners to collaboratively develop specific projects as more information is provided.

5.3.3 Nonpoint Source Pollution

This section provides a brief overview of nonpoint source pollution in the Merrimack River basin. Identifying specific sources of nonpoint source pollution was not the main emphasis of Phase I of the Merrimack watershed Assessment Study. The general information below is the result of a quick survey of watershed stakeholders and published information. Much more work is needed in this area to target specific areas and recommend solutions to nonpoint source pollution problems.

Discussions with agencies and watershed groups about water quality problems from Concord, NH downstream suggest a general awareness that nonpoint-source pollution problems exist throughout the watershed and contribute to poor water quality on the mainstem of the Merrimack and its major tributaries. These watershed-wide water quality issues are primarily the result of a combination of increased development and agricultural practices.

Many municipalities bordering the Merrimack are currently implementing Phase II stormwater requirements mandated by EPA under the National Pollutant Discharge Elimination System (NPDES) permit program. This includes all communities on the river south of Hookset in New Hampshire, and all communities in Massachusetts.

Phase I of the program, begun in 1990, regulates communities of more than 100,000 with municipal separate storm sewer systems (MS4s). By definition, this does not include communities with combined sewer systems. In 2003, EPA began Phase II, to regulate communities with MS4s in "urbanized areas" defined by the census, and construction activities which disturb 1–5 acres. For communities with both combined and separate systems, the NPDES stormwater requirements only affect those areas serviced by the separate system.

Under NPDES Phase II requirements, the communities are required to develop a storm water management program that implements six minimum measures, which focus on a Best Management Practice (BMP) approach. The BMPs chosen by the MS4 must significantly reduce pollutants in urban storm water in a cost-effective manner.

1. **Public Education and Outreach Program** on the impacts of storm water on surface water and possible steps to reduce storm water pollution. The program must be targeted at both the general community and commercial, industrial and institutional dischargers.
2. **Public Involvement and Participation** in developing and implementing the Storm Water Management Plan.
3. **Elimination of Illicit Discharges to the Separate Storm Sewer System**.
4. **Construction Site Storm Water Runoff Ordinance** requires the use of appropriate BMPs, pre-construction review of Storm Water Pollution Prevention Plans (SWP3s), site inspections during construction for compliance with the SWP3, and penalties for non-compliance.
5. **Post-Construction Storm Water Management Ordinance** that requires the implementation of structural and non-structural BMPs within new development and redevelopment areas, including assurances of the long-term operation of these BMPs.
6. **Pollution Prevention and Good Housekeeping** for municipal operations such as efforts to reduce storm water pollution from the maintenance of open space, parks and vehicle fleets.

Thus, the NPDES Phase II program provides the permitting framework and impetus for many of the non-point measures recommended in this report. Communities will be challenged to find funds and the technical capacity to carry out some of these measures. Furthermore, the effectiveness of these efforts will be challenging to predict or quantify.

Implementation of best management practices (BMPs) throughout the watershed (both urban and agricultural) as well as maintenance of existing BMPs is critical to the ultimate success of nonpoint source control. Development using low impact development (LID) techniques has the potential to minimize development impacts on water quality. These techniques are particularly well suited for lake and stream-front properties where development is taking place within the riparian buffer.

NHDES has been working with The Merrimack County Conservation District and the Natural Resource Conservation Service (NRCS) at Morrill's Farm in Concord, NH. The Morrills currently pasture a portion of their livestock herd on land directly adjacent to the Merrimack River.

The livestock are allowed free access to the river, resulting in deposition of manure directly in the river and increased erosion along the banks. Installation of electric fencing and pasture pumps will separate the cows from the river and provide the herd with fresh water on a year round basis. NHDES would be a willing partner on a project at this site.

A project at this location will not only have direct impacts on improving the water quality (both bacteria and nutrients) in the Merrimack River but will also promote the continuation of responsible farming along the banks of the Merrimack River. Preservation of rural character of the region is usually a high priority for town planning efforts. This project would also afford an opportunity to establish some test plots for varying-width buffers along the river.

Historically, the reach of the Merrimack River above the Amoskeag Dam has been a roosting area for gulls and other waterfowl, as well as for bald eagles. Gulls have the potential to greatly influence the concentrations of bacteria and nutrients in the river above the dam and downstream. While numbers of gulls has declined since the closure of the Manchester landfill west of Route 293, there remains a substantial population.

The size and impact of this residual population and perhaps others along the river should be evaluated and measures to further discourage roosting (such as eliminating anthropogenic food sources) could be investigated. However, as this area is also an important roosting area for eagles, any programs to discourage gulls should be done with the utmost care to avoid disturbance to these important predators.

Before any planning on work near the Amoskeag Dam, detailed discussions should be held with groups knowledgeable about the area and the eagles, including US Fish and Wildlife, Manchester Conservation Commission, and NH Fish and Game Department.

Salmon Brook is a major tributary of the Merrimack River in Nashua. The brook has high bacteria counts and many sources of nonpoint pollution from erosion, roads and parking lots, residential and commercial property, trash, animal waste and stormwater drains. The portion of the brook that includes Fields Grove Park is heavily polluted from trash dumping, runoff from eroded banks, animal waste and road and parking lot runoff.

The City of Nashua and the Salmon Brook Greenway Committee (SBGC) have applied for a Watershed Assistance and Restoration Grant from NHDES. The following are included in the proposed erosion-control restoration plan: a neighborhood clean-up day, and development and implementation of a plan to reduce runoff entering the brook.

If the proposed plan receives funding, Nashua and SBGC would test bacteria counts from May through October at several key locations to identify the major contributing bacterial sources. Volunteers would work with Nashua's Department of Public Works (DPW) to re-vegetate eroding areas in the park.

Also included in the Salmon Brook restoration plan are efforts to educate local businesses and abutters on the importance of vegetating streambanks on their property. The restoration goals include plans to:

- Assess bacteria counts and identify sources from Fields Grove Park up to the Main Street section of the brook
- Reduce animal waste, fertilizers, and petroleum by-products entering the brook by 33% by re-vegetating and planting shrubs and grasses in open areas abutting the brook in Fields Grove Park
- Add vegetation along the Chestnut Street entrance to Fields Grove Park to capture road runoff; re-vegetate four heavily eroded banks in Fields Grove Park and abutting properties
- Stabilize approximately 1000 feet of the brook's banks from Fields Grove Park to Main Street
- Remove trash from the brook from Fields Grove Park to Main Street

5.3.4 Soils and Riverbank Erosion Control

Erosion in the Merrimack watershed can be split into two general categories: (1) Loss of topsoil in the watershed due to disturbances such as site development and transportation projects; and (2) river shoreline or bank erosion. Both types of erosion can significantly alter the water quality and ecology of receiving waters by adding nutrients, covering critical aquatic habitat, filling wetlands and impounded areas and reducing water clarity.

Erosion control represents another tool for improving water quality and aquatic habitat. This section presents opportunities previously identified by NHDES, as well as those identified during this study.

In November and December 2002, the study team performed a reconnaissance-level survey of eroded banks, discharge pipes, culverts and tributaries discharging into the

Merrimack River from Hooksett, New Hampshire to Plum Island, Massachusetts (November 2003). Results are documented in the interim task report entitled *Summary of Information on Pollution Sources (*CDM, 2004).

During the assessment, erosion areas greater than 50 feet in length (estimated length along the river bank) were visually inspected and photographed. The assessment was performed along 10 reaches. The individual river reaches and the number of erosion sites documented per river reach is listed in Table 5-2.

Table 5-2: Number of Documented Streambank Erosion Sites on the Merrimack River

River Reach	Documented Erosion Sites
Hooksett	20
Manchester	5
Nashua North	6
Nashua South	17
Tyngsborough	2
Lowell South	4
Lawrence	11
Essex	0
Haverhill	0
Amesbury	0
Total	**65**

The bank erosion observed along the Merrimack River can be divided into two major types: full bank and bank toe. Full bank erosion was the dominant type observed, with some undercutting of the bank toe. Where full bank erosion was observed, the banks appeared to consist of fine-grained soil, had little vegetative cover and had a steep slope angle (Figure 5-1).

Where undercutting was observed, the erosion appeared to be limited to the lower portion of the bank (Figure 5-2). Most of the observed bank erosion was found along undeveloped sections of the river, although some development (roads and buildings) encroached into the riparian zone.

In general, bank erosion can be a significant source of sediment loading within a drainage basin. Since the objective of the assessment was solely to identify and document areas where bank erosion is evident, insufficient information is presently available to estimate how much sediment is being contributed to the Merrimack River from these areas.

Data required to needed to estimate of the amount of sediment produced from these areas include, at a minimum: the rate of erosion, dimensions of the eroded areas, and characterization of bank material grain size. Currently, information on the rate of sediment loss from streambanks is limited, thus it is difficult to assess its impact on aquatic habitat.

Based on observations made during the assessment, large-scale bank erosion along the lower Merrimack River is not evident, but localized areas of erosion have been identified.

While erosion is generally an undesirable process, it does have a positive side: erosion of riverbanks adds large woody debris to the river. These branches and limbs provide instream habitat for fish and are a significant natural nutrient source for aquatic organisms.

Figure 5-1: Example of full bank type erosion along the Merrimack River in Hooksett, Nee Hampshire

Figure 5-2: Example of bank erosion by undercutting near Nashua, NH

The restoration of riverbanks to reduce the contribution of sediment and sediment-associated nutrients to the Merrimack River could be accomplished using a phased approach. The first phase of this process, the identification of eroding banks, has been partly completed with the survey performed as part of this study.

The second phase would be to prioritize the riverbanks based on the risk posed to important infrastructure (bridges, roads, houses and utilities) and aquatic/riparian habitat. This phase would require a more detailed field survey to identify those locations where infrastructure and/or habitat are or potentially are at risk.

In the third phase, the sites identified as being high priority would be surveyed so that conceptual restoration designs could be prepared. In developing a conceptual restoration design, bioengineering techniques should be considered.

Bioengineering reduces the use of hard structures such as retaining walls or rock rip rap in the riparian zone, as they have little habitat value. Re-grading and replanting riverbanks is proven to reduce bank erosion. Where necessary, biodegradable materials such as soil control blankets, coir logs, coir-fiber geotextiles and soilbags, can be used to stabilize steeply-sloping riverbanks.

Additionally, NHDES has identified three bank stabilization opportunities along tributaries of the Merrimack River that could benefit the watershed.

The first potential project is Thoreau's Landing, a 34-acre complex of 94 condominiums along the Merrimack and Nashua Rivers in Nashua, NH. The area is losing riverbank and trees along the Merrimack River at an alarming rate. Slumping and undercutting threatens to undermine several buildings.

Evidence of sediment deposition is found throughout the main river channel at and below the project site. Approximately 230 shoreline trees are in danger of collapsing into the river. The loss of existing riverbank soils has been estimated to be between 500-1000 cubic yards.

The City of Nashua has applied for an Emergency Status Wetland Dredge and Fill Permit in order to stabilize a 2800-foot section of the northwest shoreline of the river as soon as possible. This would be a highly visible project site and a good opportunity to incorporate natural channel design techniques and biostabilization practices.

A project at Thoreau’s landing would require involvement the US Army Corps of Engineers (COE), Federal Emergency Management Agency (FEMA), NHDES, and the City of Nashua.

The second of three streambank stabilization projects under consideration by NHDES is on the Baker River in Warren Village and the Town of Rumney, NH. In the 1940s, approximately 7,000 feet of the Baker River were dredged, straightened, channelized and diked. This has resulted in bank instability and lateral channel migration that now threatens infrastructure and degraded in-stream habitat and biota.

NHDES is studying several reaches on the Baker for restoration projects. NHDES, NHF&G and the NH Dept of Transportation (NHDOT) are all involved in scoping projects on the river. River restoration is needed to stabilize the river and to establish a sustainable channel that will pass floodwaters without damaging homes and businesses along the river.

Repairs to two town-owned bridges in Warren Village are required after nearly every flood event.

There is extensive active erosion along the entire reach and many sections of the river are braided. As a result, aquatic habitat has been severely degraded and there is a significant sediment and nutrient load delivered to the river system during high water. In 2004, a private consulting firm completed a geomorphic assessment and developed a restoration plan for the entire reach.

The Town of Rumney has held two public meetings and is very supportive of the project, though they have minimal funds to contribute. Additionally, all abutting landowners within 5,000 feet of the project reach (phase 1) have given written permission for the project to proceed, as the construction would occur on their properties. NHDES has some funding set aside for this effort but requires non-federal match to get things started.

The third restoration project under consideration by NHDES and Trout Unlimited is on the Pemigewasset River at Exit 31 on Route 93 in Woodstock, NH. Many years ago flooding breached an active gravel operation and much of the channel flow was re-routed. Sediment filled a significant volume of the gravel pit, reducing the depth of the pond that had become a well-known cold-water fishery. The NH Trout Unlimited Council has been working on a restoration plan for approximately 4,800 feet of the river for a number of years.

Preparation of the restoration plan was funded under a NHDES Watershed Restoration Grant awarded to the Pemigewasset Chapter of Trout Unlimited in 2003. The goals of the restoration project include: stabilization of the river, reduction of bank erosion and land loss (over 350 feet of west bank breach), restoration of the pond to the west (formerly 30-acre pond reduced to approximately 19 acres), and enhancement of in-stream and off-channel fisheries habitat.

This restoration plan will return the channel to a more natural condition and continue to allow access to the pond during high flows in order to provide access to spawning and nursery habitat for juvenile fish species. There are signed letters from abutting property owners along the reach that indicate their support for a restoration project. The local chapter of Trout Unlimited has been the driving force behind this project. This would be a highly visible project since it can be seen from I-93 near Exit 31.

5.3.5 Terrestrial Rare Species and Wetlands

NHF&G considers the protection and enhancement of rare or declining nongame species and communities to be a priority within the watershed. According to NHF&G Wildlife Action Plan (2005), the following species are found in the watershed and could benefit from enhancement, restoration and protection of targeted habitat: the New England Cottontail Rabbit (*Sylvilagus transitionalis*), Brook Floater Mussel (*Alasmidonta varicosa*), Eastern Hognose Snake (*Heterodon platyrhinos*), Blanding's Turtle (*Emydoidea blandingii*), and Bald Eagle (*Halaieetus leucocephalus*). Pine barrens and forested floodplains are particularly rare and valuable habitats worthy of protection.

Both NHF&G and Massachusetts FWS have a list of such potential ecological restoration projects including:

- Protection of riparian and wetland habitats for breeding and wintering bald eagles (throughout the study area) and protection of coastal habitats for breeding and migrating piping plovers (in the lower river);

- Protection of wetland, riparian, and upland forest habitats important to state-listed species; and
- Acquiring agricultural properties with areas such as freshwater marshes, oxbows, etc. for migratory birds and waterfowl.

Bald Eagle Habitat

There is a high-profile opportunity to protect Bald Eagle wintering and nesting habitat from Concord, NH south to the estuary. Eagles roam over large stretches of the riverbank; protecting and enhancing habitat for eagles also benefits a number of other species. Construction of a new bridge Manchester Airport will result in additional monitoring and enhancement (artificial nesting platforms) of eagle habitat as the NH Department of Transportation fulfills its permit obligations.

The airport project will also produce a bald eagle habitat management plan for selected public properties in the study area; this report is of interest as it may identify further restoration or enhancement opportunities.

Wetlands

Freshwater wetlands have the capacity to directly influence water quality of surface and ground waters. The water quality functions of wetlands are well documented, and include reducing flood flows, removing and retaining sediment and toxics, uptake of nutrients, and stabilizing shoreline.

Wetlands are important buffers against upland non-point pollutant sources by filtering and cleansing runoff before it reaches a surface water body. Other functions such as fish and wildlife habitat, groundwater recharge and discharge, aesthetic and recreational values combine to make wetlands an important natural resource both directly bordering the Merrimack and higher in the watershed.

Opportunities to restore and enhance wetlands will increase the functional capacity of the wetlands, and ultimately provide water quality benefits to downstream waters.

As an example of a wetland restoration project, the Nashua River Watershed Association (NRWA) plans to remove an infestation of water chestnut (*Trapa natans*). The aquatic water chestnut was widely cultivated in Europe and Asia. It is not the same species whose roots you encounter in dishes at a Chinese restaurant; that is the Chinese water chestnut, *Eleocharis dulcis*. *Trapa natans* escaped cultivation in North America in the 1800s, and is a non-native, invasive species. It has spread to cover over 45 acres in Pepperell Pond, an impoundment on the Nashua River located in Pepperell and Groton, Massachusetts (See Figure 5-3).

Water chestnut has also taken root farther upstream in the Nashua region of the Nashua River. The plants create an impenetrable mat of growth that makes the water inaccessible to boating and fishing. Their growth can replace more ecologically valuable native plant species. When the dense mats die off in the fall, they sink and decay, which depletes oxygen levels vital to fish and aquatic life and produces a noxious odor.

Recreational on and near the river have been impacted. There is a high potential for the plants to spread and invade downstream areas. Attempts have been made to hand-pull the weed from Pepperell Pond using canoes and kayaks. However, the extent of the infestation has grown to the point where the only practical method of plant removal is mechanical harvesting.

Such a project would likely take three to five years, working each summer, to remove the plant to the point where controlling the weed by hand pulling is again feasible. Harvesting would take place for approximately four weeks each summer at the critical time before the plant reaches maturity and drops its seed nuts.

NRWA has organized a committee of stakeholders, including the conservation agents from the towns of Groton and Pepperell, to evaluate the water chestnut situation and pursue funding for its removal.

Some of the logistical issues involved with the eradication include:

- Determining if a commercial harvesting company is most efficient to remove the weeds, or if a harvester and operator can be borrowed from governmental agencies or local groups (e.g., FWS, lakes associations);
- Locating and building a landing area for removal of the plant to the shore;
- Finding a location to compost the large mass of plant material (local farmers would benefit from the plant as compost; farmers near Lake Champlain in Vermont readily use the plants on fields);
- Pursuing equipment (e.g., dump trucks, backhoes) and funding from Pepperell and Groton to help move the plants from the shore to the composting area;
- Pursuing funding and cooperation from organizations, such as bass fishing groups and Ducks Unlimited.

The total cost for the project is estimated to be approximately $500,000 for commercial harvesting performed by professional weed control specialists. This cost includes the harvesting equipment, operators, and offshore movement of plant material. It does not include building a ramp for offloading the chestnuts or preparing the associated filings for permits.

NRWA and the stakeholders are eager to move forward with this restoration project, as the situation becomes exponentially worse with each passing year.

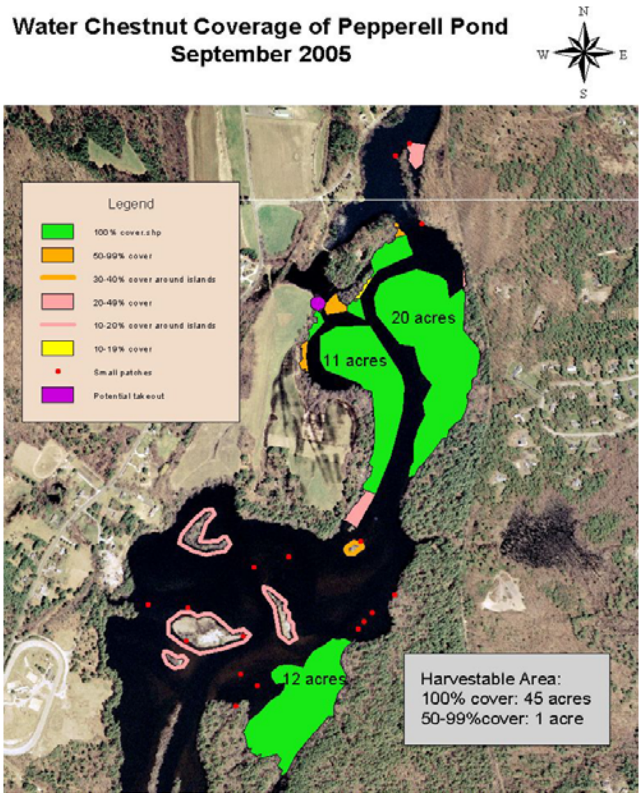


Figure 5-3: **Water Chestnut in Pepperell Pond**

The Piscataquog River Watershed Association (PWA) has prepared a Conservation Plan that identifies locations of rare species habitat in need of restoration and locations of invasive species that should be addressed.

The South Branch of the Piscataquog in New Boston, New Hampshire south of Gregg Mill contains former brook floater mussel habitat that has been heavily impacted by fishermen. The brook floater has been steadily declining in this area; a 2004 survey found none. Stream bank restoration is needed to mitigate in-stream impacts.

Wild Blue Lupine (*Lupinus perennis*) habitat could be restored on the banks of the Merrimack River below the Route 114 Bridge. Some efforts have been made to replant this species after a landowner dumped material on the riverbank and destroyed the native bed. This area also contains habitat for other rare species, including the frosted elfin butterfly (*Callophrys irus*) which is dependent on native lupine.

The invasive aquatic plant species Eurasian Water-Milfoil (*Myriophyllum spicatum*) has been identified in Scoby Pond in Francestown, NH and Gorham Pond in Dunbarton, NH. Removal of these infestations could allow for native species to flourish in these locations. Terrestrial invasive species Japanese knotweed (*Polygonum cuspidatum*) and honeysuckle have been encroaching on the rich native habitat on the riverbank of the Piscataquog River behind the County Home in Goffstown, NH.

5.3.6 Marine/Estuarine

Activities and processes in the watershed have altered the Merrimack River estuary. The estuary may be among the most vulnerable of the resources of the Merrimack River since it is located at the downstream end of the watershed and, as such, the ecological community is a reflection of the cumulative impact of all of the activities that occur in the watershed.

Impacts to the resources of the estuary are the result of nutrient, and bacterial loading, sedimentation, shoreline erosion and changes in populations of anadromous and catadromous fish species. Marine and estuarine opportunities include restoration of critical habitats such as eelgrass and salt marsh, as well as restoration of soft-shell clam harvesting areas.

The Massachusetts Office of Coastal Zone Management (CZM) has identified restoration of eelgrass beds within the Great Marsh as a high priority. The Great Marsh is the largest continuous stretch of salt marsh in New England, extending along the northern Massachusetts coast from Cape Ann, MA north to New Hampshire, including the mouth of the Merrimack River.

Eelgrass beds are important shallow water habitat for juvenile finfish, crustaceans, and shellfish, which commonly inhabit sea grass meadows. Eelgrass meadows form the foundation for primary production that supports numerous species. These meadows are very important to the coastal marine ecosystem.

Human activities have caused the loss of many coastal eelgrass beds in Massachusetts; however, restoration of these beds is possible. Eelgrass meadows can restore themselves naturally by spreading from healthy environments to adjacent sediments. However, physical and biological changes that take place at a site after eelgrass disappears can make natural re-colonization difficult. Direct transplantation can accelerate the process by decades.

In addition, the removal of wastewater inputs, heavy organic loads, and siltation is very important to successful eelgrass restoration efforts. Water quality improvements can result in measurable reversal of environmental degradation; a decrease in nutrient loading, particularly nitrogen levels, increases water clarity and eelgrass survival by decreasing epiphytic growth and algal blooms. Macroalgal growth within the meadows, which can shade out newly developing eelgrass shoots, is diminished.

CZM's Wetland Restoration Program (WRP) has identified numerous potential salt marsh restoration sites within the Great Marsh. While the effort is still in the draft stage, it includes approximately 15 sites in Salisbury at the mouth of the Merrimack. The projects range from less than 1 acre to over 50 acres in size and involve physical habitat alterations such as dredge material removal and elimination of tidal restrictions. T

The restorations would result in enhancement of many coastal wetland functions, including a reduction of invasive plant species such as Phragmites (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*), a concurrent increase in native salt marsh species, and improved tidal exchange, fish and wildlife habitat, recreation and aesthetics.

The WRP is in the process of prioritizing the various salt marsh restoration sites in Great Marsh, with a summary report to be released in early 2006. Assistance in restoring some of these sites could improve the ecological functioning of the salt marshes and estuary in the Merrimack, enhancing existing functions and providing more long-term stability against rising sea levels.

In addition to CZM's work within the Great Marsh, researchers at UNH's Jackson Lab have identified Joppa Flats, at the mouth of the Merrimack River in Newburyport, MA for eelgrass replanting. It is likely that low salinity prevented eelgrass from extending upstream, but within Newburyport an extensive eelgrass bed and associated fish and bird species were historically supported. The eelgrass bed died in the 1980s because of water quality issues.

Various species of algae (both phytoplankton and macroalgae) thrived because of higher nutrient concentrations; resulting phytoplankton blooms reduced light penetration, eliminating eelgrass in areas of insufficient light. Epiphytic macroalgae further exacerbated this problem by colonizing the remaining eelgrass strands and weighing them down so that the blades were kept below the optimal light zone. Improvements to water quality could reduce the phytoplankton and algae blooms, and give replanted eelgrass beds a high chance of survival.

The MA Division of Marine Fisheries has closed several softshell clam beds in the Merrimack estuary due to high fecal coliform bacteria counts. The Division has made efforts to re-open these beds and expects to re-open some of them soon for depuration harvesting.

Depuration is a process that permits the purging of shellfish gastrointestinal contents under controlled conditions to remove microbes or chemicals which may be injurious to the consumer. State regulations require closure of shellfish beds within a buffer zone around wastewater discharges. There are a number of flats in Newburyport that are outside the buffer zone, but close enough to the buffer that the state believes adequate warning cannot be provided to diggers when water quality conditions deteriorate.

In Salisbury, MA some flats are closed because of high fecal coliform counts. Poor water quality conditions in the tributary creeks are probably related to development and failing septic systems. Improvements to water quality throughout the river may allow these shellfish beds to be reopened, and the potential exists for them to be restocked and/or managed for increased yield. Decisions to close flats are often made based on rainfall, a less expensive (and less accurate) measure than water sampling. A change in sampling methods could potentially result in fewer closures in some areas.

The Merrimack Valley Planning Commission (MVPC) has been working to develop a circulation model of the lower part of the Merrimack River estuary. They plan to use dye tracers to examine how water moves through the estuary, as well as to identify a typical "time of travel" for waters moving through the estuary and out into the ocean. The MVPC has applied for a grant to conduct a portion of the dye trace work. The results will assist in future planning efforts to reduce impacts to new shellfish beds within the estuary.

5.3.7 Riparian Resources

The riparian zone is critical to the functioning of a healthy river ecosystem. This "edge" provides habitat for a number of plant and animal species reliant both on upland and water resources. In addition, the riparian zone provides a critical buffer between activities on the land and the river and tributaries.

In recent years, development and transportation have been pushed into the riparian zone throughout the watershed. Ironically, some of this encroachment into the riparian zone has been in response to improvements in the condition of the river, which have changed proximity to the river from a detriment to an asset.

One example is the Riverwalk and related development in Manchester, NH. The challenge is to develop near the river in a manner that showcases the river while preserving the natural functions of the riparian zone and the species that depend on it.

The Upper Merrimack River Local Advisory Committee (UMRLAC) has identified some small projects mostly focused on river access points because of the potential for nonpoint source contaminants to concentrate. A "car-top" river access in Boscawen, NH, could be converted to porous pavement to stabilize bank erosion and prevent additional damage.

In Concord, NH, a new river access point proposed behind the Everett Arena could be redesigned to reduce the potential for shoreline erosion and nutrient transport.

UMRLAC is also looking at the historic rail lines along the river as greenway connections between Boscawen & Canterbury, NH. Purchase of these parcels or placement of them under conservation easement could allow for future protection of these ecological corridors.

The location of rail corridors prohibits development along the riverbank and serves as a buffer to wildlife. Similar situations, rail corridors or other lands along the river which may be conserved for additional protection of riparian communities, may exist in other communities along the river.

5.4 Literature Review and Contacts

5.4.1 Literature Review

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5.4.2 Contacts List

The persons contacted during the writing of Section 5.3 are listed below. The authors wish to thank the below for their kind assistance with this work.

- Peter Thippen, Merrimack Valley Planning Commission (MVPC) and Mass Bays, phone and email
- Al Macintosh, MVPC, email
- Elizabeth Campbell, Nashua River Watershed Association, phone, email

- Tony Wilbur, MA Coastal Zone Management (CZM)
- Hunt Durey, MACZM Wetland Restoration Program, phone
- Cheri Patterson, NH Fish and Game Department (NHF&G)
- Joan Kimball and Cindy Delpapa, MA Waterways
- John Magee, NH F&G, phone
- Eric Derleth, US Fish and Wildlife Service (FWS)
- Steve Landry and Eric Williams, NH Department of Environmental Services (NH DES)
- Todd Baldwin, Merrimack Valley Chapter of Trout Unlimited
- Michelle Tremblay, Upper Merrimack River Local Advisory Committee, phone
- Nancy Bryant, SuAsCo Watershed Community Council
- Fred Short, University of New Hampshire- Jackson Lab, phone and email
- Stephanie Cunningham, MADMF, phone
- Tim Purinton, Riverways Program, email
- Lori Sommer, NHDES Wetlands Bureau, phone
- Margaret Watkins, Piscataquog Watershed Association, phone
- Fred Britton, Thoreau's Landing Condominium Association, phone, email
- Paul Currier, NH Department of Environmental Services, phone
- David Neils, NH Department of Environmental Services, phone

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Section 6
Alternative Watershed Plans

6.1 Metrics Used in Evaluation

The simulation models used in this study were capable of outputting information in terms of pollutant concentrations and flows in 140 reaches of the mainstem Merrimack River, and over various time intervals. The project stakeholders were convened in a workshop setting to define the most effective ways to aggregate this data into "performance measures" for evaluating river improvements under various restoration/abatement strategies.

6.1.1 Summary of Prospective Performance Measures

The following organizations participated in the workshop to define the performance measures used in the simulation modeling:

- United States Army Corps of Engineers, New England District
- Sponsor Communities
- United States Environmental Protection Agency
- Massachusetts Department of Environmental Protection
- New Hampshire Department of Environmental Services
- United States Geological Survey
- Merrimack Valley Planning Commission
- Merrimack River Watershed Council

Prospective performance measures were grouped into a matrix of four categories (as illustrated in Table 6–1):

- Evaluating water quality improvements using water quality standards (discrete scale, Yes/No)—*Upper left quadrant of Table 6–1*
- Evaluating water quality improvements using comparative or relative measures (continuous scale)—*Upper right quadrant of Table 6–1*
- Evaluating attainment of beneficial uses using compliance with water quality standards (discrete scale, Yes/No)—L*ower left quadrant of Table 6–1*
- Evaluating attainment of beneficial uses using comparative improvements in water quality (continuous scale)—*Lower right quadrant of Table 6–1*

Naturally, many of the performance measures were included in multiple categories, as a way of distinguishing not only what key measures are important, but *why* they are important.

Table 6–1: Prospective Performance Measures for Simulation Modeling

Study Objective	Specific Drivers	Output Measure (based on hourly and seasonal analyses)	
		Compliance/Threshold Indicators	Comparative Output Measure (relative to existing conditions)
Recommend pollution abatement strategies that will provide the most significant return on investment with respect to **water quality**	Fecal coliform, *E. coli*, and *Enterococcus* counts	1. River segments/duration below state thresholds or EPA guidance limits	11. By reach: Reductions in peak concentration, average concentration, and total mass load for bacterial indicators (and visual comparison of traces)
		2. River segments/duration below other public health thresholds (1,000, 10,000…)	
	Dissolved oxygen levels	3. River segments/duration above state thresholds	12. By reach: Increase in peak DO concentration, average DO concentration, and min DO concentration (and visual comparison of traces)
	Nutrient/ chlorophyll-a levels	4. River segments/duration below national guidance limits	13. By reach: Reductions in peak concentration, average concentration, and total mass load for nutrients and chlorophyll -a (and visual comparison of traces)
		5. River segments/duration below other incremental thresholds	
Recommend pollution abatement strategies that will provide the most significant return on investment with respect to **beneficial uses.**	Recreation (primary and secondary contact)	6. River segments/duration below state thresholds or EPA guidance limits for bacterial indicators	14. Flow by river segment and seasonally
			15. Transparency relationships (e.g: chlorophyll-a vs. Secchi depth)
	Aquatic Habitat	7. River segments/duration above state thresholds for DO	16. By reach: Increase in peak DO concentration, average DO concentration, and min DO concentration (and visual comparison of traces)
		8. Not Used	17. Not Used
			18. Daily and Monthly flow
			19. Extent of tidal influence
	Shellfishing	9. Estuary segments/duration below state thresholds or EPA guidance limits for bacterial indicators	20. By estuary reach: Reductions in peak concentration, average concentration, and total mass load for bacterial indicators (and visual comparison of traces)
		10. Estuary segments/duration below national guidance limits for nitrogen	21. By estuary reach: Reductions in peak concentration, average concentration, and total mass load for nitrogen (and visual comparison of traces)
			22. Seasonal mass flux of nitrogen into estuary
	Water Supply	No compliance thresholds	23. Percentage of river withdrawn during low flow compared with existing conditions
			23a. Risk of pathogens affecting water supply
	Hydropower	No compliance thresholds	24. Compliance with state water quality standards and USEPA nation guidance by river segment and seasonally
	ALL USES		25. Projected use attainability for all applicable uses in each segment
	Aesthetics		26. Transparency relationships (e.g: chlorophyll-a vs. Secchi depth)

6.1.2 Prioritization of Performance Measures

Using a non-binding exercise, each workshop participant was given eight "votes" to prioritize the performance measures from Table 6–1 that would be most useful for their organizations to examine. Each person could use up to three votes for any single measure. The votes were tracked by the nature of the participants' organizations (CDM facilitated this process, but did not cast votes):

Blue:	Project Sponsors (48 total votes)
Green:	Regulatory Agencies (47 total votes)
Red:	State and Federal Scientific Agencies (16 total votes)
Yellow:	Other Stakeholders (32 total votes)

The results of the voting exercise are included as Figures 6–1. The results were non-binding (due to the imbalance in representation among participant groups) but the exercise did yield a consensus group of performance measures that were carried forward for the remainder of the study. Institutional preferences and a summary of the consensus performance measures are discussed in the following section.

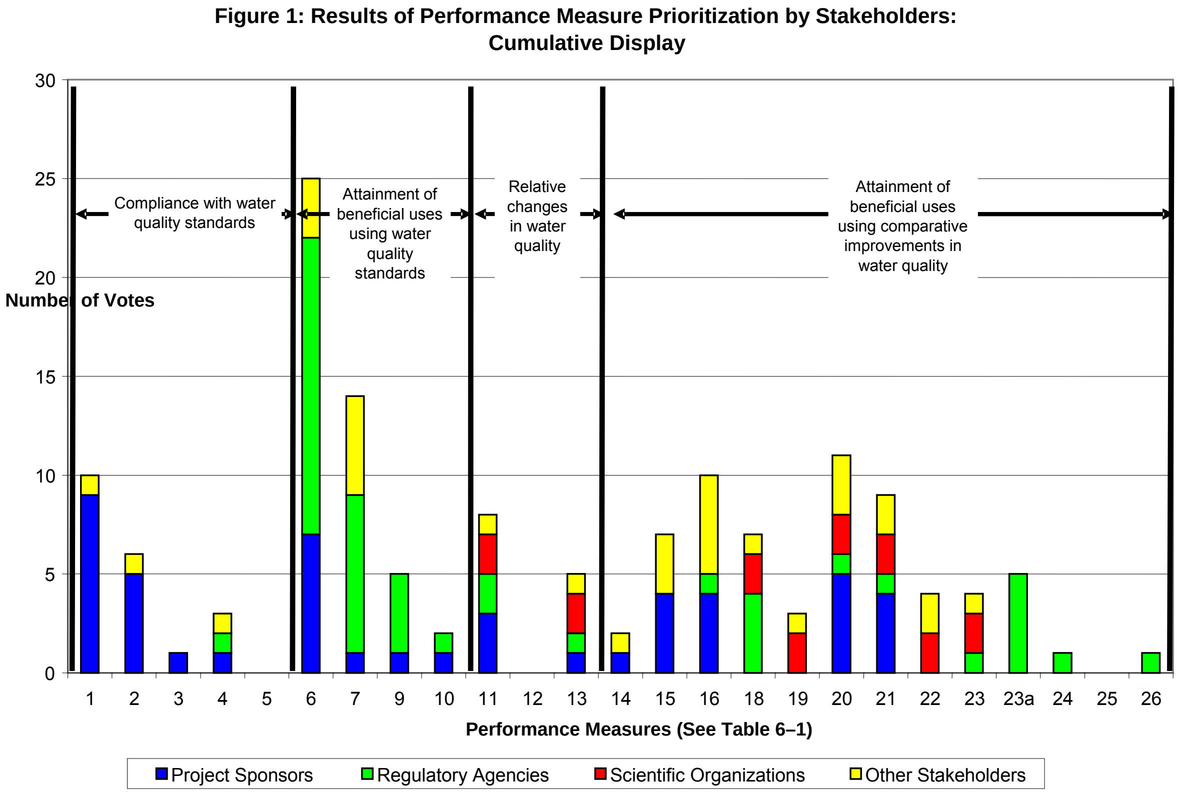


Figure 6–1
Stakeholder Prioritization of Performance Measures

6.1.3 Consensus on Key Performance Measures

This section summarizes the institutional preferences of the participating agencies, and concludes with identification of the consensus performance measures that were used for the simulation modeling. Reference numbers are taken from Table 6–1 and Figure 6–1.

Summary of Institutional Preferences

Project Sponsors: The two performance measures receiving the highest priority from the project sponsors were:

- #1: River segments/duration below state thresholds or EPA guidance limits for bacteria in the context of water quality
- #6: River segments/duration below state thresholds or EPA guidance limits for bacteria in the context of recreational uses of the river

Other measures receiving comparatively high priorities from project sponsors were river segments/ duration below other public health levels for bacterial indicators (#2), and bacterial flux into the estuary in the context of impacts to shellfishing (#20).

Regulatory Agencies: The two performance measures receiving the highest priority from the regulatory agencies were:

- #6: River segments/duration below state thresholds or EPA guidance limits for bacteria in the context of recreational uses of the river
- #7: River segments/duration above state thresholds for dissolved oxygen in the context of aquatic habit as a beneficial use.

Other measures receiving comparatively high priorities from the regulatory agencies were estuary segments/duration below state thresholds or EPA guidance limits for bacterial indicators in the context of supporting shellfishing (#9), daily and monthly river flows as a comparative measure of relative improvement in the support of aquatic habitat (#18), and the comparative risk of pathogens affecting water supply via proximity (#23a).

State and Federal Scientific Agencies (USGS): As the only state/federal scientific agency represented at the meeting, the USGS divided its priorities equally among eight alternatives (#11, #13, and #18 – #23). The first two deal with relative improvements in bacterial and nutrient concentrations, in the context of improved water quality. The other six deal with comparative improvements in the ability of the river to support aquatic habitat, shellfishing, and water supply.

Other Stakeholders The two performance measures receiving the highest priority from the other stakeholders were:

- #7: River segments/duration above state thresholds for dissolved oxygen in the context of aquatic habitat as a beneficial use.

- #16: Relative improvements in dissolved oxygen concentrations in the context of aquatic habitat as a beneficial use.

Other measures receiving comparatively high priorities from the other stakeholders were river segments/duration below state thresholds or EPA guidance limits in the context of recreational uses of the river (#6), transparency relationships in the context of supporting recreational uses (#15), and bacterial flux into the estuary in the context of impacts to shellfishing (#20)

Areas of Consensus

- Generally, the participants placed more emphasis on performance measures targeted at evaluating the attainment of beneficial uses than on evaluating water quality for its own sake, with the exception that project sponsors ranked the evaluation of compliance to bacterial standards for water quality improvement as the top priority. This does not suggest a significant divergence in thinking, however, as evidenced by the following bullet (bacterial indicators as a top priority can be considered in both contexts – compliance with standards and attainment of uses).

- By far, the greatest overall consensus was on the use of performance measure #6: River segments/duration below state thresholds or EPA guidance limits for bacterial indicators in the context of recreational uses of the river. This performance measure was given high priority by project sponsors, regulators (highest priority), and other stakeholders.

- Regulatory agencies and other stakeholders also ranked #7 as a high priority: River segments/duration above state thresholds for dissolved oxygen in the context of aquatic habitat as a beneficial use (though this was not a high priority for project sponsors).

- Project sponsors indicated that the flux of pollutants into the estuary in the context of shellfishing impacts was also a relatively high priority (#20 and #21). These measures also received votes from each other type of organization, though the vote count was comparatively small from the regulatory participants. This is significant because only two other measures received votes from all four types of organization (#11 and #13), and those votes were minimal.

Therefore, the following performance measures were used as the primary model output for the duration of the simulation study:

- *#6: River segments & duration below state thresholds or EPA guidance limits for bacterial indicators in the context of recreational uses of the river.*
- *#7: River segments/duration above state thresholds for dissolved oxygen in the context of aquatic habitat as a beneficial use.*
- *#20: Flux of bacteria into the estuary.*
- *#21: Flux of nitrogen into the estuary.*

All four of these primary performance measures were selected because of their broad appeal to numerous organizations, and because of the comparatively high emphasis that was placed on them.

Results of the modeling clearly showed that dissolved oxygen levels in the river are not impaired to the point at which they violate state water quality standards. Additionally, the types of management measures simulated did very little to increase the already high levels of dissolved oxygen levels in the river. Hence, this performance measure did little to differentiate alternative abatement strategies, and was effectively set aside with the understanding that pollution in the Merrimack River does not cause significant or worrisome oxygen depletion in the water column.

6.2 Reason for Selecting and Combining Alternatives

Table 6–2 lists the alternatives selected for modeling and evaluation, briefly discusses the reason that each alternative was included in this study, and why certain alternatives were combined:

Table 6–2: Watershed Management Alternatives

Scenario Code	Scenario Description	Details	Reason for Selection
6A	Phase I CSO Control Plan: **Manchester**	• WWTP upgraded to 70 mgd • Elimination of CSOs discharging to Piscataquog • Elimination of CSOs at Victoria St, Crescent Rd, Poor St, and Schiller Rd.	Ongoing programs in accordance with EPA consent agreements – selected in order to understand quantitative benefits to be expected. These alternatives are combined into #6F because all communities are expected to complete Phase I programs.
6B	Phase I CSO Control Plan: **Nashua**	• WWTP upgraded to 110 mgd • Upgraded and/or separated CSOs 001, 002, 003, 004, 005	
6C	Phase I CSO Control Plan: **Lowell**	• WWTP upgraded to 110 mgd • Improved grit and diversion facilities • Partial sewer separation: Sixth/ Emory Ave, Gorham St, Warren St.	
6D	Phase I CSO Control Plan: **GLSD**	• Improved grit removal and screening • Increased secondary treatment capacity • Secondary bypass/disinfection facilities • 10-acre disconnecton at Honeywell site • Separation along Broadway	
6E	Phase I CSO Control Plan: **Haverhill**	• Improved primary treatment • Improved grit removal • WWTP upgraded to 60 mgd • Numerous overflow weirs raised • Essex and Lafayette CSOs closed • Siphon gates remain open during storms	
6F	All Phase I CSO Control Plans	All 5 communities simulated with Phase I CSO improvements listed in 6A – 6E	
7A1	Long-Term CSO Control Alternatives: **Manchester**	• Screening/Disinfection of remaining CSOs to 4 OF/year level (Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge.) • Use 3-month design storms for sizing	Alternatives for Manchester subsequent to Phase I CSO Control
7A2		• Full separation of remaining CSOs	
7A3		• Storage to 3-month level at Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge. • Use design storms for sizing	
7A4		• Storage to 6-month level at Pennacook, Cemetery, Stark, Granite Street, Tannery Brook & East Bridge. • Use design storms for sizing	

Scenario Code	Scenario Description	Details	Reason for Selection
7B1	Long-Term CSO Control Alternatives: **Nashua**	• Full Separation	Alternatives for Nashua subsequent to Phase I CSO Control
7B2		• Screening/Disinfection at E. Hollis/Burke St (49.4 MGD peak capacity) • 40,000 Gallon storage at Farmington Road CSO • 10,000 Gallon storage at Burke Street CSO	
7C1	Long-Term CSO Control Alternatives: **Lowell**	• Separation of Warren Street (Area A, ~757 ac) • WWTP upgrade (to 150 MGD) • Beaver Brook – Pipeline storage • Tilden Street – $6 million partial storage • Merrimack – Separate 110 acres	Alternatives for Lowell subsequent to Phase I CSO Control
7C2		• Storage of remaining Warren St area (Area B- ~727 ac and Area C- ~542 ac) • WWTP upgrade (to 150 MGD) • Beaver Brook – Pipeline storage • Tilden Street – $6 million partial storage • Merrimack – Separate 110 acres	
7D1	Long-Term CSO Control Alternatives: **GLSD**	• Do Nothing	Alternatives for GLSD subsequent to Phase I CSO Control
7D2		• Expand WWTP to 165 MGD	
7D3		• Partial separation to 3-month level of control	
7D4		• Satellite storage facilities, 0.245 mg at CSO 002 and 3.39 mg at CSO 004 (Table 7-10, LTCP)	
7E1	Long-Term CSO Control Alternatives: **Haverhill**	• Do Nothing	Alternatives for Haverhill subsequent to Phase I CSO Control
7E2		• 7.8 MGD (0.2 acre) Treatment facility at Bradford Ave (3 Month Control Level) • 9.1 MGD (0.45 acre) treatment facility at Little River (3 Month Control Level)	
7F	All Communities: Representative Long-Term CSO Alternatives	Combination of Scenarios 7A3, 7B2, 7C2, 7D2, 7E2, implemented together	Combination of most likely long-term control plans
8	Full CSO Separation	All combined sewer systems simulated as fully separated	Basis of comparison to specific options
9A	NPS Reduction Only	Bacteria concentrations in stormwater throughout watershed reduced by approximately 20%. Also, background concentrations of fecal coliform in extremely polluted tributaries (Salmon Brook, Spickett River, Shawsheen River) reduced to 5,000 counts per 100 ml.	Understand the quantitative impacts of nonpoint source pollution abatement by itself and in conjunction with CSO abatement to see if a balanced approach is warranted
9B	NPS Reduction & Phase I CSO Control		
9C	NPS Reduction & Long-Term CSO Control		
9D	NPS Reduction & Full CSO Separation		

6.3 Screening of Alternatives with Model Results

Each alternative in Table 6–2 was analyzed with the simulation models discussed in Section 4.4 for three representative hydrologic seasons; wet, dry, and normal. Metrics were extracted from each model run in terms of the stakeholder-preferred metrics discussed in Section 6.1. River miles in compliance and frequency of exceedence of various bacteria levels were compared directly (see Section 4.4 and Appendix B), and were also normalized to cost in order to understand relative value of each alternative, or strategy.

Figure 6–2 illustrates the simulated results for dissolved oxygen in the river. The graph illustrates the minimum oxygen level simulated at each of the 140 river stations over the 180-day periods. It shows that at no time during any simulation run for existing conditions did dissolved oxygen levels in the river drop below the regulatory threshold of 5.0 mg/l. This includes the 7Q10 conditions that occurred in 1993. This finding was corroborated by the river monitoring program (see Section 4.2), during which oxygen levels were consistently measured above the threshold of 5.0 mg/l (including measurements during the six field surveys and two continuous 30-day surveys in Amoskeag and Pawtucket impoundments). Because existing conditions do not create impaired oxygen levels in the Merrimack River, it was not studied further as a response indicator for the abatement alternatives.

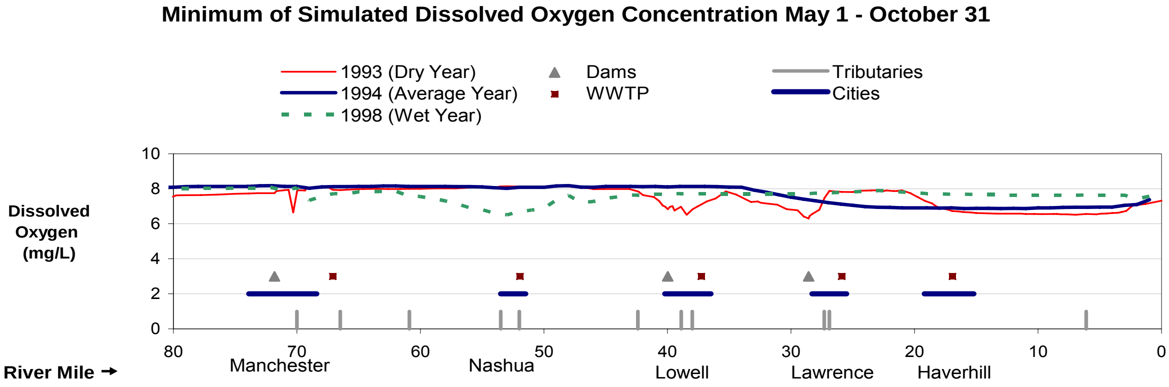
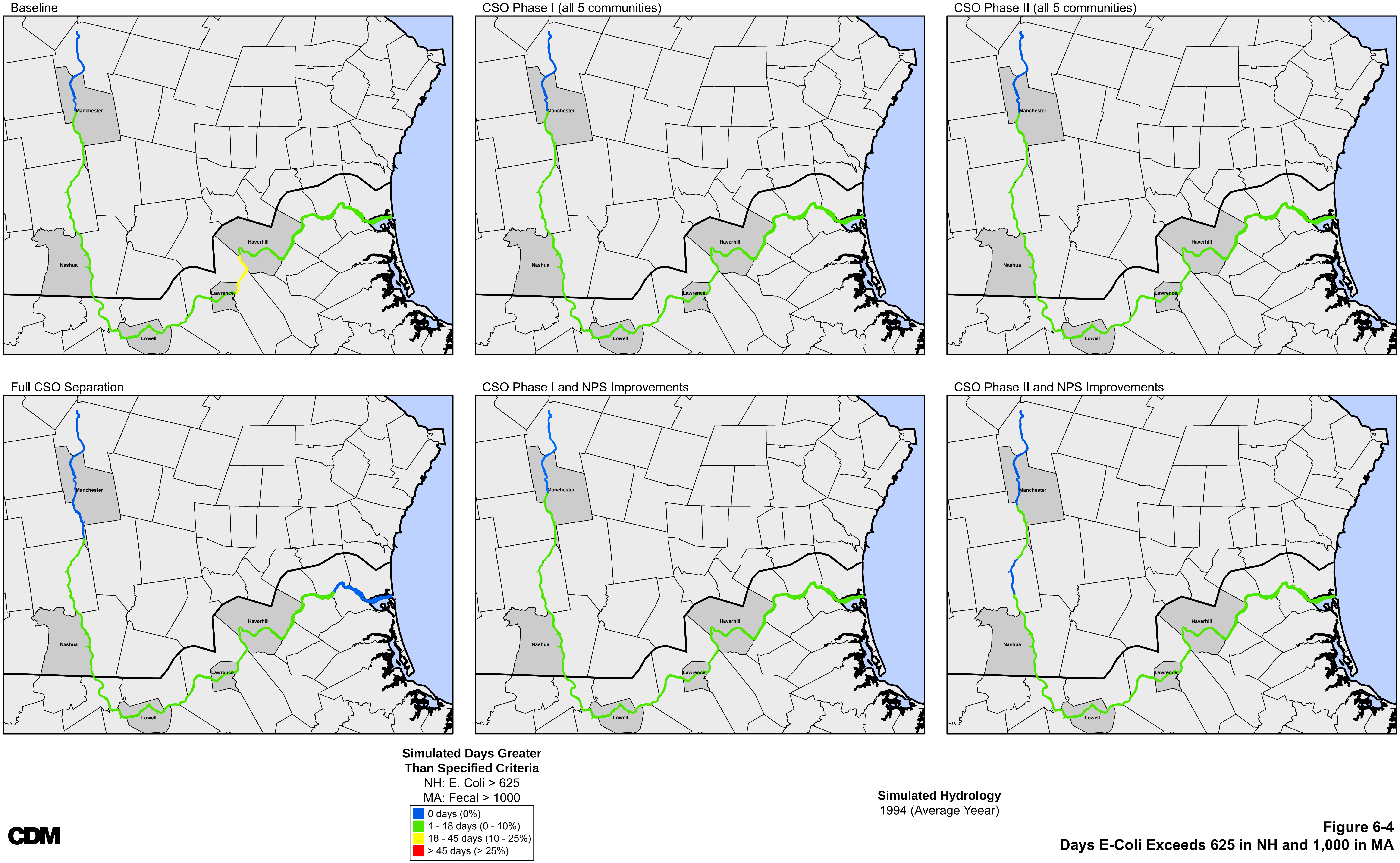


Figure 6–2
Modeling Results for Minimum Dissolved Oxygen – Existing Conditions

Figures 6–3 through 6–6 summarize the modeling results with respect to bacterial pollution abatement in the Merrimack Watershed. Figures 6-3 and 6-4 illustrate the number of days (out of the 180 day season with normal hydrology) that each of the 140 river segments exceeds *E. coli* standards or guidance levels. Figure 6–5 presents similar information with higher resolution, and Figure 6–6 illustrates how the modeling results translate into compliance with water quality standards. Recall from Section 4.2 (Table 4–6) that a surrogate standard was applied for New Hampshire reaches in addition to the published geometric mean standard to help distinguish the benefits of various abatement strategies.



Baseline

CSO Phase I (all 5 communities)

CSO Phase II (all 5 communities)

Full CSO Separation

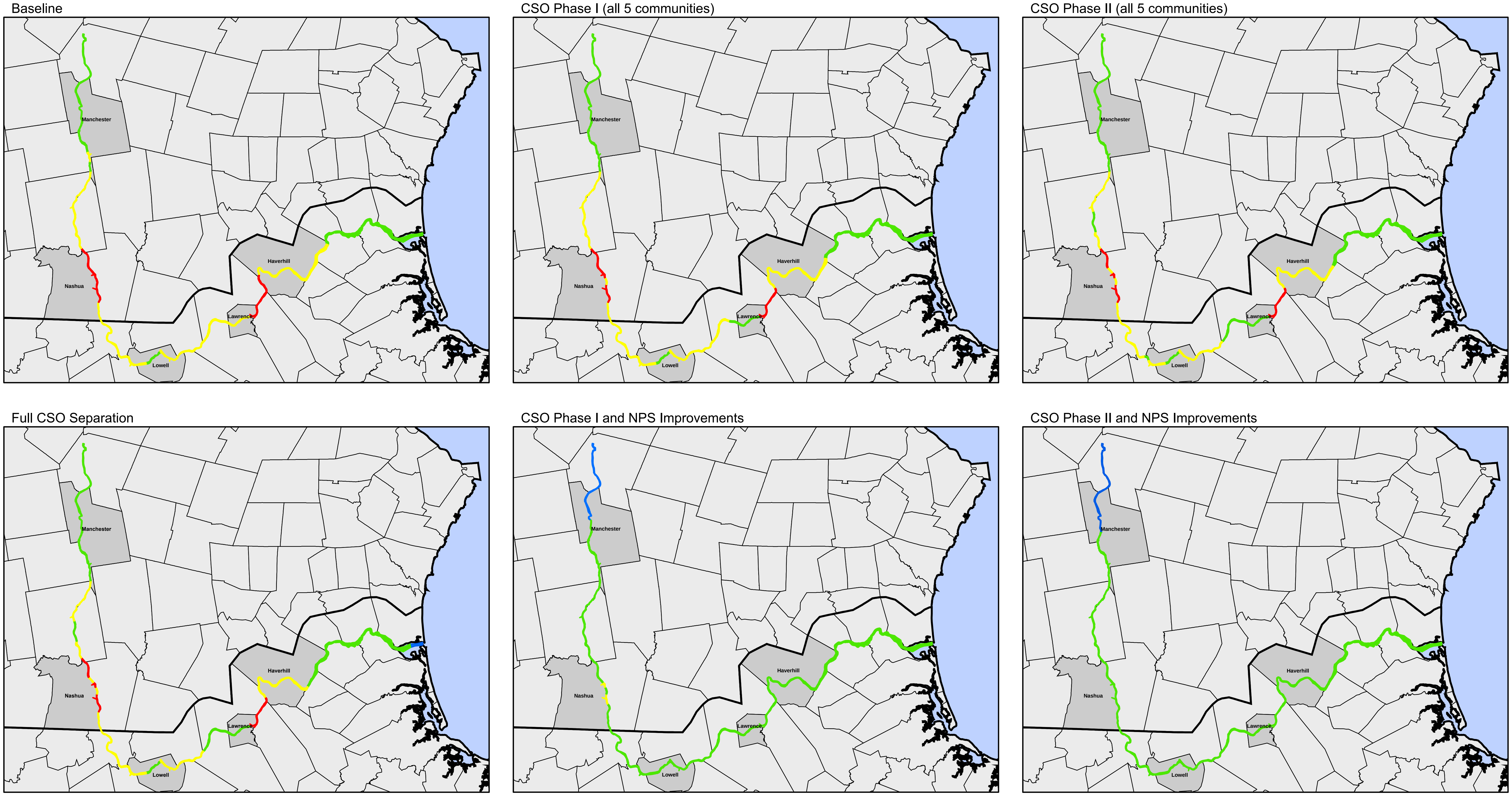
CSO Phase I and NPS Improvements

CSO Phase II and NPS Improvements

Simulated Hydrology
1994 (Average Yeear)

CDM

Figure 6-4
Days E-Coli Exceeds 625 in NH and 1,000 in MA



Simulated Days Greater Than Specified Criteria
NH: E. Coli > 235
MA: Fecal > 400

- 🟦 0 days (0%)
- 🟩 1 - 18 days (0 - 10%)
- 🟨 18 - 45 days (10 - 25%)
- 🟥 > 45 days (> 25%)

Simulated Hydrology
1994 (Average Yeear)

CDM

Figure 6-3
Days E-Coli Exceeds 235 in NH and 400 in MA

Figure 6–5 shows the same type of information as shown in Figure 6–3, but the *E. coli* threshold for New Hampshire is 200/100ml, which represents the surrogate standard (in lieu of the single-sample maximum of 406 org/100ml, per the note accompanying Table 4–6). Indications of compliance in New Hampshire using the large model output records were based on the published standard for the geometric mean, and the threshold that no more than 10% of all daily values should exceed 200 org/100ml.

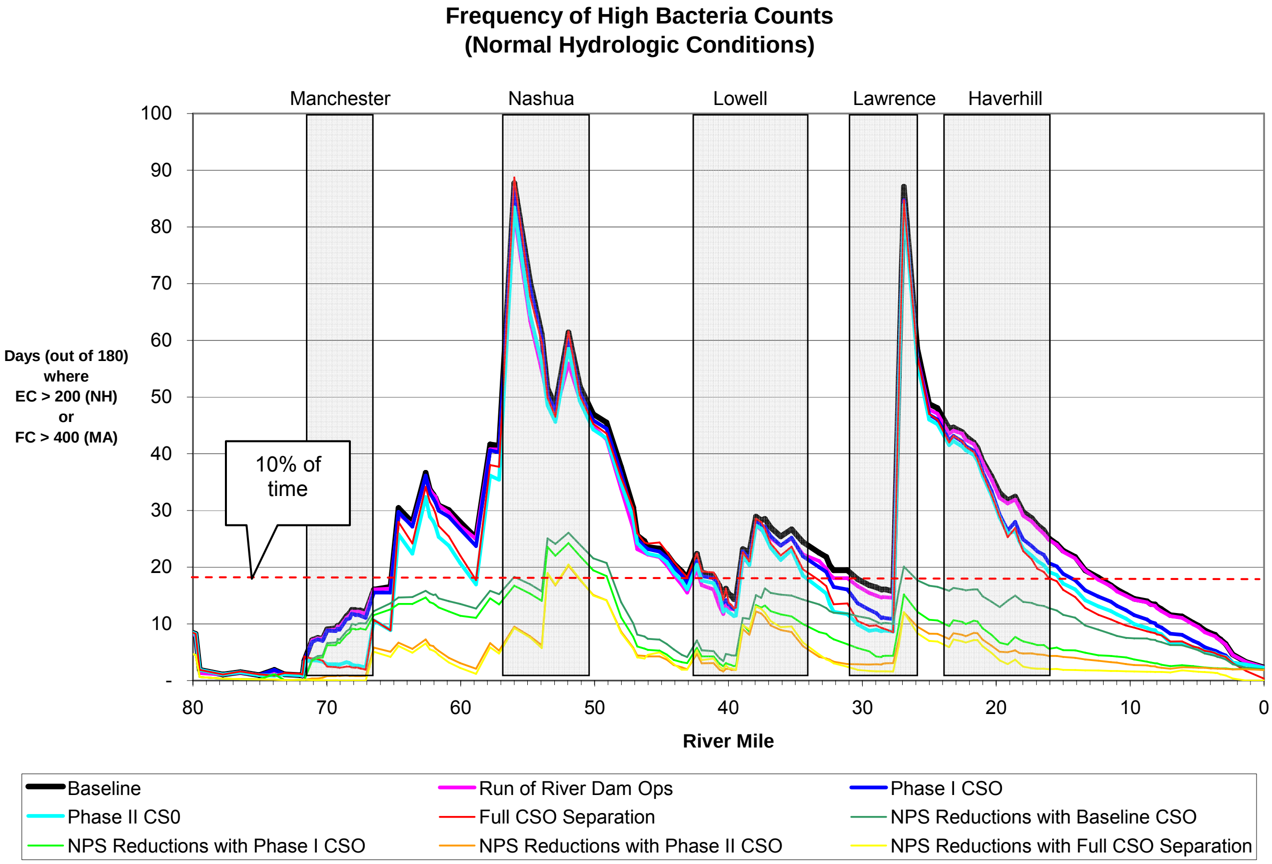


Figure 6–5
Impacts of Abatement Strategies on Frequency of High Bacteria Levels

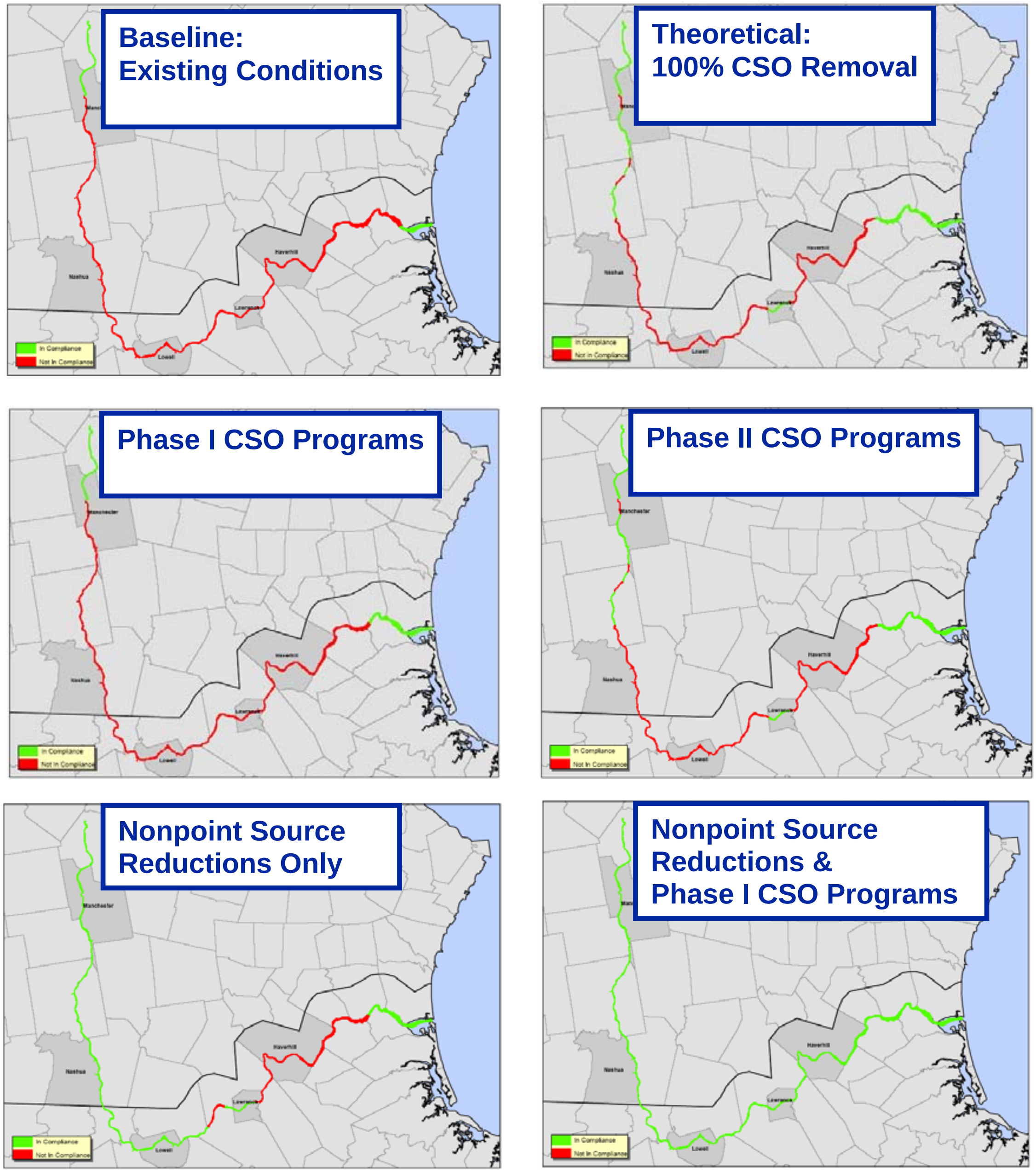


Figure 6–6
Compliance Summary for Watershed-Wide Abatement
Normal Hydrologic Conditions

The preceding figures clearly illustrate that CSO abatement on its own would do very little to reduce the frequency of exceedence of the bacteria standards in the river. Most of the river from Manchester to Haverhill would exceed state standards more than 10% of the time. Phase I CSO control plans would yield only isolated areas of improvement, but would certainly not improve the river globally. Likewise, Phase II CSO control plans and even the full separation of sewers in each city would yield only slight additional improvements in isolated areas.

However, Phase I CSO control plans combined with modest levels of nonpoint source reductions throughout the watershed would yield significant benefits with respect to river compliance (reference scenarios 9B and 9C in Table 4–9). The model suggests that under normal hydrologic conditions, the river would comply with bacterial standards in all areas except for several river segments in Nashua (recall that a surrogate standard in New Hampshire was applied for the instantaneous maximum value in order to distinguish improvements between alternatives – see footnote under Table 4–6). Phase II CSO controls coupled with the same nonpoint source reductions would yield only a marginal additional improvement beyond Phase I CSO controls and nonpoint source reductions.

Figure 4–22 illustrates that most of the river currently complies with EPA guidance levels of bacteria for secondary contact recreation.

A more complete comparison of abatement plans, associated benefits using a variety of metrics, and costs is included in Section 6.4.

6.4 Trade-Off Analysis

Alternatives were compared with respect to their expected improvements in the river, using metrics developed by the project stakeholders, and also with respect to expected cost of implementation. Hence, this trade-off study takes the form of a cost-benefit analysis, but the benefits are evaluated in environmental terms, rather than economic terms. That is, economic benefits in the form of increased commerce or development were not identified, and this study was not intended to evaluate the National Economic Development (NED) potential of the proposed alternatives.

6.4.1 Environmental Benefits

As discussed in Section 4.4 and 6.3, environmental benefits, or "river improvements," were determined with the suite of dynamic simulation models. Municipal combined sewer systems were simulated with pre-existing models developed with SWMM, with the exception of Nashua, which was modeled in MOUSE. Watershed runoff and nonpoint source loads were simulated with HSPF. Hydraulic routing in the mainstem was simulated with the EXTRAN block of SWMM, and water quality in the mainstem was simulated with WASP.

Output of the dynamic models was translated into the metrics defined by stakeholders and described in Section 6.1. Dissolved oxygen output was generated by the models, but was not translated into comparative measures because it was determined that the river is not impaired with respect to dissolved oxygen. Hence, environmental benefits were measured with the following primary metrics:

- Reduction of days that river reaches downstream of the mainstem urban cities would be noncompliant with bacteria standards.
- Additional river miles that would be compliant with bacteria standards.
- Seasonal bacteria flux to the estuary.
- Seasonal nitrogen flux to the estuary.[*]

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[*] *It was determined with sensitivity analysis prior to simulating the specific alternatives that nitrogen loads were most sensitive to concentrations in wastewater treatment plant effluent and to nonpoint source loads. However, the modest reductions in nonpoint source loads evaluated as a realistic alternative would not be enough to significantly reduce nitrogen flux to the estuary (sensitivity analysis evaluated 90% removal of all nitrogen from nonpoint sources). No significant improvements of nitrogen flux would result from CSO abatement. Hence, the comparison of reduction of nitrogen into the estuary is a theoretical comparison, and not based on the simulation of specific alternatives.*

6.4.2 Estimated Costs of Alternatives

Costs for each alternative were estimated and included in the comparative analysis. Costs for CSO abatement alternatives for each city were extracted from published Long-Term CSO Control Plans, or represent adjusted numbers that the cities are currently using in their planning processes.

Costs for nonpoint source reductions were more difficult to quantify. Cost estimation techniques for specific nonpoint source abatement projects are well-documented, but a review of available literature revealed very little guidance for general reduction of nonpoint bacteria loads for a watershed the size of the Merrimack. With 5,000 square miles and more than 170 communities, the Merrimack Watershed is too extensive and diverse to identify specific projects for each community.

In lieu of detailed cost estimates for specific nonpoint source projects, a general range of nonpoint source abatement costs was established, and allocated to each community in the basin by scaling the range to population within the communities. This method was employed for each city or town with at least 50% of its land mass within the Merrimack Watershed (174 incorporated towns and cities).

Each community was assigned a representative cost to reflect the generalization in the model that nonpoint source reductions of 20% would be realized throughout the watershed. *This exercise in no way implies that each community should expect to have to pay these costs, nor that every community will be responsible for 20% reduction of bacterial loads in nonpoint sources. This exercise was simply an idealized method of developing a planning-level cost for a very large and diverse watershed to correspond with a very generalized modeling approach.*

The method employed for this study was predicated on the assumption that costs for modest reductions in nonpoint bacteria loads in small communities would be on the order of $1,000,000. At the other end of the scale, modest reductions in nonpoint bacteria loads in large communities is approximated at $5,000,000. These values were allocated to the smallest and largest communities in the basin, and costs for all other communities were scaled linearly by population percentile. While the distribution of costs using this method is likely unrealistic, the total cost for the watershed is probably a reasonable estimate. (It is also acknowledged that the distribution of nonpoint source reductions throughout the basin would not likely need to be as evenly distributed as the generalized modeling assumptions might imply).

Costs are tabulated in Table 6–3. Comparison of costs and environmental benefits are included in Section 6.4.3.

Table 6–3
Estimated Costs of Alternatives

Category	Alternative	Estimated Cost
Baseline	Existing Conditions	$ –
Dam Ops	Run of River Operations at Dams	Lost hydro revenue*
Phase I CSO Control Plans	Phase I CSO - Manchester	$ 52,000,000
	Phase I CSO - Nashua	$ 27,000,000
	Phase I CSO - Lowell	$ 65,700,000
	Phase I CSO - GLSD	$ 21,300,000
	Phase I CSO - Haverhill	$ 10,500,000
	Phase I CSO - All Communities	**$ 176,500,000**
Long-Term CSO Control Plans	Phase II CSO - Manchester - 3 month Storage	$ 271,000,000
	Phase II CSO - Nashua - Screening/Disinfection & Storage	$ 37,500,000
	Phase II CSO - Lowell - Storage & Separation	$ 215,700,000
	Phase II CSO - GLSD - WWTP to 165 mgd	$ 39,800,000
	Phase II CSO - Haverhill - Treatment at Bradford & Little River	$ 15,300,000
	Phase II CSO - All Communities	**$ 579,300,000**
Sewer Sep.	Full CSO Separation in all cities	$ 1,303,000,000
Balanced Abatement	NPS Reductions Only	$ 521,000,000
	NPS Reductions with Phase I CSO	$ 697,500,000
	NPS Reductions with Long Term CSO	$ 1,100,300,000
	NPS Reductions with Full CSO Separation	$ 1,824,000,000

**Changes to hydropower revenues associated with run-of-river operations were not estimated as part of this study.*

6.4.3 Comparison of Costs and River Improvements

The following figures represent watershed-wide costs and river improvements. City-specific comparisons are included in Appendices C–G. Days of improvement were evaluated at critical (and impaired) reaches downstream of each CSO community. Improved river miles were evaluated along the entire 80-mile mainstem study area from upstream of Manchester to the Atlantic Ocean. Improvements were also evaluated at key resource areas along the mainstem, including six municipal drinking water intakes and two public beach areas.

The figures that follow represent model results from the normal hydrologic season. Results from the wet and dry seasons are similar enough to effectively lead to the same conclusions. Detailed model results for all hydrologic conditions are included in Appendices B–G for reference.

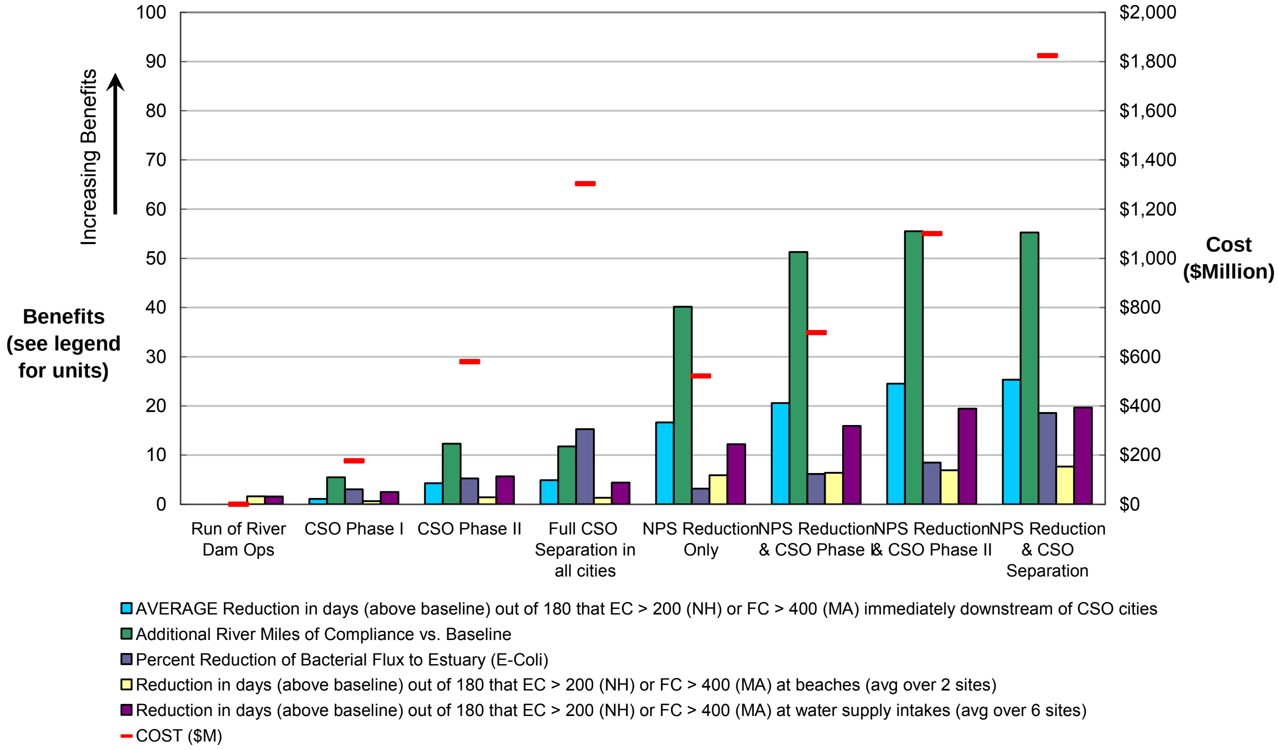

Figure 6–7
Cost:Benefit Summary – Normal Hydrologic Year

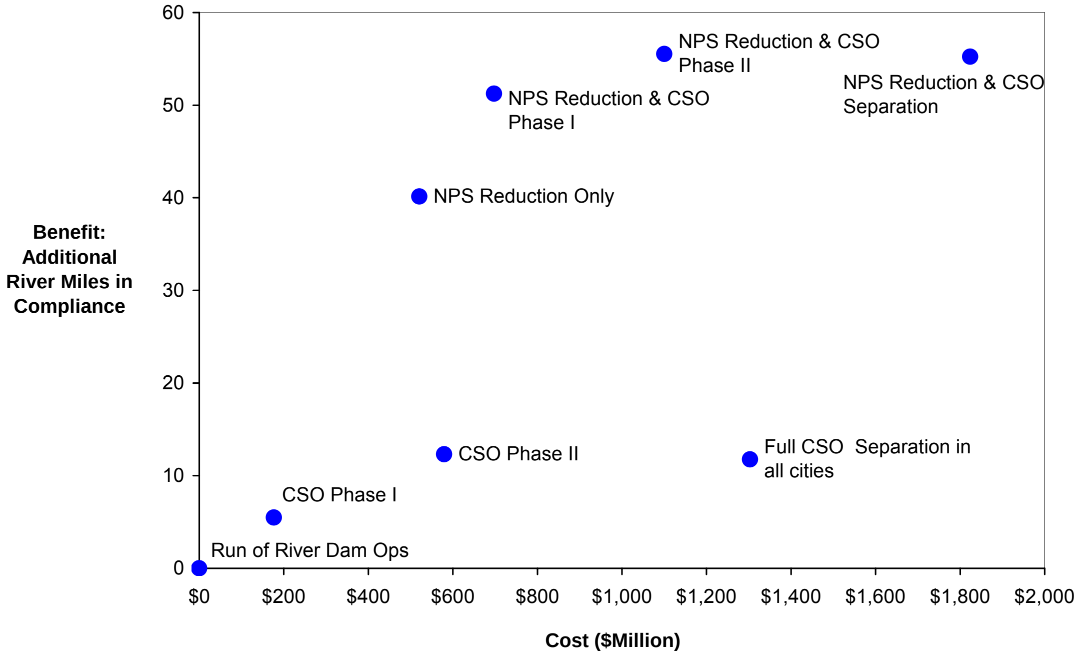

Figure 6–8
Comparative Value of Alternatives

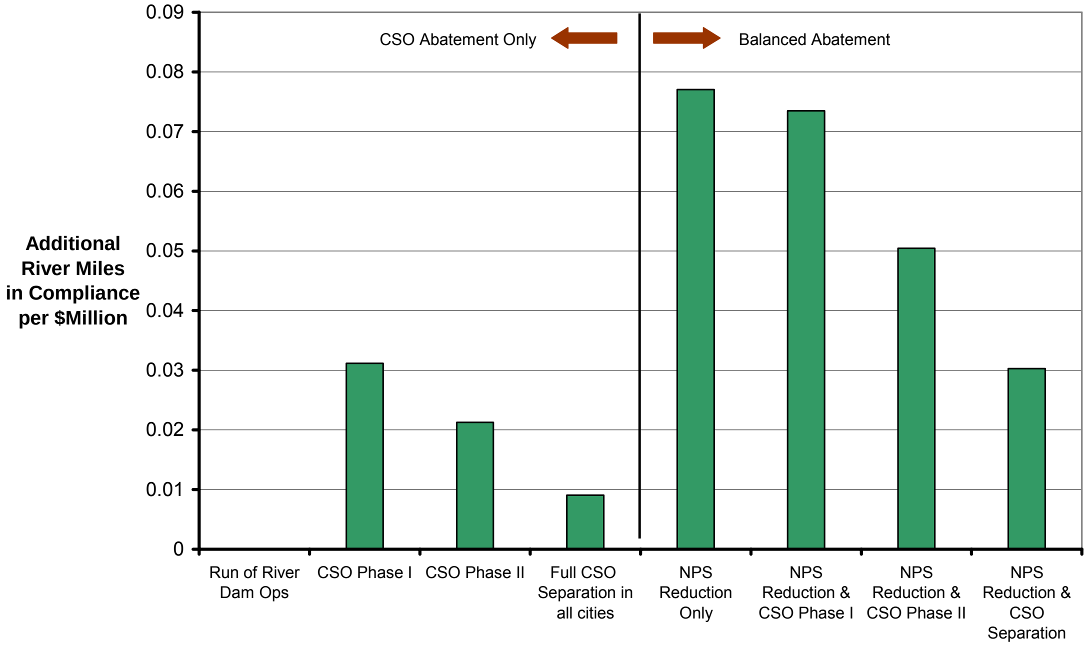

Figure 6–9
Incremental Value of Abatement Dollars With Respect to River Miles

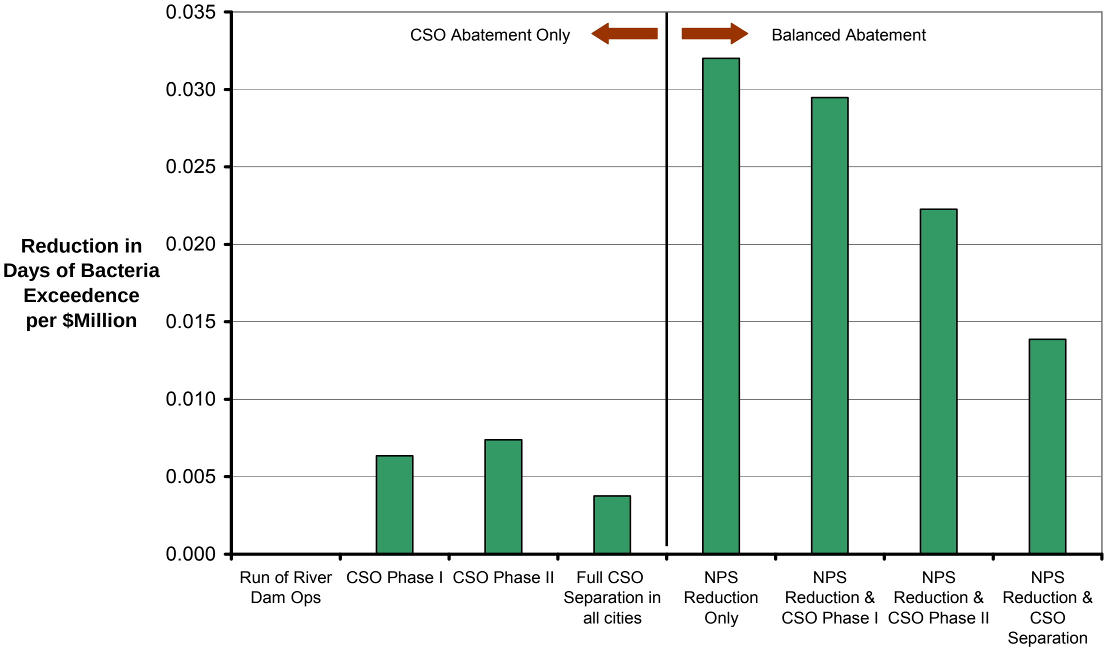

Figure 6–10
Incremental Value of Abatement Dollars With Respect to Days of Compliance
(Measured as average values for reaches immediately downstream of CSO communities)

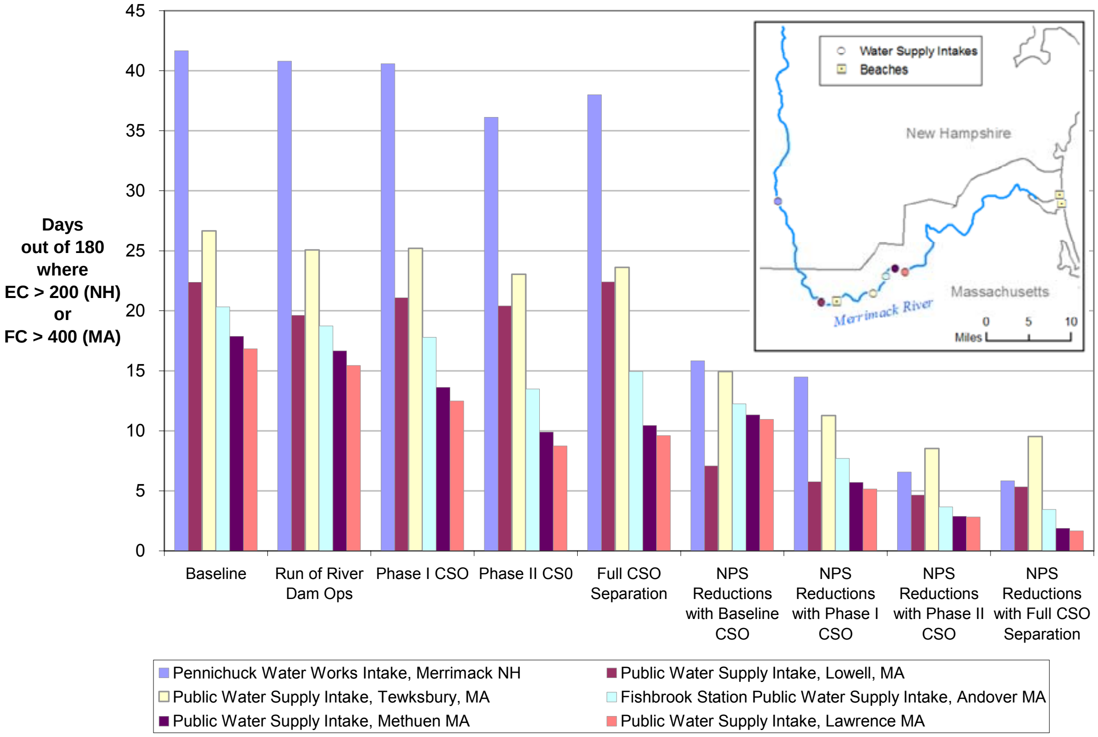

Figure 6–11
Impacts of Alternatives at Mainstem Municipal Water Intake Facilities

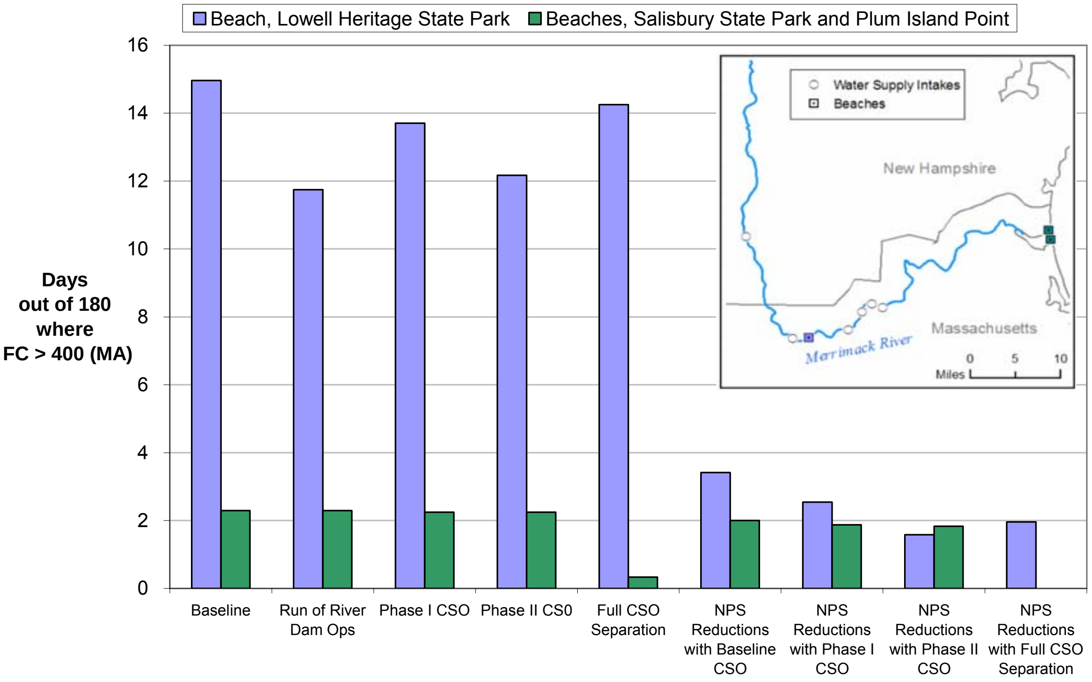

Figure 6–12
Impacts of Alternatives at Mainstem Beaches

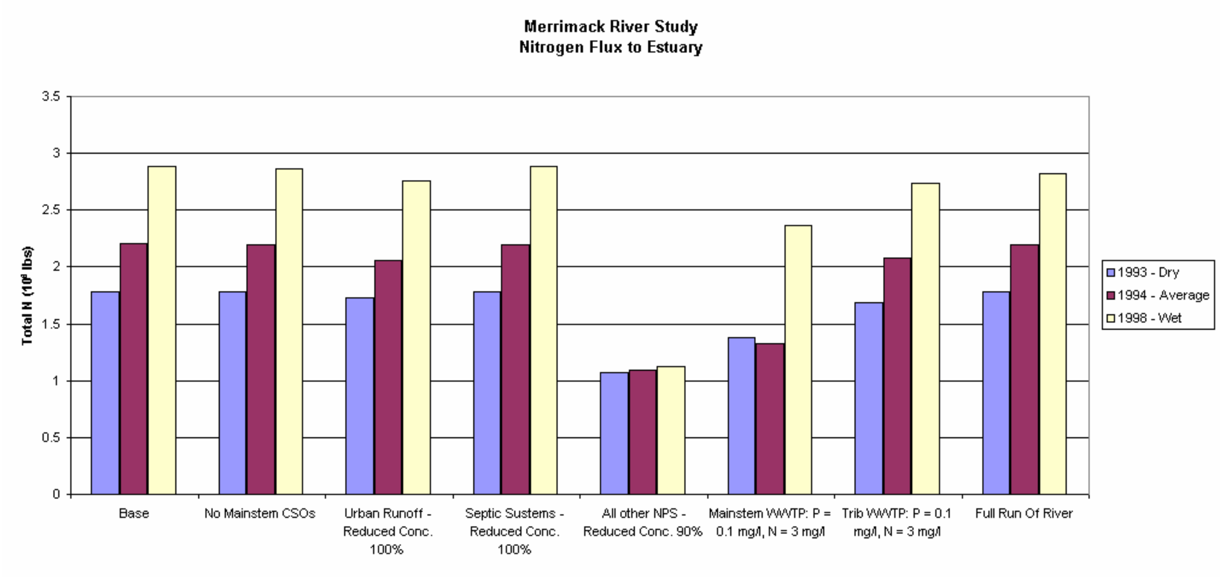

Figure 6–13
Nitrogen Flux to Estuary

The results shown in the preceding figures and tables are based upon an evenly distributed reduction of nonpoint source loads throughout the watershed. Such an even distribution is not necessarily required, nor is it a specific recommendation of this report. However, the likely aggregate effect of such reduction, and its likely regional cost, are reasonable for comparative planning purposes.

By far, the greatest value in abatement dollars can be realized with nonpoint source abatement and Phase I CSO controls. Phase II CSO offers much lower value. In this case, value is measured in terms of river miles or days of compliance that can be achieved for every million dollars spent. Results suggest that a balanced watershed management plan that includes modest CSO abatement coupled with reasonable levels of nonpoint source reduction should form the basis of watershed management decisions in the Merrimack Basin.

A balanced approach that includes Phase I CSO plans, 20% reduction in bacteria concentrations in runoff, and reducing background levels of bacteria in highly polluted tributaries to 5,000 org/100ml would be approximately 4 times more cost-effective than Long-Term CSO control plans in terms of river miles in compliance per million dollars.

Results also suggest that such a balanced strategy would be 8 times more cost-effective than full CSO separation using this same metric. In addition to being more cost-effective, the balanced approach would offer significantly more benefits than CSO abatement alone, and would result in a river that would likely comply with water quality standards under most conditions.

While these results are representative of normal hydrologic conditions, it was determined that the same general conclusions can be inferred from the results regardless of the climate and hydrologic conditions. Dry-year and wet-year simulation results yielded very similar improvements in the river.

Section 7
Coordination and Stakeholder Participation

7.1 Overview

The overall purpose of the Merrimack River Watershed Assessment Study, as stated in Section 2, is to develop a comprehensive Watershed Management Plan that can be used to guide investments in the basin. The Plan should encompass the diverse interests and goals of the various partners and stakeholders throughout the Merrimack River watershed, including state, local, and Federal governments, industry, and concerned citizen groups.

To ensure that the plan properly addresses these diverse interests and goals, input from the various partners and stakeholders is crucial. Therefore, a watershed partnership was formed.

7.2 Establishment of Watershed Partnership (Federal, State, Local Interest)

The communities (Manchester NH, Nashua NH, Lowell MA and Haverhill MA) and sanitary district (Greater Lawrence Sanitary District, GLSD) first formed the Merrimack River Basin Community Coalition to promote a concerted, watershed-wide assessment. The ultimate goal was to help ensure that the money spent on pollution abatement and restoration would be targeted at all major contributing sources and that investments would yield scientifically defensible environmental benefits.

The communities enlisted the help of the U.S. Army Corps of Engineers for watershed planning efforts. In the Water Resources Development Act (WRDA) of 2000, Section 437 directed the Corps to conduct a study of the comprehensive water resources needs of the Merrimack River Basin in Massachusetts and New Hampshire in accordance with Corps Section 729 watershed study authority per WRDA of 1986. The authority provided in WRDA 2000 allows the Corps to conduct multi-objective watershed planning in collaboration with stakeholders for the Merrimack River Watershed.

The communities and the Corps sought to work together with others in the basin, seeking input and information from many stakeholder organizations throughout the watershed. The organizations which provided input are listed in Section 7.3.

7.3 Stakeholder Organizations

The following organizations participated as stakeholders during the project:

- United States Army Corps of Engineers, New England District (ACE)

- Merrimack River Basin Community Coalition - Manchester NH, Nashua NH, Lowell MA and Haverhill MA and Greater Lawrence Sanitary District, GLSD (the sponsors)
- United States Environmental Protection Agency (EPA)
- Massachusetts Department of Environmental Protection (DEP)
- Massachusetts Division of Marine Fisheries (DMF)
- New Hampshire Department of Environmental Services (DES)
- United States Geological Survey (USGS)
- Merrimack Valley Planning Commission (MVPC)
- Merrimack River Watershed Council (MRWC)

7.4 Input

The input of stakeholders was highly valued by the project team and sponsors throughout the study. Input was particularly useful during the following specific tasks:

- Defining and approving the field program through planning meetings and review of the Quality Assurance Project Plan and Field Sampling Plan (Section 5.2). This included involvement from EPA, DEP, DES, DMF, MVPC, USGS, and sponsors.
- Developing and reviewing the model through technical review committees and meetings (Section 4.4.4). This included involvement from EPA, DEP, DES, and sponsors.
- Defining the performance measures for the study through a workshop (Section 6). This included involvement from EPA, DEP, DES, USGS, MVPC, MRWC, and the sponsors.

Section 8
Conclusions

Based on six extensive field-monitoring surveys of the Merrimack River, two additional 30-day continuous-monitoring surveys of dissolved oxygen, and detailed dynamic simulation modeling of the entire watershed and the receiving water in the mainstem of the Merrimack River, the following conclusions can be drawn from this study.

Existing Conditions:

- The mainstem of the river from Manchester, NH to the Atlantic Ocean is impaired with respect to bacteria standards, although many reaches exhibit satisfactory bacteria counts during dry weather.
- Many of the tributaries are impaired with respect to bacteria standards, as measured and simulated upstream of combined sewer outfalls.
- The mainstem of the river from Manchester to the Atlantic Ocean is not impaired with respect to dissolved oxygen standards. Measured and simulated concentrations of dissolved oxygen were always well above the threshold of 5 mg/L.

Abatement Strategies:

- Phase I and Long-Term CSO improvements, including partial separation, storage, increased treatment capacity, etc. will reduce the frequency, magnitude, and duration of overflows, but will not significantly improve compliance with bacterial water quality standards. This is because overflow events taken as a whole occur for a very small percentage of the time in any given year. The remainder of the time, the river system is dominated by stormwater and background concentrations that often exceed bacteria standards. The river would still be significantly impaired after Long-Term CSO plans are implemented.
- Full Separation of combined sewers would offer very little improvement in river water quality for the same reasons as stated above.
- Reasonable levels of nonpoint source control, as defined by approximately 20% reduction in all runoff concentrations and reduction of background concentrations in highly-polluted tributaries to 5,000 org/100ml (still well above standard), will offer significant improvements in compliance with bacteria standards.
- Nonpoint Source (NPS) controls coupled with Phase I CSO controls may be sufficient to achieve compliance. In fact, the implementation of the nonpoint source reductions described above would actually increase the effectiveness of

Phase I CSO controls by bringing the river closer to compliance and closing the gap that CSO abatement would need to bridge. Model results suggest that under normal hydrologic conditions, the river would be fully compliant with bacteria standards with the suggested nonpoint source reductions and Phase I CSO abatement. During dry and wet years, there may still be small isolated reaches that do not fully comply.

- Long-Term CSO abatement offers very little additional improvement in compliance when compared to either Phase I abatement alone or to Phase I abatement AND nonpoint source reductions. There are very few appreciable instream benefits of Long-Term CSO control plans beyond the Phase I programs already in progress, whether or not such plans are coupled with nonpoint source abatement. However, the long-term alternatives will reduce the occurrence of very high bacteria counts in the river, though these occur during a total of just a few days during each year.

- By far, the greatest value in abatement dollars can be realized with nonpoint source abatement and Phase I CSO controls. Phase II CSO offers much lower value. In this case, value is measured in terms of river miles or days of compliance that can be achieved for every million dollars spent. Results suggest that a balanced watershed management plan that includes modest CSO abatement coupled with reasonable levels of nonpoint source reduction should form the basis of watershed management decisions in the Merrimack Basin.

- A balanced approach that includes Phase I CSO plans, 20% reduction in bacteria concentrations in runoff, and reducing background counts of bacteria in highly polluted tributaries to 5,000 org/100ml would be approximately 4 times more cost-effective than Long-Term CSO control plans in terms of river miles in compliance per million dollars. Results also suggest that such a balanced strategy would be 8 times more cost-effective than full CSO separation using this same metric. In addition to being more cost-effective, the balanced approach would offer significantly more benefits than CSO abatement alone, and would result in a river that would likely comply with water quality standards under most conditions.

Ecological Opportunities

Ecological restoration opportunities were categorized under six types of projects. These are: fisheries/aquatic species, water quality, soils/erosion control, terrestrial rare species and wetlands, marine/estuarine, and riparian resources. A survey of published plans and local contacts revealed many projects in each of the categories. Although specific example projects are included in Section 5, a summary of the types of projects under each category are included below.

- Fisheries/aquatic species—Habitat improvement and enhancement opportunities in the watershed for fish and aquatic species include activities such as streambed enhancement or naturalization, riparian habitat improvement, upstream and downstream fish passage improvement, provision of adequate stream flow and restoration of natural temperatures or mitigation of temperature changes, among others.

- Water quality—Nonpoint source water quality problems exist throughout the watershed and contribute to degraded water quality on the mainstem of the Merrimack and the major tributaries. These watershed-wide water quality issues are primarily the result of a combination of increased development and agricultural practices. Implementation of best management practices (BMPs) for the control of non point pollution throughout the watershed (both urban and agricultural) as well as maintenance of existing BMPs is critical to the ultimate success of nonpoint source control. Development using low impact development (LID) techniques also has the potential to minimize development impacts on water quality. In addition, wetlands are important buffers against upland non-point pollutant sources by filtering and cleansing runoff before it reaches a surface water body. Wetland protection, creation or restoration can also improve water quality in the river.

- Soils/erosion control— Erosion of soil can significantly alter the water quality and ecology of receiving waters by adding nutrients, covering critical aquatic habitat, filling wetlands and impounded areas and reducing water clarity. Erosion in the Merrimack watershed can be divided into two general categories. Erosion related to site development and transportation projects and shoreline or bank erosion. Of these two types, shoreline and bank erosion directly impacts in-stream water quality, while erosion due to site development and transportation projects is largely addressed through current Phase II EPA regulations. Shoreline and bank erosion therefore receives the focus here. The restoration of riverbanks to reduce the contribution of sediment and their associated nutrients to the Merrimack River could be accomplished using a phased approach. The first phase, the identification of eroding banks has been partly completed and is summarized in Section 5. The second phase would be to prioritize the riverbanks based on the risk posed to important infrastructure (bridges, roads, houses and utilities) and aquatic/riparian habitat. In the third phase the sites identified as being high priority would be surveyed in more detail so that conceptual restoration designs could be prepared. In the development of the conceptual restoration design, the use of bioengineering techniques should be given consideration.

- Terrestrial rare species and wetlands—Protection/enhancement of rare or declining non-game species and communities can best be achieved through enhancement, restoration and protection of targeted habitats. These include habitat for the New England cottontail rabbit (*Sylvilagus transitionalis*), brook floater mussel (*Alasmidonta varicosa*), eastern hognose snake (*Heterodon platyrhinos*), and Blanding's turtle (*Emydoidea blandingii*), as well as pine barrens and forested floodplain communities.

- Marine/estuarine—The estuary may be among the most vulnerable of the resources of the Merrimack River since it is located at the downstream end of the watershed and, as such, the ecological community is a reflection of the cumulative impact of all of the activities that occur in the watershed. Impacts to the resources of the estuary are the result of nutrient, and bacterial loading, sedimentation, shoreline erosion and changes in populations of anadromous and catadromous fish species. Marine and estuarine opportunities include restoration of critical habitats such as eelgrass and salt marsh, as well as restoration of soft-shell clam harvesting areas.

- Riparian resources—The riparian zone provides habitat for a number of plant and animal species reliant both on upland and water resources. In addition, the riparian zone provides a critical buffer between activities on the land and the river and tributaries. In recent years, development and transportation have been pushed into the riparian zone throughout the watershed. The challenge is to develop near the river in a manner that showcases the river while preserving the natural functions of the riparian zone and the species that depend on it. Projects to reduce paved area in the riparian zone, to provide for buffer zones and conservation easements, and to reduce the impact of recreation in these areas are all potentially relevant.

Section 9
List of Interim Task Reports Prepared for This Study

Numerous studies and reports have been completed to date for this project. These are summarized below. Electronic versions of these reports have been included on the attached CD.

All of the below listed reports were completed under the Merrimack River Watershed Assessment Study, and prepared for the New England District of the U.S. Army Corps of Engineers. The project sponsor communities are Manchester, NH; Concord, NH; Lowell, NH; GLSD, MA; and Haverhill, MA.

- Description of Existing Conditions – January 2003 – Reviews and discusses existing documentation on the Merrimack River watershed, including water quality, water quantity, dams and impoundments, sediment quality, biological resources and habitat, designated water uses and attainment, and limited discussion of pollution sources within the watershed. The report includes no new findings, but summarizes other documents issued primarily within the past ten years.

- Modeling Methodology – March 2003 – Presents modeling methodology used to simulate water quality and hydraulic regimes in the mainstem Merrimack under low-flow, baseflow, and storm events.

- Field Sampling Plan – May 2003 – Discusses the protocols and procedures for the field sampling plan, including sampling locations and conditions, staffing and responsibilities, and parameters.

- Quality Assurance Project Plan – May 2003 – Discuss the quality assurance and checking measures proposed for use in data acquisition and generation, field sampling program implementation, and data review, verification and validation by CDM and associated subcontractors.

- Summary of Information on Pollutant Sources – January 2004 – Presents a summary and discussion of pollutant sources in the watershed, including combined sewer overflows, stormdrain outfalls, municipal and privately-owned treatment plants and industrial point sources, and other sources of pollutants such as sediments, air deposition, groundwater plumes from landfills, streambank erosion, septic system failures, pump station overflows, and illicit wastewater discharges to stormdrains.

- Hydrology and Hydraulics Assessment – March 2004 – Presents a summary of the hydrology and hydraulics data collected, including streamflow and precipitation data, hydropower facilities and operations, time of travel study results, and bathymetry data related to the project.

- Screening Level Model – March 2004 – Presents results of the Watershed Management Model (WMM), including an assessment of the relative contribution of pollutant sources from geographic and physical source areas throughout the watershed, key pollutants and geographic areas, and sensitivity of model results to select model assumptions. The model predicts loads only on a seasonal basis.

- Merrimack River Monitoring Report – May 2006 – Presents the results of the comprehensive field monitoring study of the Merrimack River done for this project. The objectives of the monitoring study were to collect water quantity and streamflow data for calibration and validation of models, and to collect water quality data to determine the likelihood that segments of the river meet state water quality standards.

- Simulation Model Development – August 2005 – Presents the hydrologic, hydraulic, and water quality models created as tools to assist in evaluating and comparing watershed management strategies and in prioritizing potential improvements in the watershed, including a detailed description of the models and their calibration/verification. Predictive analysis using the models is not included.