Draft

Total Maximum Daily Load for Nutrients in the Upper/Middle Charles River, Massachusetts

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DISCLAIMER

Front Cover:
Left=Canoe on free-flowing reach of Middle Charles
Right=South Natick Dam showing excessive algae growth

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ACKNOWLEDGEMENTS

This TMDL study was developed by the Charles River Watershed Association (CRWA) under contract with Massachusetts Department of Environmental Protection (MassDEP) and the New England Region of the United Sates Environmental Protection Agency (US-EPA) with support from Numeric Environmental Services (NES) in Beverly Farms, Massachusetts under CRWA sub-contract. Water quality monitoring and data preparation were performed by CRWA. An HSPF water quality model for the Upper/Middle Charles River used for this TMDL was developed by CRWA and NES. Completion of this study depended on the generous informational and data support from the various groups. Special acknowledgement is made to the following people and organizations for the development of this TMDL.

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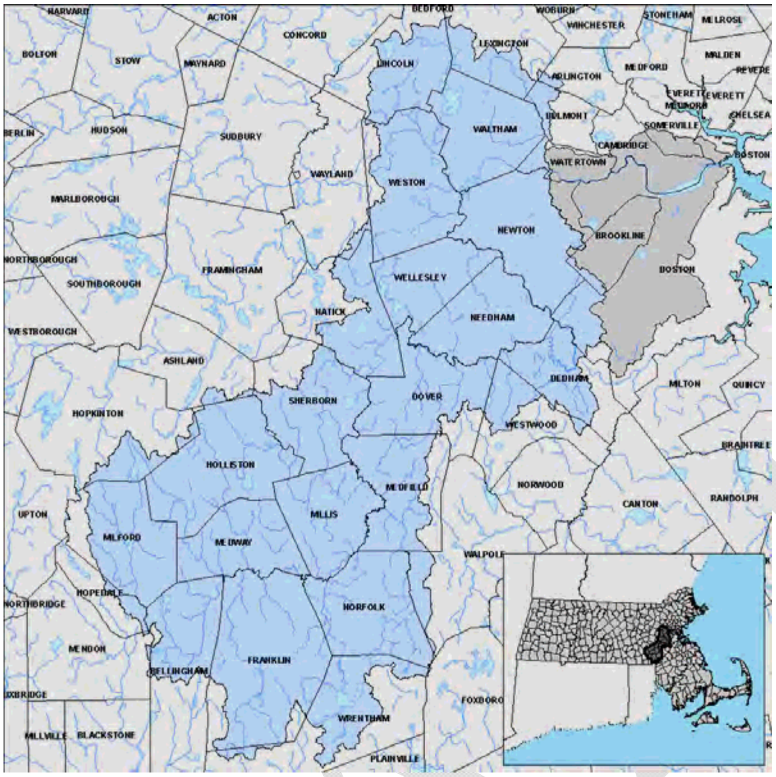
LIST OF ACRONYMS AND UNITS

ANP	– American National Power
BG	– Background Load Sources
BMP	– Best Management Practice
BOD	– Biochemical Oxygen Demand
BPJ	– Best Professional Judgment
CDM	– Camp Dresser and McKee
CFS	– Cubic Feet per Second
CMR	– Code of Massachusetts Regulations
CRPCD	– Charles River Pollution Control District
CRWA	– Charles River Watershed Association
CSO	– Combined Sewer Overflow
CWA	– Clean Water Act
DCR	– Department of Conservation and Recreation
GIS	– Geographic Information System
HRU	– Hydraulic Response Unit
HSPF	– Hydrologic Simulation Program – Fortran
IDDE	– Illicit Discharge Detection and Elimination
LA	– Land-area Allocation
LID	– Low Impact Development
MassDEP	– Massachusetts Department of Environmental Protection
MassHighway	– Massachusetts Highway Department
MassPike	– Massachusetts Turnpike Authority
MAWQS	– Massachusetts Water Quality Standards
MGD	– Million Gallons per Day
MOS	– Margin of Safety
MS4	– Municipal Separate Storm Sewer System
MWRA	– Massachusetts Water Resources Authority
NPDES	– National Pollutant Discharge Elimination System
NRCS	– Natural Resources Conservation Service
PO4-P	– Orthophosphate
QAPP	– Quality Assurance Project Plan
SAP	– Sampling Analysis Plan
SRF	– State Revolving Fund
SWMP	– Storm Water Management Plan
TMDL	– Total Maximum Daily Load
TN	– Total Nitrogen
TORP	– Total Organic Phosphorus
TP	– Total Phosphorus
UA	– Urbanized Area
US-EPA	– United States Environmental Protection Agency
USGS	– United States Geological Survey
WLA	– Waste Load Allocation
WSGP	– Watershed-Specific General Permits
WWTF	– Wastewater Treatment Facility

SUMMARY



Key Features: Nutrient TMDL for an impounded river with stormwater and wastewater sources

Location: Towns of Hopkinton, MA to Watertown, MA - US-EPA Region 1; and surrounding watershed; Ecoregion XIV, subregion 59.

Scope/ Size: Watershed 268 mi^2, length of main stem 70 miles

Towns: Watershed contains 5 communities in their entirety (Medway, Millis, Needham, Waltham, and Wellesley) and includes portions of 28 more (Arlington, Ashland, Bellingham, Belmont, Boston, Brookline, Dedham, Dover, Foxborough, Franklin, Holliston, Hopedale, Hopkinton, Lexington, Lincoln, Medfield, Mendon, Milford, Natick, Newton, Norfolk, Sherborn, Walpole, Watertown, Wayland, Weston, Westwood, and Wrentham).

Land Uses: Forest 27.9%, Water/Wetland 13.0%, Open 8.7%, Residential 42.5%, and Commercial and Industrial 7.9 % (MassGIS, 1999).

303(d) segments: Phosphorus/Eutrophication/Enrichment (25), Macrophytes/Algae (17), Dissolved Oxygen (15), and Turbidity/Transparency (11) on 9 mainstem, 9 tributaries, and 12 connected ponds.

Data Sources: Charles River Watershed Association (CRWA), Massachusetts Water Resources Authority (MWRA), Massachusetts Department of Environmental Protection (MassDEP), United States Geological Survey (USGS), and American National Power (ANP).

Data Evaluation: HSPF 12 model, Massachusetts Water Quality Standards, US-EPA Nutrient Criteria Guidance, Weight of Evidence.

Controls: Upgrade of wastewater treatment plants (WWTFs) and stormwater best management practices (BMPs) to reduce phosphorus from runoff.

Monitoring Plan: Detailed monitoring plan still to be developed.

EXECUTIVE SUMMARY

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's Water Quality Planning and Management Regulations (Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require states to identify impaired water bodies and develop Total Maximum Daily Loads (TMDLs) for each impaired segment. A TMDL establishes the amount of a given pollutant that a waterbody can assimilate without exceeding water quality standards. TMDLs provide the scientific basis for a state to establish water quality-based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of the state's water resources (US-EPA, 1991).

A TMDL for a given pollutant and waterbody is composed of the sum of individual allocations for point sources (called wasteload allocations or "WLAs") and nonpoint sources (called load allocations or "LA"). It also takes into consideration natural background levels. In addition, the TMDL must include an implicit or explicit margin of safety (MOS) to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody.

This project establishes a nutrient Total Maximum Daily Load (TMDL) and corresponding implementation plan for the Upper/Middle Charles River. The Upper/Middle Charles nutrient TMDL will address all nutrient related issues in the listed segments (MassDEP, 2008b) of the watershed above the Watertown Dam and will meet the loading requirements established in the Lower Charles TMDL (US-EPA, 2007). The Upper/Middle Charles watershed is 70 miles long, covers 268 square miles in area, and ends at the Watertown Dam where it connects to the Lower Charles. The watershed contains 5 communities in their entirety (Medway, Millis, Needham, Waltham, and Wellesley) and includes portions of 28 more (Arlington, Ashland, Bellingham, Belmont, Boston, Brookline, Dedham, Dover, Foxborough, Franklin, Holliston, Hopedale, Hopkinton, Lexington, Lincoln, Medfield, Mendon, Milford, Natick, Newton, Norfolk, Sherborn, Walpole, Watertown, Wayland, Weston, Westwood, and Wrentham). Land use in the watershed can be summarized as follows: Forest 27.9%, Water/Wetland 13.0%, Open 8.8%, Residential 42.5%, and Commercial and Industrial 7.9 %.

A TMDL is essentially a pollutant budget and establishes the maximum amount of pollutant by pollution source that can be introduced into a body of water while still attaining water quality standards. A TMDL provides a defensible basis for allocating pollutants to sources and identifying remediation responsibilities. The final TMDL load is allocated among point sources (WLAs) and non-point source (LAs) with an appropriate margin of safety.

A nutrient TMDL is required for this watershed because the State of Massachusetts has placed many reaches in the Charles River Watershed on the Category 5 or "impaired" waters list for excessive nutrients (MassDEP 2008b). Both water quality monitoring data and visual evidence demonstrate that the Upper/Middle Charles is significantly impaired from excessive nutrients with excessive algae blooms and large extents of aquatic plant growth. The "impaired" nutrient categorization was based on available water quality monitoring data and nutrient response variables including dissolved oxygen, pH, macrophytes/algae, phosphorus, and turbidity. The listed segments include nine mainstem segments, nine tributaries, and twelve connected ponds. Especially of concern is phosphorus, considered the controlling nutrient in many surface waters.

Regular occurrences of severe algal blooms during the summer months have been observed to reduce water clarity and contribute to anoxic bottom waters that do not support aquatic life. Water quality data indicate the Upper/Middle Charles River is undergoing cultural eutrophication, which is the process of producing excessive plant life because of excessive pollutant inputs from human activities. The algal blooms in the Charles are directly responsible for degrading the aesthetic quality of the river, reducing water clarity, and impairing the designated uses. Some cyanobacteria (blue-green) species known to be toxic have been consistently observed in the Lower Charles during all summers when algal sampling has been conducted (US-EPA, 2007).

The Massachusetts Water Quality Standards identify the Upper/Middle Charles River as a Class B water that is designated to support aquatic life and recreational uses. The water quality standards that apply to the Upper/Middle Charles River and were used to set targets and calculate the total allowable loads are presented in Table ES-1.

Table ES-1. Massachusetts Water Quality Standards for Nutrient-Related Parameters

Pollutant	Criteria	Source
Dissolved Oxygen	Shall not be less than 6.0 mg/l in cold water fisheries and not less than 5.0 mg/l in warm water fisheries. Where natural background conditions are lower, DO shall not be less than natural background conditions. Natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained.	314 CMR: 4.05: Classes and Criteria (3)(b) 1
pH	Shall be in the range of 6.5 - 8.3 standard units and not more than 0.5 units outside of the background range. There shall be no change from background conditions that would impair any use assigned to this class.	314 CMR: 4.05: Classes and Criteria (3)(b) 3
Solids	These waters shall be free from floating, suspended, and settleable solids in concentrations and combinations that would impair any use assigned to this Class, that would cause aesthetically objectionable conditions, or that would impair the benthic biota or degrade the chemical composition of the bottom.	314 CMR: 4.05: Classes and Criteria (3)(b) 5.
Color and Turbidity	These waters shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this Class.	314 CMR: 4.05: Classes and Criteria (3)(b) 6
Aesthetics	All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum or other matter to form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life.	314 CMR: 4.05: Classes and Criteria (5)(a)
Nutrients	Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established by the Department pursuant to 314 CMR 4.00. Any existing point source discharge containing nutrients in concentrations that would cause or contribute to cultural eutrophication, including the excessive growth of aquatic plants or algae, in any surface water shall be provided with the most appropriate treatment as determined by the Department, including, where necessary, highest and best practical treatment (HBPT) for POTWs and BAT for non POTWs, to remove such nutrients to ensure protection of existing and designated uses. Human activities that result in the nonpoint source discharge of nutrients to any surface water may be required to be provided with cost effective and reasonable best management practices for nonpoint source control.	314 CMR: 4.05: Classes and Criteria (5)(c)

The pollutant of concern for this TMDL study is phosphorus because it is directly contributing to the excessive algal biomass in the Upper/Middle and Lower portions of Charles River. Although phosphorus is ubiquitous in natural soils and vegetation, additional human inputs in the watershed come from five active municipal wastewater treatment facilities (WWTFs) and stormwater runoff from developed land uses. Even though wastewater discharges are currently treated, they still have significant phosphorus loads. Stormwater runoff includes inputs from fertilized soils and lawns; leaf litter and other vegetative debris; car wash products and some detergents; auto exhaust, fuel, and lubricants; and pet waste. Developed land uses like high-density residential, commercial, and industrial have higher loadings of phosphorus per unit area.

A target for the Upper/Middle Charles River was established based on a two-tiered approach. First, the annual phosphorus load at Watertown Dam outlet must meet the inlet load specified by the Lower Charles TMDL. As specified in the Lower Charles TMDL, the average annual phosphorus load contribution from the Upper/Middle Charles River cannot exceed 15,109 kg/yr at the Watertown Dam. Second, the phosphorus loads in the Upper/Middle Charles River must also be low enough to achieve instream water quality targets and response variables for excess nutrients and algal biomass in the river system during low flow conditions and assuming that all point sources are discharging at their current design flows.

The water quality targets were developed from the water quality standards in Table ES-1, best professional judgment (BPJ), and a “weight-of-evidence” approach. In general, targets included water quality parameters that are the most sensitive measures of nutrient impacts. The targets were selected for consistency with applicable water quality standards, the Lower Charles nutrient TMDL, US-EPA guidance documents, and MassDEP experience with nutrient TMDL development in river systems. The metrics chosen for this TMDL are listed in Table ES-2.

Since the Water Quality Standards do not contain specific numeric criteria for phosphorus, it was necessary to calculate a numerical endpoint to address the excessive algal biomass resulting from excessive nutrient input to the Upper/Middle and Lower Charles River. To do this, targets were established for low and variable dissolved oxygen and chlorophyll-*a*. The last parameter served as surrogate water quality target to define the assimilative capacity of the Upper/Middle Charles River since chlorophyll-*a* is the photosynthetic pigment found in algae and is, therefore, a direct indicator of algal biomass. Since the eutrophication-related impairments in the Charles River are the result of excessive amounts of algae, a chlorophyll-*a* target can be used as a surrogate to reasonably define acceptable amounts of algae that will support the designated uses.

The chosen chlorophyll-*a* target of 10 µg/L for the Upper/Middle Charles TMDL is consistent with the Lower Charles TMDL and is a site-specific target for this river. The seasonal average is defined as the mean chlorophyll-*a* concentration in the Charles between April and October of each year. This period represents critical conditions when algal blooms are typically most severe in the Charles River and have the greatest impact on designated uses. The chlorophyll-*a* target was set at a level that will result in reductions in eutrophication sufficient to enable the Upper/Middle Charles River to attain all applicable Class B narrative (nutrients, aesthetics, and clarity) and numeric (dissolved oxygen and pH) standards. Achieving the seasonal average chlorophyll-*a* target will reduce algal biomass to levels that are consistent with a mesotrophic status, will address aesthetic impacts, and attain clarity standards. A maximum chlorophyll-*a* target of 18.9 µg/L was established to ensure good aesthetic quality and water clarity at times when extreme periodic algal blooms could occur during the growing season.

ES-2. Selected Nutrient Water Quality Metrics and Guidance Values

Metric	Acceptable Range	Rational for Metric	Source
Numeric Water Quality Standard			
Dissolved Oxygen	> 5 mg/L	MassDEP Surface Water Quality Standards	MassDEP (2007b)
pH[1]	6.5 – 8.3	MassDEP Surface Water Quality Standards	MassDEP (2007b)
Related Nutrient TMDLs			
Seasonal Mean Chlorophyll-a	< 10 ug/L	Target applied in Lower Charles TMDL	US-EPA (2007)
Peak Chlorophyll-a	< 18.9 ug/L	Target Applied in Lower Charles TMDL	US-EPA (2007)
Dissolved Oxygen Saturation	< 125%	Best Professional Judgment, applied in the Assabet River Nutrient TMDLs	MassDEP (2004)
Guidance			
Total Phosphorus	< 0.025 ug/L	EPA-within lakes or reservoir	US-EPA (1986)
Total Phosphorus	< 0.050 ug/L	EPA-entering lakes of reservoirs	US-EPA (1986)
Total Phosphorus	< 0.100 ug/L	EPA- in streams or other flowing waters not discharging directly to lakes or impoundments	US-EPA (1986)

[1] used to evaluate state of river only - not used for scenario target

Additional goals are to also ensure the minimum dissolved oxygen criterion is met and to reduce the duration of dissolved oxygen supersaturation. A target of 125% dissolved oxygen saturation was used as a reasonable target for control of excessive fluctuations in dissolved oxygen. This metric is consistent with the approach used in other nutrient TMDLs (MassDEP, 2004).

Finally, a comparison was made of in-stream total phosphorus concentrations (although not a target) to US-EPA guidance to further validate the model and weight-of-evidence approach. The "Gold Book" (US-EPA, 1986) states that "to prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphates as phosphorus (P) should not exceed 50 µg/L in any stream at the point where it enters any lake or reservoir, nor 25 µg/L within the lake or reservoir. A desired goal for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments is 100 µg/L total P". Thus, this guidance provides a range of acceptable criteria for phosphorus based upon specified conditions.

The identified targets were used in a "weight of evidence" approach and is consistent with the TMDL evaluation for the Lower Charles TMDL.

For the Upper/Middle Charles TMDL, an HSPF (Hydrologic Simulation Program – Fortran) water quality model (Bicknell, et al., 1993) was developed and calibrated to existing water flow and quality data (CRWA, 2009). An extensive monitoring program for water quality and flow was implemented to supplement existing data and provide a sound platform to establish a well-calibrated water quality model. The HSPF model simulates water column and sediment nutrient cycling and algae dynamics coupled with one-dimensional transport in the Charles River. The calibrated HSPF model was used to evaluate nutrient reduction scenarios for the TMDL. The scenarios were evaluated relative to the approved WLA for the Upper/Middle Charles established by the Lower Charles River TMDL (US-EPA, 2007) at the Watertown Dam, and selected water quality targets in the Upper/Middle Charles River.

The results from the scenario evaluation identified that an overall annual reduction in total phosphorus of 49% is required to meet the desired targets with an explicit 7.8% margin of safety. To achieve this annual reduction, this TMDL assigns WLAs requiring a 62% reduction in annual phosphorus load from wastewater discharges and a 51% reduction in annual phosphorus load from stormwater (Table ES-2).

Table ES-3. Annual Phosphorus WLAs for the Upper/Middle Charles TMDL

Source	Current Load (kg/yr)	Reduction (%)	TMDL Load (kg/yr)
Milford WWTF (MA0100579)	3,407	66	1,149
CRPCD (MA0102598)	4,278	65	1,483
Medfield WWTF (MA0100978)	1,174	66	398
MCI Norfolk (MA0102253)	406	20	324
Wrentham Dev Ctr (MA0102113)	345	11	308
WASTEWATER	**9,611**	**62**	**3,663**
Water/Wetland	126	0	126
Forest	4,394	0	4,394
Open/Agriculture	1,504	35	977
Low Density Res.	4,979	45	2,739
Medium Density Res.	5,505	65	1,927
High Density Res./MF*	5,964	65	2,088
Commercial/Industrial*	6,294	65	2,203
Transportation	2,167	65	759
STORMWATER	**30,934**	**51**	**15,212**

* MF=multi-family residential, Commercial/Industrial with no Transportation

For point sources, the TMDL establishes total phosphorus (TP) wastewater discharge limits for major WWTFs at 0.1 mg/L TP during the summer months and 0.3 mg/L TP during the winter months and for minor WWTFs at 0.1 mg/L TP (summer) and 1.0 mg/L TP (winter). The summer time reductions are needed to protect the Upper/Middle Charles River from summertime algal blooms and the winter limits are necessary to achieve the loading requirement established by the Lower Charles River TMDL at the Watertown Dam. These limits will require total phosphorus reductions from current conditions for major WWTFs as: Milford WWTF 66%; Charles River Pollution Control District 65%; and Medfield WWTF 66%. For minor WWTFs the reductions are: Massachusetts Correctional Institute at Norfolk 20% and Wrentham Development Center 11%.

For nonpoint sources, the TMDL sets phosphorus discharge limits for stormwater by land use category. The total phosphorus reductions from current conditions are as follows:

Water/Wetland 0%; Forest 0%; Open/Agriculture 35%; Low Density Residential 45%; Medium Density Residential 65%; High Density Residential/Multi-Family 65%; Commercial/Industrial 65%; and Transportation 65%.

The TMDL implementation plan sets out the tasks required to meet this TMDL requirement. In particular, the plan envisions a transitional period for major WWTFs by setting an interim winter limit of 0.5 mg/L phosphorus which should be reevaluated after the first 5-year period to attain to the final 0.3 mg/L winter limit for total phosphorus. This transitional period was deemed necessary to allow plant operators some flexibility for a period of time to evaluate the capability of their facilities and operations to achieve the desired goal during the winter months which they have not yet been required to achieve..

Reasonable assurances that the TMDL will be implemented include both application and enforcement of current regulations, availability of financial incentives including low or no-interest loans to communities for wastewater treatment facilities through the State Revolving Fund (SRF), and the various local, state and federal programs for pollution control.

1 INTRODUCTION

1.1 Description of the River

The Charles River starts above Echo Lake in Hopkinton and flows about 79 miles in a north-easterly direction to the coast. The river flows through many of the surrounding Boston communities before discharging into Boston Harbor. The river drops 310 ft in its journey to the coast and the watershed drains an area of 311 square miles. The steepest elevation change is in the headwaters with the rest of the watershed being gently sloped.

For the purposes of this report, the Upper Charles is the area above United Stages Geological Survey (USGS) Dover Gauge (see Figure 1) and is slightly more than half of the drainage area (182 square miles) and half of the river length (45 miles) while the Lower Charles is the drainage area below the Watertown Dam (see Figure 1) and is about 43 square miles and 9 miles long. The Middle Charles is the 25-mile section of the river in between. The combined Upper/Middle Charles watershed is 70 miles long and covers 268 square miles in area (see Figure 2).

Inside of Interstate I-95 (Route 128) is the highly urbanized Greater Boston area, while outside of Interstate I-95 is predominantly suburban residential development with smaller urban cores and significant areas of forested landscape. The land use breakdown of the Upper/Middle Charles is as follows: Forest 27.9%, Water/Wetland 13.0%, Open 8.8%, Residential 42.5%, and Commercial and Industrial 7.9% (MassGIS, 1999). The watershed has predominantly moderately- to well-drained soils with the surficial geology being categorized as Sand and Gravel 42.6%, Till & Bedrock 51.3%, and Alluvium 6.1%.

The Upper/Middle Charles Watershed contains 5 communities in their entirety (Medway, Millis, Needham, Waltham, and Wellesley) and includes portions of 28 more (Arlington, Ashland, Bellingham, Belmont, Boston, Brookline, Dedham, Dover, Foxborough, Franklin, Holliston, Hopedale, Hopkinton, Lexington, Lincoln, Medfield, Mendon, Milford, Natick, Newton, Norfolk, Sherborn, Walpole, Watertown, Wayland, Weston, Westwood, and Wrentham).

Visual evidence and data show that the Upper/Middle Charles is significantly impaired by large extents of algae and aquatic plant growth resulting from excessive nutrients. As a result, the Upper/Middle Charles River has been listed for nutrients on the Massachusetts Integrated List thus requiring the development of this TMDL (MassDEP 2008b). Especially of concern is phosphorus, considered the controlling nutrient (see section 4.1). Although phosphorus is ubiquitous in the natural environment since it exists in natural soils and vegetation, additional inputs in the Upper/Middle Charles come from human activities and alterations to the natural hydrological system.

The principal sources of phosphorus are the five active municipal wastewater discharges (see Figure 2) and stormwater runoff. Stormwater runoff includes inputs from fertilized soils and lawns; leaf litter and other vegetative debris; car wash products and some detergents; auto exhaust, fuel, and lubricants; and pet waste. Stormwater runoff is conveyed quickly to the rivers via impervious surfaces and connected stormwater pipes. The effects of excessive nutrients are exacerbated by the numerous impoundments which are sensitive to nutrient enrichment and identified as critical reaches for this study (see Figure 2).

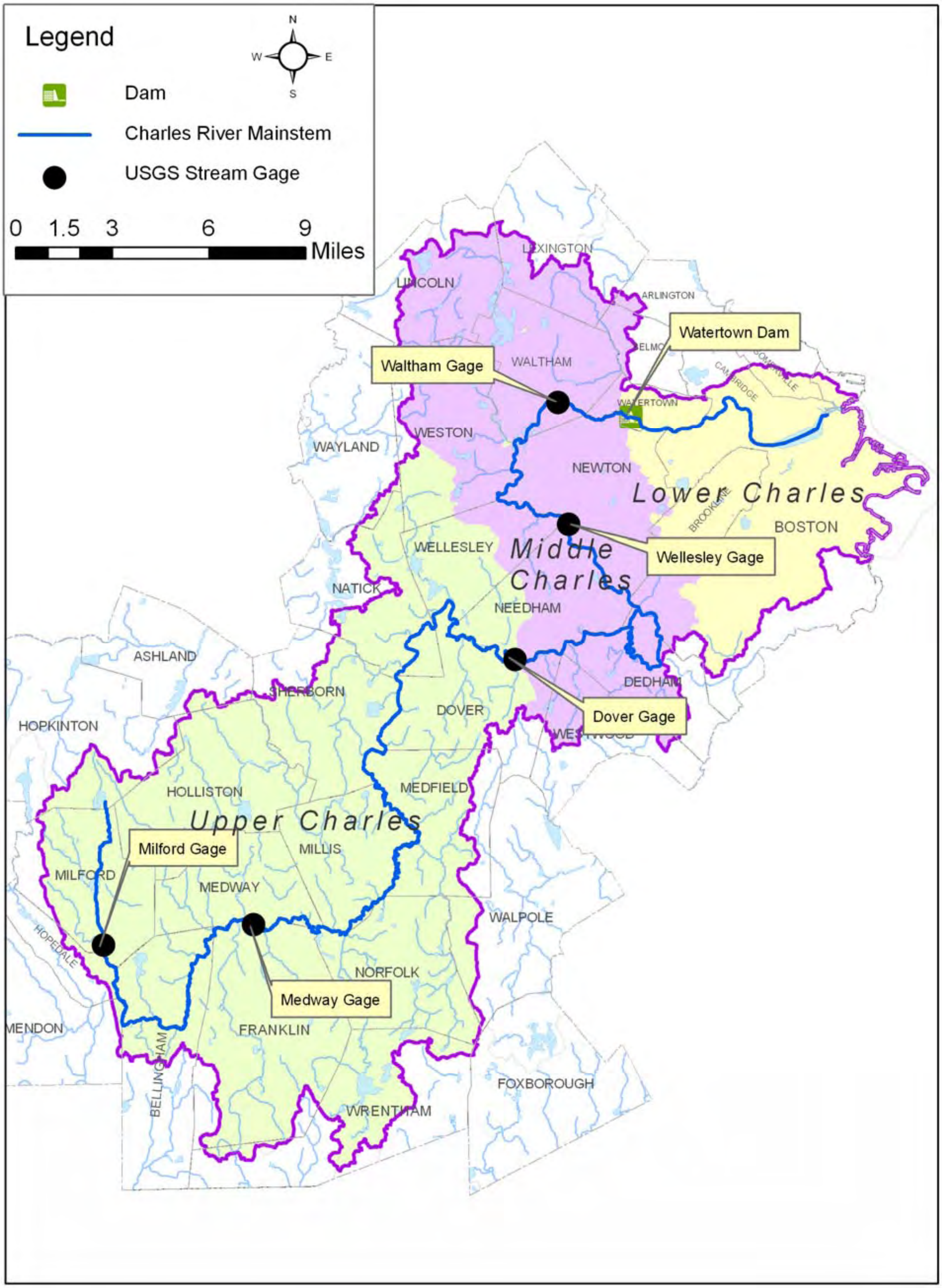


Figure 1. The Charles River Watershed

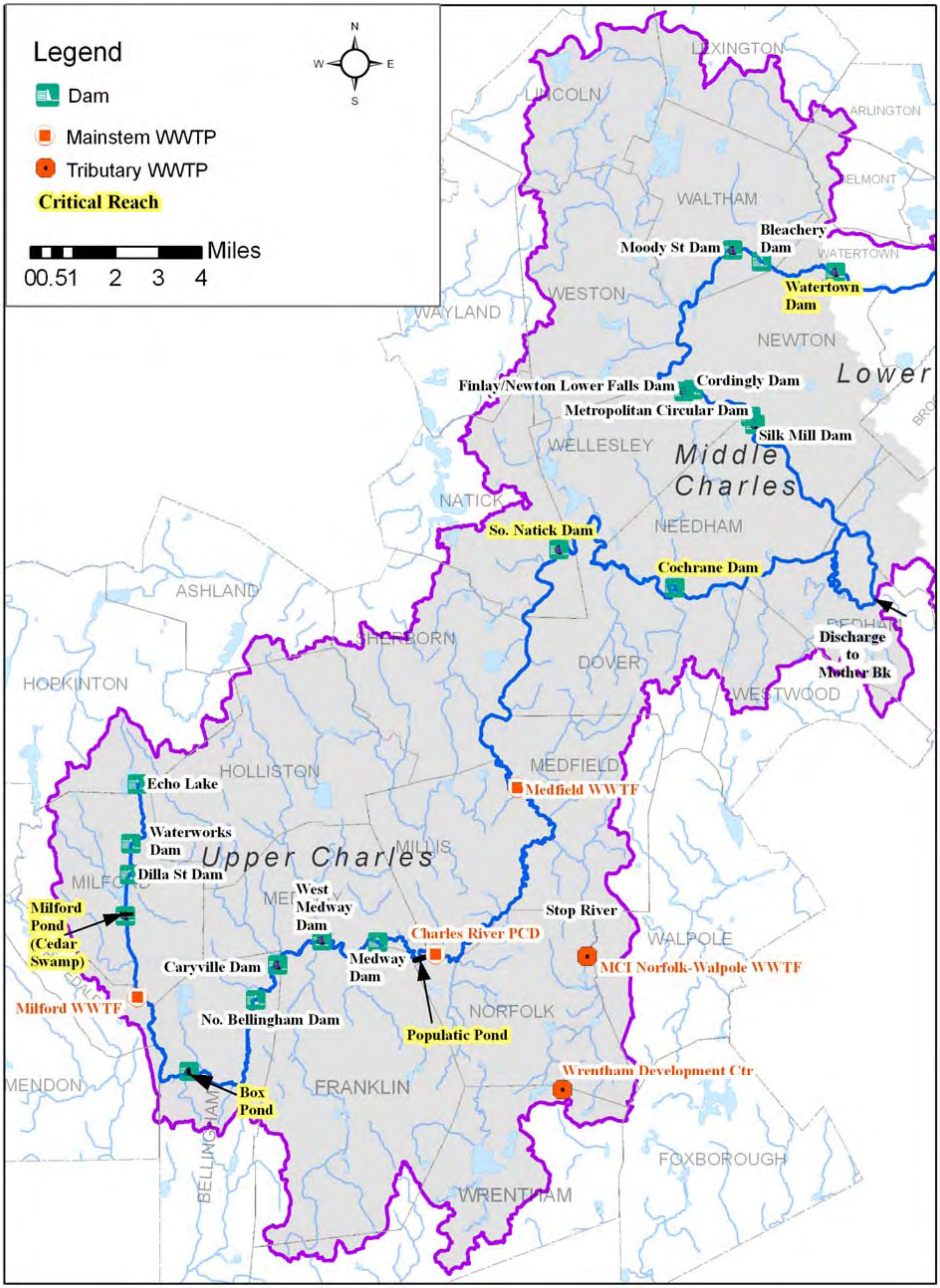


Figure 2. The Upper/Middle Charles River Watershed

1.2 The TMDL Process

This project establishes a nutrient Total Maximum Daily Load (TMDL) and corresponding watershed plans for the Upper/Middle Charles River and corresponding communities. The Upper/Middle Charles watershed is 70 miles long, covers 268 square miles in area, touches 33 communities, and ends at the Watertown Dam where it connects the Lower Charles. A final nutrient TMDL has already been developed and approved for the Lower Charles (US-EPA, 2007). Under current conditions, the outlet load from the Upper/Middle watershed exceeds the target inlet load to the Lower Charles. Therefore, reductions in the nutrient load from the Upper/Middle Charles watershed will be needed in order to meet the target nutrient load for the Lower Charles.

The Upper/Middle Charles River is a high priority for development of a TMDL based on local concerns and the extent of the excessive nutrients and aquatic plant growth in the river. This priority is in accord with the Massachusetts Department of Environmental Protection (MassDEP) five-year strategy to initiate work on significant but complicated long-term TMDLs. The large open-water extent of the Lower Charles is recognized as one of the most used public water bodies in the world for recreation (US-EPA, 2009). Recently, the Lower Charles Nutrient TMDL was completed (US-EPA-2007) and its success in reducing algae in the Lower Charles is inextricably tied to reductions in phosphorus loads from the Upper/Middle Charles River.

A TMDL is essentially a pollutant budget and establishes the maximum amount of pollutant by pollution source that can be introduced into a body of water while attaining water quality standards. A TMDL provides a defensible basis for allocating pollutants to sources and remediation responsibilities.

Assessment of water quality by the states under the Clean Water Act, sections 303(d) and 305(b), results in an Integrated List of Waters Report that divides water bodies into one of five categories based on existing water quality. Category 5 waters are the lowest quality waters and these are placed on the "impaired" waters or 303(d) list. These "impaired" waters do not or will not meet applicable water quality standards after the application of technology-based controls and require the preparation of a TMDL. TMDLs provide the scientific basis for a state to establish water quality-based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of the state's water resources (US-EPA, 1991).

A TMDL for a given pollutant and water body is composed of the sum of individual waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background levels. In addition, the TMDL must include an implicit or explicit margin of safety (MOS) to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving water body. The TMDL components are illustrated using the following equation:

$$\text{TMDL} = (\text{LA}+\text{BG}) + \text{WLA} + \text{MOS}$$

where LA+BG is the load allocation for nonpoint sources including background, WLA is the waste load allocation, and MOS is the margin of safety.

The Upper/Middle Charles River is designated as a Class B water under the Massachusetts water quality standards [314 CMR 4.05(3)b]. Class B waters are designated as capable of providing and supporting habitat for fish and other aquatic wildlife, and for primary and secondary contact recreation. Primary recreation includes any activity with prolonged or intimate contact with water, such as swimming or windsurfing. Any recreational activity where contact with the water is incidental or accidental is considered secondary contact recreation, such as boating and fishing. The goal for the river is to achieve water quality standards as defined in Massachusetts 314 CMR 4.0. The water quality standards provide numerical and narrative criteria for six-nutrient related parameters to meet the water body's designated uses (see Table 2).

The development of this nutrient TMDL addresses the issue of eutrophication, or the over-enrichment of nutrients, which results in excessive algae and aquatic plant growth and low and/or highly variable dissolved oxygen (DO) levels. Many reaches in the Upper/Middle Charles River are classified as "impaired" since they do not meet water quality standards for nutrients, dissolved oxygen (DO) and turbidity and also have high levels of algae and aquatic plants. In most freshwater systems, phosphorus is the limiting nutrient that controls eutrophication; reducing phosphorus reduces algae and could limit long-term macrophyte growth while also improving DO levels instream (Thomann and Mueller, 1987).

Water quality monitoring for the TMDL involved two rounds of dry- and wet-weather sampling and five years of flow measurements at both tributary and main stem sites. Data from the Massachusetts Water Resources Authority, Massachusetts Department of Environmental Protection and other relevant data sources were also used. Water quality monitoring data were evaluated by comparing results to the TMDL parameter action limits based on regulatory thresholds or water quality criteria and to trophic indicator criteria, which indicates the biological productivity of a water body. A weight-of evidence approach was used that considered all nutrient related parameters.

An HSPF (Hydrologic Simulation Program – Fortran) water quality model (Bicknell, et al., 1993) was developed and calibrated to existing water flow and quality data (CRWA, 2009). The calibrated HSPF model was used to estimate source nutrient loads and evaluate remediation scenarios by comparing simulated river nutrient concentrations, DO, and algae growth (chlorophyll *a*).

The HSPF model was used to evaluate a number of management scenarios and assist in selecting the scenario that best meets the TMDL targets (see Section 5.0). The Upper/Middle TMDL must also produce an outlet phosphorus load that satisfies the Lower Charles TMDL inlet load. The TMDL must also meet specific water quality targets (chlorophyll-*a*, DO, and phosphorus concentrations) especially in the critical reaches like impoundments (e.g. Box Pond, Populatic Pond) and below wastewater treatment discharges.

To prevent further degradation in water quality and to ensure that the Upper/Middle Charles River meets state water quality standards, the nutrient TMDL requires a 49% decrease in total phosphorus loadings from current conditions. The TMDL outlines corrective actions to achieve that goal. In the Implementation Plan (Section 7.0), the two primary sources from stormwater and wastewater are targeted for reductions.

Required reductions in annual stormwater loads are: 0% for water/wetland and forest; 35% for agriculture and open land; 45% for low density residential; 65% for medium/high density residential, multi-family, and commercial, industrial or transportation. Active mainstem wastewater treatment facilities will ultimately be required to meet summer (Apr-Oct) total phosphorus limits of 0.1 mg/L and 0.3 mg/L during the winter (Nov-Mar) while tributary facilities must meet summer limits of 0.1 mg/L and 1.0 mg/L during the winter.

1.3 Impaired Segments

Section 303(d) of the Clean Water Act (CWA) regulation requires states to identify and list those water bodies that are not expected to meet surface water quality standards after the implementation of technology-based controls and, as such, require the development of TMDLs. Water bodies requiring TMDL development are identified under Category 5 of the Massachusetts Integrated list of Waters which includes a listing of the specific cause(s) of the impairment (if known). Waters were listed in Category 5 if they were identified as impaired (i.e., not supporting one or more intended use), the impairment was related to the presence of one or more "pollutants", and the source of those pollutants was not considered to be natural.

Based on the water quality data available for the Upper/Middle Charles River, the Massachusetts Department of Environmental Protection (MassDEP) has included a number of the Upper/Middle Charles River mainstem segments, tributaries, and ponds on the State's 2008 section 303(d) lists for the following pollutants (MassDEP, 2008a, b):

- Aquatic macroinvertebrate bioassessments
- Aquatic plants or Macrophytes
- Excessive algae/excess algal growth
- Non-native Aquatic Plants
- Nutrients/Eutrophication biological Indicators
- Organic enrichment/low dissolved oxygen/dissolved oxygen saturation
- Secchi disc transparency
- Sedimentation/siltation
- Taste, odor, and color
- Total Phosphorus
- Turbidity

This TMDL report addresses the nutrient/eutrophication, phosphorus, and aquatic plant listings as well as associated water quality impairments such as low and variable dissolved oxygen, dissolved oxygen saturation, turbidity and Secchi disc transparency. Pathogen impairments were previously addressed in the Charles River Pathogen TMDL (MassDEP, 2007a). Increased nutrient loads to the Upper/Middle Charles contribute to excessive algal biomass and the growth of aquatic macrophytes throughout the system.

Regular occurrences of severe algal blooms during the summer months reduce water clarity and contribute to anoxic bottom waters that do not support aquatic life. Algae, or phytoplankton, are microscopic plants and bacteria that live and grow in water using energy from the sun through photosynthesis and available nutrients as food. Many species of algae contribute significantly to the base of the food web and are, therefore, a valuable part of the aquatic ecosystem. Conversely, excessive growth of algae populations can lead to a number of water quality related problems affecting both aquatic life and recreational water uses.

Algal blooms and other water quality parameters (i.e., nutrients, water clarity, chlorophyll-*a* and low or high dissolved oxygen) indicate the Upper/Middle Charles River is undergoing cultural eutrophication. Cultural eutrophication is the process of producing excessive plant life because of excessive pollutant inputs from human activities. Nutrient loads from the Upper/Middle Charles also contribute to water quality impairments in the Lower Charles. In both the Upper/Middle and the Lower Charles, the blooms are directly responsible for degrading the aesthetic quality of the river, reducing water clarity, and impairing recreational uses such as boating and swimming. Eutrophication of the Charles River also affects resident aquatic life by altering dissolved oxygen levels and producing algal species that are of little food value or, in some cases, toxic. Of particular concern to the Charles River is the potential presence of toxic algal species. Some cyanobacteria (blue-green) species known to be toxic have been consistently observed in the Lower Charles during all summers when algal sampling has been conducted (US-EPA, 2007).

The nutrient-related pollutants of concern for this TMDL study are those pollutants that are thought to be directly causing or contributing to the excessive algal biomass in the Charles River and pollutants that will or might require reductions to attain the applicable Massachusetts Water Quality Standards (MAWQS). Phosphorus is a primary pollutant of concern for contributing to excessive algal growth and the proliferation of undesirable algae species in both the Upper and Lower Charles River system.

The Upper/Middle Charles nutrient TMDL will address all nutrient related issues in the listed segments of the watershed above the Watertown Dam and will meet the loading requirements established in the Lower Charles TMDL. The mainstem and tributary segments that will be addressed by this TMDL are listed in Table 1 and mapped in Figure 3. The list includes nine mainstem segments, nine tributaries, and twelve ponds that are connected to tributaries. Mainstem segments will be fully addressed since those reaches are directly modeled by HSPF while tributaries will be addressed since they are modeled as large land segments with a connecting reach to the mainstem. The rational for including tributaries and tributary ponds is that the TMDL requires nonpoint source reductions in these impaired segments in order to meet the nutrient loading requirements to achieve the TMDL and at the Watertown Dam.

Tributary water bodies that do not receive point source discharges are expected to meet water quality standards in a reasonable timeframe as the result of nonpoint source implementation required to meet this TMDL Although the Stop River was identified on the 2008 Integrated List, it was excluded from the list in Table 1, because the TMDL does not fully evaluate the local impacts of point source loads from MCI Norfolk/Walpole and the Wrentham Development Center WWTFs..

Table 1. Impaired Waters in the Upper/Middle Charles River Watershed*

Mainstem Segments

Waterbody	DEP ID	Description	Size	Impairments
Charles River (7239050)	MA72-01_2008	Headwaters, outlet Echo Lake, Hopkinton to Dilla Street (just upstream of Cedar Swamp Pond), Milford.	2.5 miles	Low flow alterations Other flow regime alterations **Dissolved Oxygen** Mercury in Fish Tissue
Milford Pond, Charles River (72016)	MA72016_2008	Also known as Cedar Swamp, Milford	99.0 acres	Non-native Aquatic Plants **Dissolved Oxygen**
Charles River (7239050)	MA72-33_2008 (formerly part of MA72-02)	Outlet Cedar Swamp Pond, Milford to the Milford WWTF discharge, Hopedale.	2.0 miles	Escherichia coli Physical substrate habitat alterations **Nutrient/Eutrophication Biological Indicators**
Charles River (7239050)	MA72-03_2008	Milford WWTF discharge, Hopedale to outlet Box Pond (formerly segment MA72008), Bellingham.	3.4 miles	DDT **Dissolved oxygen saturation** Escherichia coli [5/22/2007CN156.0] **Excess Algal Growth** **Organic Enrichment Sewage Biological Indicators** **Phosphorus Total**
Charles River (7239050)	MA72-04_2008	Outlet Box Pond, Bellingham to inlet Populatic Pond, Norfolk/Medway.	11.5 miles	Escherichia coli [5/22/2007CN156.0] Fishes Bioassessments Other flow regime alterations Mercury in Fish Tissue Other
Populatic Pond, Chalres River (72096)	MA72096_2008	Norfolk	41.9 acres	**Dissolved oxygen saturation** **Excess Algal Growth** **Dissolved Oxygen** **Nutrient/Eutrophication Biological Indicators** Mercury in Fish Tissue [12/20/2007NEHgTMDL]
Charles River (7239050)	MA72-05_2008	Outlet Populatic Pond, Norfolk/Medway to South Natick Dam, Natick.	18.1 miles	**Dissolved oxygen saturation** **Excess Algal Growth** Non-native Aquatic Plants **Dissolved Oxygen** **Turbidity** **Nutrient/Eutrophication Biological Indicators** **Phosphorus Total** Mercury in Fish Tissue Aquatic Macroinvertebrate Bioassessments
Charles River (7239050)	MA72-06_2008	South Natick Dam, Natick to Chestnut Street, Needham/Dover.	8.4 miles	DDT Eurasian Water Milfoil, Myriophyllum spicatum **Excess Algal Growth** Fishes Bioassessments Non-native Aquatic Plants Other flow regime alterations **Nutrient/Eutrophication Biological Indicators** **Phosphorus Total** PCB in Fish Tissue Other
Charles River (7239050)	MA72-07_2008	Chestnut Street, Needham to Watertown Dam, Watertown.	24.8 miles	DDT Escherichia coli [5/22/2007CN156.0] FishPassage Barrier Fishes Bioassessments Non-native Aquatic Plants Other flow regime alterations **Nutrient/Eutrophication Biological Indicators** **Phosphorus Total** PCB in Fish Tissue

Table 1. List of Impaired Waters in the Upper/Middle Charles River Watershed (cont.)

Tributary Segments				
Waterbody	**DEP ID**	**Description**	**Size**	**Impairments**
Alder Brook (7239475)	MA72-22_2008	Headwaters northwest of the Route 135 and South Street intersection, Needham to	0.28 miles	**Nutrient/Eutrophication Biological Indicators** Aquatic Macroinvertebrate Bioassessments
Beaver Brook (7239125)	MA72-28_2008	Headwaters, north of Route 2, Lexington through culverting to Charles River, Waltham.	5.5 miles	Escherichia coli [5/22/2007CN156.0] **Excess Algal Growth** Non-native Aquatic Plants Other anthropogenic substrate alterations Other flow regime alterations **Dissolved Oxygen** Sedimentation/Siltation **Turbidity** Organic Enrichment Sewage Biological Indicators Taste and Odor **Phosphorus Total**
Cheese Cake Brook (7239100)	MA72-29_2008	Emerges south of Route 16, Newton to confluence with the Charles River, Newton.	1.4 miles	**Dissolved oxygen saturation** Escherichia coli [5/22/2007CN156.0] **Excess Algal Growth** Other anthropogenic substrate alterations **Phosphorus Total** Alteration in streamside or littoral vegetative covers
Fuller Brook (7239625)	MA72-18_2008	Headwater south of Route 135, Needham to confluence with Waban Brook, Wellesley.	4.3 miles	Escherichia coli [5/22/2007CN156.0] Physical substrate habitat alterations Sedimentation/Siltation **Nutrient/Eutrophication Biological Indicators**
Rock Meadow Brook (7239500)	MA72-21_2008	Headwaters in Fisher Meadow, Westwood through Stevens Pond and Lee Pond, Westwood to confluence with Charles River, Dedham.	3.8 miles	**Excess Algal Growth [5/22/2007CN156.0]** **Dissolved Oxygen** **Nutrient/Eutrophication Biological Indicators** **Phosphorus Total** **Aquatic Plants Macrophytes** Aquatic Macroinvertebrate Bioassessments
Rosemary Brook (7239325)	MA72-25_2008	Headwaters, outlet Rosemary Lake, Needham to confluence with the Charles	3.3 miles	**Dissolved Oxygen** **Phosphorus Total**
Sawmill Brook (7239400)	MA72-23_2008	Headwaters, Newton to confluence with Charles River, Boston.	2.4 miles	Chloride Escherichia coli [5/22/2007CN156.0] **Dissolved Oxygen** **Organic Enrichment Sewage Biological Indicators** **Phosphorus Total**
South Meadow Brook (7239375)	MA72-24_2008	From emergence west of Parker Street, Newton to confluence with the Charles River, Newton (sections culverted).	1.7 miles	Debris/Floatables/Trash Escherichia coli [5/22/2007CN156.0] **Dissolved Oxygen** Physical substrate habitat alterations **Turbidity** **Phosphorus Total** Bottom Deposits
Trout Brook (7239575)	MA72-19_2008	Headwaters, outlet Channings Pond, Dover to confluence with Charles River,	2.8 miles	Temperature, water **Nutrient/Eutrophication Biological Indicators**

Table 1. List of Impaired Waters in the Upper/Middle Charles River Watershed (cont.)

Onstream Ponds				
Waterbody	**DEP ID**	**Description**	**Size**	**Impairments**
Cambridge Res, Upper Basin, Hobbs Bk (72156)	MA72156_2008	Lincoln/Lexington	44.0 acres	**Turbidity** **Aquatic Plants Macrophytes**
Factory Pond, Bogastow Bk (72037)	MA72037_2008	Holliston	9.7 acres	Non-native Aquatic Plants **Aquatic Plants Macrophytes**
Franklin Reservoir NE, Miller Bk (72095)	MA72095_2008	Franklin	21.0 acres	**Turbidity** **Aquatic Plants Macrophytes**
Franklin Reservoir SE, Miller Bk (72032)	MA72032_2008	Franklin	13.1 acres	**Turbidity** **Aquatic Plants Macrophytes**
Hardys Pond, Beaver Bk (72045)	MA72045_2008	Waltham	42.8 acres	**Excess Algal Growth** Non-native Aquatic Plants **Turbidity** **Phosphorus Total**
Houghton Pond, Bogastow Bk (72050)	MA72050_2008	Holliston	17.5 acres	**Excess Algal Growth** Non-native Aquatic Plants **Turbidity**
Linden Pond, Bogastow Bk (72063)	MA72063_2008	Holliston	1.4 acres	**Turbidity** **Aquatic Plants Macrophytes**
Lymans Pond, Unnamed Trib (72070)	MA72070_2008	Dover	4.4 acres	**Turbidity** **Aquatic Plants Macrophytes**
Mirror Lake, Stony Bk (72078)	MA72078_2008	Wrentham/Norfolk	61.6 acres	Non-native Aquatic Plants **Secchi disk transparency** **Nutrient/Eutrophication Biological Indicators** **Phosphorus Total**
Lake Pearl, Eagle Bk (72092)	MA72092_2008	Wrentham	237 acres	Eurasian Water Milfoil, Myriophyllum spicatum Non-native Aquatic Plants **Dissolved Oxygen**
Uncas Pond, Uncas Bk (72122)	MA72122_2008	Franklin	17.3 acres	Non-native Aquatic Plants **Dissolved Oxygen**
Lake Winthrop, Winthrop Canal (72140)	MA72140_2008	Holliston	131 acres	Non-native Aquatic Plants 2,3,7,8Tetrachlorodibenzopdioxin only **Aquatic Plants Macrophytes**

* Impairments addressed in this TMDL highlighted in bold in Table.

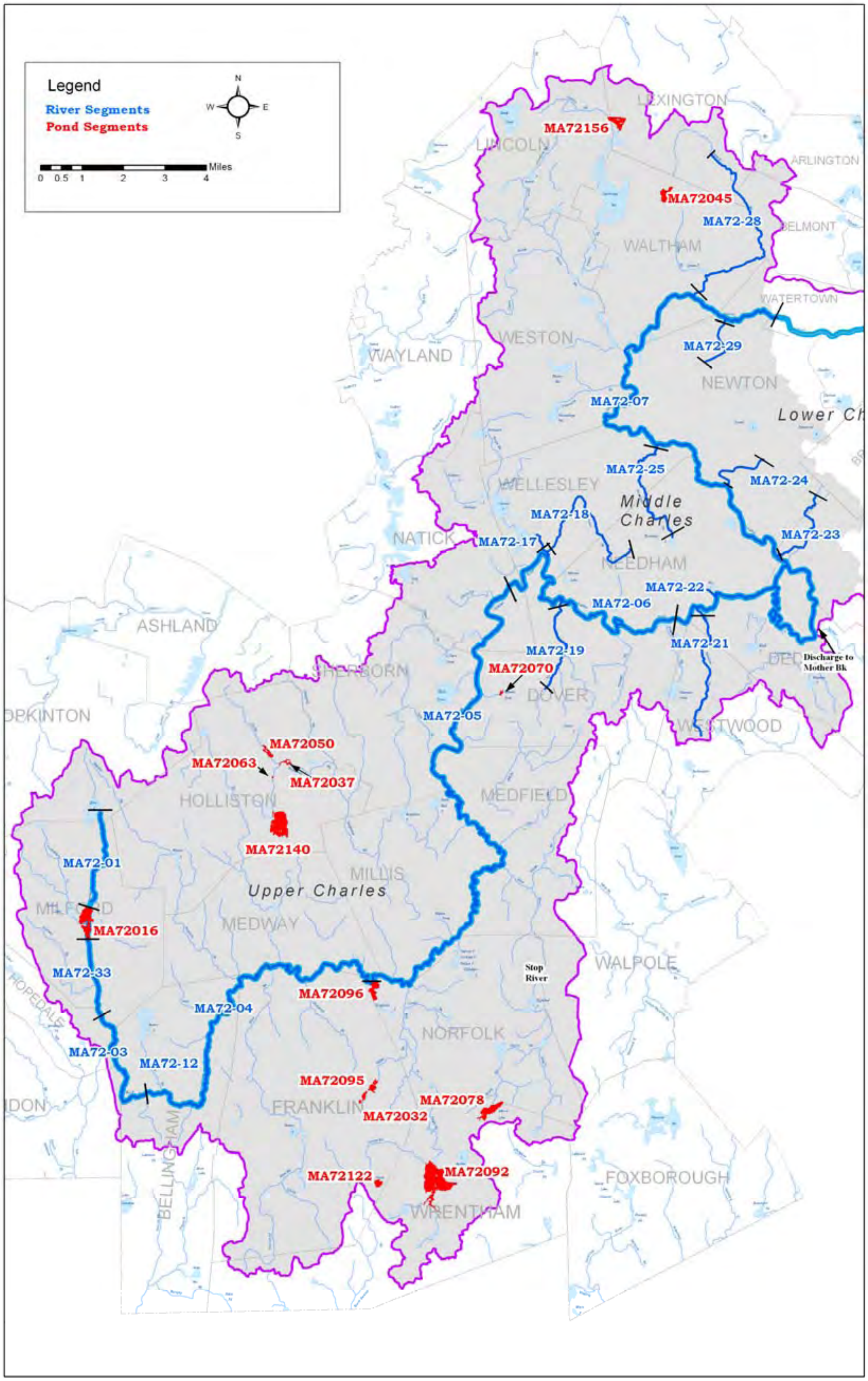


Figure 3. Impaired Waters in the Upper/Middle Charles

2 ASSESSING WATER QUALITY

2.1 Massachusetts Water Quality Standards

The Upper/Middle Charles River is designated as a Class B water under the Massachusetts surface water quality standards (MassDEP, 2007b) in section 314 CMR 4.05(3)(b). Class B waters are designated as providing and supporting habitat for fish and other aquatic wildlife and for primary and secondary contact recreation, and shall have consistently good aesthetic value. Primary recreation includes any activity with prolonged or intimate contact with the water (i.e., swimming, windsurfing, etc.). Any recreational activity where contact with the water is incidental or accidental is considered secondary contact recreation, such as boating and fishing. The goal for the river is to achieve water quality standards as defined in Massachusetts 314 CMR 4.0. The water quality standards provide numerical and narrative criteria for the six nutrient-related parameters given in Table 2.

Table 2. Massachusetts Water Quality Standards for Nutrient-Related Parameters

Pollutant	Criteria	Source
Dissolved Oxygen	Shall not be less than 6.0 mg/l in cold water fisheries and not less than 5.0 mg/l in warm water fisheries. Where natural background conditions are lower, DO shall not be less than natural background conditions. Natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained.	314 CMR: 4.05: Classes and Criteria (3)(b) 1
pH	Shall be in the range of 6.5 - 8.3 standard units and not more than 0.5 units outside of the background range. There shall be no change from background conditions that would impair any use assigned to this class.	314 CMR: 4.05: Classes and Criteria (3)(b) 3
Solids	These waters shall be free from floating, suspended, and settleable solids in concentrations and combinations that would impair any use assigned to this Class, that would cause aesthetically objectionable conditions, or that would impair the benthic biota or degrade the chemical composition of the bottom.	314 CMR: 4.05: Classes and Criteria (3)(b) 5.
Color and Turbidity	These waters shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this Class.	314 CMR: 4.05: Classes and Criteria (3)(b) 6
Aesthetics	All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum or other matter to form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life.	314 CMR: 4.05: Classes and Criteria (5)(a)
Nutrients	Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established by the Department pursuant to 314 CMR 4.00. Any existing point source discharge containing nutrients in concentrations that would cause or contribute to cultural eutrophication, including the excessive growth of aquatic plants or algae, in any surface water shall be provided with the most appropriate treatment as determined by the Department, including, where necessary, highest and best practical treatment (HBPT) for POTWs and BAT for non POTWs, to remove such nutrients to ensure protection of existing and designated uses. Human activities that result in the nonpoint source discharge of nutrients to any surface water may be required to be provided with cost effective and reasonable best management practices for nonpoint source control.	314 CMR: 4.05: Classes and Criteria (5)(c)

2.2 US-EPA Guidance on Nutrient Criteria

Three crucial guidance documents relative to nutrient criteria for rivers and streams have been published by US-EPA in the last two decades. The first document was entitled "Quality Criteria for Water" is commonly referred to as the "Gold Book" (US-EPA, 1986). The "Gold Book" states that "To prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphates as phosphorus (P) should not exceed 50 µg/L in any stream at the point where it enters any lake or reservoir, nor 25 µg/L within the lake or reservoir. A desired goal for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments is 100 µg/L total P". This guidance provides a range of acceptable criteria for phosphorus based upon specific stream conditions (see Table 3).

The second set of documents was the "Nutrient Criteria Technical Guidance Manuals" for "Lakes and Reservoirs" (US-EPA, 2000a) and "Rivers and Streams" (US-EPA, 2000b). The purpose of these manuals was to provide scientifically defensible guidance to assist States and Tribes in developing regionally based numeric nutrient and algal criteria for rivers and streams with lakes and reservoirs. These documents describe candidate response variables that can be used to evaluate or predict the condition or degree of eutrophication in water bodies. Those variables include direct measurement of nutrient concentrations as well as observable response variables such as biomass and turbidity. The river document emphasized periphyton (attached or floating algae) as a measure for assessing nutrient enrichment. The guidance also notes the need for an adaptive management approach where uncertainty exists.

The third more specific document was the "Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion XIV (US-EPA, 2000c). Based on statistical analyses, nutrient criteria were developed for all of Ecoregion XIV (eastern coast of the United States) and for sub-ecoregion 59 (where the Upper/Middle Charles is located). The instream total phosphorus criteria were 0.03125 and 0.02375 mg/L while the total nitrogen criteria were 0.71 and 0.57 mg/L for Ecoregion XIV and sub-ecoregion 59, respectively. The chlorophyll-*a* criterion for Ecoregion XIV was 3.75 µg/L and there was no criterion for sub-ecoregion 59. These criteria represent the 25th percentile of available data collected from these regions including both impaired and unimpaired waters (see Table 3).

Table 3. US-EPA Recommended Nutrient Criteria

Parameter	Criteria	Source
Total phosphates as P within impoundment (mg/L)	0.025	US-EPA (1986)
Total phosphates as P entering impoundment (mg/L)	0.050	US-EPA (1986)
Total phosphates as P for free-flowing river (mg/L)	0.100	US-EPA (1986)
Total phosphorus (mg/L)	0.02375	US-EPA (2000c)
Total nitrogen (mg/L)	0.57	US-EPA (2000c)
Chlorophyll *a* (µg/L)	3.75	US-EPA (2000c)

Although these documents are excellent resources, each has some shortcomings. The Gold Book and EcoRegion criteria were not based upon in-stream response variables or site-specific conditions which is critical to the success of any nutrient management strategy. US-EPA clearly acknowledges the lack of definitive numerical criteria and the need for criteria that vary not only by ecoregion but also by site-specific conditions. To account for site specific conditions in the Upper/Middle Charles River, response indicators such as variable dissolved oxygen and aquatic plant biomass as measured by chlorophyll-*a* are thought to be more representative measures for assessing nutrient enrichment in some segments of the river (see Section 2.4).

2.3 Trophic Status

Trophic state refers to the biological production of a water body, both in terms of plant and animal life. The trophic state is generally driven by nutrient levels in the water body. There are three trophic state categories: 1) oligotrophic waters are clear with low biological productivity; 2) mesotrophic waters have intermediate biological productivity; and 3) eutrophic waters have high biological productivity relative to natural levels due to increased nutrient supply. The effects of eutrophication include increased aquatic plant growth and biomass which consequently decreases dissolved oxygen and increases turbidity and color. Total phosphorus, total nitrogen, chlorophyll-*a,* and Secchi depth are commonly used as indicators to classify the trophic state of freshwater lakes and impounded river systems. With the exception of Secchi depth, the indicators are defined in the sections above. Secchi depth is a measure of water clarity and reflects the presence of algal and non-algal particulate matter and other dissolved constituents suspended in the water column (US-EPA, 2000b).

To establish trophic levels in the Upper/Middle Charles River, water quality data from the various studies are compared to available literature values for total phosphorus and chlorophyll-*a.* Few Secchi depth data are available except for the US-EPA monitoring that measured water clarity as part of their program. Table 4 lists literature values for the mean and range of total phosphorus, chlorophyll-*a,* and peak chlorophyll-*a* for different trophic states. Peak chlorophyll-*a* values are presented because they represent instantaneous blooms which could occur even if average chlorophyll-*a* levels are acceptable.

2.4 Aquatic Plant Coverage

Cultural eutrophication of the Upper/Middle Charles River may be demonstrated by one or both of the following factors: elevated levels of nutrients or chlorophyll-*a* in the water column; and dense coverage and high biovolume of macrophytes and/or periphyton (attached or floating algae). Because watermeal, duckweed, and algae react very quickly to nutrient inputs and blooms occur immediately, they are good indicators of eutrophication and this response is easily quantified by measurements of chlorophyll-*a*. On the other hand, it is more difficult to directly correlate increases of macrophytes and periphyton to anthropogenic causes.

Chlorophyll-*a* concentration only represents the phosphorus and plant biomass suspended in the water column. Where extensive coverage of periphyton and macrophytes exist, significant phosphorus and biomass amounts are tied up in these attached or floating plant groups. For those sites where periphyton and/or macrophytes dominate the system, a more qualitative approach that also looks at the amount and diversity of periphyton and macrophytes, measured by areal extent, biovolume and/or biomass, and the number of species, might be necessary to quantify the eutrophication impact.

Table 4. Trophic Indicator Criteria

Variable	Oligotrophic	Mesotrophic	Eutrophic	Source
Total Nitrogen (mg/l)				
Mean	0.66	0.75	1.9	US-EPA (2000a)
Range	0.31 – 1.60	0.36 – 1.40	0.39 – 6.10	US-EPA (2000a)
Total Phosphorus (mg/l)				
Mean	0.008	0.027	0.084	US-EPA (2000a)
Range	0.003 - 0.018	0.011 - 0.096	0.016 - 0.39	US-EPA (2000a)
Mean Chlorophyll-*a* (µg/l)				
Mean	1.7	4.7	14	US-EPA (2000a)
Range	0.3 - 4.5	3 - 11	2.7 - 78	US-EPA (2000a)
Range	0.3 to 3	2 to 15	>10	Wetzel (2001)
Range	0.8 to 3.4	3 to 7.4	6.7 to 31	Ryding and Rast (1989)
Range		3.5 to 9	-	Smith (1998)
Range	>10	4 to 10	< 4	Novotny and Olem (1994)
Peak chlorophyll-*a* (µg/l)				
Mean	4.2	16	43	US-EPA (2000a)
Range	1.3 - 11	5 - 50	10 - 280	US-EPA (2000a)
Range	2.6 - 7.6	8.2 – 29	16.9 –107	US-EPA (2003)

after Vollenweider and Kerekes (1980) and US-EPA (2003)

Although there are no specific biomass criteria or standards, MassDEP has suggested natural system have less than 200 mg/m2 of benthic algae biomass for protection of aesthetic uses (MassDEP, 2009).

2.5 Evaluation Metrics

As described in 2.1 above, the Massachusetts Water Quality Standards provide numerical and narrative criteria to sustain Class B waters designated as supporting habitat for fish and other aquatic wildlife and for primary and secondary contact recreation. MassDEP has set numeric criteria for dissolved oxygen (DO>5 mg/L) and pH (6.5-8.3) (MassDEP, 2007). For nutrients, however, Massachusetts relies on narrative criteria since the relationship between nutrient concentrations and environmental responses is complex and varied. Narrative standards are aimed at controlling cultural eutrophication, including the excessive growth of aquatic plants or algae. Additional goals are designed to minimize photosynthetic effects that lead to extreme diurnal dissolved oxygen fluctuations and dissolved oxygen supersaturation.

In the absence of numeric criteria for nutrients in the Massachusetts State Water Quality Standards, MassDEP uses best professional judgment (BPJ) and a “weight-of-evidence” approach that considers all available information to set site-specific permit limits, pursuant to 314 CMR 4.05(5)(c). The water quality metrics selected for the Upper/Middle Charles are summarized in Table 5 below. These metrics will be refined into specific TMDL targets later in this report (see Section 4.3). This weight-of-evidence approach considers water quality standards, related TMDL project experience (e.g., Assabet River Phosphorus TMDL, Lower Charles River Phosphorus TMDL), as well as available guidance documents (US-EPA, 1986). A description of the rationale for numeric chlorophyll-*a*, total phosphorus and dissolved oxygen percent saturation metrics for the Upper/Middle Charles TMDL follows.

Table 5. Selected Nutrient Water Quality Metrics and Guidance Values

Metric	Acceptable Range	Rational for Metric	Source
Numeric Water Quality Standard			
Dissolved Oxygen	> 5 mg/L	MassDEP Surface Water Quality Standards	MassDEP (2007b)
pH[1]	6.5 – 8.3	MassDEP Surface Water Quality Standards	MassDEP (2007b)
Related Nutrient TMDLs			
Seasonal Mean Chlorophyll-a	< 10 ug/L	Target applied in Lower Charles TMDL	US-EPA (2007)
Peak Chlorophyll-a	< 18.9 ug/L	Target Applied in Lower Charles TMDL	US-EPA (2007)
Dissolved Oxygen Saturation	< 125%	Best Professional Judgment, applied in the Assabet River Nutrient TMDLs	MassDEP (2004)
Guidance			
Total Phosphorus	< 0.025 ug/L	EPA-within lakes or reservoir	US-EPA (1986)
Total Phosphorus	< 0.050 ug/L	EPA-entering lakes of reservoirs	US-EPA (1986)
Total Phosphorus	< 0.100 ug/L	EPA- in streams or other flowing waters not discharging directly to lakes or impoundments	US-EPA (1986)

[1] used to evaluate state of river only - not used for scenario target

The target value for chlorophyll-*a* was adopted from the Lower Charles River TMDL. The relationship between nutrient levels and specific response variables such as algae and macrophytes is complex and highly dependent on the physical and hydraulic characteristics of the system. Little guidance is available relative to specific response variables such as biomass and aesthetics; therefore, defining the total allowable pollutant concentration for the Upper/Middle Charles River required the interpretation of applicable narrative water quality criteria to select an appropriate numeric water quality target.

The approach used in the Lower Charles TMDL was to select a response indicator as an instream water quality metric. Chlorophyll-*a* was chosen as the surrogate water quality metric for the Lower Charles River. Chlorophyll-*a* is the photosynthetic pigment found in algae and is, therefore, a direct indicator of algal biomass. Since the eutrophication-related impairments in the Lower Charles River and Upper/Middle Charles River are the result of excessive amounts of algae, chlorophyll-*a* can be used as a surrogate metric in the Upper/Middle Charles River to reasonably define acceptable amounts of algae that will support the designated uses. The approach for developing the chlorophyll-*a* metric was defined in the Lower Charles TMDL report (US-EPA, 2007). The chosen chlorophyll-*a* target is a seasonal average of 10 µg/L (June 1 to October 1). This period represents critical conditions when algal blooms are typically most severe in the Lower Charles River and have the greatest impact on designated uses. The maximum chlorophyll-*a* value was derived from a correlation between the seasonal mean and the seasonal 90th percentile chlorophyll-*a* values. The maximum target chlorophyll-*a* value of 18.9 µg/L corresponded to the seasonal mean value of 10 µg/L. The 90th percentile value (maximum) was selected because it represents an infrequent high chlorophyll-*a* value of short duration, and also corresponds with Massachusetts' assessment protocol for water clarity, which states that no less than 90 percent of the measurements should fall below the minimum clarity threshold. Similar analysis conducted for the Upper/Middle Charles water quality data yielded comparable values for mean and 90th percentile chlorophyll-*a* which further supports the use of these chlorophyll-*a* targets.

No single instream target concentration for total phosphorus will be established for the Upper/Middle Charles TMDL. Under the weight-of-evidence approach all available information will be used to set site-specific permit limits. The overall goal is to significantly reduce the amount of biomass in the system fully recognizing that not all the biomass (attached macrophytes) can be removed and that some level of biomass is necessary to provide habitat to fish and other aquatic organisms. Additional goals are to also ensure the minimum dissolved oxygen criterion is met and to reduce the duration of dissolved oxygen supersaturation. A comparison of in-stream total phosphorus concentrations, although not a target, to US-EPA guidance was used to further validate the model and weight-of-evidence approach. The "Gold Book" (US-EPA, 1986) states that "to prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphates as phosphorus (P) should not exceed 50 µg/L in any stream at the point where it enters any lake or reservoir, nor 25 µg/L within the lake or reservoir. A desired goal for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments is 100 µg/L total P". Thus, this guidance provides a range of acceptable criteria for phosphorus based upon specified conditions. US-EPA, in summarizing their available guidance, clearly acknowledges the lack of definitive numerical criteria and the need for criteria that vary not only by ecoregion but also by site-specific conditions. As a result, a major effort involving detailed water quality sampling, model development and the use of the model in a predictive mode was undertaken to assess the site-specific impacts and multiple response variables to phosphorus loading in the Upper/Middle Charles River. Likewise a target of 125% dissolved oxygen saturation was used as a target for control of excessive fluctuations in dissolved oxygen. This metric is consistent with the approach used in other nutrient TMDLs (MassDEP, 2004). The specific targets for evaluation of scenarios in the Upper/Middle Charles TMDL will be discussed further in Section 4.3.

3 THE STATE OF THE RIVER

3.1 Water Quality Monitoring Programs

All available data affecting water quality loads were reviewed to determine the present condition of the Upper/Middle Charles River. Since loads are a product of flow and concentration, both water quality concentrations and flow measurements are discussed. This section catalogs the available water quality data and describes the current state of the river based on these data by comparing the data to the evaluation metrics outlined in the previous section.

Water quality data for the Upper/Middle Charles River were obtained from Charles River Watershed Association (CRWA), Massachusetts Water Resources Authority (MWRA), Massachusetts Department of Environmental Protection (MassDEP), US Environmental Protection Agency (US-EPA), and Camp Dresser and McKee (CDM). The US-EPA data were not used as there were only two stations within the study area, the chlorophyll-*a* data were not corrected for pheophytin, and the sites were duplicated by CRWA and MWRA. The CDM data were used to validate the model results after the calibration process (CRWA, 2009) but were not used for TMDL development directly because they were collected prior to the dates used for model calibration. (CDM, 1997). Only the relevant nutrient-based water quality data, including total nitrogen, total phosphorus, chlorophyll-*a*, dissolved oxygen, and pH, are discussed here.

Total nitrogen and phosphorus are essential plant nutrients that are found in small amounts in natural waters, however, at elevated levels it can cause eutrophic conditions in lakes, ponds and impoundments and create excessive plant growth. Total nitrogen is the sum of organic nitrogen, ammonia, nitrate and nitrite. In some monitoring programs, total nitrogen was measured directly while in others it was computed from the individual components.

Chlorophyll-*a* is the principle photosynthetic pigment in algae and vascular plants and is an indicator of algae concentrations and over-enrichment by nutrients. Chlorophyll-*a* measures the phytoplankton algae in the water column and does not represent the plant biomass associated with either macrophytes (aquatic plants and floating algae mats) or periphyton (attached algae).

Dissolved oxygen (DO) is the most important dissolved gas in river water as it is essential to most aquatic organisms, especially fish. Oxygen is produced during photosynthesis of green plants while plants and animals use it during respiration. pH is an important water quality indicator that measures of the acidity or alkalinity of the water; pH ranges from 0 to 14. A pH equal to 7 is neutral, a pH greater than 7 is basic, and a pH less than 7 is acidic.

The water quality monitoring programs in the Upper/Middle Charles River watershed are described below. Figure 4 shows the sampling locations while Table 6 provides a comprehensive list of the sampling sites with identification numbers for all monitoring programs.

3.1.1 CRWA TMDL Water Quality Monitoring

From 2002 to 2005, CRWA performed two wet-weather and two dry-weather sampling events to characterize water quality conditions in the Upper/Middle watershed. CRWA sampled 18 mainstem and 10 tributary sites in the Upper/Middle Charles (Table 6). All these data were summarized in two detailed data reports (CRWA, 2003a; CRWA, 2006).

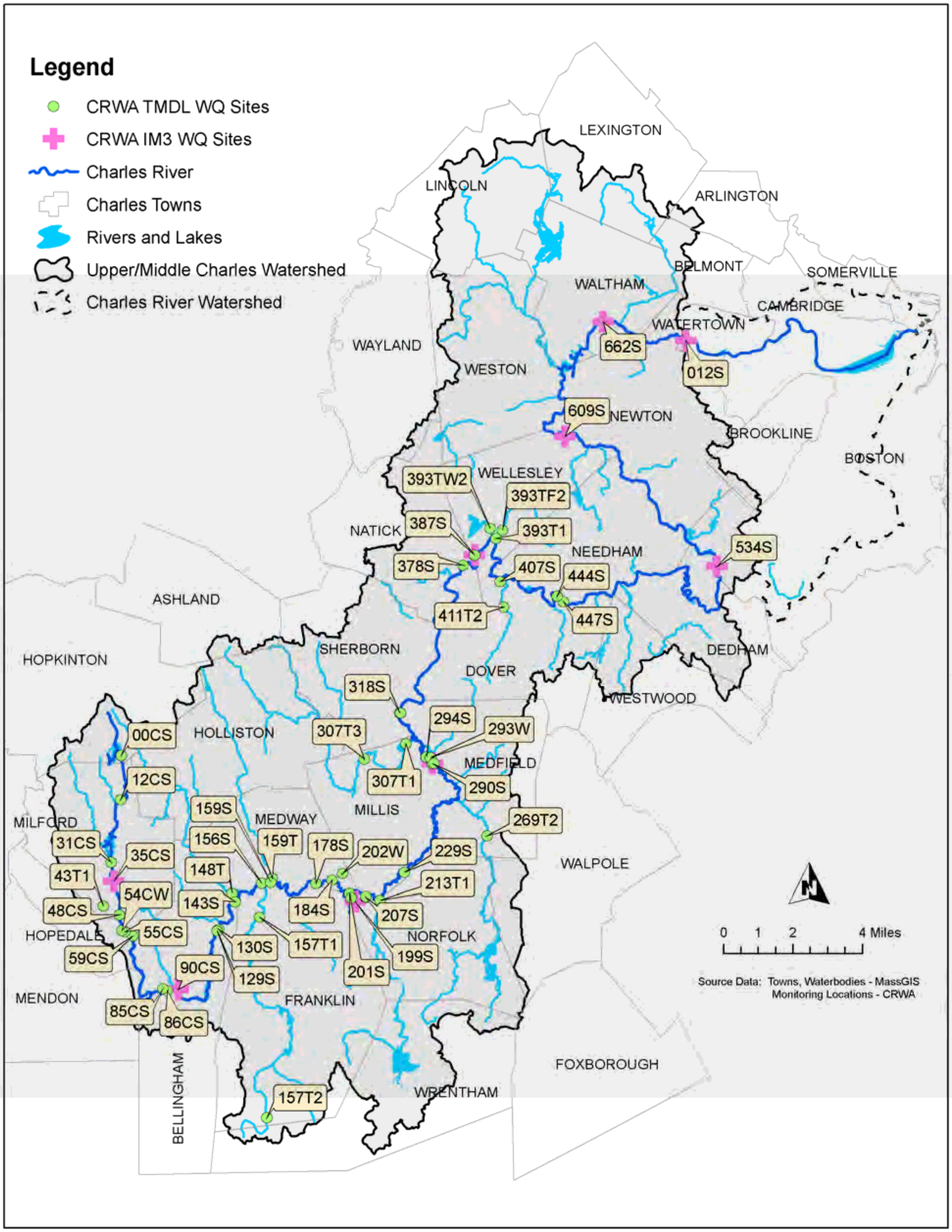


Figure 4. Monitoring Sites in the Upper/Middle Charles

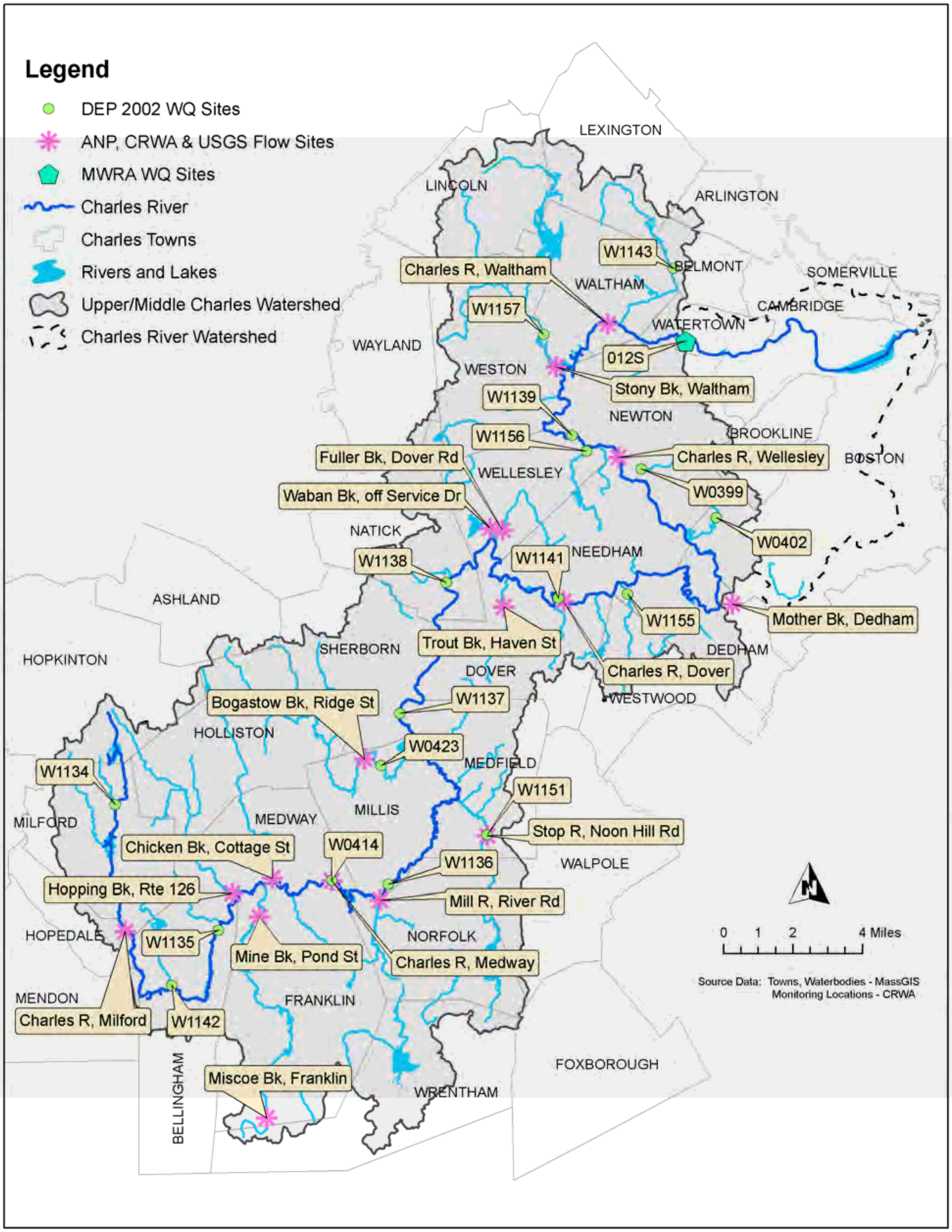


Figure 4. Monitoring Sites in the Upper/Middle Charles (cont.)

Table 6. Sampling Sites in the Upper/Middle Charles

Reach ID*	Reach Name	Town	Reach Num*	River Mile*	Main/ Trib/ WWTF	Flow	TMDL WQ	IM3 WQ	DEP WQ	CDM WQ	EPA WQ	MWRA WQ	TMDL Diurnal DO	TMDL Sonde DO	Aquatic plants	Sediment Efflux	Bathymetry & Sediment
00CS	Outlet Echo Lake	Hopkinton	1	0.0	M									X			
12CS	Above Waterworks Dam	Milford	3	1.2	M		X										
20CS	Waterworks to Dilla Dam	Milford	5	2.0	M				W1134								
31CS	Outlet Milford Pond	Milford	7	3.1	M		X						X	X	X	CRWA1	X
35CS	Central St Culvert	Milford	10	3.5	M			X									
43T1	Outlet Godfrey Brook	Milford	213	4.3	T		X										
48CS	Howard St below Godfrey Bk	Milford	13	4.8	M		X						X				
54CW	Milford WWTF	Milford	-	5.4	W		X										
55CS	Milford ANP Gage below WWTF	Hopedale/Milford	15	5.5	M	ANP											
59CS	Mellen St	Milford	16	5.9	M		X						X				
85CS	Outlet Box Pond	Bellingham	19	8.5	M									X	X	CRWA2	X
86CS	Depot Rd	Bellingham	20	8.6	M		X						X				
88T	Outlet Beaver Brook	Bellingham	221	8.8	T				W1142								
90CS	N Main St / Rt 126	Bellingham	21	9.0	M			X									
129S	Outlet N Bellingham Dam	Bellingham	26	12.9	M									X	X	CRWA3	X
13CS	Maple St	Bellingham	27	13.0	M		X		W1135				X				
143S	Outlet Caryville Dam	Bellingham	30	14.3	M		X						X		X	CRWA4	X
148T	Hopping Bk at Hartford Ave / Rt 126	Bellingham	232	14.8	T	CRWA	X										
156S	Inlet W Medway Dam	Franklin/Medway	32	15.6	M		X						X				
157T1	Mine Bk at Pond St	Franklin/Medway	233	15.7	T	CRWA	X										
157T2	USGS Miscoe Bk Gage at South St	Franklin/Medway	333	15.7	T	USGS	X										
159S	Outlet W Medway Dam	Franklin/Medway	33	15.9	M		X						X	X	X	CRWA5	X
159T	Chicken Brook at Cottage St	Franklin/Medway	234	15.9	T	CRWA	X										
178S	Outlet Medway Dam	Franklin/Medway	37	17.8	M								X	X	X	CRWA6	X
184S	USGS Medway Gage at Walker St	Medway	38	18.4	M	USGS	X		W0414				X				
199S	Populatic Pond	Norfolk	40	19.9	M			X									
201S	Outlet Populatic Pd	Medway/Norfolk	41	20.1	M		X			CR-1			X	X	X	CRWA7	X
202W	CRPCD WWTF	Medway	-	20.2	W		X			CRPCD							
207S	Below CRPCD WWTF	Millis/Norfolk	43	20.7	M		X						X	X	X		
213S	Above Mill River	Millis/Norfolk	44	21.3	M					CR-2							
213T1	Mill River at River Rd	Millis/Norfolk	245	21.3	T	CRWA	X			MR-1							
219S	Pleasant St	Millis	45	21.9	M				W1136								
229S	Baltimore St/115	Millis	46	22.9	M		X						X				
243S	Forest Rd	Medfield/Millis	48	24.3	M					CR-3							
269S	Above Stop River	Medfield/Millis	53	26.9	M									X			
269T	Stop River at Causeway St	Medfield	254	26.9	T					SR-1							
269T2	Stop River at Noon Hill Rd	Medfield	254	26.9	T	CRWA	X		W1151								
290S	Above Medfield WW	Medfield/Millis	56	29.0	M		X	X		CR-4			X				
293W	Medfield WWTF	Medfield	-	29.3	W		X			MWWTP							
294S	Below Medfield WW	Medfield/Millis	57	29.4	M		X								X		
307T1	Bogastow Bk at S End Pond	Millis	260	30.7	T					BB-1							
307T2	Bogastow Bk at Orchard St	Millis	260	30.7	T				W0423								
307T3	Bogastow Bk at Ridge St	Millis	260	30.7	T	CRWA	X										
318S	S Main St / Rt 27	Medfield/Sherborn	60	31.8	M		X		W1137	CR-5			X	X			
343S	Farm Rd/Bridg St	Dover/Sherborn	64	34.3	M					CR-6							
374S	Inlet S Natick Dam	Natick	68	37.4	M				W1138								
378S	Outlet S Natick Dam	Natick	69	37.8	M					CR-7	CRBL01		X	X	X	CRWA8	X
387S	Cheney Bridge	Dover/Wellesley	70	38.7	M		X	X									
393T1	Fuller / Waban Brook confluence	Wellesley	274	39.3	T		X			WB-1							
393TF2	Fuller Brook at Dover St	Wellesley	274	39.3	T	CRWA											
393TW2	Waban Brook at Dirt Rd off Service Dr	Wellesley	274	39.3	T	CRWA											
400S	Charles River Rd	Dover/Needham	73	40.0	M					CR-8							
407S	Claybrook Rd	Dover	74	40.7	M		X								X		
411T2	Trout Bk at Haven St	Dover	276	41.1	T	CRWA	X										
444S	Outlet Cochrane Dam	Dover/Needham	79	44.4	M					CR-9				X	X	CRWA9	X
447S	USGS Dover Gage below Cochrane Dam	Dover/Needham	80	44.7	M	USGS	X		W1141				X				
469T	Rock Meadow Bk at Dedham CC	Dedham	284	46.9	T				W1155								
524T	USGS Mother Bk gage/discharge at Rt 1	Dedham	292?	52.4	T	USGS											
534S	Inlet Silk Mill Dam / Rt 109	Dedham/W Roxbury	93	53.4	M			X									
548T	Vine / Sawmill Bk above Baker St	Newton	296	54.8	T				W0402								
582T	S Meadow Bk below Needham St	Newton	299	58.2	T				W0399								
591S	USGS Wellesley Gage, outlet Circular Dam	Newton/Wellesley	101	59.1	M	USGS											
607T	Rosemary Bk above Barton St	Wellesley	304	60.7	T				W1156								
609S	Outlet Finlay Dam	Newton/Wellesley	106	60.9	M			X	W1139								
642T	USGS Stony Brook Gage below Reservoir	Waltham	309	64.2	T	USGS			W1157								
662S	Outlet Moody St Dam	Waltham	110	66.2	M			X									
666S	USGS Waltham Gage	Waltham	111	66.6	M	USGS											
668T	Beaver Bk above Mill Pond	Waltham	311	66.8	T				W1143								
012S	Outlet Watertown Dam	Watertown	113	69.1	M			X			CRBL02	X					
743S	Western Ave	Boston/Cambridge	117	74.3	M			X									
763S	Massachusetts Ave	Boston/Cambridge	118	76.3	M			X									
784S	Outlet New Charles Dam	Boston	121	78.4	M			X									

*** Reach ID is the CRWA reach identification label, Reach Num is the reach number for the HSPF model, River Mile is the miles downstream from the outlet of Echo Lake**

Wet-weather samples were collected over multiple days. An ideal wet weather flow regime was defined in the TMDL Quality Assurance Project Plan (QAPP) (CRWA, 2002) as greater than 1.0 inch of rainfall for wet soil, greater than 1.5 inches of rain for dry soil, or greater than 2 cfsm of runoff at the tributary gauges. Measurements were made for ammonia, nitrate, nitrite, total Kjeldahl nitrogen, orthophosphate, total phosphorus, chlorophyll-*a*, temperature, dissolved oxygen, and pH.

The results from the dry and wet weather monitoring events were combined as one sample set because the differences in nutrient concentrations between dry and wet weather events were relatively small. In general, there is greater variation between concentrations between seasons than between different weather conditions in the same season because the permit levels for treated effluent discharges from the WWTFs change from season to season.

CRWA performed a number of additional dissolved oxygen (DO) surveys to help define DO levels and diurnal range. Water quality sondes were used to measure continuous DO at nine impoundment and three river sites in August and September 2002 to better define the daily DO fluctuation in the Upper/Middle Charles. In addition, CRWA measured both the horizontal and vertical variability of DO at the 12 sites by performing five depth profiles across each impoundment. CRWA also measured diurnal DO fluctuations at 18 sites on two separate occasions to document diurnal range of DO concentrations from the morning to the afternoon.

CRWA surveyed nine impoundments and ponds to determine bathymetry and sediment thickness during summer and fall of 2002 and the summer of 2003. The bathymetric survey determined the storage capacity and quantified the thickness of sediments in each impoundment and pond. In the summer of 2005, an aquatic plant survey was conducted in the same nine impoundments plus three river sites to measure number of aquatic plant species, areal extent, and biomass.

CRWA contracted UMass-Dartmouth in 2005 to design and conduct a sediment nutrient and oxygen flux study in the Upper/Middle watershed. The goal was to obtain rates of sediment nutrient release and oxygen demand to support the parameterization of the water quality model. The same nine impoundment sites were studied. Sediment cores were collected at two to five stations at each site and were incubated to determine both aerobic and anaerobic nutrient release rates and sediment oxygen demand.

CRWA and contracted laboratories followed the procedures and guidelines outlined in the approved TMDL QAPP (CRWA, 2002). UMass-Dartmouth worked under an approved Sampling Analysis Plan (SAP) approved general QAPP for the sediment testing.

3.1.2 CRWA IM3 Water Quality Monitoring

Since 1996, as part the Integrated Monitoring, Modeling, and Management (IM3) program (CRWA, 1997), CRWA has routinely sampled the entire river on a monthly basis for bacteria. On a quarterly basis, nine locations in the Upper/Middle Charles River were also monitored for a suite of nutrient parameters including ammonia, nitrate+nitrite, total nitrogen, orthophosphate, total phosphorus, chlorophyll-*a*, pheophytin, temperature, and pH (Table 6).

Quarterly nutrient monitoring occurs every March, June, September and December. A dry weather event is defined as less than 0.1 inches of total rainfall in the previous 72 hours. Total rainfall equal to or greater than 0.1 inches over the past 72 hours is considered a wet weather event. CRWA collected all data in accordance with an approved QAPP (CRWA, 2001; CRWA, 2007).

3.1.3 MWRA Water Quality Monitoring

Since 1996, MWRA has routinely sampled the outlet of the Watertown Dam (Site 012S) on a weekly basis for several nutrient-related parameters including ammonia, nitrate+nitrite, total nitrogen, orthophosphate, total phosphorus, chlorophyll-*a*, pheophytin, temperature, DO, and pH (Table 6). This weekly sampling at the downstream boundary of the Upper/Middle Charles River provides an excellent record of nutrient loads at the lower boundary for the model. Over 350 samples were collected year-round in both dry and wet weather. MWRA collected their data in accordance with an approved QAPP.

3.1.4 MassDEP Water Quality Monitoring

MassDEP conducts watershed assessments throughout the State on a five-year cycle. In 2002, MassDEP collected water quality data from the Charles River watershed at eight mainstem sites and 10 tributaries located in the Upper/Middle Charles River (Table 6). A total of 14 surveys were conducted in 2002; of which, five included analyses of nutrients. Measurements of ammonia, total phosphorus, temperature, DO, and pH were made.

3.2 Current Water Quality Conditions

To characterize water quality conditions of the Upper/Middle Charles River watershed, CRWA calculated several summary statistics (mean, median, range and number of samples) of the available nutrient-related water quality data collected by CRWA, MWRA, MassDEP, and US-EPA and compared them to Massachusetts surface water quality standards, US-EPA's nutrient guidance levels , trophic indicator criteria, and the ratio of nitrogen to phosphorous which is used to determine the limiting nutrient of concern . A qualitative assessment of aquatic plants extent, biovolume, and species is also included.

3.2.1 Total Nitrogen Data

Nitrogen in surface waters is typically not the limiting nutrient. When the ratio of nitrogen-to-phosphorus exceeds 7.2 on a weight basis, phosphorus becomes the limiting nutrient (Chapra, 1997). These ratios in the Upper/Middle Charles generally far exceed this value (see Section 4.1).

Since nitrogen does not control algal growth, limiting nitrogen concentration will not limit algal growth in the Upper/Middle Charles, thus it will not be the focus of this nutrient TMDL. Nitrogen concentration could be important at the outlet of the Charles River when it discharges into the Bay of Massachusetts, since in marine water, nitrogen is generally the limiting nutrient.

Nitrogen concentrations in the Upper/Middle Charles are high relative to most nutrient or eutrophic criteria, averaging about 2.3 mg/L, with extreme values up to 20 mg/L. The MWRA samples for total nitrogen at the Watertown dam (012S) average about 1.0 mg/L and demonstrate a flat trend over time.

3.2.2 Total Phosphorus Data

Table 7 summarizes the mean, minimum, and maximum concentrations with the number of samples for total phosphorus at each site for all the monitoring programs in the Upper/Middle Charles river watershed. The table is ordered by river mile from the top of the watershed. The main stem wastewater discharge sites are the Milford WWTF (5.4 miles), Charles River Pollution Control District or CRPCD (20.2 miles), and the Medfield WWTF (29.3 miles).

Most of the total phosphorus samples and statistics exceed the US-EPA nutrient criteria guidance values except for a few sample sites in the uppermost part of the watershed in Milford. The MWRA samples at the Watertown dam (012S) show a flat trend until 2004 then a downward trend probably reflecting new WWTF permit discharge for phosphorus. Summer limits for phosphorus discharge were lowered to 0.2 mg/L in late 2000 and additional winter limits of 1.0 mg/L were imposed for all but one treatment plant in 2005.

The individual monitoring programs can be summarized as follows:

1. CRWA TMDL Data (2002-2005) – 31 sites
   a. Only 2 sites (31CS, 43T1) had means less than 0.025 mg/L
   b. No sites had means above 0.10 mg/L
   c. 21 sites had minimums less than 0.025 mg/L
   d. 5 sites had maximums above 0.10 mg/L

2. CRWA IM3 Data (1996-2006) – 9 sites
   a. All sites had means much greater than 0.025 mg/L
   b. No sites had means greater than 0.10 mg/L
   c. 2 sites had minimums below the 0.025 mg/L
   d. All 9 sites had maximums above the 0.10 mg/L
   e. Concentrations were lowest in March, highest in summer, then decreased in fall

3. MWRA Data (1997-2007) – 1 site at Watertown Dam
   a. Mean greater than 0.025 mg/L
   b. Minimum below the 0.025 mg/L
   c. Maximum above the 0.10 mg/L
   d. Decreasing trend since 2004

4. MassDEP Data (2002) – 18 sites
   a. All sites had means greater than 0.025 mg/L
   b. 3 sites (269T2, 469T, 548T) had means greater than 0.10 mg/L
   c. 4 sites had minimums below the 0.025 mg/L
   d. 6 sites had maximums above the 0.10 mg/L
   e. Concentrations lowest in April and highest in summer

Table 7. Total Phosphorus Data from Upper/Middle Charles Monitoring

Name	CRWA ID	Site ID	River Mile	Years	Mean (mg/L)	Min (mg/L)	Max (mg/L)	Num. Samples	Site Description
TMDL	31CS	31CS	3.1	02-05	0.020	0.013	0.032	8	Outlet Milford Pond
TMDL	43T1	43T1	4.3	02-05	0.018	0.011	0.027	3	Outlet Godfrey Brook
TMDL	48CS	48CS	4.8	02-05	0.057	0.027	0.120	8	Howard St below Godfrey Bk
TMDL	59CS	59CS	5.9	02-05	0.090	0.036	0.267	8	Mellen St
TMDL	86CS	86CS	8.6	02-05	0.038	0.029	0.051	8	Depot Rd
TMDL	13CS	13CS	13.0	02-05	0.037	0.020	0.064	8	Maple St
TMDL	143S	143S	14.3	02-05	0.035	0.029	0.044	8	Outlet Caryville Dam
TMDL	148T	148T	14.8	02-05	0.051	0.026	0.077	6	Hopping Bk at Hartford Ave / Rt 126
TMDL	156S	156S	15.6	02-05	0.037	0.028	0.046	8	Inlet W Medway Dam
TMDL	157T1	157T1	15.7	02-05	0.048	0.033	0.075	6	Mine Bk at Pond St
TMDL	157T2	157T2	15.7	02-05	0.026	0.018	0.045	6	USGS Miscoe Bk Gage at South St
TMDL	159S	159S	15.9	02-05	0.050	0.030	0.082	8	Outlet W Medway Dam
TMDL	159T	159T	15.9	02-05	0.080	0.046	0.180	6	Chicken Brook at Cottage St
TMDL	184S	184S	18.4	02-05	0.044	0.026	0.051	8	USGS Medway Gage at Walker St
TMDL	201S	201S	20.1	02-05	0.054	0.039	0.075	8	Outlet Populatic Pd
TMDL	207S	207S	20.7	02-05	0.053	0.043	0.072	8	Below CRPCD WWTF
TMDL	213T1	213T1	21.3	02-05	0.038	0.019	0.106	6	Mill River at River Rd
TMDL	229S	229S	22.9	02-05	0.038	0.023	0.054	8	Baltimore St/115
TMDL	269T2	269T2	26.9	02-05	0.089	0.038	0.131	6	Stop River at Noon Hill Rd
TMDL	290S	290S	29.0	02-05	0.041	0.030	0.048	8	Above Medfield WW
TMDL	294S	294S	29.4	02-05	0.062	0.041	0.100	8	Below Medfield WW
TMDL	307T3	307T3	30.7	02-05	0.066	0.041	0.098	6	Bogastow Bk at Ridge St
TMDL	318S	318S	31.8	02-05	0.053	0.038	0.069	8	S Main St / Rt 27
TMDL	387S	387S	38.7	02-05	0.046	0.031	0.060	8	Cheney Bridge
TMDL	393T1	393T1	39.3	02-05	0.052	0.027	0.084	6	Fuller / Waban Brook confluence
TMDL	407S	407S	40.7	02-05	0.049	0.037	0.056	8	Claybrook Rd
TMDL	411T2	411T2	41.1	02-05	0.030	0.018	0.054	6	Trout Bk at Haven St
TMDL	447S	447S	44.7	02-05	0.042	0.029	0.057	8	USGS Dover Gage below Cochrane Dam
IM3	35CS	35CS	3.5	96-06	0.057	0.012	0.240	36	Central St Culvert
IM3	90CS	90CS	9.0	96-06	0.077	0.027	0.296	37	N Main St / Rt 126
IM3	199S	199S	19.9	96-06	0.063	0.000	0.102	21	Populatic Pond
IM3	290S	290S	29.0	96-06	0.089	0.035	0.356	36	Above Medfield WW
IM3	387S	387S	38.7	96-06	0.091	0.028	0.335	35	Cheney Bridge
IM3	534S	534S	53.4	96-06	0.070	0.025	0.133	38	Inlet Silk Mill Dam / Rt 109
IM3	609S	609S	60.9	96-06	0.072	0.031	0.131	33	Outlet Finlay Dam
IM3	662S	662S	66.2	96-06	0.063	0.026	0.115	38	Outlet Moody St Dam
IM3	012S	012S	69.1	96-06	0.068	0.034	0.121	37	Outlet Watertown Dam
MWRA	012S	012S	69.1	97-06	0.068	0.022	0.214	374	Outlet Watertown Dam
DEP	20CS	W1134	2.0	02	0.029	0.021	0.041	4	Waterworks to Dilla Dam
DEP	88T	W1142	8.8	02	0.026	0.024	0.030	4	Outlet Beaver Brook
DEP	13CS	W1135	13.0	02	0.051	0.037	0.068	4	Maple St
DEP	184S	W0414	18.4	02	0.038	0.029	0.055	4	USGS Medway Gage at Walker St
DEP	219S	W1136	21.9	02	0.042	0.028	0.061	4	Pleasant St
DEP	269T2	W1151	26.9	02	0.111	0.100	0.140	4	Stop River at Noon Hill Rd
DEP	307T2	W0423	30.7	02	0.064	0.043	0.089	4	Bogastow Bk at Orchard St
DEP	318S	W1137	31.8	02	0.059	0.035	0.086	4	S Main St / Rt 27
DEP	374S	W1138	37.4	02	0.069	0.045	0.120	4	Inlet S Natick Dam
DEP	447S	W1141	44.7	02	0.059	0.023	0.100	5	USGS Dover Gage below Cochrane Dam
DEP	469T	W1155	46.9	02	0.113	0.034	0.170	5	Rock Meadow Bk at Dedham CC
DEP	548T	W0402	54.8	02	0.137	0.067	0.190	5	Vine / Sawmill Bk above Baker St
DEP	582T	W0399	58.2	02	0.090	0.076	0.110	4	S Meadow Bk below Needham St
DEP	607T	W1156	60.7	02	0.080	0.041	0.120	5	Rosemary Bk above Barton St
DEP	609S	W1139	60.9	02	0.066	0.038	0.077	4	Outlet Finlay Dam
DEP	642T	W1157	64.2	02	0.027	0.022	0.036	5	USGS Stony Brook Gage below Reservoir
DEP	668T	W1143	66.8	02	0.070	0.046	0.098	5	Beaver Bk above Mill Pond

░ 0.025 to 0.05 mg/L ▒ 0.05 to 0.10 mg/L ▓ Exceeds 0.10 mg/L

3.2.3 Chlorophyll-a Data

Table 8 summarizes the mean, minimum, and maximum chlorophyll-*a* concentrations with the number of samples at each site for all the monitoring programs in the Upper/Middle Charles river watershed. The table is ordered by river mile from the top of the watershed. The main stem wastewater discharge sites are the Milford WWTF (5.4 miles), CRPCD (20.2 miles), and the Medfield WWTF (29.3 miles).

The MWRA samples at the Watertown dam (012S) show a decline until 2002, an increase until 2004, then a further decline after 2004. The later decline probably reflects new WWTF permit limits for phosphorus. Summer limits for phosphorus discharge were lowered to 0.2 mg/L in late 2000 and additional winter limits of 1.0 mg/L were imposed for all but one treatment plant in 2005. Minimum chlorophyll-*a* concentrations are expected to be low because algae die off in the winter.

The individual monitoring programs can be summarized as follows:

1. CRWA TMDL Data (2002-2005) – 31 sites
    a. All sites had means less than 10 µg/L
    b. All sites had minimums less than 10 µg/L
    c. 3 sites had maximums above 18.9 µg/L
    d. High chlorophyll-*a* concentrations occurred downstream of the CRPCD WWTF and in the Stop River tributary (269T2) which has 2 small WWTFs

2. CRWA IM3 Data (1996-2006) – 9 sites
    a. 4 sites had means greater than 10 µg/L
    b. All sites had minimums below 10 µg/L
    c. All sites had maximums above 18.9 µg/L
    d. Trend of increasing chlorophyll-*a* with increasing distance downstream

3. MWRA Data (1997-2007) – 1 site
    a. Mean less than 10 µg/L
    b. Mean less than 10 µg/L
    c. Maximum above 18.9 µg/L
    d. Decreasing trend from 1998-2005

4. MassDEP Data (2002)
    a. No chlorophyll-*a* data were collected

Table 8. Total Chlorophyll-*a* Data from Upper/Middle Charles Monitoring

Name	CRWA ID	Site ID	River Mile	Years	Mean (µg/L)	Min (µg/L)	Max (µg/L)	Num. Samples	Site Description
TMDL	31CS	31CS	3.1	02-05	3.3	1.4	7.8	8	Outlet Milford Pond
TMDL	43T1	43T1	4.3	02-05	1.6	0.6	3.6	3	Outlet Godfrey Brook
TMDL	48CS	48CS	4.8	02-05	4.6	0.6	6.0	8	Howard St below Godfrey Bk
TMDL	54CW	54CW	5.4	02-05	0.6	0.6	0.6	4	Milford WWTF
TMDL	59CS	59CS	5.9	02-05	3.3	0.6	10.4	8	Mellen St
TMDL	86CS	86CS	8.6	02-05	5.0	2.4	10.2	8	Depot Rd
TMDL	13CS	13CS	13.0	02-05	3.3	0.6	5.9	8	Maple St
TMDL	143S	143S	14.3	02-05	1.8	0.6	3.1	8	Outlet Caryville Dam
TMDL	148T	148T	14.8	02-05	2.2	0.6	5.7	6	Hopping Bk at Hartford Ave / Rt 126
TMDL	156S	156S	15.6	02-05	1.9	0.6	3.3	8	Inlet W Medway Dam
TMDL	157T1	157T1	15.7	02-05	2.6	0.6	5.3	6	Mine Bk at Pond St
TMDL	157T2	157T2	15.7	02-05	2.9	0.6	12.6	6	USGS Miscoe Bk Gage at South St
TMDL	159S	159S	15.9	02-05	2.9	1.2	5.4	8	Outlet W Medway Dam
TMDL	159T	159T	15.9	02-05	6.1	0.6	18.4	6	Chicken Brook at Cottage St
TMDL	184S	184S	18.4	02-05	3.3	0.6	6.0	8	USGS Medway Gage at Walker St
TMDL	201S	201S	20.1	02-05	7.4	0.6	24.4	8	Outlet Populatic Pd
TMDL	202W	202W	20.2	02-05	0.6	0.6	0.6	4	CRPCD WWTF
TMDL	207S	207S	20.7	02-05	7.2	0.6	22.3	8	Below CRPCD WWTF
TMDL	213T1	213T1	21.3	02-05	2.1	0.6	7.6	6	Mill River at River Rd
TMDL	229S	229S	22.9	02-05	3.8	1.2	7.0	8	Baltimore St/115
TMDL	269T2	269T2	26.9	02-05	5.5	0.6	19.4	6	Stop River at Noon Hill Rd
TMDL	290S	290S	29.0	02-05	3.9	1.4	8.8	8	Above Medfield WW
TMDL	293W	293W	29.3	02-05	1.3	0.6	2.2	4	Medfield WWTF
TMDL	294S	294S	29.4	02-05	3.6	1.5	8.8	8	Below Medfield WW
TMDL	307T3	307T3	30.7	02-05	1.2	0.6	2.8	6	Bogastow Bk at Ridge St
TMDL	318S	318S	31.8	02-05	3.9	1.8	11.3	8	S Main St / Rt 27
TMDL	387S	387S	38.7	02-05	3.1	1.8	5.3	8	Cheney Bridge
TMDL	393T1	393T1	39.3	02-05	3.6	1.2	7.0	6	Fuller / Waban Brook confluence
TMDL	407S	407S	40.7	02-05	4.9	1.6	17.1	8	Claybrook Rd
TMDL	411T2	411T2	41.1	02-05	1.3	0.6	3.7	6	Trout Bk at Haven St
TMDL	447S	447S	44.7	02-05	4.5	1.8	12.3	8	USGS Dover Gage below Cochrane Dam
IM3	35CS	35CS	3.5	96-06	4.2	0.0	50.0	33	Central St Culvert
IM3	90CS	90CS	9	96-06	4.3	0.0	21.0	34	N Main St / Rt 126
IM3	199S	199S	19.9	96-06	14.3	2.0	64.0	17	Populatic Pond
IM3	290S	290S	29	96-06	5.2	1.0	34.0	33	Above Medfield WW
IM3	387S	387S	38.7	96-06	4.9	1.0	22.0	30	Cheney Bridge
IM3	534S	534S	53.4	96-06	10.2	1.0	70.0	37	Inlet Silk Mill Dam / Rt 109
IM3	609S	609S	60.9	96-06	10.9	2.0	84.0	31	Outlet Finlay Dam
IM3	662S	662S	66.2	96-06	12.5	1.0	67.0	36	Outlet Moody St Dam
IM3	012S	012S	69.1	96-06	7.4	1.0	79.0	34	Outlet Watertown Dam
MWRA	012S	012S	69.1	97-06	7.5	0.6	47.0	370	Outlet Watertown Dam

▨ Average exceeds 10.0 µg/L or Maximum exceeds 18.9 µg/L

3.2.4 pH Data

Table 9 summarizes the mean, minimum, and maximum pH data with the number of samples at each site for all the monitoring programs in the Upper/Middle Charles river watershed. The table is ordered by river mile from the top of the watershed. As previously noted the main stem wastewater discharge sites include the Milford WWTF (5.4 miles), CRPCD (20.2 miles), and the Medfield WWTF (29.3 miles).

Water column pH is also an indicator of eutrophic conditions. Like dissolved oxygen, a water body's pH can vary diurnally and typically increases during the daylight hours as carbon dioxide is taken up by photosynthesis and decreases at night when algal respiration releases carbon dioxide to the water. The changes in carbon dioxide concentrations affect the equilibria of the overall carbonate system thus causing changes in pH (US-EPA, 2007). During periods of excessive aquatic plant growth, pH values can often exceed 8.3, the maximum limit of the range of pH allowed in the MA Water Quality Standards.

The individual monitoring programs can be summarized as follows. Not all the sites in the IM3 program were summarized, only those that also had nutrient data.
:

1. CRWA TMDL Data (2002-2005) – 27 sites
   a. 2 sites (157T1, 157T2) had means less than the lower limit of 6.5
   b. 5 sites had minimums less than the lower limit
   c. 4 sites had maximums above the Upper/Middle limit of 8.3

2. CRWA IM3 Data (1996-2006) – 9 sites
   a. No sites had means less than the lower limit of 6.5
   b. 8 sites had minimums less than the lower limit
   c. 3 sites had maximums above the Upper/Middle limit of 8.3

3. MWRA Data (1997-2007) – 1 site
   a. Mean not less than lower limit of 6.5
   b. Minimum less than the lower limit
   c. Maximum above the Upper/Middle limit of 8.3

4. US-EPA Data (1998-2006) – 2 sites
   a. No sites had means less than the lower limit of 6.5
   b. 2 sites had minimums less than the lower limit
   c. No sites had maximums greater than the Upper/Middle limit of 8.3

5. MassDEP Data (2002)
   a. 2 sites (20CS, 88T) had means less than the lower limit of 6.5
   b. 5 sites had minimums less than the lower limit
   c. 1 site (20CS) had maximum less than the lower limit
   d. 1 site (374S) had maximum greater than the Upper/Middle limit of 8.3

Table 9. pH Data from Upper/Middle Charles River Monitoring

Name	CRWA ID	Site ID	River Mile	Years	Mean (-)	Min (-)	Max (-)	Num. Samples	Site Description
TMDL	31CS	31CS	3.1	02-05	6.8	6.3	7.7	9	Outlet Milford Pond
TMDL	43T1	43T1	4.3	02-05	7.2	6.5	7.8	3	Outlet Godfrey Brook
TMDL	48CS	48CS	4.8	02-05	7.1	6.9	7.6	9	Howard St below Godfrey Bk
TMDL	59CS	59CS	5.9	02-05	7.1	6.8	7.6	9	Mellen St
TMDL	86CS	86CS	8.6	02-05	7.5	6.6	8.0	9	Depot Rd
TMDL	13CS	13CS	13	02-05	7.3	6.7	7.8	9	Maple St
TMDL	143S	143S	14.3	02-05	7.5	7.3	7.7	5	Outlet Caryville Dam
TMDL	148T	148T	14.8	02-05	7.1	6.6	8.3	7	Hopping Bk at Hartford Ave / Rt 126
TMDL	156S	156S	15.6	02-05	7.2	6.7	7.4	7	Inlet W Medway Dam
TMDL	157T1	157T1	15.7	02-05	6.3	5.5	7.1	6	Mine Bk at Pond St
TMDL	157T2	157T2	15.7	02-05	6.0	5.5	6.9	5	USGS Miscoe Bk Gage at South St
TMDL	159S	159S	15.9	02-05	7.1	6.7	7.4	8	Outlet W Medway Dam
TMDL	159T	159T	15.9	02-05	6.9	6.2	7.9	6	Chicken Brook at Cottage St
TMDL	184S	184S	18.4	02-05	7.6	6.9	8.8	7	USGS Medway Gage at Walker St
TMDL	201S	201S	20.1	02-05	8.0	7.2	9.5	6	Outlet Populatic Pd
TMDL	207S	207S	20.7	02-05	7.6	7.2	8.3	6	Below CRPCD WWTF
TMDL	213T1	213T1	21.3	02-05	7.3	6.8	7.8	5	Mill River at River Rd
TMDL	229S	229S	22.9	02-05	7.4	7.1	7.8	6	Baltimore St/115
TMDL	269T2	269T2	26.9	02-05	7.0	6.8	7.4	6	Stop River at Noon Hill Rd
TMDL	290S	290S	29	02-05	7.5	7.0	8.1	6	Above Medfield WW
TMDL	294S	294S	29.4	02-05	7.4	7.1	7.8	6	Below Medfield WW
TMDL	307T3	307T3	30.7	02-05	6.9	6.6	7.4	6	Bogastow Bk at Ridge St
TMDL	318S	318S	31.8	02-05	7.3	7.0	8.2	8	S Main St / Rt 27
TMDL	387S	387S	38.7	02-05	7.3	7.0	7.5	8	Cheney Bridge
TMDL	393T1	393T1	39.3	02-05	7.2	6.7	7.7	7	Fuller / Waban Brook confluence
TMDL	407S	407S	40.7	02-05	7.5	7.1	8.5	9	Claybrook Rd
TMDL	411T2	411T2	41.1	02-05	6.8	6.3	7.6	7	Trout Bk at Haven St
TMDL	447S	447S	44.7	02-05	7.5	7.1	8.4	9	USGS Dover Gage below Cochrane Dam
IM3	35CS	35CS	3.5	96-06	6.9	6.0	7.8	65	Central St Culvert
IM3	90CS	90CS	9	96-06	7.2	6.1	7.9	64	N Main St / Rt 126
IM3	199S	199S	19.9	96-06	7.4	6.5	9.1	48	Populatic Pond
IM3	290S	290S	29	96-06	7.0	6.1	8.1	59	Above Medfield WW
IM3	387S	387S	38.7	96-06	7.2	6.2	8.0	65	Cheney Bridge
IM3	534S	534S	53.4	96-06	7.3	6.2	8.9	72	Inlet Silk Mill Dam / Rt 109
IM3	609S	609S	60.9	96-06	7.2	6.3	8.1	68	Outlet Finlay Dam
IM3	662S	662S	66.2	96-06	7.3	6.2	8.6	66	Outlet Moody St Dam
IM3	012S	012S	69.1	96-06	7.1	6.3	7.4	59	Outlet Watertown Dam
MWRA	012S	012S	69.1	97-06	7.2	4.3	9.3	209	Outlet Watertown Dam
DEP	184S	W0414	18.4	02	7.2	6.2	8.3	18	USGS Medway Gage at Walker St
DEP	20CS	W1134	2	02	5.7	5.3	6.1	9	Waterworks to Dilla Dam
DEP	13CS	W1135	13	02	7.2	6.6	8.0	10	Maple St
DEP	219S	W1136	21.9	02	7.3	6.8	7.9	10	Pleasant St
DEP	318S	W1137	31.8	02	7.3	6.6	8.3	10	S Main St / Rt 27
DEP	374S	W1138	37.4	02	7.3	6.6	8.5	10	Inlet S Natick Dam
DEP	609S	W1139	60.9	02	7.3	6.9	8.0	10	Outlet Finlay Dam
DEP	447S	W1141	44.7	02	7.2	6.8	7.9	10	USGS Dover Gage below Cochrane Dam
DEP	582T	W0399	58.2	02	6.8	6.6	7.0	17	S Meadow Bk below Needham St
DEP	548T	W0402	54.8	02	6.7	6.5	7.1	16	Vine / Sawmill Bk above Baker St
DEP	307T2	W0423	30.7	02	6.8	6.5	7.1	10	Bogastow Bk at Orchard St
DEP	88T	W1142	8.8	02	6.4	6.1	6.6	9	Outlet Beaver Brook
DEP	668T	W1143	66.8	02	6.7	6.4	6.9	10	Beaver Bk above Mill Pond
DEP	269T2	W1151	26.9	02	6.8	6.5	7.0	11	Stop River at Noon Hill Rd
DEP	469T	W1155	46.9	02	6.5	6.2	6.9	9	Rock Meadow Bk at Dedham CC
DEP	607T	W1156	60.7	02	6.7	6.5	7.1	10	Rosemary Bk above Barton St
DEP	642T	W1157	64.2	02	6.8	6.6	7.4	12	USGS Stony Brook Gage below Reservoir

▨	Below pH 6.5	■	Exceeds pH 8.3

3.2.5 Dissolved Oxygen Data

Dissolved oxygen (DO) data were analyzed differently from the previous data sets. The statistics presented include the average diurnal DO range (mg/L), minimum DO (mg/L), and the maximum percent DO saturation (%). Diurnal DO range is given for information only and is not used as a target. Only summary data from the TMDL DO measurements are presented. The TMDL sonde (identified as TMDLS in Table 10) measurements were made by deploying a DO sonde in selected river reaches for a number of days and were considered the highest priority so all sites are summarized. The TMDL diurnal range (identified as TMDLD in Table 10) measurements were, made early morning and mid-afternoon measurements at selected sites and are only summarized for sites not in the TMDLS data set. The remaining TMDL DO measurements (TMDL) were made at the time that the water quality samples were taken and are only summarized for sites not in the TMDLS and TMDLD data sets.

Table 10 summarizes the above statistics with the number of samples for DO at each site for all the monitoring programs in the Upper/Middle Charles river watershed. The table is ordered by river mile from the top of the watershed. For reference the main stem wastewater discharge sites are the Milford WWTF (5.4 miles), CRPCD (20.2 miles), and the Medfield WWTF (29.3 miles).

About half of the DO mean diurnal ranges exceed 2.0 mg/L. These sites were selected to be critical slow-moving sites for DO fluctuation so other river reaches will have less diurnal range. Minimum DO fell to less than that the 5 mg/L standard mostly for selected tributaries. About one-third of the maximum DO saturation values exceeded the 125% guidance value.

The individual monitoring programs can be summarized as follows:

1) CRWA TMDLS Data (2002) – 12 sites
    a) 1 site (31CS) had minimum DO below the minimum limit (5.0 mg/L)
    b) 4 sites had maximum DO saturation greater than 125 %

2) CRWA TMDLD Data (2005) – 14 sites excluding TMDLS sites
    a) 1 site (157T1) had minimum DO below the minimum limit of 5.0 mg/L
    b) 1 site had maximum DO saturation greater than 125%

3) CRWA TMDL Data (2002-2005) – 9 sites excluding TMDLS/TMDLD sites
    a) 4 tributary sites had minimum DO below the minimum limit (5.0 mg/L)
    b) 1 site (294S) had maximum DO saturation greater than 125%

4) MassDEP Data (2002) – 16 sites
    a) 8 tributary and 2 main stem sites had minimum DO below the minimum limit (5.0 mg/L)
    b) 3 sites had maximum DO saturation greater than 125%

5) MRWA (1997-2007) – 1 site
    a) No DO data

Table 10. Dissolved Oxygen Data from Upper/Middle Charles Monitoring

Name	CRWA ID	Site ID	River Mile	Years	Mean DO Diff (mg/L)	Min DO (mg/L)	Max DOsat (%)	Num. Samples	Site Description
TMDLS	00CS	00CS	0	02	0.5	7.8	106.1	5	Outlet Echo Lake
TMDLS	31CS	31CS	3.1	02	0.1	2.0	44.0	5	Outlet Milford Pond
TMDLS	85CS	85CS	8.5	02	2.2	8.85	153.3	7	Outlet Box Pond
TMDLS	129S	129S	12.9	02	3.4	5.3	122.6	5	Outlet N Bellingham Dam
TMDLS	159S	159S	15.9	02	2.2	5.8	102.5	5	Outlet W Medway Dam
TMDLS	178S	178S	17.8	02	1.2	5.6	99.0	7	Outlet Medway Dam
TMDLS	201S	201S	20.1	02	3.5	8.8	162.7	4	Outlet Populatic Pd
TMDLS	207S	207S	20.7	02	3.5	8.0	152.7	4	Below CRPCD WWTF
TMDLS	269S	269S	26.9	02	2.2	6.8	113.9	5	Above Stop River
TMDLS	318S	318S	31.8	02	0.4	7.0	127.4	5	S Main St / Rt 27
TMDLS	378S	378S	37.8	02	0.9	5.8	117.6	6	Outlet S Natick Dam
TMDLS	444S	444S	44.4	02	0.8	6.3	101.5	6	Outlet Cochrane Dam
TMDLD	43T1	43T1	4.3	05	-0.2	7.79	89.9	1	Outlet Godfrey Brook
TMDLD	48CS	48CS	4.8	05	-0.1	5.11	67.6	2	Howard St below Godfrey Bk
TMDLD	59CS	59CS	5.9	05	2.0	6.42	102.5	2	Mellen St
TMDLD	86CS	86CS	8.6	05	0.2	5.81	80.6	2	Depot Rd
TMDLD	13CS	13CS	13	05	3.7	7.3	134.7	1	Maple St
TMDLD	143S	143S	14.3	05	0.0	6.59	80.8	2	Outlet Caryville Dam
TMDLD	148T	148T	14.8	05	-0.1	6.55	74.1	1	Hopping Bk at Hartford Ave / Rt 126
TMDLD	156S	156S	15.6	05	1.6	7.17	106.5	1	Inlet W Medway Dam
TMDLD	157T1	157T1	15.7	05	2.1	4.75	82.9	1	Mine Bk at Pond St
TMDLD	159T	159T	15.9	05	-0.2	6.49	74.4	1	Chicken Brook at Cottage St
TMDLD	184S	184S	18.4	05	0.5	8.12	105.9	2	USGS Medway Gage at Walker St
TMDLD	229S	229S	22.9	05	2.2	6.83	104.5	1	Baltimore St/115
TMDLD	290S	290S	29	05	0.7	8.42	109.2	1	Above Medfield WW
TMDLD	447S	447S	44.7	05	1.2	8.34	114.9	1	USGS Dover Gage below Cochrane Dam
TMDL	157T2	157T2	15.7	02-05	-	2.7	66.8	6	USGS Miscoe Bk Gage at South St
TMDL	213T1	213T1	21.3	02-05	-	4.2	109.9	5	Mill River at River Rd
TMDL	269T2	269T2	26.9	02-05	-	4.2	82.9	5	Stop River at Noon Hill Rd
TMDL	294S	294S	29.4	02-05	-	5.8	128.7	7	Below Medfield WW
TMDL	307T3	307T3	30.7	02-05	-	4.1	111.3	6	Bogastow Bk at Ridge St
TMDL	387S	387S	38.7	02-05	-	5.3	81.6	8	Cheney Bridge
TMDL	393T1	393T1	39.3	02-05	-	6.3	120.2	6	Fuller / Waban Brook confluence
TMDL	407S	407S	40.7	02-05	-	5.9	101.8	8	Claybrook Rd
TMDL	411T2	411T2	41.1	02-05	-	5.0	86.6	6	Trout Bk at Haven St
DEP	20CS	W1134	2	02	-	1.6	97.5	9	Waterworks to Dilla Dam
DEP	88T	W1142	8.8	02	-	4.9	90.2	9	Outlet Beaver Brook
DEP	13CS	W1135	13	02	-	5.6	127.6	10	Maple St
DEP	184S	W0414	18.4	02	-	7.3	123.1	10	USGS Medway Gage at Walker St
DEP	219S	W1136	21.9	02	-	7.0	122.1	10	Pleasant St
DEP	269T2	W1151	26.9	02	-	3.0	111.6	11	Stop River at Noon Hill Rd
DEP	307T2	W0423	30.7	02	-	5.2	90.9	10	Bogastow Bk at Orchard St
DEP	318S	W1137	31.8	02	-	6.7	133.1	10	S Main St / Rt 27
DEP	374S	W1138	37.4	02	-	2.7	131.9	10	Inlet S Natick Dam
DEP	447S	W1141	44.7	02	-	3.7	105.0	10	USGS Dover Gage below Cochrane Dam
DEP	469T	W1155	46.9	02	-	0.5	88.5	9	Rock Meadow Bk at Dedham CC
DEP	548T	W0402	54.8	02	-	2.2	89.3	10	Vine / Sawmill Bk above Baker St
DEP	582T	W0399	58.2	02	-	3.5	75.0	9	S Meadow Bk below Needham St
DEP	607T	W1156	60.7	02	-	3.6	80.0	10	Rosemary Bk above Barton St
DEP	609S	W1139	60.9	02	-	5.6	117.5	10	Outlet Finlay Dam
DEP	642T	W1157	64.2	02	-	5.5	91.0	9	USGS Stony Brook Gage below Reservoir
DEP	668T	W1143	66.8	02	-	4.4	84.8	10	Beaver Bk above Mill Pond

▨ Minimum DO below 5.0 mg/L or DO Saturation exceeds 125%

In addition, CRWA measured both the horizontal and vertical variability of DO at the TMLDS sites by performing five depth profiles across each impoundment. In general, the sites could be divided into two categories - uniform profile versus non-uniform profile. Sites such as Populatic Pond (201S), Echo Lake (00CS), , Milford Pond (31CS), below CRPCD WWTF outfall (207S), and Box Pond (85CS) had non-uniform profiles with significant decreases of DO concentrations (greater than 2.0 mg/L) and temperature with increasing water depth (CRWA, 2004). Echo Lake is a very deep and clean water body so this decrease in DO is probably due to vertical stratification and inadequate mixing or lack of light penetration and subsequent drop in photosynthetic activity. The sediment oxygen demand was high at the other sites (CRWA, 2006). Many of these sites also violated the minimum DO standard at depths greater than three feet. In contrast, West Medway Dam, South Natick Dam, South Main St./Rte. 27 in Medfield (318S) Cochrane Dam, Stop River/Charles River confluence, North Bellingham Dam and Medway Dam showed more uniform profiles of DO concentrations and temperature, indicating they are well-mixed impoundments with minimal stratification and/or sediment oxygen demand.

3.2.6 Flow Data

Flow data for the Upper/Middle Charles River watershed were obtained from the United States Geological Survey (USGS), American National Power (ANP), and Charles River Watershed Association (CRWA). Figure 4 shows all of the Upper/Middle watershed streamflow monitoring locations.

USGS operates a number of streamflow gauges in the Upper/Middle watershed of which five mainstem gauges and three tributary gauges were used in this study. American National Power measures streamflow at a railroad bridge near South Howard Street, just upstream of the Mellon Street bridge in Milford (IM3/TMDL Site 59CS). See Table 11 for a list of USGS and ANP streamflow monitoring stations.

CRWA also installed and operated nine tributary gauges for this study (Table 11). Rating curves were developed at each site by simultaneously measuring streamflow and water levels under different flow regimes. In 2002, CRWA installed depth loggers at the tributaries to measure water level and streamflow continuously.

More information about streamflow monitoring methodology and data collected for the Upper/Middle TMDL is available from the Phase I Final Report (CRWA, 2004) and the Phase II Final / Phase III Data Report (CRWA, 2006).

3.2.7 Ponds and Impoundments

As part of the Upper/Middle Charles River TMDL Project, CRWA performed several studies in the nine ponds and impoundments in the Upper/Middle watershed with a summary of results listed in Table 12. More details are in the project data reports (CRWA, 2003a; 2006).

Table 11. Streamflow Monitoring Stations in the Upper/Middle Charles

Name	Site ID	River Mile	Years	River / Tributary	Communities	Station Description
ANP	55CS	5.5	95-05	Charles River	Hopedale/Milford	Milford ANP Gage below WWTF
USGS	157T2	15.7	97-05	Miscoe Brook	Franklin/Medway	USGS Miscoe Bk Gage at South St
USGS	184S	18.4	97-05	Charles River	Medway	USGS Medway Gage at Walker St
USGS	447S	44.7	37-05	Charles River	Dover/Needham	USGS Dover Gage below Cochrane Dam
USGS	524T	52.4	31-05	Mother Brook	Dedham	USGS Mother Bk gage/discharge at Rt 1
USGS	591S	59.1	59-05	Charles River	Newton/Wellesley	USGS Wellesley Gage, outlet Circular Dam
USGS	642T	64.2	99-05	Stony Brook	Waltham	USGS Stony Brook Gage below Reservoir
USGS	666S	66.6	31-05	Charles River	Waltham	USGS Waltham Gage
CRWA	148T	14.8	02-05	Hopping Brook	Bellingham	Hopping Bk at Hartford Ave / Rt 126
CRWA	157T1	15.7	02-05	Mine Brook	Franklin/Medway	Mine Bk at Pond St
CRWA	159T	15.9	02-05	Chicken Brook	Franklin/Medway	Chicken Brook at Cottage St
CRWA	213T1	21.3	02-05	Mill River	Millis/Norfolk	Mill River at River Rd
CRWA	269T2	26.9	02-05	Stop River	Medfield	Stop River at Noon Hill Rd
CRWA	307T3	30.7	02-05	Bogastow Brook	Millis	Bogastow Bk at Ridge St
CRWA	393TW2	39.3	02-05	Waban Brook	Wellesley	Waban Brook at Dirt Rd off Service Dr
CRWA	393TF2	39.3	02-05	Fuller Brook	Wellesley	Fuller Brook at Dover St
CRWA	411T2	41.1	02-05	Trout Brook	Dover	Trout Bk at Haven St

The studies included a bathymetry and sediment thickness survey, an aquatic plant survey, and a sediment nutrient flux and oxygen demand study. Water volume, plant biovolume (water volume occupied by plants), and nutrient efflux rates from sediments were used as inputs to the TMDL model. Sediment thickness was used to estimate the potential sediment removal cost. Aquatic plants extent and biovolume were used to assess aesthetic and designated use impacts. High biovolume means that the water column is choked with plants and could have impaired recreational use, lowered aesthetic value, and low and/or variable DO.

Table 12. Pond and Impoundment Data in the Upper/Middle Charles

Site ID	Description	Area (ac)	Water (ft)	Sed-iments (ft)	Bio-volume (%)	Top Biovolumes Species
31CS	Milford Pond	118.4	2.0	5.4	50.2	Variable milfoil, White water lily, Cattail
85CS	Box Pond	42.6	2.3	1.2	33.8	Algae-floating, Waterweed, Floating-leafed pondweed
129S	North Bellingham Dam	3.3	1.0	0.9	29.8	Phragmites, Burreed-emergent, Purple loosestrife
143S	Caryville Dam	6.1	1.2	0.5	38.0	Phragmites, Cattail, Waterweed
159S	West Medway Dam	11.8	2.0	0.8	12.7	Purple loosestrife, Waterweed, Pondweed
178S	Medway Dam	4.9	3.0	0.3	0.0	Purple loosestrife, Yellow water lily, Pickerelweed
201S	Populatic Pond	49.1	5.7	5.4	2.2	Algae-submerged, Algae-floating, Yellow water lily
378S	South Natick Dam	13.5	3.5	1.0	6.5	Coontail, Big-leaf pondweed, Algae-floating
444S	Cochrane Dam	10.4	4.5	0.8	7.1	Algae-floating, White water lily, Purple loosestrife

Biovolume decreased downstream from 50% at Milford Pond to 0% at the Medway Dam then increased again to 7.1% at the Cochrane Dam. Milford Pond, the largest pond in area, had the highest percent biovolume of aquatic plants. The small impoundment upstream of Caryville Dam in Bellingham was also densely vegetated with a percent biovolume of 38%. The large Box Pond and the small impoundment upstream of North Bellingham Dam also had extensive vegetation throughout them with percent biovolumes of 34% and 30%, respectively. The remaining five sites had percent biovolumes ranging from 0% at Medway Dam to 12.7% at West Medway Dam. The impoundment upstream of Medway Dam was sparsely vegetated, which may have been largely due to the small volume of sediments and deep waters compared to the other sites.

Twenty-three different species of vegetation were identified in Milford Pond with the top three biovolume species being variable milfoil (*Myriophyllum heterophyllum)*, white water lily (*Nymphaea odorate*), and cattail (*Typha sp.)*. The top plant species near Caryville Dam were common reed (*Phragmites australis*), cattail (*Typha sp.)* and waterweed (*Elodea nuttallii)*. The top three plant species found throughout Box Pond were algae-floating (*Lyngbya sp.*), waterweed (*Elodea nuttallii)*, and floating-leafed pondweed (*Potamogeton natans*) and common reed (*Phragmites australis*), burreed-emergent (*Sparganium sp.*), and purple loosestrife (*Lythrum salicaria*) were observed near North Bellingham Dam. Purple loosestrife (*Lythrum salicaria*) and algae-floating (*Lyngbya sp.*) were observed in three out of the five remaining sites.

Box Pond, Populatic Pond, and Cochrane Dam had significant quantities of floating algae while Populatic Pond also had significant areas of submerged algae. Floating and submerged algae can have large diurnal effects on dissolved oxygen concentrations over and above those caused by algae in the water column as measured by chlorophyll-*a*. Macrophytes and periphyton (attached or floating algae) can also sequester large amount of phosphorus from the water column during the growing season and release it later when they senesce.

3.2.8 Aesthetics and Fisheries

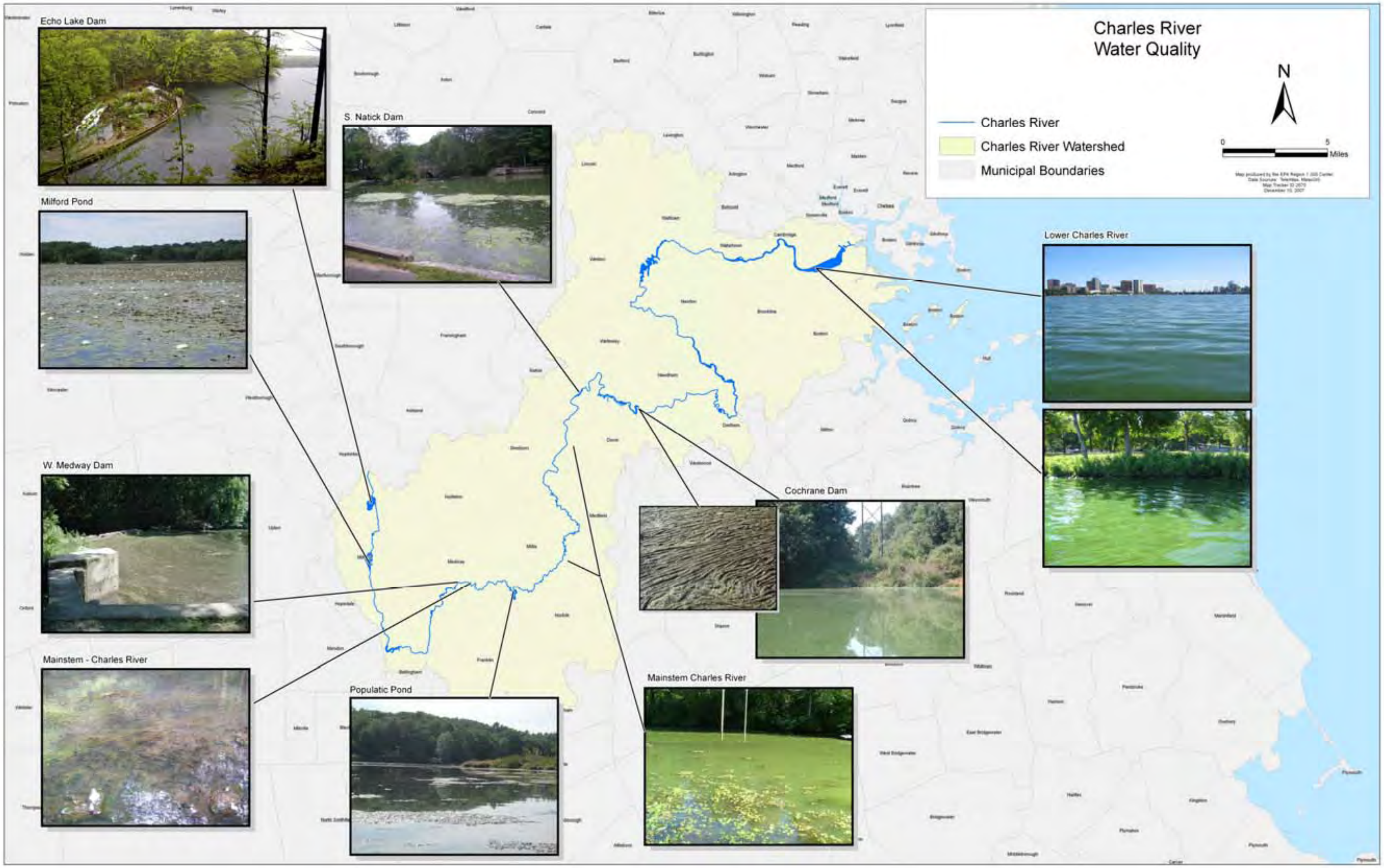
Sections of the Upper/Middle Charles River watershed, especially in the ponds and impoundments, have poor aesthetic quality because of nutrients and other pollutants that cause objectionable algal blooms, deposits and scum, produce objectionable odors, color and turbidity, and produce undesirable species of aquatic life. Excessive plant biomass is unacceptable as it contributes to non attainment of Massachusetts WQS by impairing designated uses.

As part of the Nutrient TMDL for the Lower Charles River, the relationship between algae levels and aesthetic impacts were evaluated through the review of user perception-based studies conducted in other water bodies. Most of the studies reviewed for the Lower Charles TMDL indicated that chlorophyll-*a* concentration higher than 20 µg/L have consistently resulted in perceived aesthetic impairments among users (US-EPA, 2007). Individual chlorophyll-*a* measurements greater than 20 µg/L have been consistently measured each summer in the Upper/Middle watershed and more frequently in the Lower Charles.

The extensive nature of aquatic plants in the Upper/Middle watershed can create an unattractive appearance of the river, such as in the case of Populatic Pond where although percent plant biovolume was very low (2%), algae scum was prevalent throughout the pond in the summertime. Dense stands of aquatic plants can also impede recreational passage in the river, for example, in any of the Upper/Middle four impoundments. Figure 5 shows photographs of the type and extent of aquatic plants in some areas of the Charles River watershed. Aquatic plants also directly affect water clarity since they obstruct light penetration and contribute to turbidity. Although water clarity was not quantified using a Secchi disk, CRWA has observed high turbidity in the river on numerous occasions in the summer and early fall.

Sediments also have a significant impact on aesthetics in the river. Sediments are deposited onto the river bottom creating thick, mucky and obnoxious conditions. At several locations including Milford Pond, Box Pond, Populatic Pond, and South Natick Dam, mean sediment depths are one to five feet deep. Upon disturbance of the bottom sediments, turbidity increases in the surrounding water column and objectionable odors may be emitted.

Impaired river water quality has created poor habitat for fish affecting the types and numbers of fish found in the river. A recent study by Massachusetts Division of Fish and Wildlife and CRWA found that 98% of the fish in the river are comprised of macrohabitat generalists, fish species that can live in a wide range of habitats including lakes, streams and reservoirs and do not require free-flowing water for any part of their life cycle (CRWA, 2003b). Examples of common macrohabitat generalists in the Charles River are common carp, largemouth bass, and redbreast sunfish. Many of these macrohabitat generalist species are also considered to be pollutant tolerant species (MassWildlife, 2009).



a) *Spatial Extent of the Problem*

Figure 5. Photographs of Degraded Water Quality in the Charles River Watershed (05-07)

b) White water lilies in Milford Pond in September 2005

c) Phragmites and cattails above Caryville Dam in September 2007

Figure 5. Degraded Water Quality in the Upper/Middle Charles (05-07) (cont.)

d) Floating algae above South Natick Dam in August 2007

e) Dense floating algae and duckweed above Cochrane Dam in September 2005

Figure 5. Degraded Water Quality in the Upper/Middle Charles (05-07) (cont.)

4 WATER QUALITY SUMMARY AND TARGETS

4.1 Pollutant of Concern

Phosphorus or nitrogen, two primary plant nutrients, may limit or control aquatic plant growth depending on their relative amounts in the aquatic system. Other environmental factors, such as light penetration, temperature, and residence time, may also play a role in plant growth. While phosphorus and nitrogen are both nutrients, phosphorus generally is the one judged to be limiting in freshwater (see Section 3.2.1). Some organisms can convert atmospheric nitrogen into a useable form of nitrogen thereby creating a nearly limitless supply.

To identify which nutrient is a 'limiting' factor that controls aquatic plant growth, the ratios of the total nitrogen (TN) and total phosphorus (TP) can be calculated. A typical biomass ratio of nitrogen to phosphorus is approximately 7.2 by weight (Chapra, 1997). A TN:TP ratio less than 7.2 suggests that nitrogen is the limiting factor while a ratio higher than 7.2 indicates that phosphorus will limit plant growth.

Available phosphorus and nitrogen data for the Upper/Middle Charles (Section 3) yielded ratios of TN:TP of 18.3–178 for the TMDL program and 3.65-145 for the IM3 data. From these ratios one can conclude that phosphorus is the limiting nutrient and the pollutant of concern for this nutrient TMDL.

4.2 Phosphorus Sources and Loads

Although phosphorus is ubiquitous in the natural environment, additional inputs to a watershed come from combined sewer overflows (CSOs), wastewater discharges, stormwater runoff, accumulated organic sediments on the river bottom, and some groundwater sources. There are no known CSOs in the Upper/Middle Charles study area and groundwater sources of phosphorus, including septic tank return flows from functioning systems, are normally very small because phosphorus is highly adsorbed to soil.

The primary human sources of phosphorus in the Upper/Middle Charles are wastewater, stormwater, and benthic sediments. Treated municipal wastewater is discharged from wastewater treatment facilities (WWTFs) that are regulated by the MassDEP and US-EPA permits. Stormwater runoff occurs during rainfall or snowmelt events and conveys phosphorus from land surfaces to the river system. In the fall, dead plant material and algae settle to the river bottom and the following growing season these benthic sediments release nutrients through organic decay.

The three largest WWTFs (flows reported here for 1998-2002) are on the mainstem of the Charles and include the Milford WWTF (3.5 mgd), the Charles River Pollution Control District or CRPCD in Medway serving four communities (4.4 mgd), and the Medfield WWTF (1.0 mgd). Part of the Milford discharge (0.34 mgd) is used consumptively for cooling by the Milford American National Power Plant. The three smaller WWTFs are on the Stop River and include the Caritas Hospital which ceased discharging in 2003 (0.02 mgd), the Massachusetts Correctional Institution at Norfolk (0.4 mgd), and the Wrentham Development Center (0.1 mgd). Phosphorus from wastewater discharges are mainly in the form of orthophosphate (50-80%) which is highly available for aquatic growth. Discharge is continuous so the impact is augmented in the summertime when river flows are low (less dilution) and water temperatures are high (high aquatic plant growth rates). Permitted summer limits for phosphorus discharge were lowered to 0.2 mg/L in late 2000 and winter limits of 1.0 mg/L were imposed for all but one treatment plant in 2005.

Stormwater runoff occurs from rainfall or snowmelt events when the infiltration capacity of the surface is exceeded. Much of the stormwater runoff originates from impervious surfaces like rooftops, driveways, and roadways but stormwater runoff may also come from vegetated areas, especially if the soil is compacted or saturated. The stormwater runoff carries phosphorus that is adsorbed to sediment and dissolved in the water, and might also come from wastewater sources. Wastewater enters the stormwater system illicitly via wastewater pipes that incorrectly connected to the stormwater drainage system.

Many human activities exacerbate the level of phosphorus in stormwater─ lawn fertilizers; car wash products; vegetative debris such as lawn clippings; some detergents; car exhaust and other oil byproducts, and pet waste. Urbanized zones have large extents of impervious area that produce considerable volumes of stormwater runoff that are directly connected to surface waters. Intensity of development increases phosphorus loads from stormwater both through the increase in impervious area and also the intensity of the land use. High density residential and commercial or industrial activities have higher phosphorus loads than low or medium density residential land uses (Horner et al, 1994).

Organic benthic sediment accumulates at the end of the growing season when aquatic plants senesce and settle to the bottom of the river creating a potential source of nutrients that are re-released the following growing season when the organic matter begins to decay with the increase in water temperature. Years of accumulation of organic matter on the river bottom, especially if the historic period had high phosphorus discharges from WWTFs, can create a significant source of nutrients that can be released to the water column long after the water column has been cleaned up.

Losses of phosphorus throughout the system include diversions and internal transient losses like uptake and settling. Streamflow is diverted from the Charles River at Mother Brook into the Neponset River for flood control purposes. The diversions averages about 38 mgd and can result in significant reductions in phosphorus load at the Watertown Dam outlet, especially during the high-flow periods when releases are highest. Internal growth processes result in phosphorus loss via uptake by phytoplankton and benthic algae during the growing season and a phosphorus gain at the end of the growing season from respiration and settling.

An analysis of Upper/Middle Charles total loads and losses was performed for the period 1998-2002 using the calibrated HSPF model. The predicted phosphorus loads were summed over the summer months (Apr-Oct, lb/period) and the full year (Jan-Dec, lb/yr). This five-year period was chosen to match the period used for the load calculations in the Lower Charles TMDL. All flows mentioned in this section are also for that period.

The total wastewater phosphorus load to the Upper/Middle watershed was estimated by summing the daily loads from the six WWTFs. The daily load time series were created from actual daily flows and daily concentrations estimated between measurements using step interpolation. The product of flow and concentration gave the daily load for each WWTF. Daily loads (lbs/d) were then summed to get summer, winter, and annual loads. The final wastewater loads were then converted to metric units (kg/time period).

The total stormwater phosphorus load to the Upper/Middle watershed was estimated from the hydrologic response units (HRUs) by using the calibrated HSPF model to generate the monthly phosphorus loads for groundwater and surface runoff components then accumulating across months and HRUs. Since sediments were not simulated explicitly in the HSPF, the dissolved nutrient components were used to predict the combined dissolved and particulate loads for runoff. The model generated monthly HRU loads (lb/ac/month) for orthophosphate (PO4-P) and degradable organic matter represented by biochemical oxygen demand (BOD) for the 21 pervious HRUs (3 soils x 7 land uses) and the two impervious HRUs (residential and commercial). Monthly total phosphorus (TP) loads for each HRU were calculated as the sum of the PO4-P, labile organic P (BOD/165.8), and refractory organic P (0.5*BOD/165.8) loads. Stormwater TP loads for the summer, winter, and annual (lb/period) periods were calculated using the HRU loads (lb/ac/month) and HRU areas (ac) and summing across the months and HRUs. The final stormwater loads were then converted to metric units (kg/period).

The predicted loads of total phosphorus from the Watertown Dam and Mother Brook were estimated from the hourly flow (cfs) and hourly loads (lb/hr) of PO4-P and TORP (total organic phosphorus) and converted to kg/period or kg/yr. Other total phosphorus loads and losses were also estimated from the HSPF model by turning on/off certain model components. Sources are comprised of atmospheric deposition, benthic sediment release, stormwater, and wastewater while losses are from algae uptake and settling, and diversions. The final loads and losses for the summer (Apr-Oct), winter (Nov-Mar), and whole year are summarized in Table 13. The simulated annual outlet phosphorus load from the Watertown Dam was 28,262 kg/yr which is close to the measured load of 28,925 kg/yr (EPA, 2007; CRWA, 2009).

Figure 6 shows a breakdown of the sources for both summer and winter periods. Stormwater load is the largest source in both periods. For the summer, stormwater is 78%, wastewater is 16%, and benthic sediment is 5%, while atmospheric deposition contributes 1% of the total source load. For the winter, stormwater is 70%, wastewater is 22%, and benthic sediment is 7%, while atmospheric deposition contributes 1% of the total source load.

Table 13. Calibration Phosphorus Loads and Losses in the Upper/Middle Charles (98-02)

TP Loads (kg/yr)					
Period	**Atmos. Deposition**	**Sed Release**	**Stormwater**	**Wastewater**	**Total**
Apr-Oct	158	960	16,454	3,333	20,905
Nov-Mar	150	1,346	14,480	4,518	20,494
Annual	309	2,305	30,934	7,851	41,399
TP Losses (kg/yr)					
Period	**Benth Algae**	**Settling**	**Mother Brook**	**Watertown Dam**	**Total**
Apr-Oct	6	5,288	2,238	13,273	20,805
Nov-Mar	15	3,231	2,359	14,989	20,594
Annual	21	8,519	4,597	28,262	41,399

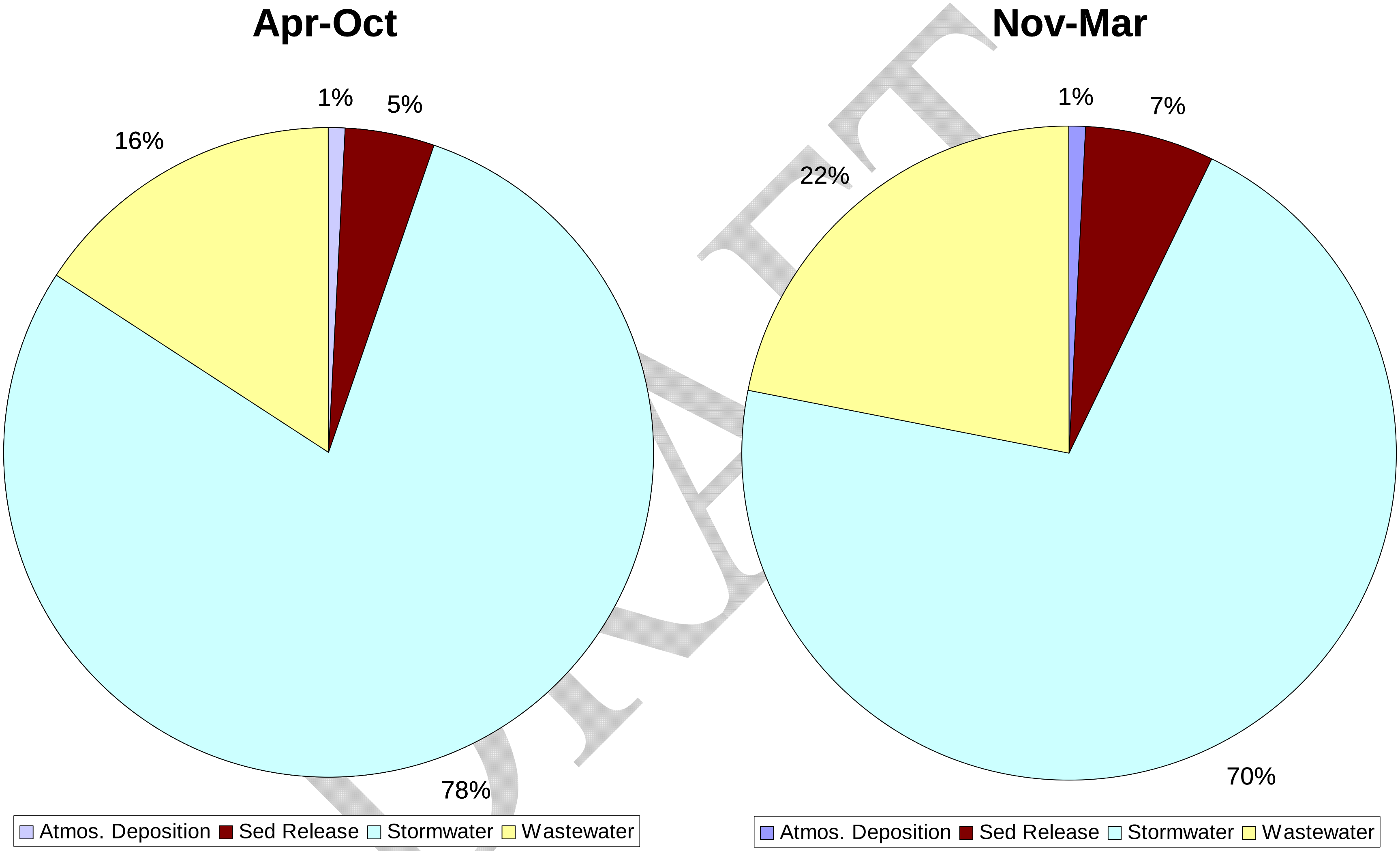


Figure 6. Seasonal Phosphorus Loads in the Upper/Middle Charles (98-02)

Figure 7 shows the monthly variation of the principal source loads from stormwater and wastewater. The stormwater nutrient loads are highest in the spring and early summer when the soils are wettest and runoff occurs readily with any rainfall event. Although significant runoff events can occur during any wet period in the summer, they are much more likely to occur in the spring. The phosphorus nutrient load from WWTFs is usually highest in the winter and lowest in the summer. This pattern occurs because both the waste flows and permitted effluent concentrations are low in the summer. Waste flow variation is governed mostly by groundwater infiltration into the pipes and the groundwater levels follow the same seasonal pattern as streamflow, that is, highest in the winter/spring and lowest in the summer/fall. Permitted phosphorus effluent concentrations are highest in the winter and lowest in the summer.

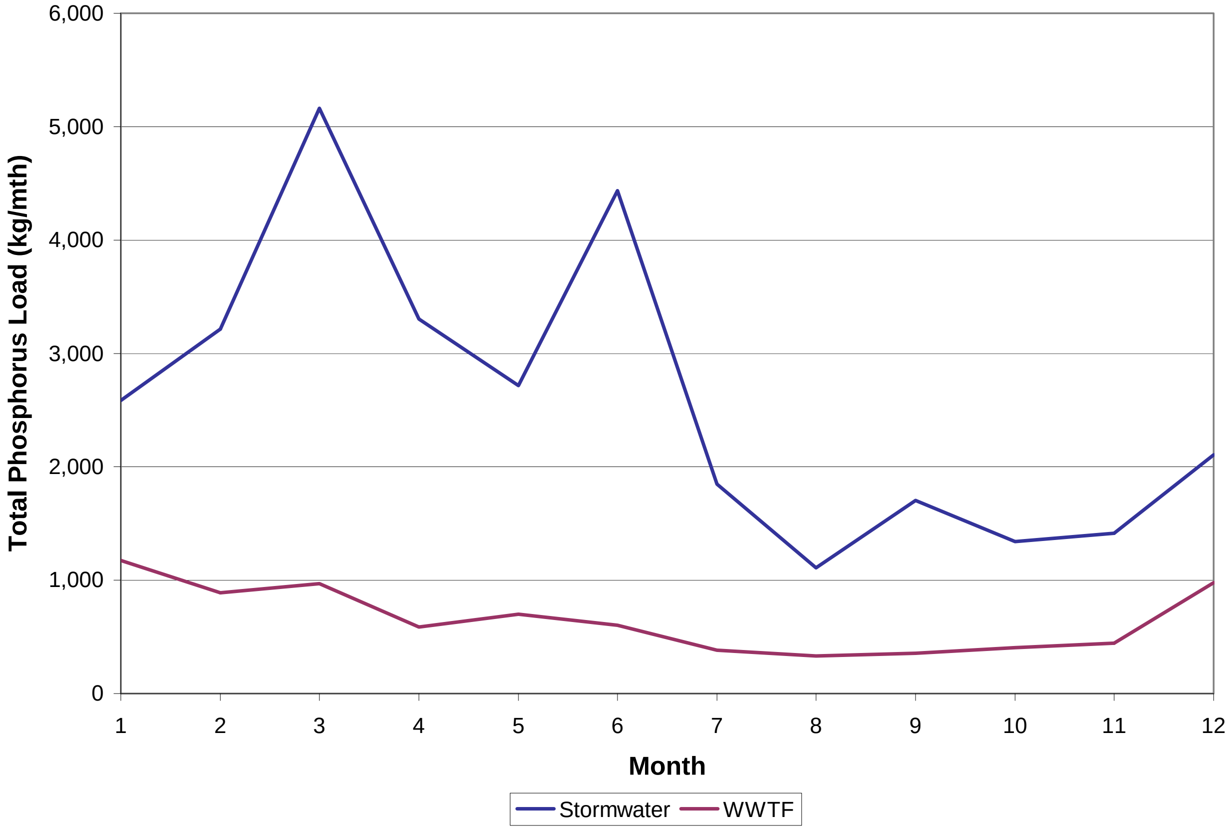


Figure 7. Monthly Trends of Key Phosphorus Loads in the Upper/Middle Charles (98-02)

Table 14 partitions the total predicted stormwater load for the Upper/Middle TMDL by land use and perviousness then compares the loads to the Lower Charles TMDL. The Lower TMDL used literature-based export coefficients (Horner, 1994) and adjusted these coefficients to match the total observed watershed phosphorus load. In general, these Lower TMDL loads were lower than those used in the Upper/Middle TMDL because the Lower Charles TMDL model used the measured load input at the Watertown Dam. As such it did not have to consider additional losses that were occurring in the Upper/Middle sections of the system. Therefore in order to account for upstream losses and still match the measured load at the Watertown Dam further adjustments to the final phosphorus export coefficients were necessary and are provided in Table 14. In general, the final export coefficients for the Upper/Middle TMDL were the lowest for Water/Wetland and Forest, intermediate for Open/Agriculture, increasing from Low Density

Residential to High Density Residential, and highest for Commercial/Industrial. The same export coefficient for impervious area is repeated for all three residential categories because only one HRU is used in the HSPF model for all residential impervious areas.

Table 14. Stormwater Phosphorus Loads by Land Use and TMDL (98-02)

Land Use	TP Load (kg/yr)		TP Load (kg/ha/yr)	
	Upper/Middle	Lower	Upper/Middle	Lower
Open/Agric	1,504	1,441	0.24	0.17
Forest	3,656	4,130	0.17	0.13
Forested Wetland	738	-	0.13	-
Water/Wetland	126	0	0.12	0.00
Low Density Res	4,979	520	0.38	0.05
Pervious	3,995	-	0.31	-
Impervious	985	-	2.22	-
Medium Density Res	5,505	3,826	0.62	0.57
Pervious	4,225	-	0.50	-
Impervious	1,280	-	2.22	-
High Density Res	5,029	5,674	1.11	1.13
Pervious	2,730	-	0.78	-
Impervious	2,299	-	2.22	-
Multi-Family	935	-	1.51	
Pervious	664	-	1.33	
Impervious	271	-	2.22	
Commercial/Industrial*	8,461	6,277	2.03	1.54
Pervious	2,231	-	1.32	-
Impervious	6,230	-	2.51	-
Average/Total	30,934	21,868	0.47	0.32

* includes Transportation defined by MassGIS as airports, docks, divided highway, freight, storage, and railroads

4.3 Water Quality Target Selection and Evaluation

The target evaluation for the Upper/Middle Charles River was based on a two-tiered evaluation approach. First, the annual phosphorus load at Watertown Dam outlet must meet the inlet load specified by the Lower Charles TMDL. Second, the phosphorus loads must be low enough to achieve instream water quality targets and response variables for excess nutrients and algal biomass in the river system during low flow conditions and assuming that all point sources are discharging at their current design flow.

The Upper/Middle Charles River model was specifically developed for this TMDL to simulate instream nutrient and algal dynamics in the Upper/Middle Charles River from Echo Lake to the Watertown Dam in response to pollutant loadings from watershed sources. The model simulates water column and sediment nutrient cycling and algae dynamics coupled with one-dimensional transport in the Charles River. Water quality target selection and evaluation involved analysis of predicted water quality both spatially along the length of the Upper/Middle Charles River system as well as temporally during critical periods of low and high flow.

The following section summarizes the rational for setting water quality targets in the Upper/Middle Charles watershed as well as the basis for analysis of instream predictions with respect to the critical river segments and critical periods.

4.3.1 Watertown Dam Target

As part of the two-tiered approach, scenarios were first screened for their ability to meet the inlet phosphorus load at Watertown Dam that was derived in the Lower Charles Phosphorus TMDL. As specified in the Lower Charles TMDL, the average annual phosphorus load contribution from the Upper/Middle Charles River can not exceed 15,109 kg/yr at the Watertown Dam (US-EPA, 2007). This target is the maximum load allocation for phosphorus from the Upper/Middle Charles River watershed that can exit the Watertown Dam in order to achieve the phosphorus TMDL for the Lower Charles. The five-year period of 1998-2002 for this TMDL was chosen to match the same period used for load calculations in the Lower Charles TMDL.

4.3.2 Water Quality Targets Selection

The water quality targets were developed from metrics identified in Section 2.5 using best professional judgment (BPJ) and a “weight-of-evidence” approach. In general, targets include water quality parameters that are the most sensitive measures of nutrient impacts. The targets were selected for consistency with applicable water quality standards, the Lower Charles phosphorus TMDL, US-EPA guidance documents, and MassDEP experience with nutrient TMDL development in river systems. The metrics chosen for this TMDL are given in Table 15.

Table 15. Water Quality Targets for the Upper/Middle Charles TMDL

Water Quality Targets (Apr-Oct 2002)	Min/Max 7-d Avg	10/90th percentile	Average
Minimum daily dissolved oxygen	>5 mg/L	>5 mg/L	>5 mg/L
Maximum daily dissolved oxygen saturation	< 125%	< 125%	< 125%
Mean daily total phosphorus in flowing waters	<0.1 mg/L	<0.1 mg/L	<0.1 mg/L
Mean daily total phosphorus on entering	<0.05 mg/L	<0.05 mg/L	<0.05 mg/L
Mean daily total phosphorus in impounded reaches	<0.025 mg/L	<0.025 mg/L	<0.025 mg/L
Mean daily chlorophyll-*a*	< 18.9 µg/L	< 18.9 µg/L	< 10 µg/L

Instream predictions of hourly water quality were generated for each reach using the calibrated HSPF model. To eliminate some of the data outliers, the hourly values were processed into daily values and the final metrics deliberately avoided overall minimum and maximum statistics. As a measure of extremes, the daily percentiles and minimum 7-day average statistics were used. A 10th percentile of daily values is expected to be lower only 10% of the days while the a 90th percentile is expected to be higher only 10% of the days. The 7-day minimum and maximum represent the lowest and highest average over seven consecutive days within the year, respectively. Only the dissolved oxygen target uses the minimum statistics while the other targets use the maximum statistics.

To evaluate the effect of different years on worst case conditions, the model was run for two periods – a single low-flow year (2002) and a ten-year period (1996-2005). The targets in Table 15 were used to compare the predicted conditions of each reach for the two periods. Output from the model was also manipulated to give the date that worst case condition occurred as well as the associated flow for each parameter of interest. This approach captured the worst case water quality predictions under both extreme low flow and high flow conditions. A comparison of the results from the two simulation periods revealed no significant differences in output. As a result it was concluded that 2002 would be the most appropriate period to use in further scenario evaluations.

The most deleterious effects of excessive nutrients are usually manifested in the summer growing season as the lower flows and warmer temperatures create a time of more rapid algae and aquatic plant growth. However, the analysis was expanded to include the late spring runoff in April when high stormwater loads can also contribute to early algae growth. The season for the Upper/Middle TMDL analysis was therefore set to from April to October.

For each scenario, from April to October 2002, the river segments where water quality targets were not achieved were tallied and the results presented in tables as river miles and percent of river. The following sections describe how the targets chosen will achieve the desired water quality objectives.

4.3.2.1 Aesthetic and Water Clarity Impacts

A seasonal average chlorophyll-*a* target of 10 µg/L for the Upper/Middle Charles TMDL is consistent with the Lower Charles TMDL and is a site-specific target for this river. The chlorophyll-*a* target is set at a level that will result in reductions in eutrophication sufficient to enable the Upper/Middle Charles River to attain all applicable Class B narrative (nutrients, aesthetics, and clarity) and numeric (dissolved oxygen and pH) standards. Achieving the seasonal average chlorophyll-*a* target will reduce algal biomass to levels that are consistent with a mesotrophic status, will address aesthetic impacts, and attain clarity standards.

Excessive algae often results in poor aesthetic quality because of coloration and reduced clarity. To evaluate the extreme levels of algae that might be encountered during a growing season, the 90th percentile of the daily average value (the value that is expected to be exceeded only 10% of days) was estimated for the period April to October. A strong relationship between the seasonal mean and the seasonal 90th percentile values (R^2=0.94) was demonstrated in the Lower Charles TMDL. For the Lower Charles, linear regression was used to establish the 90th percentile chlorophyll target of 18.9 µg/L for a seasonal mean chlorophyll-*a* concentration of 10 µg/L. The regression analysis was repeated for Upper/Middle Charles and yielded similar results.

4.3.2.2 Harmful Algal Blooms

The goal of achieving the seasonal average chlorophyll-*a* target concentration of 10 µg/L is to move the Upper/Middle Charles River from a eutrophic to mesotrophic status. A mesotrophic status for the Upper/Middle Charles River would indicate intermediate nutrient availability and biological production (US-EPA, 1990) without having an adverse impact from harmful algal blooms on the aquatic system (US-EPA, 2000a). Analysis of the patterns in algal taxonomic composition across temperate lakes of differing nutrient status (Watson et al., 1997) showed that cyanobacteria (blue-green biomass) increases markedly with increasing total phosphorus concentrations between 30 and 100 µg/L. Thus, reductions in phosphorus to achieve the 10 µg/L chlorophyll-*a* target in the Upper/Middle Charles River should result in reductions in both cyanobacteria (blue-green) biomass and the potential for nuisance and toxic blooms. Thus, achieving the seasonal average chlorophyll-*a* concentration of 10 µg/L should be adequately protective for both public health and water quality (US-EPA, 2007).

4.3.2.3 Dissolved Oxygen

Dissolved oxygen levels have been observed to fall below the minimum dissolved oxygen criterion of 5 mg/L in the water column of the Upper/Middle Charles River (see Table 10). As a result of algal photosynthetic activity, dissolved oxygen concentrations can vary considerably during the day and result in high super-saturated dissolved oxygen levels (see Table 10). Reducing the seasonal mean chlorophyll-*a* concentration to achieve the target of 10 µg/L will result in less algal biomass and, therefore, reductions in diurnal dissolved oxygen variations and super-saturated dissolved oxygen concentrations.

4.3.2.4 Phosphorus Levels

Presently the Massachusetts Water Quality Standards do not contain numeric in-stream phosphorus criteria. As such no specific in-stream target concentration for total phosphorus was established for the Upper/Middle Charles TMDL, however, published guidance values (US-EPA, 1986; 2000a; 2000b; 2000c) were considered. Under the weight-of-evidence approach all available information was used to set site-specific permit limits. The overall goal is to significantly reduce the amount of biomass in the system fully recognizing that not all the biomass, like macrophytes, can be removed and that some level of biomass is necessary to provide habitat to fish and other aquatic organisms. A comparison of relative in-stream total phosphorus concentrations, although not a target, to US-EPA guidance was used to further validate the model and weight-of-evidence approach. The “Gold Book” (US-EPA, 1986) criteria were used to provide a relative comparison of the modeled scenarios impact on reducing instream water quality predictions for total phosphorus. This guidance recommends that total phosphorus not exceed 50 µg/L in any stream at the point where it enters any lake or impoundment, nor exceed 25 µg/L within the lake or reservoir. A desired goal for the prevention of plant nuisance instream or in flowing waters not discharging directly to lakes or impoundments is 100 µg/L total phosphorus. This guidance provided a range of acceptable criteria for phosphorus based upon specified conditions.

4.3.3 Critical and Excluded Reaches

Instream water quality predictions were made for the entire length of the Upper/Middle Charles River starting at Echo Lake and ending at the Watertown Dam. Table 16 provides a summary of reaches and river miles that were identified as critical during model development. More focus was given to the analysis and interpretation of water quality predictions in these reaches.

All reaches were evaluated except the excluded reaches (the first 0.4 mi above Echo Lake plus river miles 0-3.1 and river miles 49.1-58.9

Two river segments where water quality targets were exceeded were excluded from the reach analysis. The segment starting at the headwaters to the start of the Milford Main Street Culvert (0.4 mi above Echo Lake plus river miles 0-3.1) was excluded from the analysis of instream predictions (a total of 3.5 miles). Water quality impairments in this section of the river were not related to nutrient enrichment. Although low dissolved oxygen levels were found, those levels remained consistently low and did not fluctuate a great deal. It appears that the low dissolved oxygen condition in this area is a function of natural conditions resulting from bordering vegetative wetlands and low flow conditions in the headwater reaches.

The river segment from the start of the Dedham Canal just above Mother Brook to the Silk Mill Dam (river mile 49.5-59.4) was also excluded from analysis (a total of 9.9 miles) due to limited dissolved oxygen data available for calibration of the model in this portion of the river. Decision-making was not based on the model output in this section of the river due to the lower confidence in the predicted instream water quality conditions.

In summary, 13.3 miles were excluded from the detailed instream water quality evaluation.

4.3.4 Critical Low Flow and High Flow Periods

The dynamic nature of streamflow, loads, impoundments, and residence time in the Upper/Middle Charles River makes it difficult to pick a single “critical” flow period. Early analysis of individual reaches showed the each reach had its own “critical” period. Since instream water quality impacts are often a result of extreme conditions, the Upper/Middle Charles TMDL instream predictions were evaluated over a range of low and high flow conditions.

Table 16. Critical Reaches Evaluated in the Upper/Middle Charles TMDL

Critical Reach	Description	Label	River Mile
Below Milford WWTP Outfall	WWTP inputs	MilfWW	5.5
Box Pond Outlet	Increased residence time in impounded reach can result in degraded water quality	BoxPnd	8.5
Populatic Pond	Depressed dissolved oxygen attributed to backwater effects from CRPCD effluent	PopPnd	20.1
Below Charles River Pollution Control District (CRPCD) Outfall	WWTP inputs	CRPCD	20.7
Below Stop River confluence	Tributary inputs including minor WWTF input	StopR	27.6
Below Medfield WWTP Outfall	WWTP inputs	MedWW	29.4
South Natick Dam	Increased residence time in impounded reach	SNatDm	37.8
Cochran Dam	Increased residence time in impounded reach	CochDm	44.4
Watertown Dam	Total phosphorus load to Lower Charles Rivdr evaluated	WatDm	69.1

Average monthly streamflow varies in response mostly to seasonal evaporation from high streamflow in the winter/spring to low streamflow in the summer/fall. The lowest flow conditions usually occur during a dry period in the late summer/fall while the highest flows usually occur during a wet period in the late winter/spring.

The phosphorus nutrient load from WWTFs is usually highest in the winter and lowest in the summer. This pattern occurs because both the waste flows and permitted effluent concentrations are low in the summer. The stormwater nutrient loads are highest in the spring and early summer when the soils are wettest and runoff occurs readily with any rainfall event (see Figure 7).

The residence time of the river system from Echo Lake to the Watertown Dam varies from weeks to months depending on the streamflows. An algae bloom might start in an upstream reach during a warm low flow period then move downstream as flows increase. Additionally, impoundments have long residence times and are more susceptible to algae and plant growth so they might respond to a loading source many miles upstream.

Water quality response of the river to the dynamic nature of the phosphorus loads is mostly confined to the plant growth season. Even though nutrient loads are much higher in the winter, eutrophication responses like algae and aquatic plant growth and dissolved oxygen depletion or fluctuation are muted in the cooler temperatures. The analysis is therefore confined to the growing season of April to October (see Section 4.3.2).

Massachusetts Water Quality Standards set a minimum dissolved oxygen criterion of 5.0 mg/L instream to protect warm water fish. Large fluctuations in dissolved oxygen concentration and the amount of time supersaturated conditions exist are also pronounced during low flow conditions. Large daily dissolved oxygen fluctuations result from extremely low dissolved oxygen concentrations in the early morning hours followed by supersaturated and extremely high concentrations in the late afternoon. This condition is directly related to eutrophication and the amount of both floating and rooted biomass in the system and is indicative of excessive biomass.

Massachusetts's water quality standards are devised to provide protection to water quality for low flow conditions that satisfy a certain statistical condition designated 7Q10. This 7Q10 condition is the lowest flow averaged for a consecutive 7-day period with a recurrence interval of 10 years and is determined from continuous gauging station records. Utilizing only this low-flow approach makes sense when the river contamination is dominated by WWTF loads but not when stormwater loads are also a significant source.

The low-flow approach was therefore adapted by identifying the worst seven-day condition under any flow conditions for each water quality target and for all reaches. The analysis was performed both on a one year (Apr-Oct, 2002) and a ten-year (1996-2005) period. The analysis extracted the date when the worst case condition occurred as well as the associated flow for each target of interest and reach. This approach enabled worst case water quality predictions under both extreme low flow and high flow conditions to be evaluated. A comparison of the two simulation period approaches revealed no significant difference in predicted outcomes. As a result it was concluded that the 2002 simulation period was appropriate for further scenario evaluations.

5 WATER QUALITY MODEL RESULTS

An HSPF model (Bicknell, et al., 1993) was developed and calibrated for use in this Upper/Middle Charles TMDL study. Details on the model construction and calibration are summarized in the given in the Phase III Calibration Report (CRWA, 2009). The model was calibrated to field conditions for the period 2002-2005 and validated by comparing it with continuous DO data from a prior survey (CDM, 1997).

5.1 Scenarios Modeled

The purpose of this evaluation was to determine the impact of various point source and nonpoint source reductions on water quality in the critical reaches of the Upper/Middle Charles River and their ability to meet the load requirement at the Watertown Dam necessary to protect the Lower Charles River Basin.

The Upper/Middle Charles HSPF model was run for 18 scenarios (see Table 17). All scenarios presented here are modifications of the calibrated model. The major wastewater treatment facilities (WWTFs) are Milford WWTF, Charles River Water Pollution District (CRPCD), and Medfield WWTF while the minor systems are MCI Norfolk, Wrentham Development Center, and Southwood Caritas Hospital (operated until June 2003).

Scenarios 1-6A investigate the effect of phosphorus reductions from wastewater only while 7-12A looked at the effect of phosphorus reductions from both wastewater and stormwater along with some reductions in phosphorus release from benthic sediments. The reductions in phosphorus loads from stormwater match the reductions used in the Lower Charles TMDL. The most stringent reductions used for wastewater and stormwater represent the maximum extent practicable for current control technology. Sediment efflux rates were reduced to 75% of the calibration values to represent the expected adjustment to the total load reductions.

The current (existing WWTP permit conditions) and natural (forested condition) scenarios represent baselines for comparison of scenarios.

The following briefly describes each scenario that was investigated. All scenarios were run for the period 1998-2002 to be consistent with the scenario period used for the Lower Charles TMDL (US-EPA, 2007).

Calibration Scenario

The calibrated model used 1999 land use to predict stormwater flows and loads, actual WWTF flow and loads, actual pump withdrawals and return flows, and actual Mother Brook diversions. In 2001, the discharge permits for all WWTFs lowered the summer limits for phosphorus discharge from 1.0 mg/L to 0.2 mg/L while winter limits remained unrestricted. For this run only, the Southwood Caritas Hospital WWTF was operational.

Current Scenario

This scenario represents current permitted conditions with permitted flows and discharge concentrations for WWTFs. For the Milford, Medfield, and Wrentham WWTFs, the phosphorus discharge limits were 0.2 mg/L (Apr-Oct) and 1.0 mg/L (Nov-Mar). For CRPCD and MCI Norfolk the same summer limits apply but winter effluent concentrations were based on actual values (sometimes less than permitted). All WWTFs discharge flows were set to the 12-month rolling average permit flow and seasonally varied according to the average observed monthly waste flow pattern for 1998-2002 (see Figure 7). Additionally, CRPCD summer flows were restricted to its permitted summertime flow. The permitted flows were: CRPCD=5.7 mgd with 4.5 mgd Jul-Sep, Milford=4.3 mgd, Medfield=1.52 mgd, MCI Norfolk=0.464 mgd, Wrentham Development Center=0.454 mgd, and Southwood Caritas Hospital=0 mgd)

Scenario 1 (WWTF reductions only)

This scenario represents the effect of setting the discharge phosphorus concentrations for all the major WWTFs to a low value year-round. All parameters were kept the same as the current condition except phosphorus discharge limits for major WWTFs were set at 0.2 mg/L year-round and minors at 0.1/1.0 mg/L for summer/winter.

Scenario 2 (WWTF reductions only)

This scenario represents the effect of setting the discharge phosphorus concentrations for the major WWTFs lower in the summer than the winter. All parameters were kept the same as the current condition except phosphorus discharge limits for major WWTFs were set at 0.2/0.5 mg/L and minors at 0.1/1.0 mg/L for summer/winter.

Scenario 3 (WWTF reductions only)

This scenario represents the effect of setting the discharge phosphorus concentrations for all the major WWTFs to a very low value year-round. All parameters were kept the same as the current condition except phosphorus discharge limits for major WWTFs were set at 0.1 mg/L year-round and minors at 0.1/1.0 mg/L for summer/winter.

Scenario 4 (WWTF reductions only)

This scenario represents the effect of setting the discharge phosphorus concentrations for Milford WWTF to a very low value year-round and other the major WWTFs to a low value year-round. All parameters were kept the same as the current condition except phosphorus discharge limits for Milford WWTF was set at 0.1 mg/L year-round, other major WWTFs at 0.2 mg/L year-round, and minors at 0.1/1.0 mg/L for summer/winter.

Scenario 5 (WWTF reductions only)

This scenario represents the effect of setting the discharge phosphorus concentrations for Milford WWTFs to a very low value year-round and setting other major WWTFs lower in the summer than the winter. All parameters were kept the same as the current condition except phosphorus discharge limits for Milford WWTF was set at 0.1 mg/L year-round, other major WWTFs at 0.2/0.5 mg/L for summer/winter, and minors at 0.1/1.0 mg/L for summer/winter.

Scenario 6 (WWTF reductions only)

This scenario represents the effect of setting the discharge phosphorus concentrations for Milford WWTF lower than the other major WWTFs and also setting the summer lower than the winter. All parameters were kept the same as the current condition except phosphorus discharge limits for Milford WWTF were set at 0.1/0.5 mg/L for summer/winter, other major

WWTFs at 0.2/0.5 mg/L for summer/winter, and minors at 0.1/1.0 mg/L for summer/winter.

Scenario 6A (WWTF reductions only)

This scenario represents the effect of setting the discharge phosphorus concentrations for the major WWTFs low in the summer and relatively high in the winter. All parameters were kept the same as the current condition except phosphorus discharge limits for major WWTFs were set at 0.2/1.0 mg/L for summer/winter and minors at 0.1/1.0 mg/L for summer/winter.

Scenario 7 (WWTF + SW reductions)

This scenario represents the effect of setting the discharge phosphorus concentrations for all the major WWTFs to a low value year-round and applying the Lower Charles TMDL stormwater reductions. Same as Scenario 1 with stormwater phosphorus reductions as follows: Open/Agriculture (35%), Low Density Residential (45%), Medium and High Density Residential (65%) and Commercial/Industrial (65%). Sediment efflux rates were reduced to 75% of calibration to represent the adjustment to load reductions.

Scenario 8 (WWTF + SW reductions)

This scenario represents the effect of setting the discharge phosphorus concentrations for the major WWTFs lower in the summer than the winter and applying the Lower Charles TMDL stormwater reductions. Same as Scenario 2 with stormwater phosphorus reductions as follows: Open/Agriculture (35%), Low Density Residential (45%), Medium and High Density Residential (65%) and Commercial/Industrial (65%). Sediment efflux rates were reduced to 75% of Calibration to represent the adjustment to load reductions.

Scenario 9 (WWTF + SW reductions)

This scenario represents the effect of setting the discharge phosphorus concentrations for all the major WWTFs to a very low value year-round and applying the Lower Charles TMDL stormwater reductions. Same as Scenario 3 with stormwater phosphorus reductions as follows: Open/Agriculture (35%), Low Density Residential (45%), Medium and High Density Residential (65%) and Commercial/Industrial (65%). Sediment efflux rates were reduced to 75% of Calibration to represent the adjustment to load reductions.

Scenario 10 (WWTF + SW reductions)

This scenario represents the effect of setting the discharge phosphorus concentrations for Milford WWTFs to a very low value year-round and other the major WWTFs to a low value year-round and applying the Lower Charles TMDL stormwater reductions. Same as Scenario 4 with stormwater phosphorus reductions as follows: Open/Agriculture (35%), Low Density Residential (45%), Medium and High Density Residential (65%) and Commercial/Industrial (65%). Sediment efflux rates were reduced to 75% of Calibration to represent the adjustment to load reductions.

Scenario 11 (WWTF + SW reductions)

This scenario represents the effect of setting the discharge phosphorus concentrations for Milford WWTFs to a very low value year-round and setting other major WWTFs lower in the summer than the winter and applying the Lower Charles TMDL stormwater reductions.

Same as Scenario 5 with stormwater phosphorus reductions as follows: Open/Agriculture (35%), Low Density Residential (45%), Medium and High Density Residential (65%) and Commercial/Industrial (65%). Sediment efflux rates were reduced to 75% of Calibration to represent the adjustment to load reductions.

Scenario 12 (WWTF + SW reductions)

This scenario represents the effect of setting the discharge phosphorus concentrations for Milford WWTF lower than the other major WWTFs and also setting the summer lower than the winter and applying the Lower Charles TMDL stormwater reductions. Same as Scenario 6 with stormwater phosphorus reductions as follows: Open/Agriculture (35%), Low Density Residential (45%), Medium and High Density Residential (65%) and Commercial/Industrial (65%). Sediment efflux rates were reduced to 75% of Calibration to represent the adjustment to load reductions.

Scenario 12A (WWTF + SW reductions)

This scenario represents the effect of setting the discharge phosphorus concentrations for the major WWTFs low in the summer and relatively high in the winter and applying the Lower Charles TMDL stormwater reductions. Same as Scenario 6A with stormwater phosphorus reductions as follows: Open/Agriculture (35%), Low Density Residential (45%), Medium and High Density Residential (65%) and Commercial/Industrial (65%). Sediment efflux rates were reduced to 75% of Calibration to represent the adjustment to load reductions.

Lower Final TMDL Scenario (WWTF + SW reductions)

This scenario was not run but represents the Lower Charles TMDL. Similar to Scenario 12A but with both major and minor WWTFs set at 0.2/1.0 mg/L phosphorus for summer/winter and WWTF flows set to (lower) actual flows not permitted flows. The Lower TMDL also used lower stormwater export coefficients but there was no diversion from Mother Brook, no sediment efflux, and no internal uptake.

Natural Scenario

This scenario represents near-natural conditions for water quality. All the open/agricultural, residential and commercial/industrial loads were converted to forest loads. WWTF discharges were removed completely. All pumping withdrawals and return flows were turned off but the Mother Brook diversion was retained. Sediment efflux rates were reduced to 10% of Calibration to represent near-natural conditions.

Table 17. Descriptions of Modeled Scenarios and Annual Phosphorus Loads (98-02)

Description		Major WWTFs						Minor discharges						Watertown Dam	Reduction from Permitted
		Milford		CRPCD		Medfield		MCI Norfolk		Wrentham Dev		Southwood			
Permitted Flow (MGD)		4.3 MGD 12-mth Rolling Monthly Seasonal Flow Variations		5.7 MGD Oct-Jun, 4.5 MGD Jul-Sep 12-mth Rolling Avg Seasonal Flow variations		1.52 MGD 12-mth Rolling Avg Seasonal Flow Variations		0.484 MGD 12-mth Rolling Avg Seasonal Flow Variations		0.454 MGD 12-mth Rolling Avg Seasonal Flow variations		0.055 MGD 12-mth Rolling Avg Seasonal Flow variations			
Scenario	Description	WLA-Summer (mg/L)	WLA-Winter (mg/L)	WLA-Summer (mg/L)	WLA-Winter (mg/L)	WLA-Summer (mg/L)	WLA-Winter (mg/L)	WLA-Summer (mg/L)	WLA-Winter (mg/L)	WLA-Summer (mg/L)	WLA-Winter (mg/L)	WLA-Summer (mg/L)	WLA-Winter (mg/L)	TP Load (kg/yr)	TP Load (%)
Calibration	Model calibrated to the period 2002-2005 then run for the simulatiion period	1.0/0.2	-	1.0/0.2	-	1.0/0.2	-	1.0/0.2	-	1.0/0.2	-	1.0/0.2	-	28,261	5.4
Current Permits	Current permitted conditions applied to the simulation period	0.2	1.0	0.2	-	0.2	1.0	0.2	-	0.2	1.0	0.0	0.0	29,872	0.0
1	WWTFs: at 0.2 mg/L TP year-round, all major plants.	0.2	0.2	0.2	0.2	0.2	0.2	0.1	1.0	0.1	1.0	0.0	0.0	25,653	14.1
2	WWTFs: 0.2 mg/L TP growing season and 0.5 mg/L TP non-growing all major plants	0.2	0.5	0.2	0.5	0.2	0.5	0.1	1.0	0.1	1.0	0.0	0.0	27,223	8.9
3	WWTFs: at 0.1 mg/L TP year-round, all major plants.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.0	0.1	1.0	0.0	0.0	24,755	17.1
4	WWTFs: Milford at 0.1 mg/L TP all year, Other major WWTFs (CRPCD/Medfield) at 0.2 mg/L TP year-round.	0.1	0.1	0.2	0.2	0.2	0.2	0.1	1.0	0.1	1.0	0.0	0.0	25,354	15.1
5	WWTFs: Milford at 0.1 mg/L TP year-round and other major (CRPCD/Medfield) at of 0.2 mg/L TP growing season and 0.5 mg/L TP for non-growing season.	0.1	0.1	0.2	0.5	0.2	0.5	0.1	1.0	0.1	1.0	0.0	0.0	26,361	11.8
6	WWTFs: Milford at 0.1 mg/L TP growing season, and 0.5 mg/L TP non-growing season, Other WWTFs (CRPCD/Medfield) at 0.2 mg/L TP growing season and 0.5 mg/L TP for non-growing season.	0.1	0.5	0.2	0.5	0.2	0.5	0.1	1.0	0.1	1.0	0.0	0.0	27,109	9.2
6A	WWTFs: 0.2 mg/L TP growing season and 1 mg/L TP non-growing all major plants	0.2	1.0	0.2	1.0	0.2	1.0	0.1	1.0	0.1	1.0	0.0	0.0	29,868	0.0
7	WWTFs: at 0.2 mg/L TP year-round, all major plants. + SW50 + SED75*	0.2	0.2	0.2	0.2	0.2	0.2	0.1	1.0	0.1	1.0	0.0	0.0	15,099	49.5
8	WWTFs: 0.2 mg/L TP growing season and 0.5 mg/L TP non-growing all major plants + SW50 + SED75[1]	0.2	0.5	0.2	0.5	0.2	0.5	0.1	1.0	0.1	1.0	0.0	0.0	16,681	44.2
9	WWTFs: at 0.1 mg/L TP year-round, all major plants. + SW50 + SED75[1]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.0	0.1	1.0	0.0	0.0	14,181	52.5
10	WWTFs: Milford at 0.1 mg/L TP all year, Other major WWTFs (CRPCD/Medfield) at 0.2 mg/L TP year-round. + SW50 + SED75[1]	0.1	0.1	0.2	0.2	0.2	0.2	0.1	1.0	0.1	1.0	0.0	0.0	14,794	50.5
11	WWTFs: Milford at 0.1 mg/L TP year-round and other major (CRPCD/Medfield) at of 0.2 mg/L TP growing season and 0.5 mg/L TP for non-growing season. + SW50 + SED75[1]	0.1	0.1	0.2	0.5	0.2	0.5	0.1	1.0	0.1	1.0	0.0	0.0	15,809	47.1
12	WWTFs: Milford at 0.1 mg/L TP growing season, and 0.5 mg/L TP non-growing season, Other WWTFs (CRPCD/Medfield) at 0.2 mg/L TP growing season and 0.5 mg/L TP for non-growing season. + SW50 + SED75[1]	0.1	0.5	0.2	0.5	0.2	0.5	0.1	1.0	0.1	1.0	0.0	0.0	16,564	44.6
12A	WWTFs: 0.2 mg/L TP growing season and 1 mg/L TP non-growing all major plants + SW50 + SED75[1]	0.2	1.0	0.2	1.0	0.2	1.0	0.1	1.0	0.1	1.0	0.0	0.0	19,340	35.3
Lower TMDL	WWTFs: 0.2 mg/L TP growing season and 1 mg/L TP non-growing all major plants (with actual not permitted flows) + SW50	0.2	1.0	0.2	0.1	0.2	1.0	0.2	1.0	0.2	1.0	0.0	0.0	15,109	49.4
Natural	This scenario represents a near-natural condition with no withdrawals/discharges, sediment flux at 10% of measured values and no Benthic Algae.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10,350	65.4

[1] Stormwater loads were set at 65% of actual loads for Commercial/Industrial, Multi-family Residential; High and Medium Density Residential; 45% for Low Density Residential; and 35% for open/agricultural land uses. Phosphorus sediment flux was set to 75% of the rates used were for the Actual Conditions Scenario to reflect a moderate decline in sediment efflux rates following the wastewater and stormwater reductions.

2 Grey cells for average annual phosphorus load at the Watertown Dam load meet the Lower TMDL requirement of 15,109 kg/yr

5.2 Scenario Results

All the results presented here are the average over the five-year period that spans 1998-2002.

The total phosphorus loadings (kg/yr) at the Watertown Dam for the different load reduction options are provided in Table 17 and Figure 8 along with the target phosphorus load from the Lower Charles River TMDL (15,109 kg/yr). The differences in the scenario loads can be summarized as follows:

- All scenario loads fall between Natural (10,350 kg/yr) and Current (29,872 kg/yr).
- The Current Scenario is higher than the Calibration Scenario because it uses permitted flows in place of actual flows for the WWTFs, and represents a worst case load.
- Scenarios 1-6A, which have only WWTF reductions, result in less loading than the Current Scenario but are still significantly above the Lower TMDL target.
- Scenario 6A is similar to Current Scenario because actual winter phosphorus discharge concentrations from CRPCD and Norfolk are similar to the permitted winter value used in Current Scenario.
- Scenarios 7-12A, which have both WWTF and stormwater reductions, result in much less loading than Scenarios 1-6A, and all approximate the Lower Charles River TMDL target load.
- Only the loads from Scenarios 7, 9, and 10 fall below the Lower Charles River TMDL target load (highlighted in Table 17).

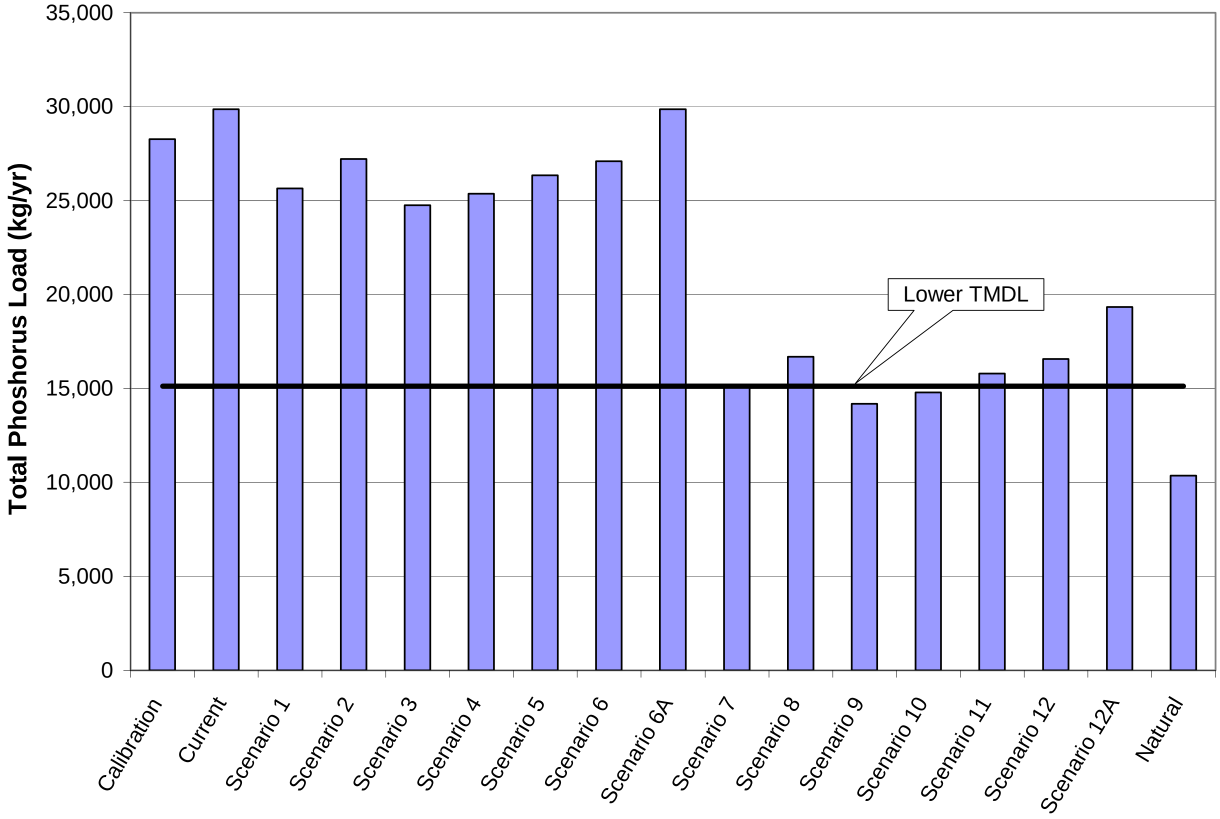


Figure 8. Total Phosphorus Loads at the Watertown Dam by Scenario (98-02)

For those scenarios that meet the Lower Charles River TMDL load target in Table 17 (Scenarios 7, 9, and 10), a detailed analysis of water quality impacts was performed on individual reaches for the period from April to October in 2002 (see table 18). This season and year were chosen as the critical period for the Upper/Middle Charles TMDL (see Section 4). All reaches were evaluated except the excluded reaches (the first 0.4 mi above Echo Lake plus river miles 0-3.7 and river miles 49.5-59.4 discussed in section 4.3.3). This analysis summarizes the impacts as the total river miles and percent of river miles that exceed the water quality targets in Table 15.

The results in Table 18 show that Scenario 9 is clearly the scenario that meets the targets most consistently. For mean chlorophyll-*a*, zero miles exceeded the 10.0 µg/L target and similarly for the 90th percentile and 7-day maximum chlorophyll-a, no miles exceeded the 18.9 µg/L target. Scenario 9 was the only scenario that achieved zero exceedence for chlorophyll-*a* other than the Natural Scenario. For dissolved oxygen, there were no differences among the three scenarios but all resulted in only 0.5 miles below the 5 mg/L target for the 7-day minimum (a relatively small violation−see discussion of Figure 10) and zero miles for the other targets. For dissolved oxygen saturation, Scenario 9 had the lowest river miles exceeding the target of 125% but the number of impacted river miles was still predicted to be higher than the Natural Scenario. Although not all reaches in Scenario 9 were reduced below the DO saturation target, in some critical reaches the DO saturation was dramatically reduced from about 170% to 130% for mean conditions and from around 200% to 160% for low flow conditions.

For total phosphorus, Scenario 9 and the Natural Scenarios did not have any exceedances of the 0.1 mg/L instream target. For the 0.05 mg/L lake-entry target, Scenario 9 had 3.6-16.4 miles in exceedence depending on the statistic, somewhat higher than Natural, but significantly lower than the other two scenarios. For the 0.025 mg/L lake-exit target, there were few differences in the impacted river miles among the load reduction scenarios and only some (2%) of the reaches evaluated met this target. Only the Natural Scenario met this 0.025 mg/L target.

Figures 9-12 plot the results from Scenario 9 as longitudinal profiles for each parameter versus river mile and also show the critical and excluded reaches. Figure 9 shows the mean chlorophyll-*a* does not exceed the target mean of 10.0 µg/L for the entire river length while the 90th percentile and 7-day maximums are also below the target maximum target of 18.9 µg/L.

In Figure 10, the mean dissolved oxygen is above target minimum of 5 mg/L for the entire length while the 90th percentile and 7-day maximums are also above that target except for a single 7-day minimum value of 4.95 mg/L at mile 44.4. Even though this could be argued as a violation of a MassDEP Water Quality standard and the reach is critical (Cochrane Dam), it is relatively small excursion from the Standard since it is only a single reach, it occurs only as a 7-day minimum, and the difference between the predicted value and the standard (5 mg/L) is well within the expected error of the analysis. Thus it was deemed acceptable.

Figure 11 shows the mean dissolved oxygen saturation does not exceed the target maximum of 125% for the vast majority of the river length except for a critical reach downstream of the CRPCD outfall. For the 90th percentile and 7-day maximums, there are two critical reaches where the target is exceeded, namely, Box Pond and downstream of the CRPCD outfall but it should be noted that although these areas are over 125% they have been greatly reduced from around 200% for the Current Scenario.

The final Figure 12 shows that Scenario 9 did not have any exceedances of the 0.1 mg/L instream target for total phosphorus. For the 0.05 mg/L lake-entry target, the mean predicted concentration was below 0.05 mg/L in most reaches throughout the river and entering critical impounded reaches. The only exception to this was in the section from the Milford WWTP to Box Pond which was slightly higher than the 0.05 mg/L target. Under extreme conditions (90th percentile and 7-day maximum of the mean daily values), the 0.05 mg/L target was exceeded in the sections from the Milford WWTP to about river mile 16.4 and in a short stretch below the Charles River Pollution Control District (which did not exceed 0.06 mg/L). These excursions were found to be acceptable, however, because they did not result in exceedances of the chlorophyll-*a* or dissolved oxygen targets. The figure also shows that all the total phosphorus statistics exceeded the lake-exit target of 0.025 mg/L for most of the river length except a small section of river above Milford WWTF. Finally, it should be noted that the average total phosphorus concentration for the Natural Scenario (completely forested conditions) was about 0.018 mg/L.

5.3 Fine-Tuning the Final TMDL Phosphorus Load

The objective of this section is to investigate whether it is possible to use slightly higher winter TP discharge limits for the WWTFs and still meet the Lower TMDL phosphorus load but make it more feasible that the treatment plants will consistently meet the higher discharge limits under the colder winter conditions.

The above analyses point to Scenario 9 as the only one that meets both the Lower Charles TMDL target phosphorus load and the selected water quality targets. This scenario has a phosphorus load of 14,181kg/yr at the Watertown Dam, that is, below the Lower TMDL target of 15,109 kg/yr by 928 kg/yr. The phosphorus load could be increased to approximate the Lower TMDL target load by adjusting the winter WWTF limits of the little effect on the summer water quality performance. Only increases in the winter limits for the major facilities (Milford WWTF, CRPCD, and Medfield WWTF) were considered.

Table 19 presents the calculations used to estimate the total phosphorus load at the Watertown Dam for a range of winter phosphorus discharge limits for the major WWTFs. Only scenarios that had the same WWTF discharge limits for summer and different discharge limits for winter were used in this estimation procedure since they would have the same winter flows and diversions from Mother Brook.

Table 18. Summary of Water Quality Performance by Preferred Scenario (Apr-Oct, 2002)

RIVER MILES EXCEEDED (13.3 mi excluded)																			
	Chlorophyll-a			**Dissolved Oxygen**			**Dissolved Oxygen Saturation**			**Total Phosphorus**									
Scenario	**Mean >10.0 ug/L**	**90th pctl >18.9 ug/L**	**7-d Mx >18.9 ug/L**	**Mean< 5 mg/L**	**10th pctl <5 mg/L**	**7-d Mn <5 mg/L**	**Mean >125%**	**90th pctl >125%**	**7-d Mx >125%**	**Mean >0.025 mg/L**	**90th pctl >0.025 mg/L**	**7-d Mx >0.025 mg/L**	**Mean >0.05 mg/L**	**90th pctl >0.05 mg/L**	**7-d Mx >0.05 mg/L**	**Mean >0.10 mg/L**	**90th pctl >0.10 mg/L**	**7-d Mx >0.10 mg/L**
Natural	0	0	0	0	0	0	0	1	1.8	0	0	0	0	0	0	0	0	0
S7	24.3	11.1	16.2	0	0	0.5	2.1	4.9	5.1	55.1	55.9	56.2	24.5	43.2	53.9	2.2	4.7	7.5
S9	0	0	0	0	0	0.5	0.6	3.1	3.7	55.1	55.9	56.2	3.6	13	16.4	0	0	0
S10	2.1	5.6	10.6	0	0	0.5	1.2	4.7	4.7	55.1	55.9	56.2	13.6	29.3	34.7	0	0	0
Current	51.7	45.6	51.7	0	0	3.3	3.9	6	11.8	56.2	56.2	56.2	55.1	55.9	55.9	3.6	11.4	29.2

PERCENT RIVER MILES EXCEEDED (13.3 mi excluded)																			
	Chlorophyll-a			**Dissolved Oxygen**			**Dissolved Oxygen Saturation**			**Total Phosphorus**									
Scenario	**Mean >10.0 ug/L**	**90th pctl >18.9 ug/L**	**7-d Mx >18.9 ug/L**	**Mean< 5 mg/L**	**10th pctl <5 mg/L**	**7-d Mn <5 mg/L**	**Mean >125%**	**90th pctl >125%**	**7-d Mx >125%**	**Mean >0.025 mg/L**	**90th pctl >0.025 mg/L**	**7-d Mx >0.025 mg/L**	**Mean >0.05 mg/L**	**90th pctl >0.05 mg/L**	**7-d Mx >0.05 mg/L**	**Mean >0.10 mg/L**	**90th pctl >0.10 mg/L**	**7-d Mx >0.10 mg/L**
Natural	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S7	43.2	19.8	28.8	0.0	0.0	0.9	3.7	8.7	9.1	98.0	99.5	100.0	43.6	76.9	95.9	3.9	8.4	13.3
S9	0.0	0.0	0.0	0.0	0.0	0.9	1.1	5.5	6.6	98.0	99.5	100.0	6.4	23.1	29.2	0.0	0.0	0.0
S10	3.7	10.0	18.9	0.0	0.0	0.9	2.1	8.4	8.4	98.0	99.5	100.0	24.2	52.1	61.7	0.0	0.0	0.0
Current	92.0	81.1	92.0	0.0	0.0	5.9	6.9	10.7	21.0	100.0	100.0	100.0	98.0	99.5	99.5	6.4	20.3	52.0

* pctl=percentile, 7-d=7-day, mx=maximum, mn=minimum

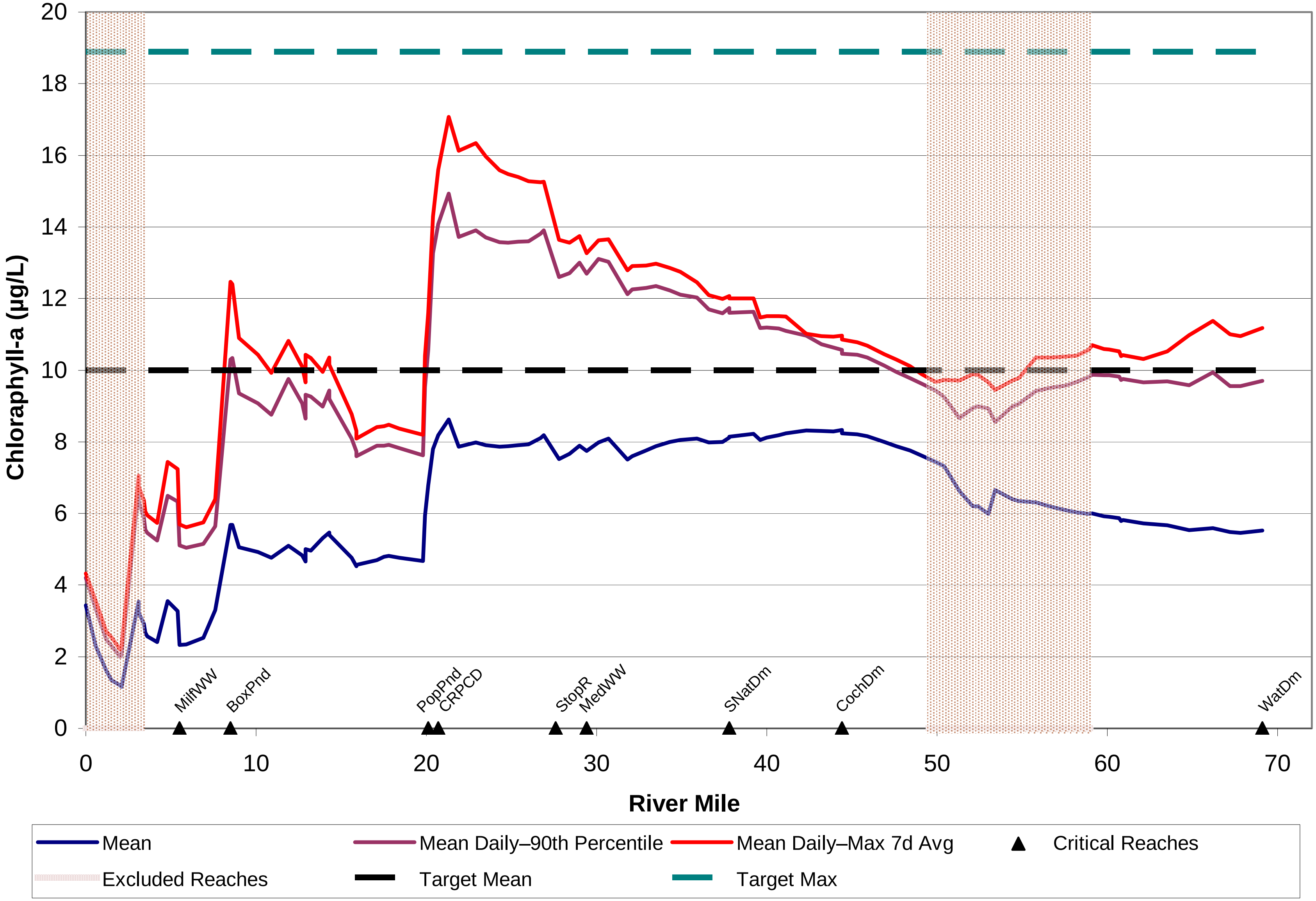


Figure 9. Longitudinal Profile of Chlorophyll-*a* for Scenario 9

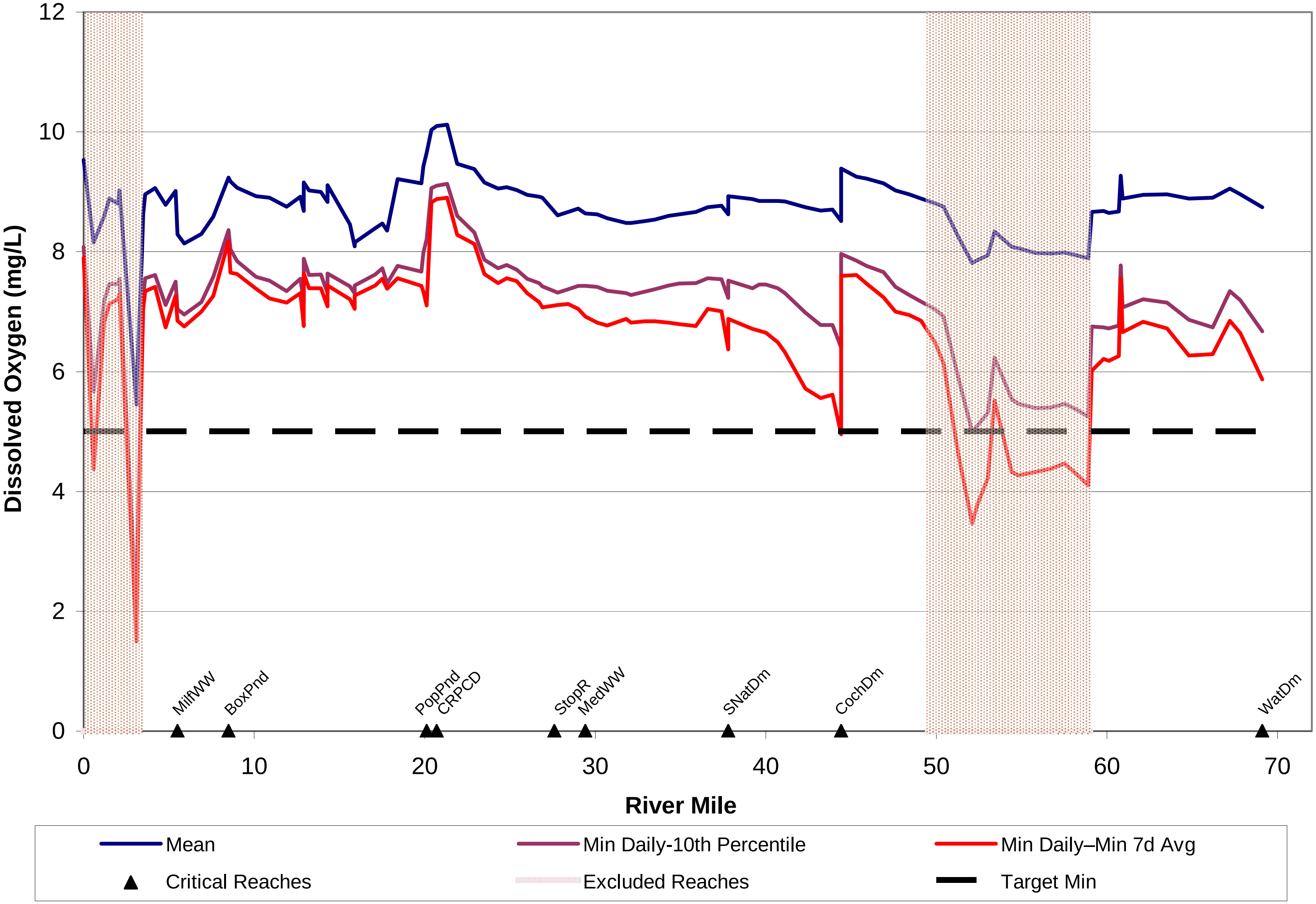


Figure 10. Longitudinal Profile of Dissolved Oxygen for Scenario 9

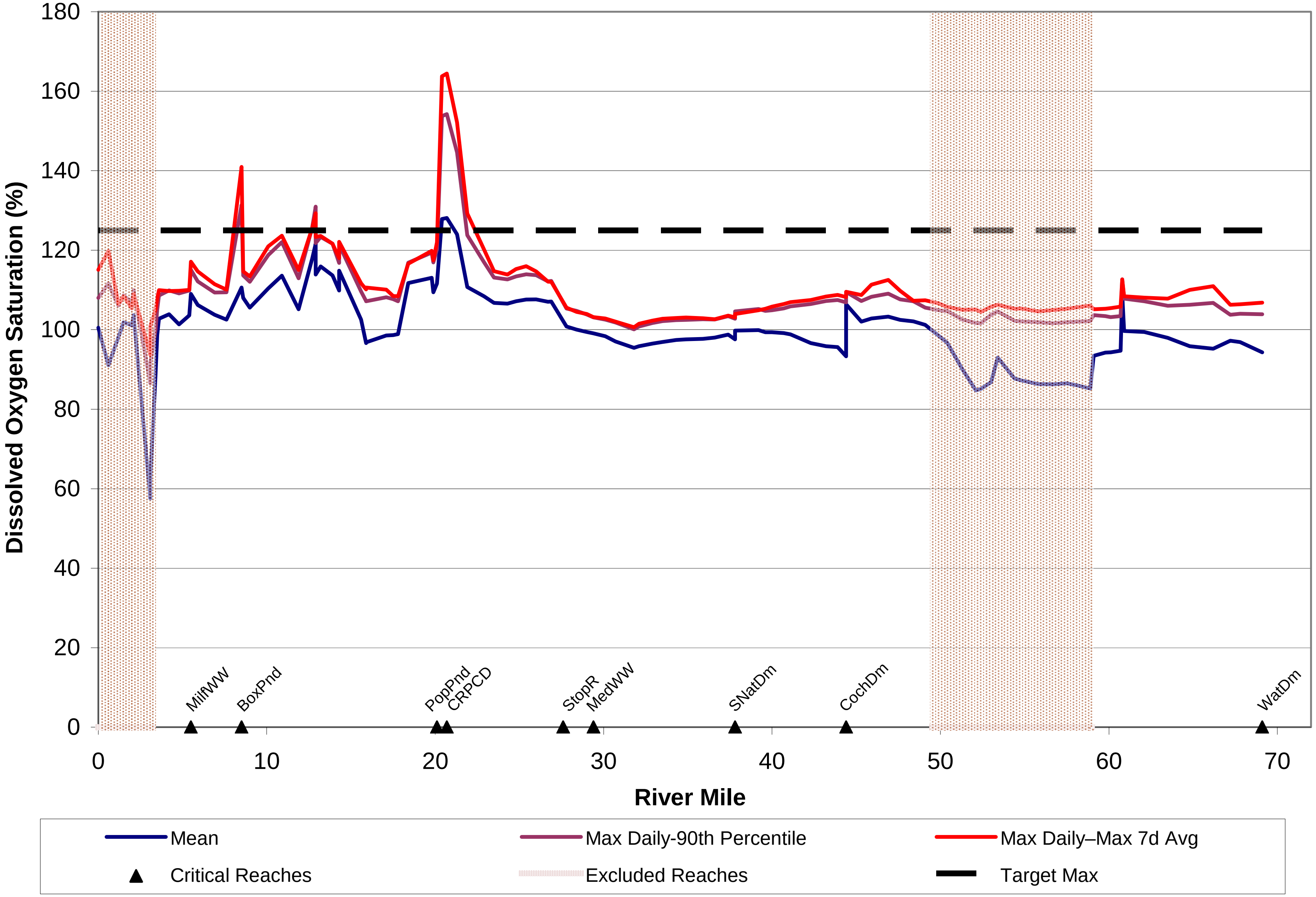


Figure 11. Longitudinal Profile of Dissolved Oxygen Saturation for Scenario 9

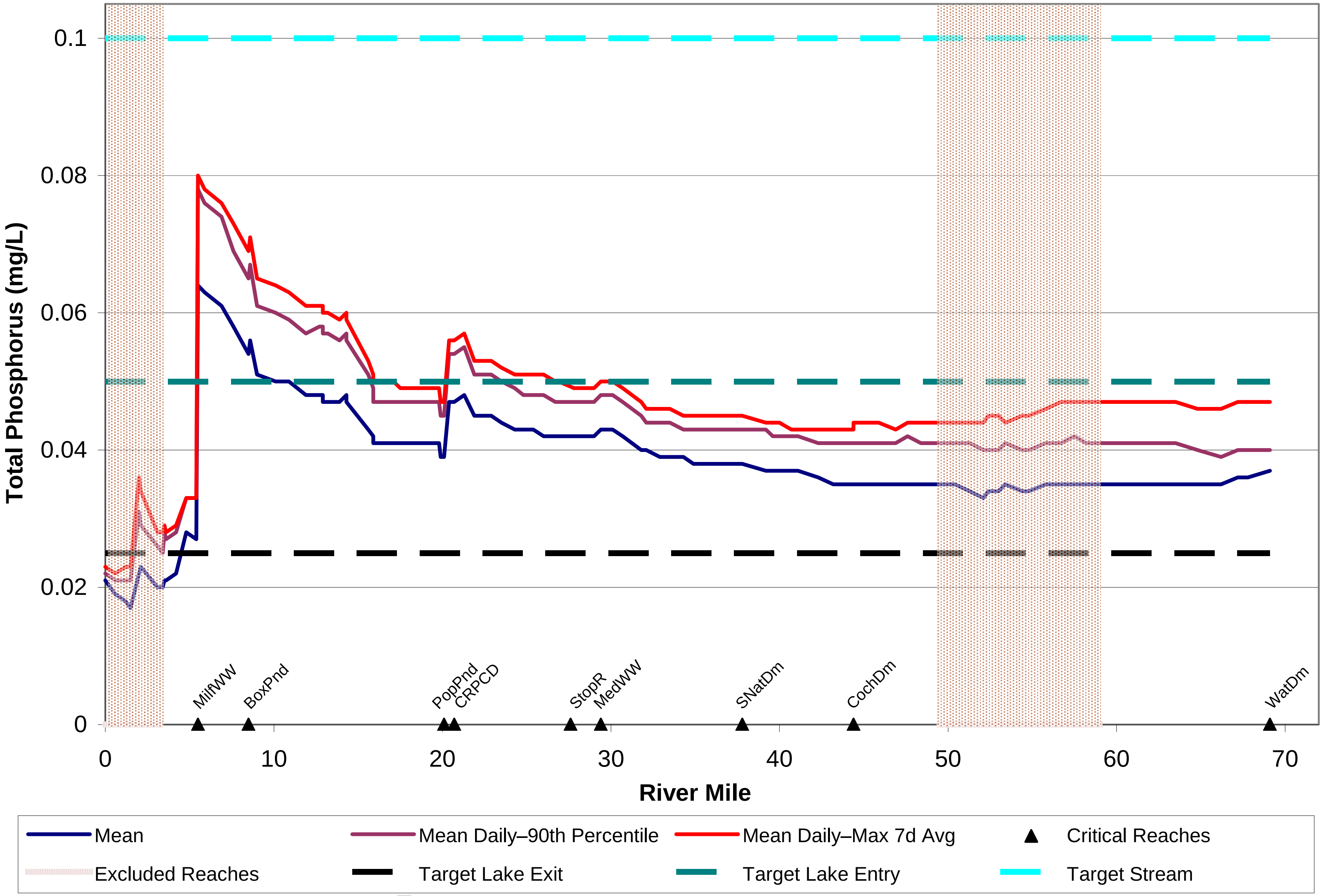


Figure 12. Longitudinal Profile of Total Phosphorus for Scenario 9

Table 19. Estimated Total Phosphorus Load for Various WWTF Winter Discharge Limits

Scen-ario	Majors		Ref. Total Load (kg/yr)*	Ref. WWTF Load (kg/yr)*	Total Load (kg/yr)	WWTF Load (kg/yr)	Total Load Change (kg/yr)	WWTF Load Change (kg/yr)	Change Tot Load / Change WW Load
	Summer TP (mg/L)	Winter TP (mg/L)							
8	0.2	0.5	15,099	3,816	16,681	5,977	1,582	2,160	73.2%
12A	0.2	1.0	15,099	3,816	19,340	9,574	4,241	5,758	73.7%
9A	0.1	0.2	14,181	2,224	**14,710**	2,944	**529**	720	**73.4%**
9B	0.1	0.25	14,181	2,224	**14,974**	3,303	**793**	1,080	**73.4%**
9C	0.1	0.3	14,181	2,224	**15,238**	3,663	**1,057**	1,440	**73.4%**

* Scenarios 8 and 12A are referenced to 7, Scenaros 9A-9C are referenced to 9, bolded are estimated

Scenario 7 was chosen as a reference condition with Scenarios 8 and 12A used to estimate the change in the total Watertown Dam load per unit of change in the WWTF loads. For Scenario 8 the change was 73.2% while for Scenario 12A the change was 73.7%, that is, about 73.4% of the change in the WWTF load (for winter changes in discharge concentrations) shows up as a change in the Watertown Dam load. The rest of the load change is lost to the Mother Brook diversion and changes in internal uptake.

Scenario 9 was then used as the reference condition for estimating the estimated total phosphorus load at the Watertown Dam for various winter discharge limits at the major WWTFs. Scenarios 9A, 9B, and 9C have winter TP limits for major WWTFs of 0.2, 0.25, and 0.3 mg/L. The new WWTFs loads and the change from the Scenario 9 WWTF load were calculated. Using the 73.5% value from above and the WWTF load change, the change in total load was calculated. The total phosphorus loads at the Watertown Dam were estimated as 14,710, 14,974, and 15,238 kg/yr, respectively.

Even though Scenario 9C was slightly (129 kg/yr, 0.9%) above the Lower Charles TMDL target phosphorus load of 15,109 kg/yr, this load was considered acceptable because it was well within the Lower Charles River TMDL target load which included an explicit margin of safety of 979 kg/yr (see further discussion in Section 6.3).

5.4 Summary and Final TMDL Scenario

The above analysis of the annual total phosphorus loads and water quality performance showed that only Scenario 9 met both the Lower Charles TMDL target phosphorus load and the selected Upper/Middle Charles River water quality targets. Post-processing analysis revealed that the winter discharge limits of 0.1 mg/L for the major WWTFs in Scenario 9 could be raised slightly to the more achievable winter value in Scenario 9C of 0.3 mg/L while still approximating the Lower Charles TMDL target at the Watertown Dam with a watershed load of 15,238 kg/yr.

Scenario 9C will now be referred to as the Final TMDL Scenario in the rest of the document. In summary, this scenario has phosphorus WWTF discharge limits for summer/winter for majors at 0.1/0.3 mg/L and for minors at 0.1/1.0 mg/L with stormwater phosphorus reductions as follows: Open/Agriculture (35%), Low Density Residential (45%), Medium and High Density Residential (65%) and Commercial/Industrial (65%).

6 TMDL ANALYSIS

6.1 Final TMDL Loads

The Upper/Middle Charles TMDL assessed the phosphorus loads from wastewater treatment facilities (WWTFs), stormwater, and accumulated benthic sediments. An HSPF (Hydrologic Simulation Program – Fortran) water quality model (Bicknell, et al., 1993) was developed and calibrated to existing water flow and quality data (CRWA, 2009). The calibrated HSPF model was used to evaluate numerous remediation scenarios by comparing simulated total phosphorus load and instream concentrations of phosphorus, dissolved oxygen, and chlorophyll-*a* (algae).

Average phosphorus loads (kg/yr) for all sources were predicted for the period 1998-2002 using the HSPF model. This period was chosen to match the load calculations for the Lower Charles TMDL. A detailed loading analysis for calibrated conditions was presented in Section 5 in Table 13. This analysis was repeated for the Current and Final TMDL Scenario to compute the percent change under permitted conditions. The Current Scenario represents the current permitted condition. The Final TMDL Scenario approximates the Lower TMDL phosphorus load requirement at the Watertown Dam with a watershed load of 15,238 kg/yr and also meets the desired water quality targets in all reaches of interest.

Stormwater loads include discharges from piped infrastructure as well as non-point source discharges from overland flow. All land use types contribute phosphorus loads through stormwater runoff including forests and wetlands. Stormwater loads also include any sanitary flows that enter the river through storm drains via illicit cross connections. The HSPF model was developed and calibrated for flow and water quality at many monitoring locations with differing upstream land uses (CRWA, 2009). The HSPF model was designed specifically to include land use as a part of the hydrological response units (HRUs). Stream reaches receive flows and loads from upland areas based on HRUs and weather inputs. Stormwater loads by land use type were then adjusted to match measured phosphorus load at the Watertown Dam and measured instream water quality responses. The HSPF model thus provides a sound basis on which to estimate and allocate stormwater loads based on land use type.

The HSPF model was used to evaluate 18 management scenarios and assist in selecting the scenario that best meets the TMDL targets (see Section 5). The Upper/Middle Charles TMDL must produce an outlet phosphorus load that is less than Lower Charles TMDL inlet load of 15,106 kg/yr. The TMDL must also meet specific water quality targets (chlorophyll-*a*, dissolved oxygen, dissolved oxygen saturation and phosphorus concentrations—see Table 15) especially in the critical reaches and below wastewater treatment discharges (see Table 16).

Table 20 provides the annual phosphorus source loads for the Current and TMDL conditions. The TMDL loads are the Waste Load Allocations (WLAs) for the Final TMDL (see section 6.1.3). Under the Current Scenario, total annual phosphorus load to the Upper/Middle Charles River is 29,872 kg/year while the TMDL load is 15,238 kg/yr. Thus, a 49% reduction in annual phosphorus load is required in order to meet water quality standards in the Upper/Middle Charles River. New development will need to minimize or offset phosphorus loads.

Table 20. Annual Phosphorus Loads for Current and TMDL Conditions (98-02)

Source	Current Load (kg/yr)	Reduction (%)	TMDL Load (kg/yr)
Wastewater	9,611	62	3,663
Stormwater	30,934	51	15,212
Benthic Efflux	2,320	25	1,740
Atmospheric Deposition	311	0	311
Other losses	-13,303	57	-5,688
TOTAL	**29,872**	**49**	**15,238**

Figure 13 graphically displays the daily phosphorus loads (98-02) by comparing the Current and Final TMDL conditions. The graph shows that the TMDL waste load reductions must be applied uniformly and consistently across throughout the year under all load conditions.

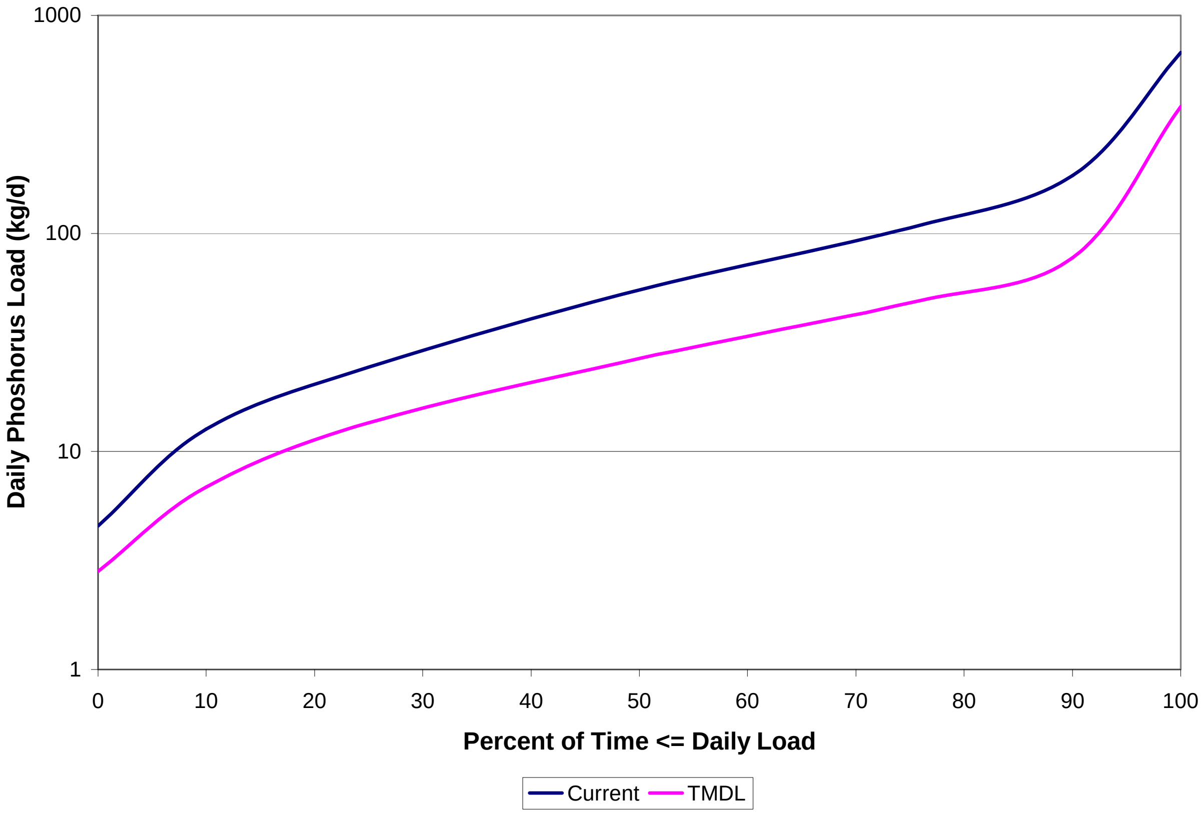


Figure 13. Daily Phosphorus Load Frequency for Current and TMDL Conditions (98-02)

6.2 Waste Load and Load Allocations

A TMDL for a given pollutant and water body is composed of the sum of land-area load allocations for nonpoint sources, individual waste load allocations for point sources, and natural background levels. In addition, the TMDL must include an implicit or explicit margin of safety to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving water body. The TMDL components are illustrated using the following equation:

$$\text{TMDL} = (\text{LA}+\text{BG}) + \text{WLA} + \text{MOS}$$

where LA+BG is the load allocation for nonpoint sources including background, WLA is the waste load allocation, and MOS is the margin of safety.

US-EPA regulations require that point sources of pollution (discharges from discrete pipes or conveyances) subject to National Pollutant Discharge Elimination System (NPDES) permits receive WLAs specifying the amount of a pollutant they can release to the water body. Non-point sources of pollution and point sources not subject to NPDES permits receive LAs specifying the amount of a pollutant that they can release to the water body.

In the case of stormwater, it is often difficult to identify and distinguish between point source discharges that are subject to NPDES regulation, and those that are not. Therefore, US-EPA has stated that where it is not possible to distinguish between point source discharges that are subject to NPDES regulation and those that are not, it is permissible to include all point source storm water discharges in the WLA portion of the TMDL.

6.2.1 Load Allocation

Both nonpoint sources of phosphorus and unregulated stormwater drainage systems exist throughout the Upper/Middle Charles River watershed. The major nonpoint source categories that contribute phosphorus to the river are diffuse overland runoff, including runoff from forest, open space and wetlands and water, and groundwater recharge to the river and tributaries. Also, there are many stormwater drainage systems in the watershed that are currently not regulated by the NPDES permit program. These systems include privately owned drainage systems serving commercial areas, small construction sites less than an acre in size, certain industrial uses, and municipal drainages systems in more rural portions of the watershed.

The level of information available for this TMDL through the specific HRU setup in the HSPF model makes it suitable for quantifying total phosphorus loadings from watershed areas by land use. Stormwater from these land uses include regulated stormwater and non-stormwater point sources, nonpoint sources, and unregulated stormwater point sources. Currently, there is insufficient information available to confidently apportion the total phosphorus loading from the various land use types to the regulated and non-regulated stormwater source categories within the watershed areas. As a result, this TMDL has assigned LAs to land use types where stormwater loads are dominated by non-point sources such as forest and open space, and WLAs to land uses where stormwater loads are dominated by point sources. LAs have also been assigned to benthic loads from sediment flux.

6.2.2 Waste Load Allocation

NPDES regulated point sources in the Upper/Middle Charles River Watershed that contribute phosphorus loads include both WWTF and stormwater sources. The majority of the watershed is comprised of communities that are subject to the Phase II NPDES stormwater regulations governing municipally owned separate stormwater sewer systems (MS4s). NPDES permits are also required for stormwater associated with construction activities disturbing greater than one acre of land and stormwater associated with certain industrial activities.

As discussed above, the WLAs for this TMDL include regulated NPDES point sources, stormwater point sources that are not currently regulated under the NPDES program, and nonpoint sources. The primary reason for including these source categories in the WLA at this time is that there is not sufficient information to apportion the total watershed phosphorus loadings to regulated and non-regulated sources. The WLA values are estimates that can be refined in the future as more information becomes available.

Table 21 contains the total phosphorus WLAs for the five WWTFs that discharge to the Upper/Middle Charles as calculated from the Current and Final TMDL scenarios. Current NPDES permits set the total phosphorus discharge limits at Milford WWTF, Medfield WWTF, and Wrentham Development Center to 0.2 mg/L in the summer (Apr-Oct) and 1.0 mg/L for the winter (Nov-Mar). Charles River Pollution Control District (CRPCD) in Medway and the Massachusetts Correctional Institute (MCI) at Norfolk only have a summer season limit of 0.2 mg/L but do not yet include the winter season limits. This TMDL sets phosphorus WWTF discharge limits for summer/winter for majors at 0.1/0.3 mg/L and for minors at 0.1/1.0 mg/L.

These wastewater reductions are needed for two specific reasons 1) additional summer time reductions were necessary over current permitted loads in order to address water quality problems in critical reaches of the Upper/Middle Charles River Watershed, and 2) winter time reductions are necessary to meet the Lower Charles TMDL load requirement at the Watertown Dam. The Lower Charles TMDL did not take into account permitted flows and loads from the treatment facilities in setting the annual load requirement at the Watertown Dam. Since the treatment facilities can discharge up to their currently permitted flows the increase in load from existing to permitted flows had to be accounted for in this TMDL.

Table 21 also contains the stormwater WLAs for total phosphorus by land use type as calculated from the Current and Final TMDL Scenarios. Natural land (Water/Wetland/Forest) has zero reductions. Open/Agriculture has a 35% reduction and Low Density Residential has a 45% reduction. All intense land uses like Medium Density Residential, High Density Residential, Multi-Family Residential, Commercial/Industrial, and Transportation have a 65% reduction requirement.

In Table 21, the modeled Commercial/Industrial/Transportation land use was split into Commercial/Industrial and Transportation categories. The Transportation category applies to transportation land uses defined by MassGIS (airports, docks, divided highway, freight, storage, railroads). Other infrastructure receives the same WLA as the land use type they are within.

Figure 14 graphically shows the reductions from current conditions to the Final TMDL loads. The Final TMDL loads are the WLAs. All loads are the average over 1998-2002 (kg/ha).

Table 21. Annual Phosphorus WLAs for the Upper/Middle Charles TMDL

Source	Current Load (kg/yr)	Reduction (%)	TMDL Load (kg/yr)
Milford WWTF (MA0100579)	3,407	66	1,149
CRPCD (MA0102598)	4,278	65	1,483
Medfield WWTF (MA0100978)	1,174	66	398
MCI Norfolk (MA0102253)	406	20	324
Wrentham Dev Ctr (MA0102113)	345	11	308
WASTEWATER	**9,611**	**62**	**3,663**
Water/Wetland	126	0	126
Forest	4,394	0	4,394
Open/Agriculture	1,504	35	977
Low Density Res.	4,979	45	2,739
Medium Density Res.	5,505	65	1,927
High Density Res./MF*	5,964	65	2,088
Commercial/Industrial*	6,294	65	2,203
Transportation	2,167	65	759
STORMWATER	**30,934**	**51**	**15,212**

* MF=multi-family residential, Commercial/Industrial with no Transportation

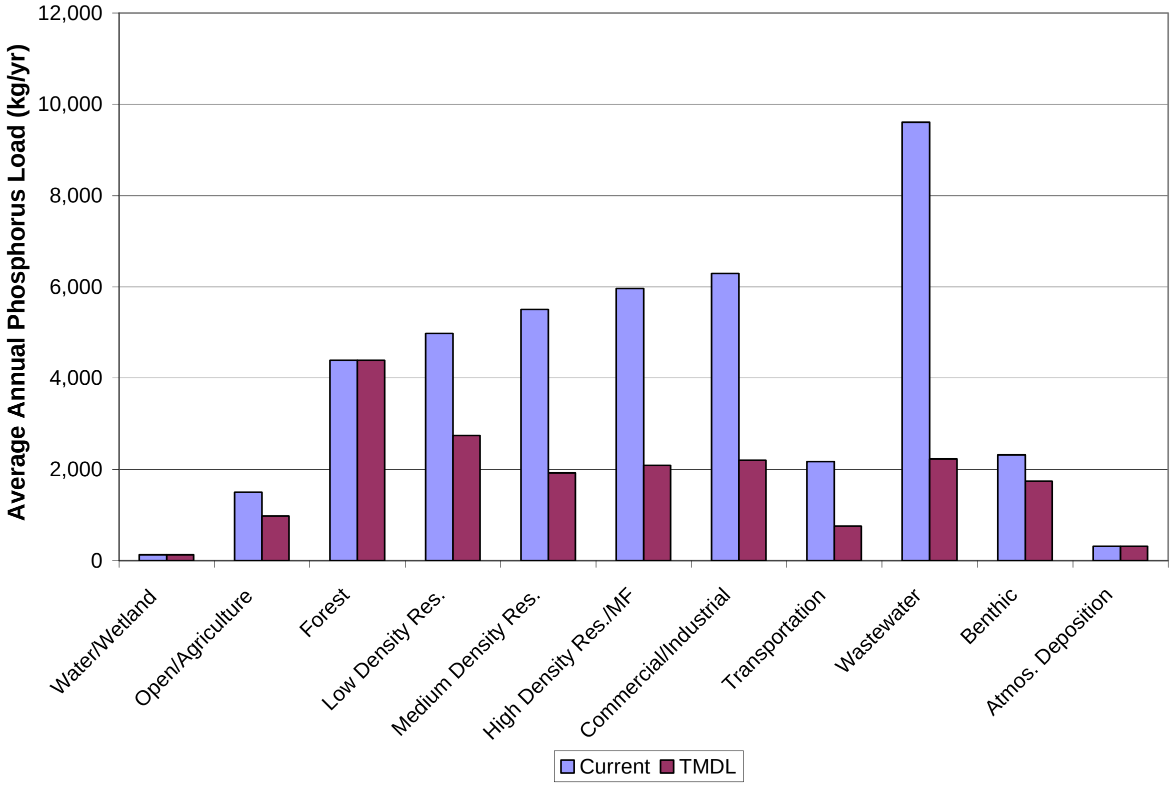


Figure 14. Annual Phosphorus WLAs for the Upper/Middle Charles TMDL

6.3 Margin of Safety

Both section 303(d) of the Clean Water Act and the regulations at 40 CFR 130.7 require that TMDLs include a margin of safety (MOS). The MOS is the portion of the pollutant loading reserved to account for any uncertainty in the data. There are two ways to incorporate the MOS (1) explicitly specify a portion of the TMDL as the MOS and use the remainder for allocations or (2) implicitly incorporate the MOS by using conservative model assumptions to develop allocations. For this TMDL analysis, the MOS is both implicit and explicit.

Because the Upper/Middle Charles TMDL is constrained by the Lower Charles TMDL load at the Watertown Dam and the Lower Charles TMDL included a margin of safety, that margin of safety also applies to the Upper/Middle Charles TMDL. The Lower Charles TMDL margin of safety was explicitly set at 979 kg/yr for a total load of 19,544 kg/yr but that number needs to be applied proportionally to the load over the Watertown Dam of 15,109 kg/yr. The Upper/Middle Charles TMDL therefore inherits an explicit margin of safety from the Lower Charles TMDL of 757 kg/yr. The Final TMDL load (15,238 kg/ha) slightly exceeds the Lower TMDL load (15,106 kg/yr), so this explicit margin of safety must be reduced by 129 kg/ha to 628 kg/ha.

The Final TMDL Scenario also assumes a reduction of the sediment efflux rate for phosphorus of only 25%. Because the total reduction of total phosphorus load for the TMDL is 49%, the long-term efflux rate is expected to eventually match this 49% reduction. The 24% difference in the assumed reduction and the expected long-term reduction in sediment efflux rates for phosphorus is considered an additional explicit margin of safety of about 557 kg/yr. The total explicit margin of safety is therefore 628+557=1,185 kg/yr or 7.8% of the Final TMDL load.

Because each reach was analyzed individually for the mean, 90th percentile, and 7-day extreme value for the target water quality parameters, the analysis methodology added an implicit margin of safety compared to one that looks at averages over multiple reaches. The Final TMDL Scenario was selected to provide the best possible protection for all reaches since it consistently meets the defined water quality targets.

The methods of analysis for determining annual average phosphorus load and achieving water quality targets in all reaches also contain an additional implicit margin of safety. The target annual phosphorus load was based on an average of 1998-2002 and this period is considered representative of a much longer flow period with low flows slightly lower than average (see Figures 5-4 and 5-5 in US-EPA, 2007). The analysis period used for the reaches was 2002 which is considered to be representative of low flow or near-7Q10 conditions (see Section 4.3.4) and should capture the worst case conditions associated with WWTF discharges.

6.4 Seasonal Variation

The federal regulations at 40 CFR 130.7 require that TMDLs include seasonal variations and take into account critical conditions for stream flow, loading, and water quality parameters. For this TMDL, nutrient loadings were determined on an hourly basis, and then accumulated to an annual figure, thus accounting for seasonality. Phosphorus sources to Upper/Middle Charles River waters arise from a mixture of dry- and wet-weather sources. The biologic response to nutrient inputs from multiple sources throughout the length of the river is complex and dependent on the loads as well as the physical and hydraulic characteristics of the receiving stream.

The Upper/Lower Charles TMDL model is a dynamic water quality model that simulates hourly water flow and quality data in response to time-varying inputs of land-derived stormwater and wastewater. The model was run for the period 1994-2005 and focused on the period 1998 to 2002 for phosphorus loads and October to April 2002 for reach responses. The 1998-2002 period was carefully selected to represent the variability in flow conditions while the summer of 2002 was chosen to represent the worst-case water quality response. These two approaches cover the widest possible range of seasonal variability that could be encountered in the Upper/Middle Charles River watershed.

The Upper/Middle Charles TMDL model was used to simulate a frequency distribution of allowable daily phosphorus loadings (see Section 6.1) as estimations of allowable maximum daily loads to the Lower Charles. Combining the frequency distribution of allowable daily loads with the allowable annual load requires that that phosphorus controls should be in place throughout the year in order to meet both the allowable annual load and the water quality targets.

7 TMDL IMPLEMENTATION PLAN

7.1 Overview and Approach

The Upper/Middle Charles River does not currently meet Massachusetts Water Quality Standards, and is impaired by excessive nutrients, organic enrichment/low dissolved oxygen and noxious aquatic plants, among other impairments. Water quality standards are established to assure that beneficial uses of the river and tributaries, such as boating, swimming, fishing and fish consumption, are protected. When water quality standards are not met, the federal Clean Water Act requires a Total Maximum Daily Load (TMDL) to be established. A TMDL determines the current amount of pollution entering a water body, identifies the sources of that pollution, and quantifies how much that pollution needs to be reduced in order to meet water quality standards. The TMDL then assigns a maximum allowable pollutant load to the major sources (an allocation) so that water quality standards will be met. The TMDL Implementation Plan (Plan) lays out a recommended approach to achieve allocated loads. The purpose of this plan is to outline an adaptive management process that identifies immediate implementation activities, as well as a framework for making continued progress in reducing pollutant loads to the Upper Charles River over the long term.

The Upper/Middle Charles River Nutrient TMDL has identified phosphorus as the pollutant of concern and determined the magnitude and extent of phosphorus-related water quality impairments in the Upper/Middle Charles River and tributaries. The sources contributing to those impairments and the required phosphorus pollutant reductions from these sources to achieve water quality standards and protect beneficial uses have also been ascertained. This TMDL has established that significant reductions in phosphorus loading are necessary.

The Upper/Middle Charles Nutrient TMDL was completed following the approval of the Lower Charles River Basin Nutrient TMDL, which provided a maximum phosphorus allocation to the Upper/Middle Charles River at the Watertown Dam. The Upper/Middle Charles River Nutrient TMDL was thus developed to achieve water quality standards in the Upper/Middle Charles River with the constraint of also meeting the allocation established in the Lower Charles TMDL.

To achieve the required reductions in phosphorus loading, decreases from both the two main sources of phosphorus to the Upper/Middle Charles River are necessary including the wastewater treatment facilities (WWTFs) and stormwater. The waste load allocations (WLAs) in this TMDL require:

1) reductions in phosphorus effluent limits at the three major WWTFs to achieve a summer time limit of 0.1 mg/L, and wintertime limit of 0.3 mg/L and at the two smaller WWTFs to achieve a summer limit of 0.1 mg/L and a winter limit of 1.0 mg/L; and
2) reductions in phosphorus loads from stormwater based upon land use, as identified in the WLAs.

Model predictions indicate that these load reductions will attain most of the TMDL targets for the Upper/Middle Charles River and achieve Massachusetts Water Quality Standards. These load reductions will also achieve the annual phosphorus load reductions required in the Lower Charles River Basin Nutrient TMDL.

7.2 Management Strategies

This Upper/Middle Nutrient TMDL has established that there are numerous sources of phosphorus to the river that are contributing to water quality impairments. The most significant sources of phosphorus, WWTF discharges and stormwater, account for 93% of the total annual phosphorus load to the Upper/Middle Charles River. Figure 6 in Section 5 showed the annual phosphorus loads to the Upper/Middle Charles River from the main sources for the period 1998-2002.

Based on the magnitude of phosphorus reductions called for in this TMDL, a watershed-wide implementation plan is needed. This plan requires the control and/or elimination of several nutrient sources to the Charles River including stormwater runoff from drainage systems, illicit discharges to stormwater drainage systems, and reductions in annual and seasonal phosphorus loadings from major publicly-owned treatment works.

TMDL implementation-related tasks are presented in Table 22. The MassDEP working with the watershed communities, US-EPA, MRWA, CRWA, and other stakeholders in the watershed will make every reasonable effort to assure implementation of this TMDL. These stakeholders can provide valuable assistance in defining hot spots and sources of nutrient contamination as well as the implementation of mitigation or preventative measures.

The TMDL Implementation Plan targets the two primary sources of phosphorus for reductions consistent with the WLAs for stormwater and WWTFs. Because of the complexity of the system being modeled, the inherent difficulties in modeling phytoplankton, and the difficulty of defining and installing necessary stormwater BMPs, an adaptive management approach is proposed, which allows for a process that is implemented in stages over time.

Achieving the Upper Charles River nutrient TMDL will require an iterative process that sets realistic implementation goals and schedules that are adjusted as warranted based on ongoing monitoring and assessment of control activities. The total phosphorus allocations presented in the TMDL represent reductions that will require substantial time and financial commitment to be attained. A comprehensive control strategy is needed to address the numerous sources of nutrients in the Charles River watershed that contribute to nutrient impairments in both the Upper and Lower Charles River.

7.2.1 Stormwater

Aggregate WLAs for stormwater discharges to the Upper/Middle Charles River were established for sources that contribute phosphorus loads. The aggregation of sources into gross or lumped allocations by land use is consistent with the level of data and information available for this TMDL. While there is reasonable confidence in the overall magnitude of the total nutrient loadings to the Upper/Middle Charles River from the identified major land use areas, there are only limited data available to determine the magnitudes of loads from individual sources. This uncertainty is due to several factors including the typical high variability associated with drainage system discharges, the lack of nutrient and flow monitoring data for specific stormwater sources, and many of the drainage system sources are influenced, to varying degrees, by illicit sewage discharges.

Table 22. Upper/Middle Charles TMDL Implementation Tasks

Task	Responsible Organization
TMDL Public Meeting	CRWA, MassDEP, and US-EPA
Response to Public Comment	MassDEP
Issue Final TMDL	MassDEP
Review and approve Final TMDL	US-EPA
Integration of TMDL with appropriate regulatory programs	Charles River Watershed Municipalities, MassDEP, and US-EPA
Identify comprehensive stormwater management strategy including cost estimates and potential funding sources	Charles River Watershed Municipalities, WWTFs, and other relevant NPDES permit holders including non-traditional MS4 permit holders (e.g. MassHighway, MassPike, and DCR)
Develop and implement stormwater management programs including BMP implementation	Charles River Watershed Municipalities, WWTFs, and other relevant NPDES permit holders including non-traditional MS4 permit holders (e.g. MassHighway, MassPike, and DCR)
Illicit discharge detection and elimination	Charles River Watershed Municipalities, WWTFs, and other relevant NPDES permit holders including non-traditional MS4 permit holders (e.g. MassHighway, MassPike, and DCR)
Modification of WWTFs permits and operations to meet TMDL	WWTFs, MassDEP, and US-EPA
Organize and implement education and outreach program	MassDEP, CRWA, and Charles River Watershed Communities
Ongoing surface water monitoring	US-EPA, MWRA, MassDEP, and CRWA
Provide periodic status reports on implementation of remedial activities	Charles River Watershed Municipalities, WWTFs, and other relevant NPDES permit holders including non-traditional MS4 permit holders (e.g. MassHighway, MassPike, and DCR)
If necessary, identify future programs to reduce phosphorus loads in targeted seasons/locations	Charles River Watershed Municipalities, WWTFs, and other relevant NPDES permit holders including non-traditional MS4 permit holders (e.g. MassHighway, MassPike, and DCR)

These WLAs were expressed in terms of both loadings and relative percent reductions. This implementation plan emphasizes the relative percent annual phosphorus load reductions needed for each land use type, which are as follows:

1. Commercial/Industrial/Transportation – 65%
2. High Density / Medium Density / Multi-family Residential – 65%
3. Low Density Residential – 45%
4. Open Space / Agriculture – 35%
5. Forest / Forested Wetlands – 0%
6. Open Water / Wetlands – 0%

These reductions are the same as those called for in the Lower Charles Nutrient TMDL. The reductions provide guidance as to the relative importance of land use categories for contributing phosphorus to the Upper/Middle Charles River. The magnitude of the loading estimates for each of the land-cover categories is based on Geographic Information system (GIS) land cover categories and literature based phosphorus export loading rates. Although this information was extremely useful in helping to calibrate and validate the HSPF water quality model it is not accurate enough to be applied at the individual site or parcel level. There is no substitute for phosphorus source assessments in each of the communities. It is possible, because of local site conditions such as soils, slope, drainage patterns, vegetative cover, and site use or activity that the actual phosphorus loading from urban sites may be less than or higher than the estimates from this analysis. Similarly, actual phosphorus loadings from less developed areas in the watershed may be higher than estimated in this analysis and should not be overlooked for control opportunities. Examples of high phosphorus loading sources in less developed areas that may be easily and cost effectively controlled include soil erosion from forested areas and construction sites. Also, open parklands adjacent to waterways may be areas where excessive fertilizers are applied and/or where waterfowl congregate and generate high phosphorus wastes in close proximity to receiving waters. Leaf litter from tree lined streets in low and medium density residential areas served with piped drainage systems may also represent relatively easy to control high source loading areas as well.

This Plan recommends that owners of stormwater drainage system discharges to the Charles River undertake an iterative approach of managing their discharges. Briefly, this approach would involve adopting initial controls to reduce phosphorus while at the same time collecting information that will better characterize their sources so that subsequent control activities can be prioritized to achieve the greatest phosphorus load reductions in the most efficient and cost effective manner.

7.2.2 Management of Stormwater from Drainage Systems

Storm water runoff can be categorized in two forms; 1) point source discharges (from discrete conveyance, including piped systems) and 2) non-point source discharges (includes sheet flow runoff). Many point source storm water discharges are regulated under the NPDES Phase I and Phase II permitting programs when discharged to waters of the United States. Municipalities that operate regulated municipal separate storm sewer systems (MS4s) must develop and implement a storm water management plan (SWMP) which must employ, and set measurable goals for the following six minimum control measures:

1. public education and outreach particularly on the proper disposal of pet waste,
2. public participation/involvement,
3. illicit discharge detection and elimination,
4. construction site runoff control,
5. post construction runoff control, and
6. pollution prevention/good housekeeping.

All or portions of the towns in this watershed are classified as Urban Areas (UAs) by the United States Census Bureau and are subject to the Stormwater Phase II Final Rule.

The NPDES permits which EPA has issued in Massachusetts to implement the Phase II Stormwater program do not establish numeric effluent limitations for storm water discharges. Rather, they establish narrative requirements, including best management practices, to meet the six minimum control measures and to meet State Water Quality Standards.

Portions of some of the municipalities in the watershed are not currently regulated under the Phase II program. It is recommended that those municipalities consider expanding some or all of the six minimum control measures and other BMPs throughout their jurisdiction in order to minimize storm water contamination.

Some stormwater point sources may not be the responsibility of the municipal government and may have to be addressed through other regulatory vehicles available to EPA and MassDEP, including, but not limited to EPA's exercise of its residual designation authority to require NPDES permits, depending upon the severity of the source. The data included in this TMDL, including wasteload allocations, demonstrates that additional controls may well be needed on many storm water discharges.

With respect to stormwater, existing stormwater management programs need to be expanded to include more specific control and monitoring activities related to nutrients (discussed below). An evaluation of the possibility for one or more targeted watershed-specific general permits (WSGP) for drainage systems that discharge to the Charles River and its tributaries is recommended prior to issuance of future statewide general stormwater NPDES permits. WSGPs may be an efficient approach to accomplish improved levels of nutrient control from stormwater drainages systems and if necessary, expand permit coverage to drainage systems that are presently not covered.

Requirements for permitted entities to conduct specific nutrient-related monitoring and control activities are necessary to achieve the specified large nutrient load reductions from sources in the contributing watersheds. A regulatory mechanism will be important to ensure that steps will be taken by watershed communities and other owners of permitted drains to make continued progress in reducing nutrient loadings and identifying/prioritizing other actions that are needed to achieve the water quality goals of the Charles River.

A list of the municipalities in Massachusetts regulated by the Phase II Rule can be viewed at http://www.epa.gov/region01/npdes/stormwater/2003-permit-archives.html along with the

Notices of Intent for each municipality.

Stormwater discharges represent a major source of nutrients to the Upper/ Middle Charles River and the current level of control is inadequate to protect both the Upper/Middle and Lower Charles River system. Initially, the owners of regulated municipal drainage systems, including communities, Massachusett Highway Department (MassHighway), Department of Conservation and Recreation (DCR), and Massachusetts Turnpike Authority (MassPike), will need to collect source monitoring data and additional drainage area information to better target source areas for controls and evaluate the effectiveness of on-going control practices. Also, while their sources are being better characterized, their existing stormwater management programs should be enhanced to optimize reductions in nutrient loadings with initial emphasis on source controls and pollution prevention practices.

Phosphorus load reductions from stormwater may be undertaken using a combination of good housekeeping practices, structural and nonstructural Best management Practices (BMPs), reductions in impervious cover, and other Low Impact Development (LID) techniques. Other approaches can also aid in this process including establishing outreach and education programs for homeowners to encourage proper lawn and garden care as well as practices for the proper disposal of pet waste. Each of these actions can significantly reduce nutrient loads. Municipal good housekeeping practices should also be adopted, including regular street sweeping and proper operation and maintenance of stormwater infrastructure, maintenance of parks and public lands, and best management practices at all municipal facilities. Adoption of local regulations and bylaws can require sediment and erosion controls, and can encourage low impact development and other infiltration practices that also mitigate flooding. Information about regulatory and non-regulatory tools can be found in The Massachusetts Clean Water Toolkit at http://www.mass.gov/dep/water/resources/nonpoint.htm on MassDEP's Nonpoint Source Pollution web page. The Toolkit provides a comprehensive resource about nonpoint source pollution, appropriate best management practices, and appropriate strategies to support development of an effective TMDL implementation program.

Although the TMDL presents quantified WLAs, EPA and MassDEP do not intend to initially include numeric effluent limitations in NPDES stormwater permits based on this TMDL. As discussed in the LA and WLA sections, all of the allocations except for WWTFs represent aggregated loads from many regulated and unregulated sources, including nonpoint sources that contribute to the overall watershed load presented. Individual source data are limited, and therefore at the present time, it is not feasible to estimate appropriate numeric effluent limitations for regulated storm water drainage systems. In the future, as more source information is developed it may become feasible to establish effluent limits for permitted drainage system discharges.

The current intention is to have the stormwater permits require best management practices (BMP-based permits) that will require permittees to develop and implement comprehensive stormwater management programs involving source monitoring to identify and prioritize pollutant source areas and to implement BMPs. MassDEP and EPA believe that BMP-based permits will initially provide an appropriate framework for developing comprehensive stormwater management programs with specific emphasis on phosphorus that contributes to the existing water quality impairment.

Comprehensive programs will be necessary to achieve the phosphorus reduction and water quality goals of this TMDL. Programs should build upon existing stormwater management to accomplish the following tasks:

- characterize the drainage areas that contribute to discharges requiring permit coverage under the Permittee's jurisdiction
- implement a comprehensive Illicit Discharge Detection and Elimination (IDDE) program
- prioritize source areas for stormwater management and control
- identify site-specific and regional opportunities for implementation of BMPs
- include the necessary structural and non-structural best management practices (BMPs) that, upon implementation, will achieve reductions in phosphorus loadings from the NPDES covered drainage areas that are consistent with the phosphorus load reductions identified in this TMDL

More detail is discussed below.

1. Drainage Area Characterization
    A. Prepare map of drainage areas showing:
        i. Outfall locations;
        ii. Pipe/drainage system network with all catch basins, underdrains, and common manholes;
        iii. Sanitary sewer system and or on-site sewage disposal systems;
        iv. Impervious cover;
        v. Land cover categories;
        vi. Parking lots ;
        vii. Vegetated areas where fertilizers are applied; and
        viii. Areas with trees bordering paved areas (i.e., trees lined streets).
    B. Divide drainage area into logical/manageable sub-drainage areas or subcatchments;
    C. Report the following information for each outfall and/or subcatchment area:
        a. Drainage area;
        b. Impervious cover area;
        c. Parking lot area;
        d. Area in each MassGIS land cover category;
        e. Vegetated areas that receive fertilizer applications;
        f. Number of catch basins;
        g. Number of common manholes serving both the drainage and sanitary sewer systems; and
        h. Length of roadways.

2. Conduct Illicit Discharge Detection and Elimination (IDDE) Program
    A. Drainage system investigations;
    B. Dry and wet-weather monitoring;
    C. Prioritize sources for elimination;
    D. Elimination of illicit sources; and

   E. Post-removal confirmation.

3. Develop and implement Baseline Storm Water Management Plan (SWMP) or good housekeeping plan to reduce phosphorus loading. The baseline SWMP must include the following components:
   A. Education:
      i. Fertilizer and grounds keeping management;
      ii. Pet waste control;
   B. Leaf litter collection/disposal program;
   C. Catch basin cleaning;
   D. street-sweeping of parking lots and roadways using vacuum assisted sweepers; and
   E. maintenance plan for existing BMPs.

4. Prioritize sources using drainage area characteristics, IDDE information, and monitoring data. Each source should be assigned a numerical ranking based on consideration of the magnitude of the phosphorus loading from the source and the likely nature of the control remedy. The ranking should indicate the priority in which sources will be addressed.

5. Develop and implement an enhanced SWMP to achieve the phosphorus loading reduction goals of TMDL. The SWMP would be improved using the information developed from the drainage area characterization task together with guidance on BMP pollutant removal performance. Currently EPA Region I is finalizing a project to develop BMP pollutant removal performance information that would be suitable for estimating phosphorus removal credits for various BMPs. The enhanced SWMP should consider the BMPs identified and discussed further below in this section.

   A. Prepare a revised SWMP to achieve TMDL phosphorus reduction goals.
      i. Identify phosphorus reduction goals;
      ii. Consider infiltration practices, bio-retention/filtration practices and other structural controls that have been shown to be consistently reliable for removing phosphorus in storm water runoff;
      iii. Consider high-efficiency street sweeping program;
      iv. Provide supporting documentation to show that the enhanced SWMP will achieve TMDL phosphorus reduction goals;
      v. Provide implementation schedule to address each ranked sources.

   B. Design and install structural and/or nonstructural BMPs to achieve TMDL phosphorus reduction goals;
   C. Provide detailed operation and maintenance plan for all BMPs including detailed schedule for all implementation activities;
   D. Maintenance plan for existing BMPs.

6. Prepare a post-implementation assessment of the enhanced SWMP. The permitttee will track and assess the pollutant reductions achieved during implementation of the SWMP and document whether or not it appears to be meeting the reduction goals of the TMDL. Best

estimates of phosphorus capture of the various non-structural and structural BMPs should be provided. Estimates need to be based on quantifiable measures to the maximum extent practicable. Examples include the amount of dust and dirt collected by street sweeping and catch basin cleanings, cubic yards of leaf litter collected, weight of dog waste bags collected from designated receptacles, amount of fertilizer applied, and amount of sediment deposition in structural BMPs.

In addition to the above, municipalities should explore the use of local ordinances to address potentially high pollutant source areas that are not directly covered by NPDES permits (shopping centers, malls, etc.).

Considering the large extent of urbanized area in the Charles River watershed, non-structural BMPs are likely to be important components of the management programs. The efficiencies of some of the more commonly used structural controls, such as detention basins and sedimentation basins, at removing smaller sized particles is often limited. Non-structural BMPs emphasize source controls such as public education, use of alternative products, street cleaning, catch basin cleaning, general maintenance, and land use controls (CGER-OSB, 2000).

Current research indicates that some of the most effective means to reduce phosphorus loads from stormwater involve infiltration practices. Phosphorus loading rates are directly related to impervious cover and how well-connected that impervious cover is to drainage systems. Not only are infiltration practices highly effective at removing phosphorus, they offer the added benefit of recharging groundwater which in turn contributes base-flow to streams and receiving waters. The added baseflow from stormwater/groundwater recharge improves aquatic habitats, increases pollutant assimilative capacity of the receiving waters, and helps to offset withdrawals from public water supplies.

Bioretention/filtration practices are another class of BMPs that hold great promise for removing phosphorus and other pollutants in storm water runoff in the Charles River watershed. Unlike infiltration practices, the implementation of bioretention practices are not limited by soil conditions and can be installed almost anywhere where space exists. Bioretention/filtration practices provide a filter media and vegetation to treat runoff. Where subsoils are poor for drainage, underdrains are used to collect treated runoff after it has passed through the vegetation and filter media.

The first step in the stormwater management program will be source monitoring and drainage area characterization. Permittees will need to map their stormwater drainage systems and characterize the drainage area (i.e., area, land uses, percent imperviousness, street miles, etc). They will also need to prioritize their nutrient sources by drainage system and identify high source areas (e.g., highly impervious areas, high erosion areas, golf courses, etc), in order to effectively focus management options. Permittees that own and operate a single separate storm sewer system will not need to go through the prioritization step. As indicated owners of permitted separate storm sewer systems in the watershed should first develop a baseline stormwater management plan that follows the aforementioned steps to reduce nutrient loading to the Charles River through source controls.

Disturbed land and construction activities continue to be significant potential sources of phosphorus loading. Regulation and enforcement of erosion and sedimentation control practices should be evaluated and expanded if appropriate to reduce phosphorus loads.

In some areas, stream bank management activities may be contributing to phosphorus loading. The use of culverts, retaining walls, rip rap and other armored stream bank treatments can increase stream velocities and increase the rate of sediment deposition in downstream areas. These practices may also lead to larger flood events which transport significant volumes of phosphorus and other pollutants to receiving waters. Stream bank restoration utilizing vegetated banks and shallow wetland shelves can significantly reduce phosphorus loads and improve water quality without increasing flood risk.

Additional activities such as the identification and removal of illicit sanitary flows from storm drains and the correction of failing septic systems will contribute to the reduction in phosphorus loading as well as address fecal contamination problems. Non-structural BMP programs such as source control programs, landscape maintenance and management programs, high-efficiency, high frequency sweeping programs for streets and parking lots, no-idling and emissions reduction programs, and public education campaigns may also provide some reduction in phosphorus loading.

7.2.3 Management of Illicit Discharges to Stormwater Drainage Systems

Both dry- and wet-weather water quality monitoring of stormwater drainage system discharges to the Charles River, show that the quality of these discharges is highly variable and that they are likely to be contaminated with illicit sources of sewage (see Lower Charles TMDL). Past and on-going investigations of stormwater drainage systems that discharge to the Lower Charles River indicated illicit sources of sewage are prevalent in tributary stormwater drainage systems and represent a substantial source of nutrient loading. Because of the presence of sewage in the stormwater drainage systems, it is difficult to determine how much of the nutrient loading is due to illicit sources and how much is due to stormwater runoff. This is likely the case in urban areas in the Upper/Middle Charles River as well.

Illicit discharges of sewage to the Charles River through the stormwater drainage system represent a substantial source of nutrients that contributes to water quality problems in the Upper/Middle Charles River as well as excessive algal biomass in the Lower Charles. Not only are illicit discharges a concentrated source of nutrients, but they pose a direct risk to human health because of the potential presence of pathogens in the discharges. Illicit discharges are prohibited in the watershed and must be eliminated to protect human health and to reduce algal biomass in the Charles River System. Since illicit discharges are associated with the stormwater drainage systems, Phase II Municipal Separate Storm Sewer System (MS4) permits are also the vehicles for implementation of controls on illicit discharges.

Individual sources must be first identified in the field before they can be abated. Pinpointing sources will require extensive monitoring of the stormwater drainage systems during both dry- and wet-weather conditions. A comprehensive program is needed in all of the Charles River watershed communities to ensure that illicit sources are identified and that appropriate actions will be taken to eliminate them. Some communities that are actively investigating illicit discharges currently sample for bacteria in their drainage system monitoring. These sampling efforts need to be expanded to include nutrients.

Guidance for implementing an illicit discharge detection and elimination program is available from several documents. EPA New England developed a specific plan for the Lower Charles River to identify and eliminate illicit discharges (both dry and wet weather) to their separate storm sewer systems (US-EPA 2004). This protocol represents just one of the approved methodologies available. More generic guidance is provided in a document prepared for EPA by the Center for Watershed Protection and the University of Alabama entitled Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments which can be downloaded from: http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/idde.htm.

In addition, practical guidance for municipalities is provided in a New England Interstate Water Pollution Control Commission publication entitled Illicit Discharge Detection and Elimination Manual, A Handbook for Municipalities available at: http://www.neiwpcc.org/iddemanual.asp. Implementation of the protocol outlined in these guidance documents satisfies the Illicit Discharge Detection and Elimination requirement of the NPDES program.

In general, the IDDE programs implemented in the Charles River watershed should contain the following components:

- Conduct comprehensive system-wide assessments of drainage systems to identify illicit sewage sources. Methodology must be consistent, at a minimum, with the protocol presented in the Appendix.
    - Conduct dry- and wet-weather nutrient sampling throughout each drainage system
    - Conduct physical inspections and investigations (e.g., manhole inspections, dye testing, videoing drains, etc.)
- Eliminate “easy to fix” sources (i.e., direct pipe connections)
- Develop prioritized plans with schedules for eliminating more complex illicit sources such as those occurring from deteriorating sewers and drain pipes and sewer underdrain connections
- Conduct on-going confirmatory monitoring program to document the elimination of illicit sources. Program shall include dry- and wet-weather sampling of drains.
- Prepare annual progress reports (to be submitted to MassDEP and US-EPA)

As with stormwater management, any monitoring or pilot studies should be well-designed and consistent throughout the watershed.

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

7.2.4 Wastewater Treatment Facilities

There are five active Wastewater Treatment Facilities (WWTFs) discharging treated sewage into the Upper/Middle Charles River watershed, three on the main stem of the Charles River and two on the Stop River, a tributary to the Charles River. Each of these facilities has a National Pollutant Discharge Elimination System (NPDES) permit which establishes phosphorus limits for the facility.

Under this Implementation Plan, regulation of WWTFs must establish effluent limits to achieve water quality standards and thus the WLAs established in this TMDL. The WLAs for these WWTFs were selected to meet the Lower TMDL total phosphorus load and also meet the target water quality criteria in all reaches in the Upper /Middle Charles.

Upon the next permit renewal for each of the five facilities, the following permit limits are recommended for phosphorus:

1) Milford WWTF, Charles River Water Pollution Control District, and the Medfield WWTF must reduce their phosphorus discharge levels to 0.1 mg/L in the summer (Apr-Oct) and 0.3 mg/L in the winter (Nov-Mar). It is anticipated however that achieving lower winter limits will take a combination of additional technology, chemical additional and/or a series of trials before this limit can be met consistently. This, combined with the fact that it will take an iterative approach to stormwater management that could take several years, it is recommended that an adaptive approach be applied to the WWTFs that would allow some flexibility to identify the best way to achieve the necessary reductions. As a result this Plan is recommending that an initial winter permit limit of 0.5 mg/L be allowed and be evaluated at the next permit cycle.
2) The Minor WWTFs (MCI-Norfolk and Wrentham Development) need to achieve 0.1 in the summer (Apr-Oct) and 1.0 mg/L in the winter (Nov-Mar).

7.3 Potential Future Management Activities

Control of stormwater runoff from drainage systems will require a significant amount of time and effort to accomplish. Given the magnitude of annual phosphorus load reductions required of many land use types, the existing level of development in the Upper/Middle Charles River watershed, and potential constraints on some sites, it is possible that some sites will be unable to achieve the total annual reductions needed to meet the TMDL. Through the adaptive management approach ongoing monitoring will be conducted and will indicate if water quality standards are being met. If this does not occur other management activities would have to be identified and considered to reach to goals outlined in this TMDL.

Potential management activities that could be considered include, but are not limited to, the following:

- Relocating WWTF outfalls to different river segments
- Reducing the phosphorus load from the WWTF and/or considering converting WWTF surface water discharges to treated groundwater discharges
- Consider a pollutant trading program
- macrophyte and benthic algae treatment
- removal or stabilization of benthic sediments
- baseflow augmentation
- the removal of select dams

Each of these potential alternatives would have to be fully investigated and considered prior to further implementation.

7.3.1 Ongoing Monitoring

Water quality and flow monitoring programs in the Upper/Middle Charles River should be continued in order to assess progress towards and success of obtaining the TMDL's water quality goals. This monitoring is necessary to determine whether water quality goals are met through the implementation of the activities. Pilot projects should include water quality monitoring to determine their effectiveness at removing phosphorus. Instream monitoring programs should be designed to capture spatial, seasonal and climatic variability. In the Upper/Middle Charles, periodic vegetative surveys should be conducted to determine the impacts of phosphorus reduction on biomass in critical reaches.

7.3.2 Refinement of the Watershed Model

The HSPF model used to develop the nutrient TMDL for the Upper/Middle Charles River must be kept "active" as part of the implementation plan and data collected in ongoing water quality monitoring programs and be utilized to update the model on a regular basis. This will allow ongoing evaluation of new stormwater and wastewater controls as they are implemented and also permit the development of additional scenarios to help prioritize implementation strategies in the future.

Periodic modeling activity is important in the Upper/Middle Charles River given some of the uncertainties of the response of nutrient reduction activities and the potential need to consider greater reductions. In an adaptive management approach, load reductions are implemented, the effects on the receiving water quality are evaluated, and further reductions are implemented if they are deemed necessary. This process is repeated until water quality goals are met.

7.3.3 Funding/Community Resources

A complete list of funding sources for implementation of nonpoint source pollution is provided in Section VII of the Massachusetts Nonpoint Source Management Plan Volume I available on line at http://mass.gov/dep/water/resources/nonpoint.htm#plan. This list includes specific programs available for nonpoint source and stormwater management and resources available for communities to manage local growth and development. The State Revolving Fund (SRF) provides low interest loans to communities for certain capital costs associated with building or improving wastewater treatment facilities. In addition, many communities in Massachusetts sponsor low cost loans through the SRF for homeowners to repair or upgrade failing septic systems.

8 REASONABLE ASSURANCE

Reasonable assurances that the TMDL will be implemented include both application and enforcement of current regulations, availability of financial incentives including low or no-interest loans to communities for wastewater treatment facilities through the State Revolving Fund (SRF), and the various local, state and federal programs for pollution control. Storm water NPDES permit coverage is designed to address discharges from municipal owned storm water drainage systems. Some stormwater sources may not be the responsibility of the municipal government. These, and in cases in which efforts under Phases I and II fail to achieve water quality standards, may have to be addressed through other regulatory vehicles available to MassDEP and US-EPA through federal and state Clean Water Acts depending upon the severity of the impact.

MassDEP also is evaluating monitoring data collected by it and others in order to help set priorities for abating impacts from storm water. Enforcement of regulations controlling non-point discharges includes local enforcement of the state Wetlands Protection Act and Rivers Protection Act Title 5 (http://www.mass.gov/dep/water/laws/regulati.htm) regulations for septic systems and various local regulations including zoning regulations. Financial incentives include Federal monies available under the CWA Section 319 Nonpoint Source program and the CWA Section 604 and 104b programs, which are provided as part of the Performance Partnership Agreement between MassDEP and the US-EPA. Additional financial incentives include state income tax credits for Title 5 upgrades, and low interest loans for Title 5 septic system upgrades through municipalities participating in this portion of the state revolving fund program. A brief summary of many of MassDEP's tools and regulatory programs is presented below.

8.1 Overarching Tools

8.1.1 Massachusetts Clean Water Act

The Massachusetts Clean Water Act (M.G.L. Chapter 21, sections 26-53) provides MassDEP with specific and broad authority to develop regulations to address both point and non-point sources of pollution. There are numerous regulatory and financial programs, including those identified in the preceding paragraph, that have been established to directly and indirectly address nutrient impairments throughout the state. Several of them are briefly described below. The Massachusetts Clean Water Act can be found at http://www.mass.gov/legis/laws/mgl/gl-21-toc.htm.

8.1.2 Surface Water Quality Standards

The Massachusetts Surface Water Quality Standards (314 CMR 4.0) assign designated uses and establish water quality criteria to meet those uses. Water body classifications (Class A, B, and C, for freshwater and SA, SB, and SC for marine waters) are established to protect each class of designated uses. The Massachusetts Surface Water Quality Standards can be found online at http://www.mass.gov/dep/water/laws/regulati.htm#wqual.

8.1.3 Ground Water Quality Standards

The Massachusetts Ground Water Quality Standards (314 CMR 6.0) consist of groundwater classifications, which designate and assign the uses for various groundwaters of the Commonwealth that must be maintained and protected. Like the surface water quality standards the groundwater standards provide specific ground water quality criteria necessary to sustain the designated uses and/or maintain existing groundwater quality. The Massachusetts Ground Water Quality Standards can be found at http://www.mass.gov/dep/water/laws/regulati.htm#gwp.

8.1.4 River Protection Act

In 1996 Massachusetts passed the Rivers Protection Act. The purposes of the Act were to protect the private or public water supply; to protect the ground water; to provide flood control; to prevent storm damage; to prevent pollution; to protect land containing shellfish; to protect wildlife habitat; and to protect the fisheries. The provisions of the Act are implemented through the Wetlands Protection Regulations, which establish up to a 200-foot setback from rivers in the Commonwealth to control construction activity and protect the items listed above. Although this Act does not directly reduce nutrient discharges it indirectly controls many sources of nutrients close to water bodies. More information on the Rivers Protection Act can be found on MassDEP's web site at http://www.mass.gov/dep/water/laws/regulati.htm.#t5regs.

8.1.5 Surface Water Discharge Permitting Program Regulations

The Massachusetts Surface Water Discharge Permitting Program Regulations (314 CMR 3.0) allow MassDEP to take action whenever it determines that a discharge from a storm drain or other source is a significant contributor of pollutants to waters of the Commonwealth. US-EPA and MassDEP have the authority to designate the discharge as a significant contributor of pollutants and require the discharger to obtain an individual surface water discharge permit and/or require through a general permit or an enforcement action that the discharger undertake additional control measures, BMPs, or other actions to ensure compliance with a general permit or water quality standards, or to protect the public health and the environment. Through its regular watershed sampling or its own investigations in response to complaints or inspections, MassDEP can determine that certain discharges from municipal storm drain systems are significant contributors of pollutants to surface waters. In that event, MassDEP can and has issued a Notice of Noncompliance to the municipality requesting that the municipality develop and implement a plan for removing illicit sanitary connections to the storm drain system. The Massachusetts Surface Water Discharge Permitting Program Regulations can be found at http://www.mass.gov/dep/water/laws/regulati.htm.

8.1.6 Stormwater Regulations

Stormwater is regulated through both federal and state programs. Those programs include, but are not limited to, the federal and state Phase I and Phase II NPDES stormwater program, and, at the state level, the Wetlands Protection Act MGL Chapter 130, Section 40), the state water quality standards, and the various permitting programs previously identified.

Existing stormwater discharges are regulated under the **Federal and State Phase 1 and Phase II Stormwater Program**. In Massachusetts there are two Phase 1 communities, Boston and Worcester. Both communities have been issued individual permits to address stormwater discharges. In addition, 237 communities in Massachusetts, and all 35 communities in the Charles River Watershed are covered by Phase II (the only exception is Boston which is covered under Phase 1). Phase II is intended to further reduce adverse impacts to water quality and aquatic habitat by instituting use controls on the unregulated sources of stormwater discharges that have the greatest likelihood of causing continued environmental degradation including those from municipal separate storm sewer systems (MS4s) and discharges from construction activity.

Other storm water discharges regulated under Phases I and II include storm water associated with industrial activities and storm water associated with construction activities. In addition, US-EPA has the authority to require non-regulated point source storm water discharges to obtain NPDES permits if it determines that such storm water discharge causes or contributes to a water quality violation, or is a significant contributor of pollutants, or where controls are needed based on a waste load allocation in an US-EPA approved TMDL (See 40 CFR § 122.26(a)(9)(i)).

The Phase II Final Rule, published in the Federal Register on December 8, 1999, requires permittees to determine whether or not stormwater discharges from any part of the MS4 contribute, either directly or indirectly, to a 303(d) listed waterbody. Operators of regulated MS4s are required to design stormwater management programs to 1) reduce the discharge of pollutants to the "maximum extent practicable" (MEP), 2) protect water quality, and 3) satisfy the appropriate water quality requirements of the Clean Water Act. Implementation of the MEP standard typically requires the development and implementation of BMPs and the achievement of measurable goals to satisfy each of the six minimum control measures. Those measures include 1) public outreach and education, 2) public participation, 3) illicit discharge detection and elimination, 4) construction site runoff control, 5) post-construction runoff control, and 6) pollution prevention/good housekeeping. In addition, each permittee must determine if a TMDL has been developed and approved for any water body into which an MS4 discharges. If a TMDL has been approved then the permittee must comply with the TMDL including the application of BMPs or other performance requirements. The permittees must report annually on all control measures currently being implemented or planned to be implemented to control pollutants of concern identified in TMDLs. The data included in this TMDL, including wasteload allocations, demonstrates that additional controls may well be needed for many storm water discharges in segments with high bacteria concentrations and nutrient loads particularly during wet weather. Finally, the Department has the authority to issue an individual permit to achieve water quality objectives. Links to the MA Phase II permit and other stormwater control guidance can be found at http://www.mass.gov/MassDEP/water/wastewater/stormwat.htm. A full list of Phase II communities in MA can be found at http://www.mass.gov/MassDEP/brp/stormwtr/stormlis.htm.

In addition to the Phase I and II programs described above, the Massachusetts Department of Environmental Protection proposed new "Stormwater Management Regulations," in the spring of 2009 that will establish as statewide general permit program aimed at controlling the discharge of stormwater runoff from certain privately-owned sites containing large impervious surfaces.

The proposed regulations are being revised based on public comment and should be available soon. The proposed regulations are available on the DEP website at (http://www.mass.gov/dep/service/regulations/newregs.htm#storm) require private owners of land containing five or more acres of impervious surfaces to apply for and obtain coverage under a general permit; implement nonstructural best management practices (BMPs) for managing stormwater; install low impact development (LID) techniques and structural BMPs at sites undergoing development and redevelopment; and submit annual compliance certifications to the Department.

Where the Department has determined that stormwater runoff is causing or contributing to violations of the Massachusetts Surface Water Quality Standards, the proposed regulations would allow MassDEP to impose the same requirements on certain private owners or land with less than 5 acres of impervious surfaces and require owners to such land to design and implement the LID techniques and stormwater BMPs needed to address these violations.

The MassDEP Wetlands regulations (310 CMR 10.0) direct issuing authorities to enforce the MassDEP Stormwater Management Policy, place conditions on the quantity and quality of point source discharges, and to control erosion and sedimentation. The Stormwater Management Policy was issued under the authority of the 310 CMR 10.0. The policy and its accompanying Stormwater Performance Standards apply to new and redevelopment projects where there may be an alteration to a wetland resource area or within 100 feet of a wetland resource (buffer zone). The policy requires the application of structural and/or non-structural BMPs to control suspended solids, which have associated co-benefits for nutrient removal. A stormwater handbook was developed to promote consistent interpretation of the Stormwater Management Policy and Performance Standards: Volume 1: Stormwater Policy Handbook and Volume 2: Stormwater Technical Handbook can be found along with the Stormwater Policy at http://www.mass.gov/dep/water/wastewater/stormwat.htm#swpwet

8.1.7 Septic System Regulations

MassDEP has Septic System (Title 5) Regulations in place that require minimum standards for the design and performance of individual septic systems. Those regulations ensure, in part, protection for nearby surface and groundwaters from bacterial contamination. The regulations also provide minimum standards for replacing failed and inadequate systems. The Department has established a mandatory requirement that all septic systems must be inspected and upgraded to meet Title 5 requirements at the time of sale or transfer of the each property.

8.2 Financial Tools

Nonpoint Source Control Program: MassDEP has established a non-point source control and grant program to address non-point source pollution sources statewide. The Department has developed a Nonpoint Source Management Plan that sets forth an integrated strategy and identifies important programs to prevent, control, and reduce pollution from nonpoint sources and more importantly to protect and restore the quality of waters in the Commonwealth. The Clean Water Act, Section 319, specifies the contents of the management plan. The plan is an implementation strategy for BMPs with attention given to funding sources and schedules. Statewide implementation of the Management Plan is being accomplished through a wide variety of federal, state, local, and non-profit programs and partnerships. It includes partnering with the Massachusetts Coastal Zone Management on the implementation of Section 6217 program. That program outlines both short and long term strategies to address urban areas and stormwater, marinas and recreational boating, agriculture, forestry, hydro modification, and wetland restoration and assessment. The CZM 6217 program also addresses TMDLs and nitrogen sensitive embayments and is crafted to reduce water quality impairments and restore segments not meeting state standards.

In addition, the state is partnering with the Natural Resource Conservation Service (NRCS) to provide implementation incentives through the national Farm Bill. As a result of this effort, NRCS now prioritizes its Environmental Quality Incentive Program (EQIP) funds based on MassDEP's list of impaired waters. Over the last several years EQIP funds have been used throughout the Commonwealth to address water quality goals through the application of structural and non-structural BMPs.

MassDEP, in conjunction with US-EPA, also provides a grant program to implement nonpoint source BMPs that address water quality goals. The section 319 funding provided by US-EPA is used to apply needed implementation measures and provide high priority points for projects that are designed to address 303d listed waters and to implement TMDLs.

Specifically in the Charles River Watershed, from 2001 to September 2009, the Department has issued 319 grants totaling $1,243,494 (not including local match) to develop and implement stormwater treatment systems and collect additional data for TMDL development. The projects will result in the installation of stormwater treatment systems to protect Hammond Pond in Newton and to treat and reduce discharges to the Charles River off Plymouth Road in Bellingham, Cold Spring Brook in Wellesley, stormwater retrofit in Franklin, and an LID Program at Jackson Square.. The 319 program also provides additional assistance in the form of guidance. The Department is in the process of updating the Massachusetts' Nonpoint Source Management Manual that will provide detailed guidance in the form of BMPs by land use to address various water quality impairments and associated pollutants.

Additional information related to the non-point source program, including the Management Plan can be found at http://www.mass.gov/dep/water/resources/nonpoint.htm.

The **State Revolving Fund (SRF) Program** provides low interest loans to eligible applicants for the abatement of water pollution problems across the Commonwealth. Since July 2002 the MassDEP has issued millions of dollars for the planning and construction of combined sewer overflow (CSO) facilities and to address stormwater pollution. Loans have been distributed to municipal governments statewide to upgrade and replace failed Title 5 systems. These programs all demonstrate the State's commitment to assist local governments in implementing the TMDL recommendations. Additional information about the SRF Program can be found at http://www.mass.gov/MassDEP/water/wastewater/wastewat.htm.

8.3 Watershed Specific Strategies

In summary, MassDEP's approach and existing programs set out a wide variety of tools both MassDEP and local communities can use to address nutrient sources to the Charles River (e.g., illicit discharges and stormwater runoff). While there are relatively few categories of nutrient sources to the Charles River, the highly variable characteristics associated with these sources make it necessary for the TMDL implementation program to include intensive investigations, reconnaissance, and characterization of nutrient sources from the watershed. This work will identify illicit sources for elimination and help to prioritize other sources for additional controls. Also, the effectiveness and potential of various control programs to reduce nutrient loadings to the Charles River such as high-efficiency street sweeping, illicit discharge detection and elimination, nutrient management, and public education will require ongoing iterations of investigation, evaluation, and revision. Local stormwater management plans will need to evolve

as new information on sources and the effectiveness of controls becomes available.
The specific strategy that US-EPA and MassDEP intend to apply to the Charles River watershed to reduce nutrient loading involves the use of the NPDES stormwater permitting program in an iterative process. Through the permitting process, IDDE programs will be developed/refined, stormwater management plans will be regularly evaluated and updated, source specific information will be collected, and control practices will be tested, evaluated and implemented. Ongoing water quality monitoring by MassDEP, US-EPA, MWRA, and the CRWA will be used to monitor progress in improving reducing algal blooms and improving water quality. Moreover, MassDEP recommends that the existing water quality model of the Charles River be maintained and used to evaluate progress as it will be help to distinguish water quality impacts associated with climatic conditions and nutrient loading.

It is MassDEP's goal to work closely with US-EPA, municipalities, CRWA, and other interested public to develop an overall implementation framework to address significant nutrient contributors and monitor progress at reducing nutrient loading to the Charles River. To accomplish this, MassDEP will consult their internal databases, as well as local data that are available and review NPDES stormwater permit annual submittals. MassDEP has the authority under M.G.L. c.21 to designate a source where necessary (or use US-EPA's authority) to require quicker action than would otherwise be achieved under existing schedules or require additional controls if it is determined that Phase II activities are insufficient to solve the problem. To aid in the collection of critical data and information, MassDEP will provide grant opportunities to collect the data necessary to prioritize nutrient source areas. Once a significant source is found, MassDEP will coordinate with the owner of the discharge to "go up the pipe" to identify illicit connections and undertake additional controls as necessary.

MassDEP's authority combined with the programs identified above provide sufficient reasonable assurance that implementation of remedial actions will take place.

9 PUBLIC PARTICIPATION

9.1 Public Meeting

A public meeting will be held on October 29, 2009 from 4 to 7 PM at the Mass Horticultural Society Elm Bank Reservation Wellesley, MA (http://www.masshort.org/directions). The Draft Total Maximum Daily Load for Nutrients in the Upper/Middle Charles River, Massachusetts (Control Number CN 272.0) was distributed for public review and solicitation of comments on September 30, 2009. Comments in the Draft document will be accepted until November 30, 2009.

9.2 Response to Comments

Please see Appendix A-1 for the response to comments.

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11 APPENDICES

Table A-1. Response to Comments