Final

Total Maximum Daily Load for Nutrients
In the Lower Charles River Basin, Massachusetts
CN 301.0

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Key to Acronyms

BMP – best management practice
BU – Boston University
BWSC – Boston Water and Sewer Commission
CMR – Code of Massachusetts Regulations
CRWA – Charles River Watershed Association
CSO – combined sewer overflow
CWA – Clean Water Act
CZM – Coastal Zone Management
EMC – event mean concentration
EPA – Environmental Protection Agency
EQIP – Environmental Quality Incentive Program
IDDE – illicit discharge detection and elimination
LA – load allocation
MassDEP – Massachusetts Department of Environmental Protection
MAWQS – Massachusetts Water Quality Standards
MEP – maximum extent practicable
MEPA – Massachusetts Environmental Policy Act
MGD – million gallons per day
MOS – margin of safety
MS4 – municipal separate storm sewer system
NOI – notice of intent
NPDES – National Pollutant Discharge Elimination System
NRCS – Natural Resources Conservation Service
PI – prediction interval
QAPP – Quality Assurance Project Plan
SRF – State Revolving Fund
SWMM – Storm Water Management Model
TMDL – Total Maximum Daily Load
TN – total nitrogen
TP – total phosphorus
UA – urbanized area
USGS – United States Geological Survey
WHO – World Health Organization
WLA – wasteload allocation
WSGP – watershed general permit
WWTF – wastewater treatment facility

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 develop Total Maximum Daily Loads (TMDLs) for impaired waterbodies. A TMDL establishes the amount of a pollutant that a waterbody can assimilate without exceeding its water quality standard for that pollutant. 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 (USEPA 1991).

A TMDL for a given pollutant and waterbody is composed of the sum of individual wasteload 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 waterbody. The TMDL components are illustrated using the following equation:

$$\text{TMDL} = \sum \text{WLAs} + \sum \text{LAs} + \text{MOS}$$

The study area for this TMDL is the Lower Charles River, which flows through eastern Massachusetts. The river flows through 23 towns and cities and five counties. This TMDL report addresses the lower portion of the river, which is an impounded section of the Charles River referred to as the Lower Charles River in this report. The Lower Charles River is located at the downstream end of the Charles River Watershed and outlets to Boston Harbor and the Atlantic Ocean.

The entire Charles River watershed drains a watershed area of 308 square miles. Two hundred and sixty-eight square miles of that watershed area drain over the Watertown Dam into the Lower Charles River. The remaining 40 square miles drain directly into the Lower Charles from small tributary streams that are mostly enclosed and piped stormwater drainage systems serving the surrounding communities. There is also a combined sewer drainage area near the downstream end of the Charles River.

The Lower Charles River is in the heart of a highly urbanized area, bordered directly by the municipalities of Boston, Cambridge, Watertown, and Newton. The land uses surrounding the Lower Charles River are predominantly residential.

This TMDL report addresses the nutrient and noxious aquatic plant impairments that were included on the Massachusetts Department of Environmental Protection's (MassDEP) 2002 and 2004 section 303(d) lists (MAEOEA 2003 and 2004). The report also addresses associated water clarity impairments such as turbidity and taste, odor and color.

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. Water quality data indicate the Lower 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 Lower Charles are directly responsible for degrading the aesthetic quality of the river, reducing water clarity, and impairing the designated uses. Additionally, eutrophication of the Lower Charles River has led to the occurrence of a very severe toxic algal bloom in the downstream portion of the Lower Charles during the summer of 2006. Monitoring conducted in the Lower Charles during August 2006 found cell counts of the toxic cyanobacteria (blue-green) organism, microcystes, to be so high that it caused the Massachusetts Department of Public Health to post warnings for the public and their pets to avoid contact with river.

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

Table ES-1. Applicable Massachusetts water quality criteria

Pollutant	Criteria	Source
Dissolved Oxygen	Shall not be less than 5.0 mg/L in warm water fisheries unless background conditions are lower; natural seasonal and daily variations above these levels shall be maintained; and levels shall not be lowered below 60 percent of saturation in warm water fisheries due to a discharge.	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	Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication.	314 CMR: 4.05: Classes and Criteria (5)(c)

The pollutant of concern for this TMDL study is phosphorus because it is directly causing or contributing to the excessive algal biomass in the Lower Charles River. Since there are no numeric criteria available for phosphorus in the Lower Charles, it was necessary to calculate a numerical endpoint to address the excessive algal biomass due to excessive nutrient input to the Lower Charles River. A surrogate water quality target had to be determined in order to calculate pollutant load reductions to the river. Chlorophyll *a* was chosen as the surrogate water quality target used to define the assimilative capacity of 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 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 is a seasonal average of 10 µg/l and is site-specific for the Lower Charles River. The seasonal average is defined as the mean chlorophyll *a* concentration in the Lower Charles between June 1 and October 31 of each year. 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 target was derived using a weight of evidence approach and is based on literature values of chlorophyll *a* relating to trophic classifications, user-perception studies that relate chlorophyll *a* to aesthetic impairments, and site-specific information concerning the physical, chemical, and biological characteristics of the Lower Charles River. The chlorophyll *a* target is set at a level that will satisfy all applicable Class B narrative (nutrients, aesthetics, and clarity) and numeric (dissolved oxygen in the photic zone of the upper water column and pH) criteria as specified in the MAWQS presented in Table ES-1.

For this TMDL a water quality model of the Lower Charles River was developed to simulate the cause and effect relationship between pollutant loadings and algal growth in the study area. The development of the model, including the estimation of pollutant loads, model set-up, and model calibration/validation, is presented in the report entitled *A Hydrodynamic and Water Quality Model for the Lower Charles River, Massachusetts* (Tetra Tech, Inc. and Numeric Environmental Services, 2006).

In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL must be established and thereby provide the basis for establishing water quality-based controls. For this TMDL, allocations are summarized into three broad categories: (1) upstream watershed at Watertown Dam, (2) non-CSO drainage areas that discharge directly to the Lower Charles River, and (3) CSO discharges. Individual allocations are provided for CSO discharges to the Lower Charles River and the WWTFs in the upstream watershed.

The allocation for sources in the upstream watershed that contribute to the phosphorus load at Watertown Dam is representative of all sources in the upstream watershed including the WWTFs, stormwater drainage systems, and nonpoint sources that eventually discharge into the Lower Charles River over the dam. The non-CSO drainage areas that discharge directly to the Lower Charles River represents point and nonpoint nutrient sources that discharge to the major tributaries and other smaller drainage systems. Gross allocations for contributing sources in the lower watershed are identified for (1) Stony Brook watershed, (2) Muddy River watershed, (3) Laundry Brook watershed, (4) Faneuil Brook watershed, and (5) all other tributary drainage systems that discharge directly to the Lower Charles. Gross watershed allocations are defined for sources to the major tributaries because there are sufficient water quality and flow monitoring data available to quantify the net loading from these watersheds. The remaining drainage system discharges to the Lower Charles are grouped together into one allocation because there are presently very little data available to characterize the loadings from each individual source.

Table ES-2 presents the total phosphorus TMDL for the Lower Charles River that will result in meeting the 10 µg/l seasonal average chlorophyll *a* water quality target. As indicated, the Lower Charles River has an annual phosphorus loading capacity of 19,544 kilograms per year. The LA, WLA, and the MOS are discussed in greater detail in Sections 5.2.1, 5.2.2, and 5.5, respectively. An explicit MOS of 5 percent was also included as well as an implicit MOS.

The aggregate phosphorus allocations summarized in Table ES-2, show that needed phosphorus loading reductions to the Lower Charles River range from 48 (upper watershed) to 96 (CSOs) percent. A summary of the total phosphorus TMDL for the Lower Charles River is presented in Table ES-2.

Table ES-2. Summary of Phosphorus TMDL for the Lower Charles River

Source	Existing Load (1998-2002) (kg/year)	WLA (kg/year)	LA (kg/year)	TMDL (kg/year)	% Reduction
Upstream Watershed at Watertown Dam[a]	28,925	15,109	0	15,109	48
CSOs[b]	2,263	90	0	90[c]	96
Stony Brook Watershed	5,123	1,950	0	1,950	62
Muddy River Watershed	1,549	590	0	590	62
Laundry Brook Watershed	409	155	0	155	62
Faneuil Brook Watershed	326	125	0	125	62
Other Drainage Areas	1,455	550	0	550	62
Explicit Margin of Safety	-	-	-	979	
TOTAL	40,050	18,565	0	19,544	54

[a]The aggregate allocation for sources in the upstream watershed includes all point and nonpoint sources in the upstream watershed. See Table 5-7 for individual allocations for the WWTFs

[b]See Table 5-6 for individual CSO allocations. 96% reduction calculated based on required CSO volume reductions in the Long Term CSO Control Plan.

[C] This value represents an estimate that would be needed under 1998-2002 conditions. The TMDL however is based on a typical year and compliance with the approved long-term control plan LTCP. Individual Wasteload Allocations for each CSO based on the LTCP can be found in Table 5-6.

A land cover phosphorus loading analysis for the Charles River watershed was also prepared to provide more information on phosphorus sources in the watershed and to estimate the magnitude of phosphorus loading reductions that are needed to meet the allowable phosphorus loading in the TMDL. Table ES-3 summarizes the results of the land cover loading analysis for the entire watershed and the reductions that are needed for each of the major land cover categories, as well as for other source categories. A land cover loading and reduction analysis was also developed for the land area in each watershed community that drains to the Charles River watershed. See Section 6.1 for more information on the land cover loading analysis for the watershed and each community.

Table ES-3. Summary of land cover phosphorus loading and TMDL loading for the Charles River Watershed

Land Cover/Source Category	Area (square miles)	1998-2002 Phosphorus Loading (kg/yr)	TMDL Phosphorus Loading (kg/yr)	Percent Load Reduction
Commercial	8.36	3676	1286	65%
Industrial	15.01	5718	1972	65%
High Density Residential	35.62	10437	3600	65%
Medium Density Residential	36.00	5278	1820	65%
Low Density Residential	42.73	503	276	45%
Agriculture	7.96	1042	672	35%
Forest	119.09	4018	4018	0%
Open Land	32.52	289	187	35%
POTW		6825	4663	32%
CSO		2263	90[1]	96%[2]
Total	**297.20**	**40050**	**18,565**	**53.6%**

[1] This value represents an estimate that would be needed under 1998-2002 conditions. The TMDL however is based on a typical year and compliance with the approved long-term control plan LTCP. Individual Wasteload Allocations for each CSO based on the LTCP can be found in Table 5-6.

[2] calculated 96% reduction based on required CSO volume reductions in the Long Term CSO Control Plan.

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1 INTRODUCTION

This report presents the components of a total maximum daily load (TMDL) study for the Lower Charles River to address water quality impairments related to excessive algal biomass as a result of eutrophication. The following elements are included in the report: (1) introduction and background on Clean Water Act section 303(d) and applicable Massachusetts Water Quality Standards; (2) description of the study area; (3) water quality of the Lower Charles River and characterization of the pollutant sources to the Lower Charles River; (4) brief description of the water quality modeling process; (5) TMDL development, including the chosen water quality target, determination of the Lower Charles River's pollutant loading capacity, pollutant allocations, critical conditions, and the margin of safety; (6) implementation plan for the TMDL; (7) reasonable assurance; (8) public participation information; and (9) follow-up monitoring and evaluations plans.

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require states to (1) identify impaired waters where required pollution controls are not stringent enough to attain water quality standards and (2) establish TMDLs for such waters for the pollutants that are contributing to the water quality impairments even if pollutant sources have implemented technology-based controls.

The impaired waters requiring the development of TMDLs are listed on the states' section 303(d) lists, which are submitted to EPA every two years for approval. A TMDL establishes the maximum allowable load (mass per unit of time) of a pollutant a waterbody is able to assimilate and still support its designated uses. The maximum allowable load is determined on the basis of the relationship between pollutant sources and in-stream water quality. A TMDL provides 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 (USEPA 1991).

TMDLs allocate allowable pollutant loadings among all contributing sources. The TMDL development process may be described in the following five steps:

1. **Description of Waterbodies and Priority Ranking:** Determination and documentation of whether or not a waterbody requires more stringent pollution controls in order to attain applicable water quality standards.

2. **Problem Assessment:** Assessment of present water quality conditions including estimation of present loadings of pollutants of concern from both point (discernable sources such as pipes) and nonpoint sources (diffuse sources that carry pollutants to surface waters through overland runoff or ground water).

3. **Linking Water Quality and Pollutant Sources:** Determination of the loading capacity of the waterbody. EPA regulations define loading capacity as the greatest amount of pollutant loading that a waterbody can receive without causing

exceedances of its water quality standards. If the waterbody is not presently supporting its designated uses, then the loading capacity will represent a reduction relative to present loadings.

4. **Total Maximum Daily Load:** Specification of load allocations, based on the loading capacity determination, for nonpoint and point sources, which will ensure that the waterbody will attain water quality standards.

5. **Public Participation:** The public is involved in the TMDL process and the TMDL is made available for review and comment by the public.

1.1 Study Area

The Charles River is a slow-moving river approximately 80 miles in length that flows through eastern Massachusetts. The river flows through 23 towns and cities in five counties. This TMDL report addresses the lower portion of the river, which is referred to as the Lower Charles River and is described below.

The section of the Charles River between the Watertown Dam and the New Charles River Dam is referred to as the Lower Charles River (Figure 1-1). The Lower Charles River flows through portions of Norfolk, Middlesex, and Suffolk Counties and is located near the downstream end of the Charles River Watershed, approximately 1.2 miles upstream from its outlet to Boston Harbor and the Atlantic Ocean. The Lower Charles is an impounded section of the Charles River that is 8.6 miles long and covers approximately 675 acres. The majority of this area exists in the lower portion of the river downstream of the Boston University (BU) Bridge (the Basin). The Basin is 2.6 miles long and has widths varying from 300 to 2,000 feet. Its water volume accounts for approximately 90 percent of the entire water volume of the Lower Charles River (MassDEP 2000, Breault et al. 2002). Water depths range from 6 to 12 feet in the Lower Charles upstream of the BU Bridge and 9 to 36 feet in the Basin.

The entire Charles River watershed drains a watershed area of 308 square miles. Two hundred and sixty-eight square miles of watershed area (upstream watershed) drain over the Watertown Dam into the Lower Charles River (Figure 1-2). The upstream watershed includes the Charles River from its headwaters at Echo Lake to Watertown Dam. The remaining 40 square miles of the watershed drain directly into the Lower Charles River from small tributary streams that are mostly enclosed and piped stormwater drainage systems serving the surrounding communities. The major tributary watersheds include Laundry Brook, Faneuil Brook, Muddy River, and Stony Brook. There is also a combined sewer drainage area near the downstream end of the river. See Figure 1-1 for the locations of the tributary watersheds and the combined sewer drainage areas. The Lower Charles River is in the heart of a highly urbanized area, bordered directly by the municipalities of Boston, Cambridge, Watertown, and Newton.

Figure 1-1. Location and major tributary watersheds of the Lower Charles River (Weiskel et al. 2005)

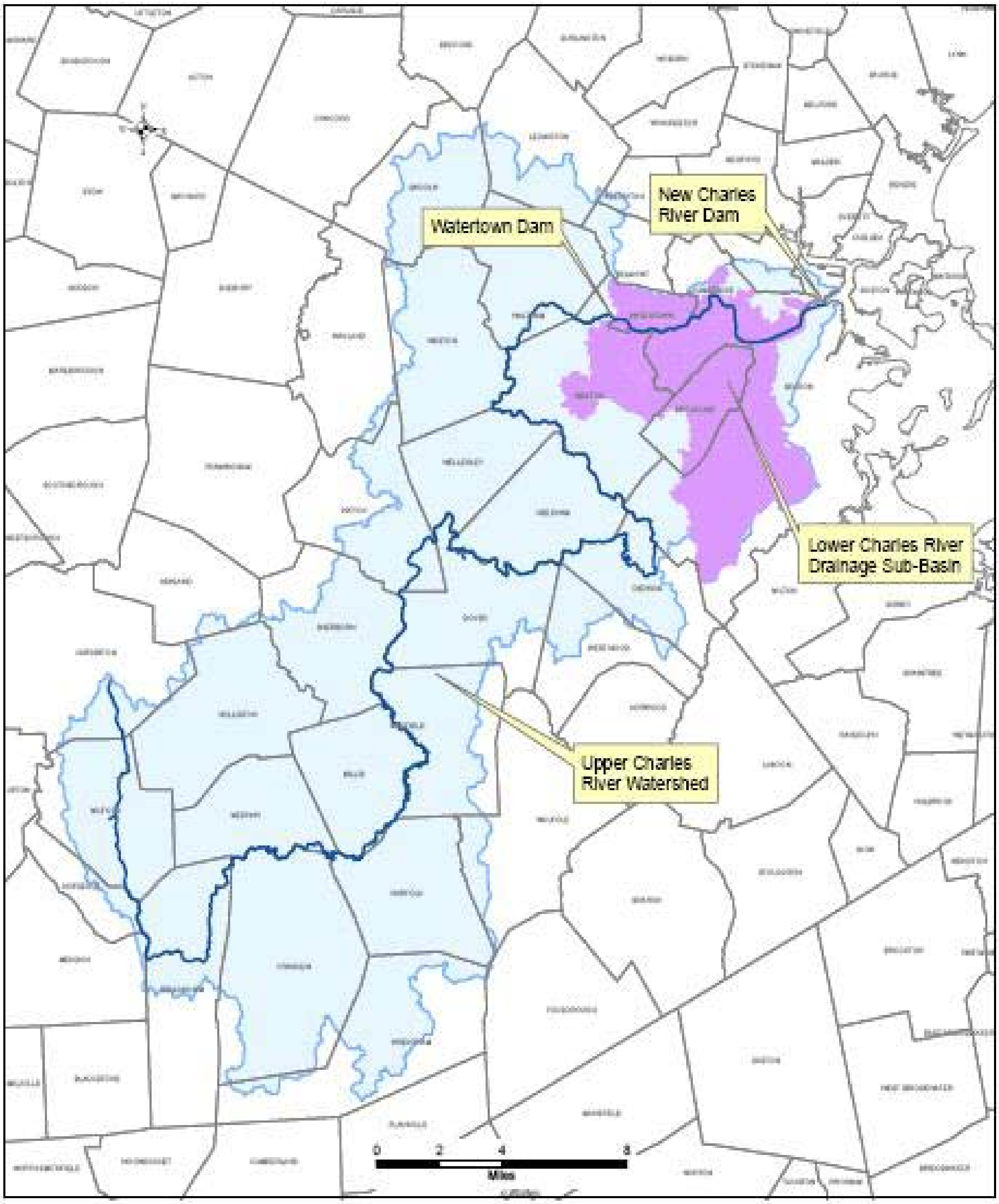

Figure 1-2. The entire Charles River watershed

The Lower Charles River is also the focal point of the Charles River Reservation, a 19,500 acre urban park that serves as a major open-space resource for the Boston metropolitan area. This park receives over 20,000 visitors daily (Breault et al. 2002) and the Esplanade, part of the Charles River Reservation, hosts more visitors than any other riverfront park in the nation (CRWA 2005). Additionally, many local universities and private and public organizations have boating and sailing facilities located on the banks of the Lower Charles River. As a result, the Lower Charles provides an ideal setting for a variety of recreational activities in and along the river, including but not limited to, rowing, sailing, concerts, running, and numerous sporting activities on the adjacent parklands.

1.2 Pollutants of Concern

Based on the water quality data available for the Lower Charles River, the Massachusetts Department of Environmental Protection (MassDEP) has included the Lower Charles River on the State's 2002 and 2004 section 303(d) lists for the following pollutants (MAEOEA 2003 and 2004):

- Unknown toxicity
- Priority organics
- Metals
- Nutrients
- Organic enrichment/low dissolved oxygen
- Pathogens
- Oil and grease
- Taste, odor, and color
- Noxious aquatic plants
- Turbidity

This TMDL report addresses the nutrient and noxious aquatic plant listings as well as associated water clarity impairments such as turbidity and taste, odor and color. This TMDL also addresses any low dissolved oxygen levels in the photic zone of the upper water column. The "noxious aquatic plants" listing refers to excessive algae biomass in the Lower Charles River. It is believed that increased nutrient loads to the Lower Charles are causing the excessive algal biomass.

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 importantly 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.

These algal blooms and other water quality data (i.e., nutrients, water clarity, and dissolved oxygen) indicate the Lower Charles River is undergoing cultural eutrophication. Cultural eutrophication is the process of producing excessive plant life because of excessive pollutant inputs from human activities. In the Lower Charles River, the blooms are directly responsible for degrading the aesthetic quality of the river, reducing water clarity, and impairing recreational uses such as boating, wind surfing, and swimming. Eutrophication of the Lower 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 Lower 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. During the summer of 2006, a very severe toxic cyanobacteria (blue-green) algal bloom occurred in the Lower Charles causing the Massachusetts Department of Public Health to post warnings for the public and their pets to avoid contact with the Lower Charles River. The bloom consisted of extremely high cell counts of over one-million cells/milliliter of the cyanobacteria (blue-green) organism, which also contained high levels of the toxic species known as microcystes. In addition to the threat to public health, the bloom caused the water of the Lower Charles to turn a bright green color.

The 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 Lower 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 and heat or thermal load has been identified as a potential pollutant of concern for contributing to excessive algal growth and the proliferation of undesirable cyanobacteria (blue-green) algae species in the Basin.

1.3 Applicable Water Quality Standards

1.3.1 Designated Uses

The applicable Massachusetts Water Quality Standards identify the Lower Charles River as a Class B water that is designated to support aquatic life and recreational uses. According to the MAWQS (MassDEP 2000), these waters are designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. These waters shall have consistently good aesthetic value.

1.3.2 Water Quality Criteria

A summary of the Massachusetts water quality criteria that are relevant to the Lower Charles River and this TMDL study are presented in Table 1-1, including those criteria that are in non-attainment because of excessive algal biomass. There are no numeric criteria specifically for excessive algal biomass, therefore criteria for pollutants that potentially contribute to excessive algal biomass in the Lower Charles River are included in Table 1-1.

Table 1-1. Applicable Massachusetts water quality criteria

Pollutant	Criteria	Source
Dissolved Oxygen	Shall not be less than 5.0 mg/L in warm water fisheries unless background conditions are lower; natural seasonal and daily variations above these levels shall be maintained; and levels shall not be lowered below 60 percent of saturation in warm water fisheries due to a discharge.	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	Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication.	314 CMR: 4.05: Classes and Criteria (5)(c)

Source: MAWQS, 314 Code of Massachusetts Regulations (CMR) 4.05 (MassDEP 2000).

Permit conditions for any discharger cannot allow a source to cause or contribute to the non-attainment of the water quality standards. The MAWQS state the following for permitted discharges: The MassDEP will limit or prohibit discharges of pollutants to surface waters to assure that surface water quality standards of the receiving waters are protected and maintained or attained. The level of treatment for an individual discharger will be established by the discharge permit in accordance with 314 CMR 3.00. In establishing water quality based effluent limitations the MassDEP shall take into consideration background conditions and existing discharges. Discharges shall be limited or prohibited to protect existing uses and not interfere with the attainment of designated uses in downstream adjacent segments. The MassDEP shall provide a reasonable margin of safety to account for any lack of knowledge concerning the relationship between the pollutants being discharged and their impact on water quality (314 CMR: 4.03: Application of Standards (1) Establishment of Effluent Limitations).

2 DESCRIPTION OF THE STUDY AREA

2.1 Land Use

The land uses surrounding the Lower Charles River are predominantly urban. The four major tributary watersheds to the Lower Charles are as follows: Stony Brook (8,393 acres), Muddy River (4,005 acres), Laundry Brook (3,038 acres), and Faneuil Brook (1,151 acres). These four watersheds have relatively large drainage areas accounting for approximately 72 percent of the Lower Charles River's immediate watershed. Land cover in these watersheds is predominantly residential (high density and multi-family). Table 2-1 identifies the tributary watersheds, drainage area size, and the dominant land use types in these watersheds (modified from Weiskel et al. 2005). Figure 2-1 depicts the land use types in the Lower Charles River watershed.

Table 2-1. Characteristics of major watersheds and small catchment areas tributary to the Lower Charles River

Major Watershed or Small Catchment Area[a]	Drainage Area (acres)	Dominant Land Uses[b]
Laundry Brook	**3,038**	**HD, MD, F**
Watertown West local drainage	153	HD, UO, C
Watertown Sq. Drain	560	HD, UO
Newton West local drainage	71	HD, C
Hyde Brook	439	HD, UO
Newton East local drainage	58	HD, T, R
Watertown Central local drainage	205	HD, I
Watertown East local drainage	97	T, R
Brighton local drainage	190	HD, T, C
Faneuil Brook	**1,151**	**HD, MF, C**
Sawins Pond Brook	579	HD, I
Shepard Brook	414	I, MF, UO
Soldier's Field Local Drainage	169	R, T
Mt. Auburn Cem. local drainage	311	UO, T
CSO (CAM 005)[c]	---	---
Sparks St. local drainage	194	MD, UO, HD
CSO (CAM 007)[c]	---	---
Harvard Square local drainage	231	MF, UO, C
CSO (CAM 009)[c]	---	---
No. Harvard Street local drainage	56	HD, UO
Harvard Bus. School Local drainage	72	UO, MF, C
CSO (CAM 011)[c]	---	---
North Putnam Ave. local drainage	132	HD, T
Western Ave. local drainage	92	HD, T, C
Cambridge Street local drainage	218	T, C, I
Riverside local drainage	68	MF, C
Smelt Creek	494	MF, HD, C
Magazine Beach local drainage	76	MF, R, UO
CSO (MWR 201; Cottage Farm)[c]	---	---
Halls Pond Drain	227	C, HD, MF, UO

Major Watershed or Small Catchment Area[a]	Drainage Area (acres)	Dominant Land Uses[b]
St. Mary's Street Drain	91	HD, C
Boston University local drainage	81	MF, UO, C
Cambridgeport local drainage	144	MF, C, UO
Muddy River Conduit	135	C, MF, UO
Bay State Rd. local drainage	31	C, T
MIT West local drainage	172	C, MF, UO
Muddy River	**4,005**	**HD, MF, UO**
CSO (BOS 046)	---	----
Stony Brook	**8,393**	**HD, MF, UO, F**
CSO (MWR 023)	---	----
MIT East local drainage	199	C, UO, T
CSO (MWR 018)[c]	---	---
CSO (MWR 019)[c]	---	---
CSO (MWR 020)[c]	---	---
CSO (MWR 021; Closed)[c]	---	---
CSO (MWR 022; Closed)[c]	---	---
CSO (CAM 017)[c]	---	---
Lechmere local drainage	120	C, MF

[a] Note that major watershed areas are in bold font.
[b]HD = High-density single-family residential; MD = Medium-density single-family residential; F = Forest; UO = urban open space; C = commercial; T = Transportation; R = Spectator or participant recreation; I = Industrial; MF = Multi-family residential
[c]Data for combined sewer overflow (CSO) catchment areas are not included because of the active sewer-separation projects occurring in these watershed areas. For current status of the Charles River CSO projects, see Massachusetts Water Resources Authority website (www.mwra.state.ma.us/).
Source: Weiskel et al. 2005

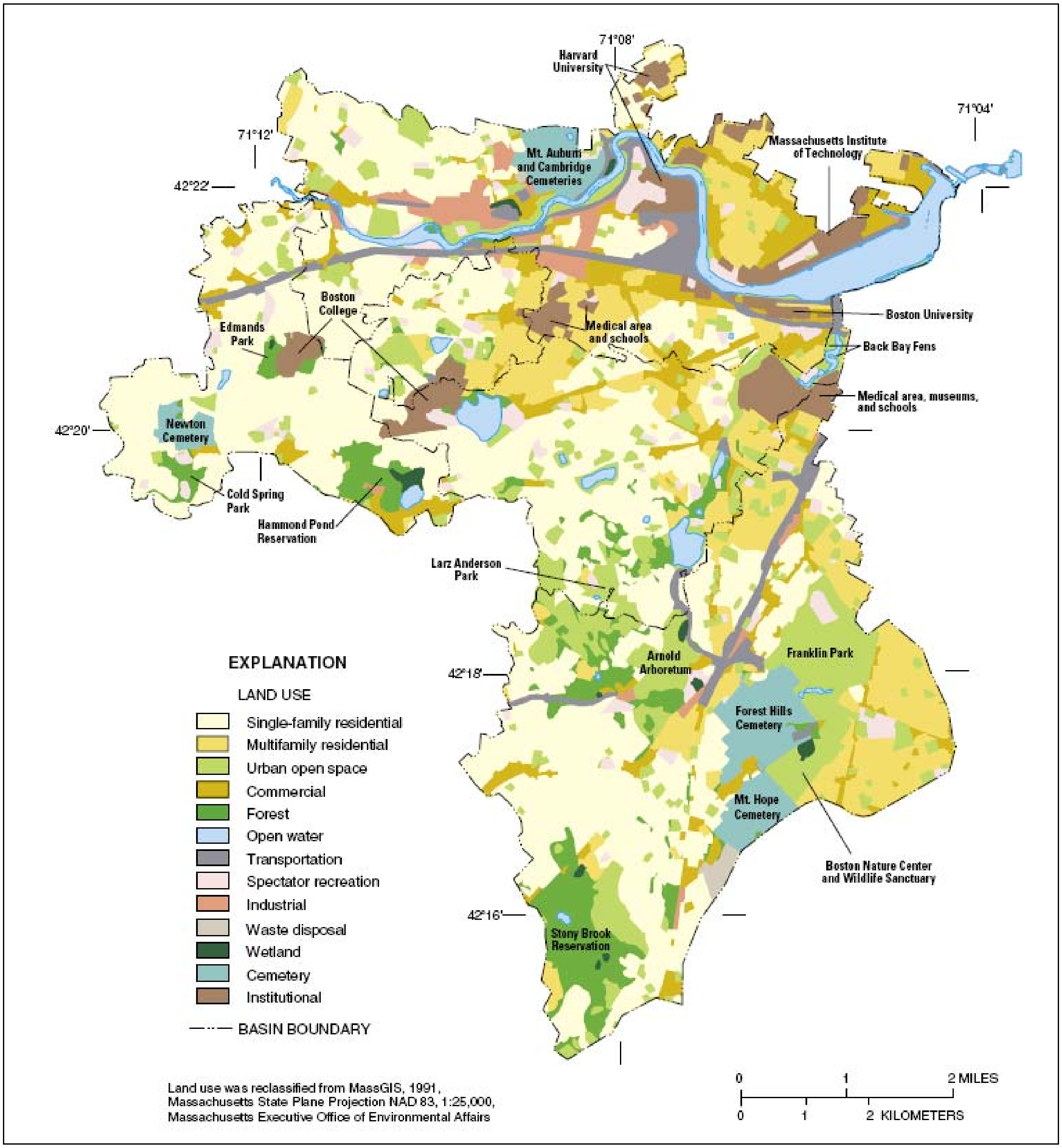

Figure 2-1. Land use types in the Lower Charles River watershed (Weiskel et al. 2005)

2.2 Soils

General soil data for the United States are provided as part of the Natural Resources Conservation Service's (NRCS) State Soil Geographic (STATSGO) database. Soil data from this database and a geographic information system (GIS) coverage from NRCS were used to characterize soils in the Lower Charles River watershed, as well as in the watershed upstream of the Watertown Dam. In general, the soil series identified in the database are well- to moderately well-drained soils that are derived from glacial till and outwash. Much of the lower watershed that drains directly to the Lower Charles River is identified as "urban land." Soils classified as urban land tend to be near the river in areas that have been historically filled to eliminate tidal marshes and mud flats (Zarriello and Barlow 2002). Since the watershed surrounding the Lower Charles River is in such a highly urbanized area, much of the area is impervious because of paving. Based on a previous modeling effort in the lower watershed, impervious percentages for single-family, multi-family, and commercial land uses were determined to be approximately 17, 73, and 86 percent, respectively (Zarriello and Barlow 2002).

2.3 Climate

The Boston area has a fairly typical four-season climate and is characterized as humid temperate. There is no wet or dry season as precipitation is reasonably consistent with about 3 inches of rain per month and average annual precipitation of 41.5 inches. The average annual snowfall of 42.4 inches usually occurs from November through early April, although, most snowfall occurs in January and February. The hottest months are July and August, while the coldest months are January and February. The average annual temperature is 51.3 degrees Fahrenheit (°F) (10.7°C). The average annual maximum temperature is 59 °F (15°C) and the average annual minimum temperature is 43.6 °F (6.4°C). Days with maximum temperatures of 90 °F (32.2°C) or greater usually occur 12 days of the year and there are approximately 97 days with minimum temperatures below freezing.

2.4 Hydrology

During any given year, the Lower Charles River experiences large variations in flow because of the size of the upstream watershed (268 square miles) draining over the Watertown Dam and the highly urbanized watershed that drains directly to the Lower Charles River. Daily average river flow data entering the Lower Charles River at Watertown Dam (1997-2004) were reviewed. During this period, flows ranged from a low of 16 cubic feet per second (cfs) to a high of 2,143 cfs. Generally, annual high flows at Watertown Dam occur during the spring thaw period and low flows occur during the summer months. Occasionally, and regardless of the time of year, large rain events occur and produce high flow conditions in the Lower Charles River.

Of particular interest is the summer period when growth conditions for algae are optimal. The low flows that occur in the Lower Charles River during the summer period favor algal growth because of the associated increase in water residence time. The impounded Basin maintains a water volume of approximately 370 million cubic feet (Cowden 2001) and tends to have relatively long water residence times (typically 4 to 10 weeks) during the summer months when river flow rates decline. As flows decline, the amount of time a unit volume of water spends in the Lower Charles River increases. Increased water residence time allows algae populations more time to grow and take advantage of the favorable sunlight, temperature, and nutritional conditions. Summer flows vary year-to-year depending primarily on the amount of rainfall in the watershed. Table 2-2 presents a summary of the average daily flows entering the Lower Charles River at Watertown Dam for the summer periods (July 1 - Sept 30) of 1997 through 2004. The table also includes the estimated summer average water residence times of the Basin assuming completely mixed conditions (i.e., without stratification) and with stratification (based on average observed pycnocline – top of salt water layer – depth of 15 feet). Salt water intrusion into the Basin through the New Charles River Dam results in a portion of the Basin becoming vertically stratified with two distinct layers; a fresh water layer overlying a more dense salt water layer (see Section 3.2.3 for more detail). When the water column of the Basin is vertically stratified the water residence time is reduced by approximately 10 percent because there is less volume to be displaced by the incoming fresh water. The seven-day low-flow at the Watertown Dam, flow that occurs over a seven day period approximately once every 10 years (7Q10 flow), and the calculated residence times are also shown in Table 2-2. Although not apparent in Table 2-2 that represents average conditions, low flows, at or near the 7Q10 flow value were observed in the Lower Charles River during the summers of 1997, 1999, 2001, and 2002.

Table 2-2. Summer average daily flow at Watertown Dam and water residence time of the Charles River Basin (July 1-September 30)

Year	Average Daily Flow At Watertown Dam (cfs)	Water Residence Time	
		Basin without stratification (days)	Basin with stratification (days)
1997	37	118	104
1998	408	11	9
1999	165	26	23
2000	183	24	21
2001	202	22	19
2002	64	68	60
2003	311	14	12
2004	244	18	16
Average/Range	202/37 – 408	38/11 – 118	20/9 – 41
7Q10	18	242	213

As indicated in Table 2-2, there is considerable variation in average summer flow conditions from year to year. The summers of 1997 and 2002 had drier weather and low-flow conditions (37 and 64 cubic feet per second (cfs), respectively), while 1998 and 2003 had more wet-weather and high-flow conditions (408 and 311 cfs, respectively). July through August of 1999 was also a very dry period and resulted in very low flows in the Lower Charles River until early September when a series of larger rain events occurred and river flows increased substantially. During the wetter years (2000, 2001, 2003, and 2004) the actual flows passing through the Lower Charles River were higher than shown in Table 2-2 because of the runoff from the tributary streams and drainage systems that directly enter the Lower Charles below Watertown Dam.

The effect on water residence time of the Lower Charles River during storm events is complicated by the operation of the New Charles River Dam. As part of its flood control procedures, operators of the Dam lower the water level of the Lower Charles River before a forecasted rain event to provide storage for the anticipated runoff from the watershed. However, in the Boston area it is not uncommon to have extended periods of dry-weather during the summer months (e.g., 1997, 1999, 2001, and 2002) when water residence times in the Basin exceed 70 days even when the Basin is vertically stratified. As evidenced by the high chlorophyll *a* concentrations measured in the Basin for each of the monitoring seasons (1998 through 2004) (see Section 3.2.1), the water residence times in the Basin during the summers are sufficiently long to support algal blooms.

3 PRESENT CONDITION OF THE WATERBODY

In order to determine the present conditions of the Lower Charles River, it was necessary to review all available water quality data. Section 3.1 provides an inventory of available water quality data, while Section 3.2 provides a description of the current state of the waterbody based on these data. Section 3.3 compares the available water quality data to the applicable water quality criteria and Section 3.4 presents the potential sources of pollutants.

3.1 Water Quality Data

Water quality data for the Lower Charles River were obtained from the EPA, the Charles River Watershed Association (CRWA), the Massachusetts Water Resources Authority (MWRA), the United States Geological Survey (USGS), and Mirant (owner/operator of the Kendall Square Station power generation facility). The water quality monitoring programs organized by these groups in the Lower Charles River watershed are described below.

EPA Water Quality Data

In 1998, EPA New England's Regional Laboratory began an annual Core Monitoring Program to document water quality conditions and track water quality improvements in the Lower Charles River as pollution controls are implemented. EPA's Core Monitoring Program was conducted annually during July, August, and September (1998-2005) when peak recreational uses occur in the Lower Charles River. The EPA monitoring program includes both dry- and wet-weather surveys. Dry-weather sampling occurred at least three times per summer at twelve stations, ten of which were located in the Lower Charles River. Wet-weather sampling occurred typically two times per summer at a minimum of six stations. Samples were analyzed for nutrients, chlorophyll *a*, color, bacteria, metals, dissolved oxygen, temperature, salinity, transparency, and turbidity. In the summer of 2002, EPA collected algal samples at a subset of stations to support development of the TMDL. Starting in 2005, EPA's Core Monitoring Program was revised to conduct dry-weather sampling six times per year from June to October for phosphorus, chlorophyll *a*, temperature, dissolved oxygen, conductivity, transmissivity, turbidity, and bacteria. During August 2006, EPA collected an algal sample in the downstream portion of the Lower Charles because of the obvious presence of a very severe bloom. The sample was analyzed by MassDEP and led to follow-up algal monitoring in the Lower Charles by the MA Dept. of Conservation and Recreation and MassDEP (see section 3.2.2).

EPA's monitoring is conducted in accordance with an approved Quality Assurance Project Plan (QAPP). Figure 3-1 shows the locations of EPA water quality monitoring stations in the Lower Charles River. EPA's Core Monitoring stations, which have been sampled every year since 1998, are identified with "CRBL" plus the station number. Additional water quality monitoring stations that were sampled during the 2002 recreational (summer) season to support the development of the TMDL are identified with “TMDL” plus the station number.

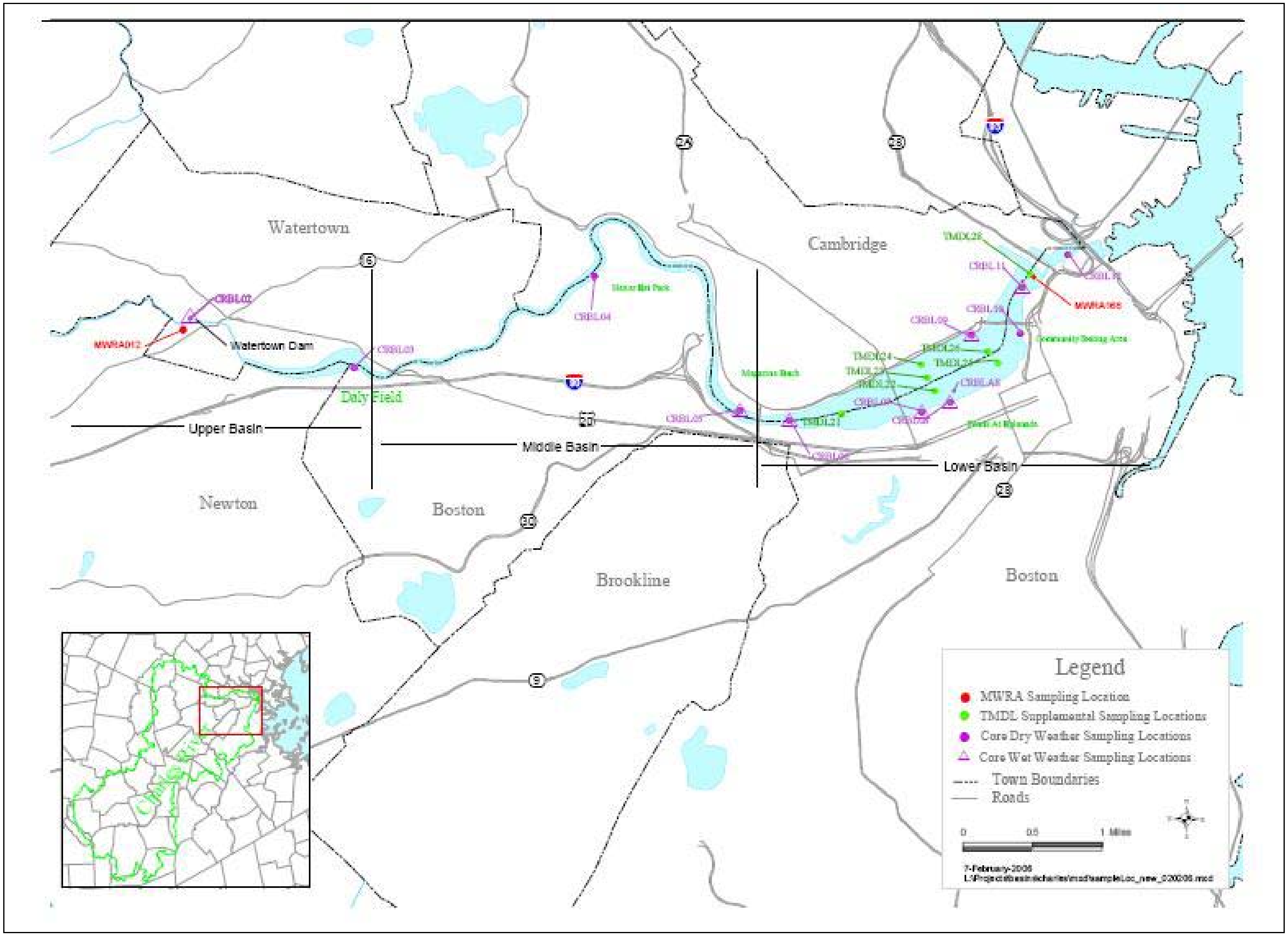

Figure 3-1. Location of the EPA and MWRA monitoring stations in the Lower Charles River

CRWA and MWRA Water Quality Data

The CRWA and the MWRA also routinely sample the Lower Charles River for several water quality parameters. CRWA has sampled four locations in the Lower Charles River quarterly, while MWRA has conducted intensive sampling of the Lower Charles River at numerous locations for over a decade. Much of the MWRA's monitoring is related to its combined sewer overflow (CSO) program and has focused on collecting indicator bacteria data. However, the MWRA has collected nutrient and chlorophyll *a* data at two key locations multiple times per month for the past 9 years. These two locations are (1) upstream of the Museum of Science in the Basin (station 166) and (2) at the Watertown Dam, the upstream boundary of the Lower Charles River (station 012). Both the CRWA and MWRA collect their data in accordance with approved QAPPs. The locations of the two MWRA water quality sampling stations are shown in Figure 3-1.

USGS Water Quality Data

Between 1998 and 2001 the USGS conducted three detailed monitoring investigations of the Lower Charles River that have contributed substantially to the current understanding of water quality conditions of the Lower Charles River. These investigations include (1) an examination of the extent and effects of salt water intrusion into the Lower Charles River from Boston Harbor through the New Charles River Dam, (2) a determination of the distribution and characteristics of bottom sediments, and (3) a pollutant load study that characterizes the sources and loading of several pollutants to the Lower Charles River. Pertinent information from the first two studies is discussed in Section 3.2.3. The latter study on pollutant loads is discussed in Section 3.4. Figure 3-2 presents the locations of the USGS water quality monitoring stations (stream gages).

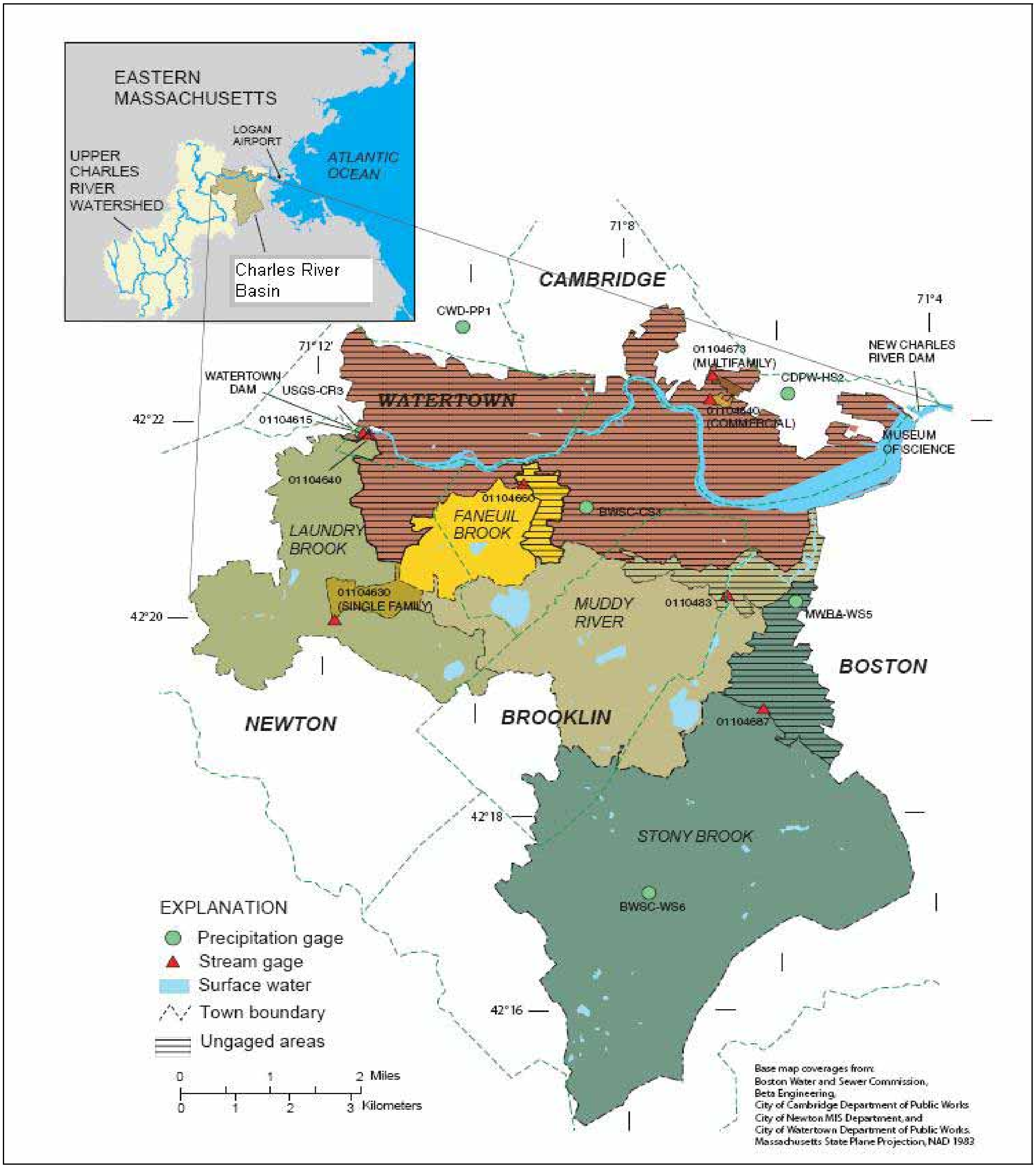

Figure 3-2. Location of the USGS water quality monitoring stations

Mirant Water Quality Data

Mirant, the owner of the Kendall Square Station, a power generation facility located in Cambridge downstream from Longfellow Bridge, also conducted water quality monitoring of the Lower Charles River during the summers of 2001 – 2004. Mirant collected water quality data as part of its re-application for a National Pollution Discharge Elimination System (NPDES) Permit for the Kendall Square Station facility. Mirant does not have an EPA approved QAPP but reportedly collects its data following in-house quality assurance/quality control procedures. Figure 3-3 presents the locations of the Mirant algal monitoring stations.

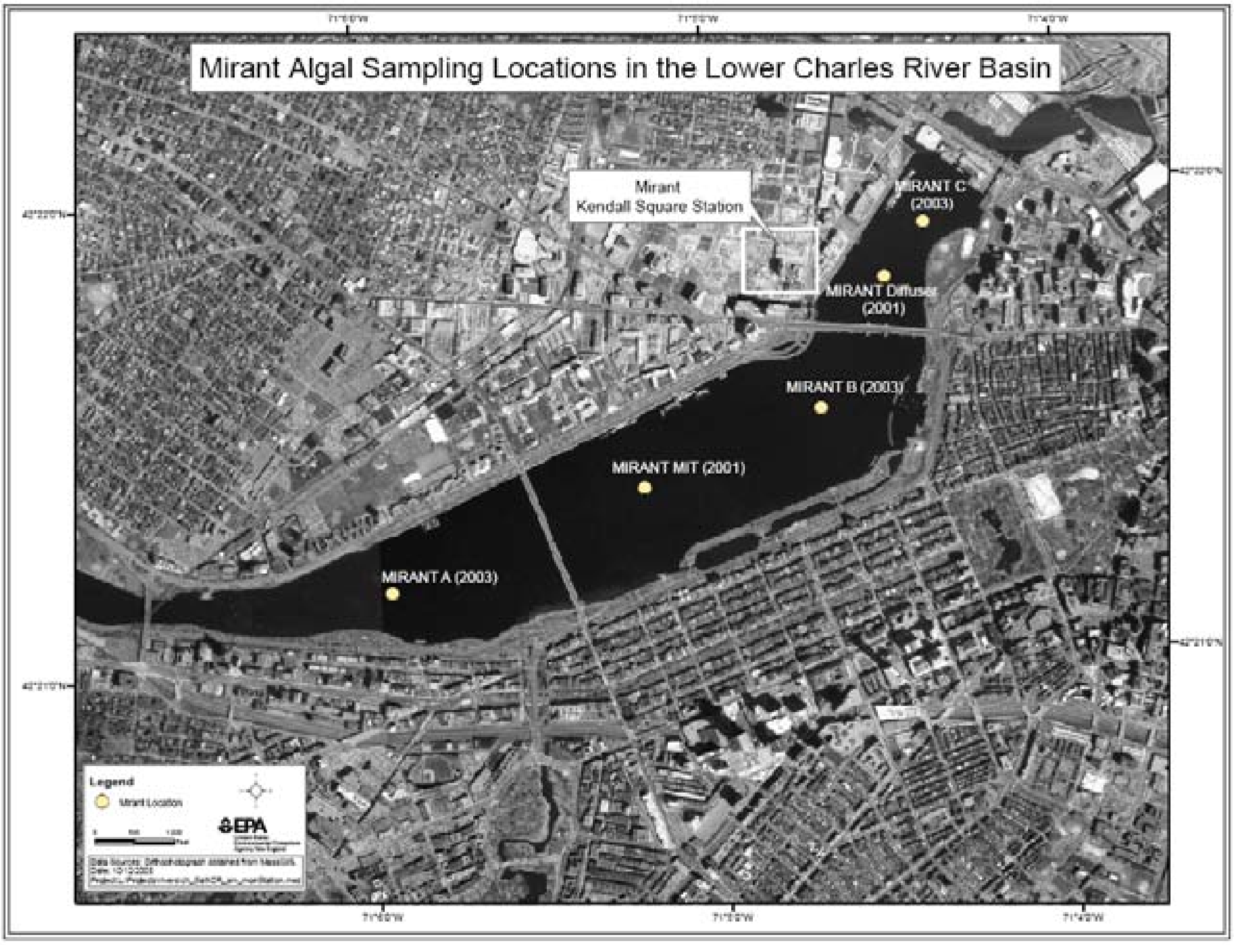

Figure 3-3. Locations of Mirant algal sampling locations in the Lower Charles River

3.2 Current Water Quality Conditions and Data Analysis

3.2.1 Trophic Condition Assessment for the Lower Charles River

This portion of the water quality analysis focuses primarily on parameters associated with the trophic state of the Lower Charles River, which is eutrophic. The trophic state is a description of the biological condition of a waterbody. There are three general trophic states: (1) oligotrophic, indicating low plant biomass; (2) mesotrophic, indicating intermediate plant biomass; and (3) eutrophic, indicating high plant biomass. The term eutrophication indicates that a waterbody is becoming more productive (i.e., producing more plant biomass). High productivity does not have to lead to high biomass if the food web is functioning efficiently, but it usually does lead to algal blooms. Cultural eutrophication, or accelerated eutrophication, indicates that a waterbody is producing more plant biomass as a result of anthropogenic activities such as the direct discharge of pollutants (e.g., nutrients) to the waterbody (USEPA 2000a).

Chlorophyll *a*, total phosphorus (TP), total nitrogen (TN), and Secchi depth are parameters of particular interest because they are commonly used to classify the trophic state of fresh water lakes and impounded river systems. Phosphorus and nitrogen are essential nutrients for plant growth and are, therefore, often used as causal indicators of eutrophication. Chlorophyll *a* and Secchi depth are response indicators that reflect the presence of algae. Chlorophyll *a* is a photosynthetic pigment present in algae cells and, therefore, is a direct indicator of algal biomass. 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 (USEPA 2000a).

Since there are no site-specific parameter values for the Lower Charles River that identify the river's trophic status, the data were compared to available literature values to provide a comparison. Tables 3-1, 3-2, and 3-3 summarize literature values for the commonly used indicator variables (chlorophyll *a*, TP, and Secchi depth) associated with the trophic status of fresh water lakes as reported by several researchers. Note that Table 3-1 provides mean values for chlorophyll *a*, while Table 3-2 provides peak chlorophyll *a* values. Peak chlorophyll *a* values are of interest because they are indicative of instantaneous bloom conditions that could result in impairment of both recreational and aquatic life uses in the waterbody even if average chlorophyll *a* is acceptable. Also shown in Tables 3-2 and 3-3 are values of the indicators for the Basin based on the EPA and MWRA water quality monitoring data, which are discussed in greater detail in the following sections.

Table 3-1. Summary of fresh water system trophic status as characterized by mean chlorophyll *a* concentrations*

Trophic Status	Wetzel (2001) (µg/l)	Ryding and Rast (1989) (µg/l)	Smith (1998) (µg/l)	Novotny and Olem (1994) (µg/l)
Eutrophic	>10	6.7 to 31	-----------	>10
Mesotrophic	2 to 15	3 to 7.4	3.5 to 9	4 to 10
Oligotrophic	0.3 to 3	0.8 to 3.4	----------	< 4

*Table taken in part from USEPA 2003a.

Table 3-2. Fresh water trophic status boundary values for peak chlorophyll *a* and peak chlorophyll *a* observed in the Lower Charles River*

Trophic Status	Peak Range (µg/l)	Charles River Basin (1998 - 2004) (µg/l)
Eutrophic	16.9 –107	41.0 to 97.0
Mesotrophic	8.2 – 29	not applicable
Oligotrophic	2.6 - 7.6	not applicable

*Table taken in part from USEPA 2003a.

Table 3-3. Trophic indicator ranges based on scientists' opinions (after Vollenweider and Carekes 1980)[a]

Variable	Oligotrophic	Mesotrophic	Eutrophic	Basin 1998 - 2004 [c]
Total phosphorus (µg/l)				
Mean [b]	8	27	84	68
Range (n)	3 – 18 (21)	11 – 96 (19)	16- 390 (71)	61 - 76
Chlorophyll *a* (µg/l)				
Mean [b]	1.7	4.7	14	17.7
Range (n)	0.3 - 4.5 (22)	3 - 11 (16)	2.7 - 78 (70)	14.8 - 21.8
Peak chlorophyll *a* (µg/l)				
Mean	4.2	16	43	54.2
Range (n)	1.3 - 11 (6)	5 - 50 (12)	10 - 280 (46)	41.0 - 97.0
Secchi depth (meters)				
Mean [b]	9.9	4.2	2.4	1.2
Range (n)	5.4 - 28 (13)	1.5 - 8.1 (20)	0.8 - 7.0 (70)	1.0 - 1.5

[a]Table taken in part from USEPA 2000b.
[b]Means are geometric annual means (log 10), except peak chlorophyll *a*.
[c]Based on data collected by the EPA and MWRA from the Charles River Basin, 1998-2004.

To characterize the Lower Charles River's water quality and trophic status, the following discussion relies primarily on the EPA and MWRA data because: (1) EPA's monitoring program has provided the greatest spatial coverage for the parameters of concern in the Lower Charles River (ten stations) during the peak recreational season (summer months) and (2) the MWRA data have provided the greatest temporal coverage for the parameters of concern at two key locations (the upper boundary at Watertown Dam and near the lower boundary, just upstream of the Museum of Science). A review of CRWA's data has found them to be consistent with the EPA and MWRA data, but because they include only one sampling event during the July - October period, they are not summarized in this report. Mirant's data have also been reviewed and found to reflect water quality conditions that are consistent with the EPA and MWRA data. Since ample water quality data collected in accordance with approved QAPPs by the EPA and MWRA are available and summarized in this report, Mirant's nutrient and chlorophyll *a* data are not presented. However, some of Mirant's data concerning algal species are discussed in Section 3.2.2.

The EPA and the MWRA used different methods to analyze samples for chlorophyll *a*. EPA's chlorophyll *a* samples were analyzed using a spectrophotometric method and were not corrected for phaeophytin in the laboratory, while the MWRA chlorophyll *a* samples were analyzed using a fluorometric method and were corrected for phaeophytins. For this report, EPA's chlorophyll *a* data have been corrected for phaeophytins using the MWRA's phaeophytin data collected at the nearest station and closest date. As discussed below, the EPA and MWRA chlorophyll *a* data are consistent and indicate similar levels of algae biomass in the Lower Charles River.

EPA Nutrient, Chlorophyll a, and Secchi Disc Depth Data

Tables 3-4, 3-5, and 3-6 summarize EPA's measurements of summer season dry-weather ambient chlorophyll *a*, TP, and Secchi disc depths, respectively, for the Lower Charles River during the years 1998 through 2004. The individual data can be found in EPA's annual Clean Charles Water Quality Reports (USEPA 1999-2005). The data have been organized into three groups: Upper, Middle, and Lower sections, to characterize varying conditions in the Lower Charles River. The Upper section is between Watertown Dam and Daly Field; the Middle section is between Daly Field and the BU Bridge, and the Lower section is downstream from the BU Bridge (see Figure 3-1). The values presented for each segment represent data from multiple stations (see notes for each Table) for the dry-weather and the pre- and post- wet-weather surveys conducted during the identified sampling season. One objective of this portion of the data analysis is to evaluate the trophic status of the Lower Charles River for the summer growing season. Considering the extended periods of dry-weather conditions that typically occur in the Lower Charles River during the summer seasons, the dry-weather data are thought to be more useful for evaluating the trophic status.

Data collected during rain events are not included in Tables 3-4 through 3-6 because wet-weather levels of chlorophyll *a*, TP, and Secchi depths are not considered to be representative of longer term ambient conditions in the Lower Charles River when algal blooms become prevalent. Because of the hydrodynamics of the Lower Charles during significant rain events (lower retention times), wet-weather nutrient, chlorophyll *a*, and secchi depth data reflect conditions in the river that occur for only short periods of time during and shorthly after rain events. Including the wet-weather data in the statistics presented in Tables 3-4 through 3-6 would bias the results and indicate higher levels of TP, slightly lower chlorophyll *a* and lower Secchi depth measurements than what typically occurs in the Lower Charles during critical growth conditions. While wet-weather phosphorus loading to the Lower Charles is a very important source that needs control, the impact of this loading on algal growth is much more prominent during dry weather when conditions are favorable for algal growth. In other words, the dry-weather data better reflect the long-term algal-related water quality impacts that occur due, in part, to wet-weather phosphorus sources (i.e., stormwater, combined sewer overflows, and nonpoint sources). As discussed below in Section 3.4.1, this TMDL fully accounts for the importance of the wet-weather phosphorus sources and loadings.

Table 3-4. Summary of EPA seasonal (July–October) dry-weather chlorophyll *a* data for the Lower Charles River

	Chlorophyll *a* (µg/l)						
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Upper Basin							
Mean	3.4	8.3	4.5	4.1	5.5	4.1	15.7
Median	3.9	5.7	4.1	4.7	5.9	4.2	6.8
Min – Max	0.8 - 4.6	2.6 - 18.8	1.2 - 6.8	1.1 - 7.4	1.1 - 11.7	2.8 - 5.4	1.6 - 42.6
Number of Surveys (s)	4	7	7	4	7	4	6
Number of Samples (n)	8	10	10	7	12	7	9
Middle Basin							
Mean	15.8	29.1	33.8	23.8	23.8	21.9	30.9
Median	15.8	29.5	32.8	23.6	24.1	15.0	26.2
Min – Max	2.6 - 69.6	9.9 - 50.3	18.3 - 63.4	4.6 - 42.4	11.4 - 34.3	9.8 - 50.8	2.9 - 53.0
Number of Surveys (s)	4	7	7	5	7	4	6
Number of Samples (n)	8	10	10	8	12	7	9

	Chlorophyll *a* (µg/l)						
	1998	1999	2000	2001	2002	2003	2004
Lower Basin							
Mean	15.1	27.1	23.5	24.6	18.4	18.4	24.0
Median	10.9	16.1	26.7	25.4	16.4	19.4	26.6
Min – Max	4.5- 46.6	7.2- 97.0	5.0 - 41.0	4.7 - 47.7	1.5 - 41.5	3.3 - 47.7	4.4 - 55.4
Number of Surveys (s)	4	7	7	5	7	4	6
Number of Samples (n)	20	34	31	23	73	22	28

*Notes: Upper Basin values represent data from EPA stations CRBL02 and 03; Middle Basin values represent data from EPA stations CRBL04 and 05; and Lower Basin values represent data from EPA stations CRBL06, 07, 8A, 09, 10, and 11. In 2002 the Lower-Basin values also represent data from EPA stations TMDL 21, 22, 23, 24, 25, 26, and 28.

Table 3-5. Summary of EPA seasonal (July–October) dry-weather total phosphorus data for the Lower Charles River

	Total Phosphorus (µg/l)						
	1998	1999	2000	2001	2002	2003	2004
Upper Basin							
Mean	155	71	82	55	55	68	49
Median	130	62	80	55	54	90	48
Min – Max	100 - 300	50 - 110	50 - 140	40 - 100	34 - 80	30 - 100	29 - 71
Number of Surveys (s)	4	7	7	5	8	4	6
Number of Samples (n)	8	10	10	8	13	7	9
Middle Basin							
Mean	119	78	112	80	61	69	57
Median	120	74	105	80	57	87	50
Min – Max	90 - 140	50 - 110	63 - 180	60 - 100	44 - 84	25 - 95	37 - 82
Number of Surveys (s)	4	7	7	5	8	4	6
Number of Samples (n)	8	10	10	8	13	7	9
Lower Basin							
Mean	108	78	83	70	50	60	46
Median	105	80	80	60	45	58	43
Min – Max	80 - 200	50 - 120	50 - 150	40 - 120	20 - 93	17 - 92	18 - 96
Number of Surveys (s)	4	7	7	6	8	4	6
Number of Samples (n)	20	34	31	27	77	22	28

*Notes: Upper Basin values represent data from EPA stations CRBL02 and 03; Middle Basin values represent data from EPA stations CRBL04 and 05; and Lower Basin values represent data from EPA stations CRBL06, 07, 8A, 09, 10, and 11. In 2002 the Lower-Basin values also represent data from EPA stations TMDL 21, 22, 23, 24, 25, 26, and 28.

Table 3-6. Summary of EPA seasonal (July – October) dry-weather Secchi depth data for the Lower Charles River

	Secchi Depth (m)						
	1998	1999	2000	2001	2002	2003	2004
Upper Basin							
Mean	0.9	1.2	1.1	1.3	1.1	1.3	1.3
Median	0.9	1.3	1.1	1.3	1.1	1.3	1.4
Min – Max	0.7 - 1.3	1.2- 1.3	0.8 - 1.5	1.2 - 1.4	0.9 - 1.4	1.2 - 1.3	1.0 - 1.5
Number of Surveys (s)	4	3	4	3	5	3	3
Number of Samples (n)	5	3	4	3	5	3	3
Middle Basin							
Mean	0.8	1.0	0.9	1.0	1.0	1.0	0.9
Median	0.8	1.1	0.9	1.1	1.0	1.0	0.8
Min – Max	0.6 - 1.0	0.7 - 1.2	0.7 - 1.1	0.6 - 1.2	0.9 - 1.4	0.7 - 1.2	0.6 - 1.3
Number of Surveys (s)	5	7	6	4	7	4	5
Number of Samples (n)	9	10	9	7	12	7	8
Lower Basin							
Mean	1.0	1.4	1.2	1.2	1.5	1.3	1.3
Median	1.0	1.4	1.1	1.0	1.4	1.2	1.3
Min – Max	0.6 - 1.5	0.7 - 1.8	0.8 - 1.7	0.8 - 1.7	1.0 - 2.2	0.7 - 1.6	0.7 - 1.8
Number of Surveys (s)	4	7	6	4	7	4	5
Number of Samples (n)	20	34	27	19	73	22	25

*Notes: Upper Basin values represent data from EPA stations CRBL02 and 03; Middle Basin values represent data from EPA stations CRBL04 and 05; and Lower Basin values represent data from EPA stations CRBL06, 07, 8A, 09, 10, and 11. In 2002 the Lower-Basin values also represent data from EPA stations TMDL 21, 22, 23, 24, 25, 26, and 28.

Tables 3-4, 3-5, and 3-6 present the number of sampling surveys (s), the number of samples (n), the ranges of the data (minimum and maximum), the medians, and the arithmetic means for each sampling season. The values for each of the parameters tend to vary considerably during the summer season. This variability is not unusual for these parameters in impounded river systems like the Lower Charles River that drain a sizeable watershed and experience wide variations in flow, merely as a consequence of precipitation and runoff. Also, chlorophyll *a* concentrations tend to be highly variable in most aquatic systems during the summer season. High variability is due to the natural cycling of the algal community as it goes through growth and death phases and according to changing environmental conditions (i.e., sunlight intensity, temperature, nutrient availability, and residence time).

Mean chlorophyll *a* concentrations reported in Table 3-4 for the Middle and Lower sections ranged from 15.8 to 33.8 µg/l and 15.1 to 27.1 µg/l, respectively. These values indicate eutrophic conditions and that moderate to severe algal blooms have occurred in this section of the Lower Charles River during each year of EPA's Core Monitoring Program. In contrast, chlorophyll *a* concentrations in the Upper section of the Lower Charles are consistently less, and are not indicative of regularly occurring algal bloom conditions. Mean chlorophyll *a* values in the Upper section during the years 1998 through 2003 ranged from 3.4 to 8.3 µg/l. During 2004, the mean chlorophyll *a* value in the Upper Basin increased (to 15.7 µg/l), in part because of an extensive bloom that developed in the river in the upstream watershed and moved into the Lower Charles River. The shorter water residence time or higher flushing rate in the Upper section is one likely reason that algae levels are lower since shorter residence times provide less time for algae to grow and accumulate. It also appears that the chlorophyll *a* levels in the Upper section are largely a function of the chlorophyll *a* levels coming over the Watertown Dam, which are typically much lower than levels in the downstream sections of the Lower Charles.

The TP concentrations summarized in Table 3-5 are also indicative of eutrophic conditions throughout the Lower Charles River with seasonal means ranging from 46 to 155 µg/l. There is a noticeable decline in seasonal mean TP concentrations after the year 2000, which coincides with when the wastewater treatment facilities (WWTF) in the upper watershed were required to reduce summertime TP concentrations in their effluent from 1000 µg/l to 200 µg/l. For instance, mean summer TP concentrations in the Lower Basin ranged from 78 to 108 µg/l from 1998 through 2000 and 46 to 70 µg/l from the summers of 2001 through 2004. While TP concentrations tend to vary considerably during the sampling season (e.g., 18 - 96 µg/l, Lower section in 2004), TP concentrations are typically at levels that are sufficient to support excessive algal growth when conditions are most favorable (i.e., increased water clarity, high sunlight intensity, and high water temperatures) (Kalff 2001).

Secchi depths indicate low water clarity and eutrophic conditions throughout the Lower Charles River with means ranging from 0.8 to 1.5 meters (Table 3-6). The highest Secchi depth measurements and water clarity consistently occur in the Lower section. However, water clarity in the Lower section is still low and indicates eutrophic conditions given that maximum Secchi depths rarely exceeded 1.8 meters. Although Secchi depths in the Lower Charles River are unquestionably affected by algae, Secchi depths are also affected by other suspended solids and the brownish-stained or “tea” color of the Charles River. The “tea” color of the Charles River varies seasonally and is discussed in Section 3.2.2 as it affects algal growth in the Basin.

MWRA Nutrient and Chlorophyll a Data

Tables 3-7, 3-8, and 3-9 summarize the MWRA data (1997 through 2004) for chlorophyll *a* and nutrient concentrations collected at two locations: (1) upstream of the Museum of Science in the Basin (MWRA station 166) and (2) at the Watertown Dam, the upstream boundary of the Lower Charles River (MWRA station 012). Refer to Figure 3-1 for the locations of MWRA stations 012 and 166. The MWRA data reflect a greater number of sampling surveys conducted during the period of interest (July to October) than do the EPA data. The greater number of surveys allow for an additional summary statistic, the 90^{th} percentile, to be provided. The MWRA data differ from the EPA dry-weather data presented in Tables 3-4 through 3-6 in that some of the MWRA data included in the analysis reflect wet-weather impacts. The MWRA’s nutrient monitoring program in the Charles River was conducted weekly throughout the year (Taylor 2002). During some of the scheduled weekly sampling events, wet-weather and residual wet-weather conditions existed.

Table 3-7. Summary of MWRA seasonal (July – October) chlorophyll *a* concentrations for the Lower Charles River

Year	MWRA Station	Station Description	Chlorophyll *a* (µg/l)				Number of Observations
			Min-Max	Median	Mean	90th Percentile	
1997	12	Watertown Dam	2.6 - 47.0	4.1	8.6	17.8	18
	166	Upstream of Museum of Science	17.6 – 88.2	37.8	44.8	81.5	18
1998	12	Watertown Dam	2.0 - 37.6	7.4	12.3	27.8	18
	166	Upstream of Museum of Science	4.7 - 48.0	16	18.3	38.4	18
1999	12	Watertown Dam	2.0 - 16.2	5.8	7.2	14.4	17
	166	Upstream of Museum of Science	5.1 - 87.6	19.2	25.7	52	17
2000	12	Watertown Dam	2.6 - 25.5	6.4	8.4	14.2	17
	166	Upstream of Museum of Science	3.4 - 42.2	19.9	19.5	31.5	17
2001	12	Watertown Dam	3.0 - 17.2	4.1	5.1	6.8	17
	166	Upstream of Museum of Science	5.3 - 45.5	26.8	25.3	37.1	18
2002	12	Watertown Dam	1.7 - 14.7	4.2	5.9	11.1	17
	166	Upstream of Museum of Science	3.4 - 35.7	20.5	21.7	33.8	16
2003	12	Watertown Dam	2.9 - 29.2	6.2	9.5	17.5	8
	166	Upstream of Museum of Science	7.4 - 39.1	21.8	22	36.9	8
2004	12	Watertown Dam	1.7 - 32.2	8.4	12.8	30.9	7
	166	Upstream of Museum of Science	2.6 - 45.7	17	20	37.6	9
1997 - 2004	12	Watertown Dam	1.7 - 47.0	5.5	8.4	16.4	119
	166	Upstream of Museum of Science	2.6 - 88.2	22.1	25.3	41.5	121

Table 3-8. Summary of MWRA seasonal (July – October) total phosphorus data for the Lower Charles River

Year	MWRA Station	Station Description	Total Phosphorus (µg/l)				Number of Observations
			Min - Max	Median	Mean	90th Percentile	
1997	12	Watertown Dam	42 - 79	60	60	74	18
	166	Upstream of Museum of Science	42 -101	61	66	98	18
1998	12	Watertown Dam	49 -165	81	86	125	18
	166	Upstream of Museum of Science	38 - 133	70	75	113	18
1999	12	Watertown Dam	50 - 124	87	82	103	15
	166	Upstream of Museum of Science	43 - 117	75	78	107	15
2000	12	Watertown Dam	49 - 121	67	69	88	17
	166	Upstream of Museum of Science	39 - 110	61	64	96	17
2001	12	Watertown Dam	49 - 157	65	78	123	17
	166	Upstream of Museum of Science	48 - 149	65	78	123	18
2002	12	Watertown Dam	29 - 93	54	59	84	15
	166	Upstream of Museum of Science	28 - 109	81	76	104	9
2003	12	Watertown Dam	50 - 108	79	77	107	8
	166	Upstream of Museum of Science	52 - 116	58	69	95	8
2004	12	Watertown Dam	54 - 108	74	79	108	7
	166	Upstream of Museum of Science	53 - 99	62	64	84	9
1997 - 2004	12	Watertown Dam	29 - 165	69	73	107	115
	166	Upstream of Museum of Science	28 - 149	65	72	105	111

Table 3-9. Summary of MWRA seasonal (July – October) total nitrogen data for the Lower Charles River

Year	MWRA Station	Station Description	Total Nitrogen (µg/l)				Number of Observations
			Min-Max	Median	Mean	90th Percentile	
1998	166	Upstream of Museum of Science	730-1,220	1,080	1,040	1,210	18
1999	166	Upstream of Museum of Science	580-1,140	800	850	1,080	15
2000	166	Upstream of Museum of Science	690-1,300	940	980	1,230	17
2001	166	Upstream of Museum of Science	650–1,400	800	920	1,290	17
2002	166	Upstream of Museum of Science	650-1,510	880	1,040	1,580	10
2003	166	Upstream of Museum of Science	560-1,180	900	910	1,110	8
2004	166	Upstream of Museum of Science	570-1,300	810	880	1,240	9
1997-2004	166	Upstream of Museum of Science	560-1,510	920	950	1,230	94

The MWRA chlorophyll *a* and TP data are similar to the EPA data. For example, chlorophyll *a* concentrations in the Basin at station 166 (Table 3-7) are elevated (1998 through 2004 means ranging from 18.3 to 25.7 µg/l) and indicate eutrophic conditions, while at the Watertown Dam (MWRA station 012) the chlorophyll *a* concentrations are significantly lower (1998 through 2004 means ranging from 5.1 – 12.8 µg/l), reflecting more mesotrophic conditions. Both the maximum and 90th percentile chlorophyll *a* values at station 166 were at levels indicating that moderate to severe blooms occurred during each of the years. Similar to the EPA data, TP concentrations at both MWRA stations 012 and 166 (Table 3-8) showed considerable range and were consistently at levels sufficient to support excessive algal growth. However, the declining trend observed in EPA's dry-weather data is not evident in the MWRA data. One possible explanation for this is the impact of wet-weather or residual wet-weather conditions on TP levels, which, as discussed above, would cause the average TP concentration to increase.

Table 3-9 summarizes MWRA's TN data for station 166. Although EPA regularly sampled for ammonia and nitrite/nitrate, the MWRA data at station 166 are used to characterize nitrogen levels in the Basin since this is the only station with a long term (1998 -2004) TN record. TN concentrations typically varied during the season by approximately a factor of two, while TN seasonal means ranged from 850 to 1,040 µg/l. Typically, TN levels were higher in the early part of the season and declined as river flow entering the Lower Charles River dropped, indicating the nonpoint sources from the upper watershed are an important source of nitrogen. Total nitrogen concentrations measured at MWRA station 166 indicate that ample nitrogen is available for algal growth in the Lower Charles River. Total nitrogen is a parameter of particular interest when evaluating eutrophic waterbodies and estimating whether nitrogen or phosphorus is the nutrient in most limited supply and controlling algal biomass (see Section 3.2.2).

Dissolved Oxygen and pH Data

Dissolved oxygen and pH data collected from the Lower Charles River also indicate eutrophic conditions. Dissolved oxygen data collected during the summer period when chlorophyll *a* levels were elevated in the Lower Charles River reveal that the upper water column was frequently supersaturated with dissolved oxygen during the daylight hours. Typically, surface water dissolved oxygen concentrations are directly proportional to the partial pressure of oxygen in the atmosphere. However, during photosynthesis algae use energy from sunlight and dissolved carbon dioxide from the water to create cell mass. A byproduct of this process is oxygen. The pure oxygen being released from the algal cells causes dissolved oxygen concentrations in the surrounding water to rise as a result of the higher partial pressure of dissolved oxygen (Thomann and Mueller 1987). High levels of dissolved oxygen supersaturation in waters are of concern because they can contribute to gas bubble disease in fish (USEPA 1986). An example of a typical range of supersaturated dissolved oxygen values and corresponding chlorophyll *a* concentrations measured in the Lower Charles River are presented in Table 3-10. In general, the more algal biomass there is in a waterbody the greater the potential is for supersaturated conditions to occur.

Table 3-10. Select late-morning dissolved oxygen, pH, and chlorophyll *a* data from the Lower Charles River for July 30, 2002

EPA Monitoring Station	Dissolved Oxygen mg/l	Dissolved Oxygen Percent Saturation	pH	Chlorophyll *a* µg/l
CRBL02	7.0	86.5	7.2	3.9
CRBL06	11.1	136	8.5	33.3
CRBL12	12.7	160	8.7	43.5
CRBL09	13.5	168	9.0	44.2

Source: USEPA 2003b

Another characteristic common to eutrophic water is large daily or diurnal variations in dissolved oxygen. While algae produce oxygen through photosynthesis during the daylight hours, algae also consume dissolved oxygen through respiration. Usually, the minimum dissolved oxygen concentration occurs in the early morning hours after the algae have respired throughout the night and prior to the onset of daytime photosynthesis. In some cases, dissolved oxygen drops below a critical threshold or criterion that is not protective of aquatic life. In the Lower Charles River, diurnal dissolved oxygen variations typically range between 1 and 5 mg/l.

Although the Lower Charles River experiences very high (supersaturated) concentrations of dissolved oxygen in the upper water column, it also has very low dissolved oxygen concentrations (0 to 3 mg/l) in the lower layer of the water column when the Basin becomes stratified. The stratification of the Basin and the resulting low dissolved oxygen concentrations are discussed in Section 3.2.3. It is not uncommon for eutrophic waters that stratify to have low dissolved oxygen in the hypolimnion (bottom layer) because of the lack of exchange with the atmosphere, algal respiration, and the decay of organic matter including the increased organic load from dead algae. This is the case for the Basin when it stratifies.

The photosynthetic activity of algae also affects a waterbody's pH, a measure of the water's acid base equilibrium. Like dissolved oxygen, a waterbody's pH can vary diurnally and typically increases during the daylight hours as carbon dioxide is converted into cell mass and decreases at night when algal respiration adds carbon dioxide to the water. Algal induced changes in carbon dioxide levels affect the equilibria of the overall carbonate system causing changes in pH. During bloom conditions in the Lower Charles River, pH values frequently exceed the upper limit of the range (6.5 to 8.3) allowed in the Massachusetts Water Quality Standards (2000). Table 3-10 shows an example of a typical range of pH values and corresponding chlorophyll *a* concentrations measured in the Lower Charles River, indicating that the higher pH values correspond to the greater amount of algal biomass present. One of the concerns associated with an increase in pH is increasing toxicity of certain compounds. For example, ammonia has been shown to be 10 times more toxic at pH 8 than at pH 7 (USEPA 1986).

3.2.2 Algal Growth in the Lower Charles River

Seasonal Algal Trends and Factors that Control Algal Growth

Algal growth is primarily a function of nutrient availability, light, and temperature (Chapra 1997). Of all the nutrients and other elements that are required by algae (i.e., carbon, oxygen, nitrogen, phosphorus, silica, sulfur, and iron), phosphorus and nitrogen are typically in limited supply, that is, in amounts that control algal growth. The relative amounts of phosphorus and nitrogen in aquatic systems determine which nutrient limits or controls algal growth. Either phosphorus or nitrogen may limit algal growth, although other factors may be just as important depending on the time of year and other environmental factors (i.e., water clarity, temperature, and residence time). With respect to algal growth, the term “limiting” is used to identify which nutrient (e.g., phosphorus or nitrogen) or other factor (e.g., light) that controls the rate of algal growth.

Based on measured amounts of nitrogen and phosphorus in the Lower Charles River, phosphorus is usually the limiting nutrient that controls algal growth during the middle to later summer period. This period of phosphorus limitation coincides with water quality and climatic conditions that are most optimal for algal growth in the Lower Charles River (e.g., improved water clarity, increased water residence times, high light intensity, and warm ambient temperatures). An analysis of paired TP and TN data collected at MWRA station 166 (July – October, 1998 through 2004) found that mass TN to TP ratios ranged from 7.8 to 26.0 with a mean and median of 14.0 and 13.8, respectively. A typical ratio of nitrogen to phosphorus in algae is 7.2:1 (Chapra 1997). Thus, TN:TP ratios less than 7.2 indicate nitrogen limitation while TN:TP ratios greater than 7.2 indicate phosphorus limitation. However, there is a range of ratios possible for different types of algae, so not all algae may be subject to the same limitation at the same time. Still, with ratios in excess of 12:1, for which 88 of 92 measurements were, phosphorus is most likely to be limiting in the Lower Charles River. Note that while phosphorus appears to be the limiting nutrient during the conditions most optimal for algal growth in the Lower Charles, nitrogen might also be limiting algal growth at certain times of the year. Although it is conceivable that nitrogen might occasionally act as the limiting nutrient, this TMDL focuses on sources of phosphorus to the Lower Charles River since phosphorus is the limiting nutrient during optimal times for algal growth.

Although phosphorus appears to be more limiting than nitrogen, other water quality data from the Lower Charles River indicate that algal growth may be limited by other factors during the early summer period. Typically, during June and early July, chlorophyll *a* concentrations are often low while corresponding TP and orthophosphate concentrations are elevated at levels that would typically indicate greater algal growth. During this time, it is likely that algal growth is limited by other factors; possibly light attenuation, consumption by zooplankton, or water temperature. Orthophosphate concentrations in the Lower Charles River are an indicator of whether phosphorus is limiting algal growth at the time of the sampling because it is the form of phosphorus that algae use for growth. If algae levels are low but orthophosphate levels are high it is likely that other factors are controlling algal levels. Conversely, during mid to late summer when conditions are typically more favorable for algae growth in the Lower Charles River, algae levels are typically elevated and orthophosphate concentrations are low, usually below detection, indicating that phosphorus is limiting.

During the early summer, water in the Charles River is highly colored or “stained” by dissolved organic matter. The presence of dissolved organic matter and color in the Charles River reduces light transmission through the water column and thus impedes or limits algal growth. A likely source of the color (staining) is the dissolved organic matter from decaying vegetation from the extensive wetland areas adjacent to the river in the upper watershed. As the summer progresses, watershed contributions of flow and pollutants (including nutrients and dissolved organic matter) to the Charles River decline significantly, resulting in improved water clarity and reduced nutrient levels in the Lower Charles River. Consequently, the amount of available phosphorus, rather than light, typically becomes the limiting factor that controls algal growth during the mid to late summer period.

Usually the most severe algal blooms occur in late July, August, and September when water temperatures are higher, water clarity is improved, and phosphorus availability limits algal growth. A review of available water quality data indicates that the increase in bloom severity coincides with declines in water color (increased water clarity) and increasing water temperatures. Increases in bloom severity also coincide with declines in river flow, which increases the water residence time in the Lower Charles and allows more time for algae to grow and accumulate. Specific growth rates of algae are species and size dependent. Algal doubling times, the time needed for the population to double in size, are typically on the order of a half day to a few days and may range from a few hours to several days (Kalff 2001). Therefore, the increased residence time encourages algae growth and accumulation. Seasonal reduction in water color is likely due to reductions in flow and pollutant loads from the watershed.

Figure 3-4 presents the seasonal trend of several water parameters and river flow observed in the Lower Charles River during the sampling season in 2002. The seasonal trends depicted for the summer of 2002 are generally consistent with seasonal trends observed for the same parameters during the other years that EPA has monitored the Lower Charles River (1998-2004). As indicated, true color (a measure of color caused by dissolved compounds), TP, and orthophosphate are higher while chlorophyll *a* is lower during the early summer period. As the summer progresses, true color and river flow decline and chlorophyll *a* increases dramatically.

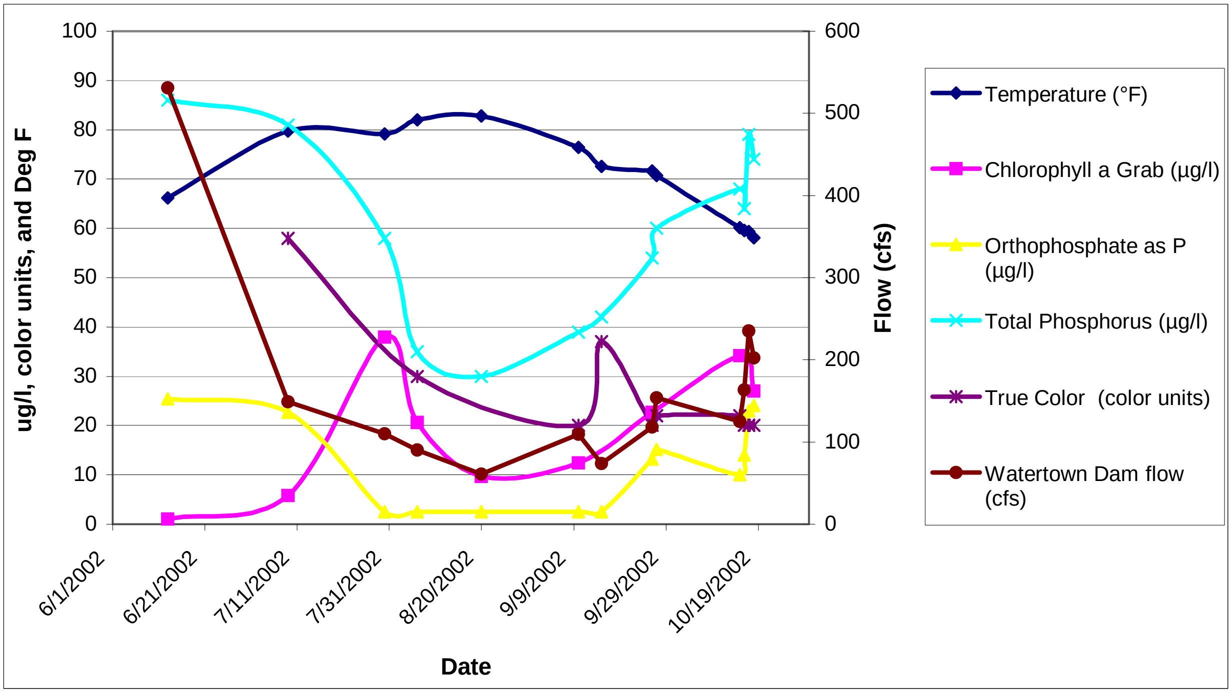

Figure 3-4. Recreational season 2002 water quality data for the Lower Charles River

Figure 3-4 illustrates the portion of the summer when phosphorus becomes the limiting factor to algae growth in the Lower Charles River. Note the similarity between the shape of the chlorophyll *a* and orthophosphate curves once true color falls below 40. As orthophosphate concentrations decline in the Lower Charles River, the chlorophyll *a* concentrations similarly decline. Also note that in September when orthophosphate concentrations increased as a result of storm events, chlorophyll *a* levels also increased. As the summer progresses, orthophosphate concentrations typically fall below the analytical detection level used by EPA (5 to 8 µg/l), indicating that algae were readily consuming available phosphorus. This pattern of orthophosphate dropping below the minimum detection limit during mid to late summer when algae blooms are typically most severe has occurred in every year (1998 through 2004) that EPA has monitored the Lower Charles River.

To further illustrate the apparent relationship between color and algal growth as indicated by chlorophyll *a*, a scatter plot of true color versus chlorophyll *a* is provided in Figure 3-5. This plot shows all of the paired chlorophyll *a* and true color data collected by EPA at station CRBL11 (Basin between the Longfellow Bridge and the Museum of Science) from 1999 through 2004. When the true color is greater than approximately 50, observed chlorophyll *a* concentrations have always been less than 20 µg/l. An analysis of the true color and river flow data shows a strong correlation ($R^2 = 0.77$) between true color values and river flow during the late spring and summer period (Figure 3-6). In the summer of 2003, when river flows remained high, the true color of the Lower Charles River remained high as well and algal blooms did not become established until late August and early September (USEPA 2003b). However, in most years, the true color fell below 50 units by middle to late July. Thus, in the Lower Charles River, algal blooms typically become a water quality concern in late July through October.

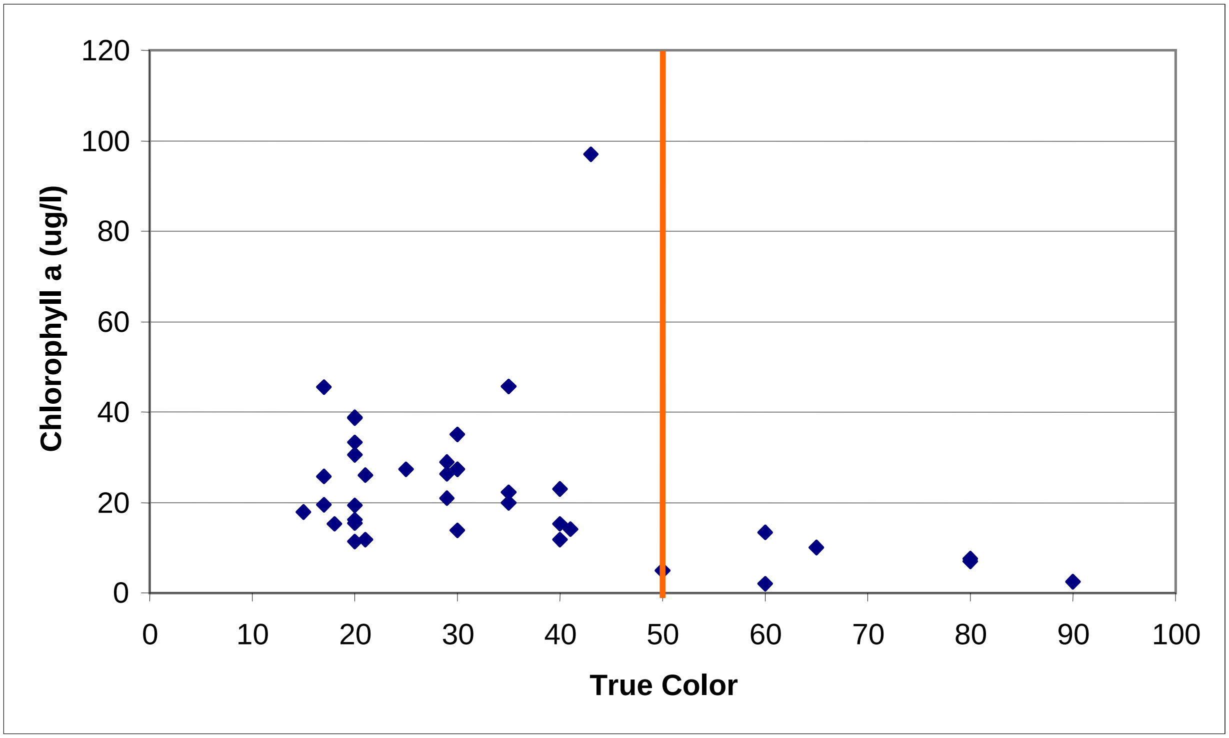

Figure 3-5. Chlorophyll *a* versus true color in the Lower Charles River (EPA station CRBL11 1999-2004)

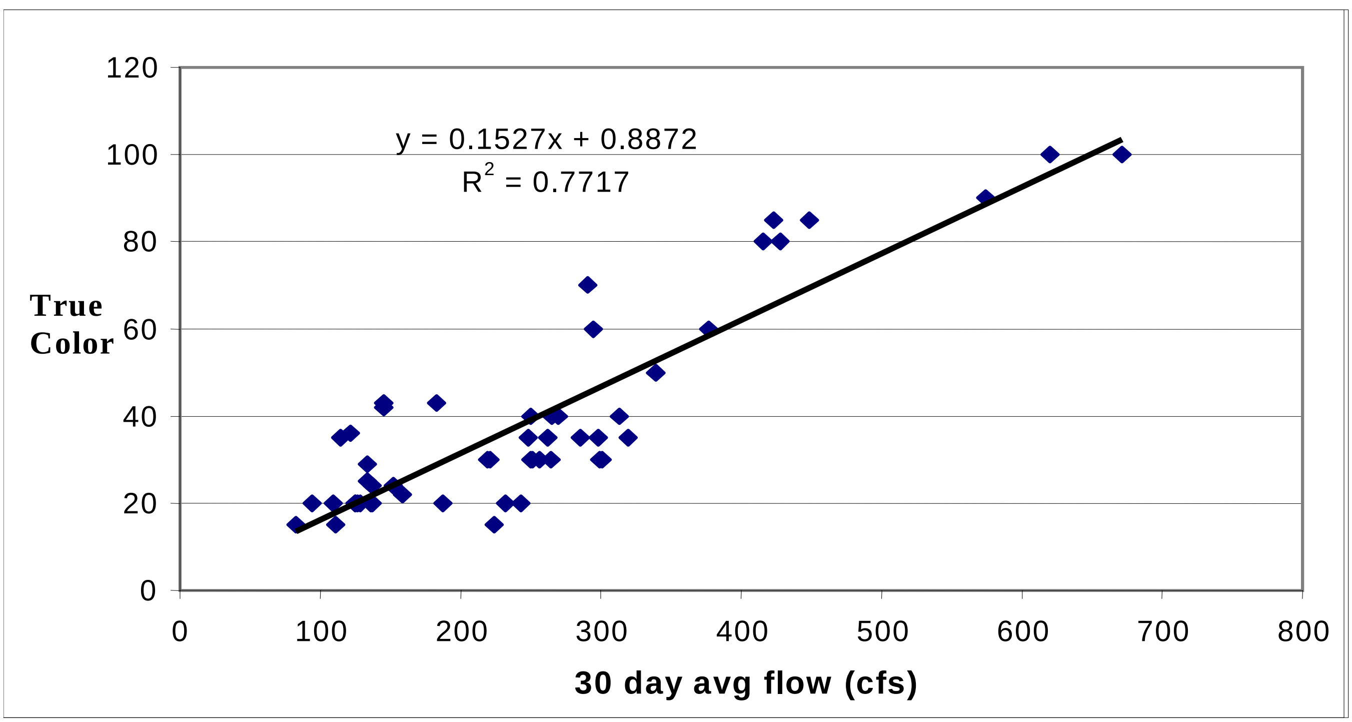

Figure 3-6. True color versus flow at the Watertown Dam (EPA station CRBL02 1999-2004)

Algal Taxonomic Data

In addition to the concern of overall algal biomass in eutrophic waterbodies, is the concern over the predominance of undesirable and potentially harmful species of algae in the community assemblage. Although many species of algae are important contributors to the base of the food web, there are species that are inedible, provide poor nutrition, and are sometimes toxic to aquatic life. Several of these species fall into a group known as “cyanobacteria or blue-greens.” The organisms are considered to be bacteria (Cyanobacteria) with a photosynthetic pigment, chlorophyll. Many cyanobacteria or blue-greens, particularly the troublesome species, can “fix” or obtain nitrogen from surrounding sources. While other algae must obtain their nitrogen from ammonium or nitrate in the water, cyanobacteria can use atmospheric nitrogen that dissolves in water. Furthermore, some of the most troublesome cyanobacteria have other characteristics, such as the ability to float, which furthers their competitive edge.

The Chesapeake Bay Program reviewed available literature relating to the effects of blue-green blooms on ecosystems. They report that numerous field studies have documented changes in zooplankton community structure associated with blooms of cyanobacteria. Zooplankton is another important component of the food web that consumes algae and is preyed upon by many fish species. The Chesapeake Bay Program found that the studies reviewed most frequently cite the inability of many zooplankton taxa to use blue-greens as a nutritive food source (USEPA 2003b). Three genera of cyanobacteria: *Anabaena, Aphanizomenon, and Microcystes*, are commonly associated with problems in fresh water lakes (Mattson et. al. 2003). All three genera have been identified in samples collected from the Charles River Basin (USEPA 2002, Mirant 2001 and 2003).

Blooms of toxic cyanobacteria or blue-green species are indicative of eutrophication and have been consistently observed in the Lower Charles during all summers when algal sampling has been conducted. During the summer of 2006, a very severe cyanobacteria bloom occurred in the Lower Charles causing the Massachusetts Department of Public Health and the Massachusetts Department of Conservation and Recreation to post warnings for the public and their pets to avoid contact with the Lower Charles River. The bloom consisted of extremely high cell counts of over one-million cells/milliliter of cyanobacteria and included the organism, *microcystes* that is toxic at elevated levels. In addition to the threat to public health, the bloom caused the water of the Lower Charles to turn a bright green color, as can be seen from the photographs taken during the bloom shown in Figures 3-7 and 3-8.

Another severe bloom moved into the Lower Charles River from the upper watershed during the beginning of early October 2004,resulting in reports from the public. Unfortunately, algal samples were not collected from the Lower Charles during this event. However, during the bloom in the upper watershed, MassDEP collected and analyzed samples from the upper Charles River Watershed that had cyanobacteria (*Oscillatoria*) cell counts of over 200,000 cells/ml (Beskenis 2005).

Figure 3-7. Cyanobacteria (Blue-green) Bloom in the Lower Charles River, August 2006

Figure 3-8. Cyanobacteria (Blue-Green) Bloom in the Lower Charles River, August 2006

Figures 3-9, 3-10, and 3-11 present the algal taxonomic data collected from the Basin (summers of 2001, 2002, and 2003). Although the datasets are not representative of the entire summer growing season for these years, each dataset indicates a trend of increasing cyanobacteria presence and predominance as the summer progresses. Also noteworthy is the variation in cell counts among the three years. Cell counts were high in 2001 and moderate in 2002 and 2003. The 2002 algal sampling was conducted only once per month and did not coincide with peak bloom conditions that chlorophyll *a* data indicate occurred in the Basin during late July and again in late September/early October.

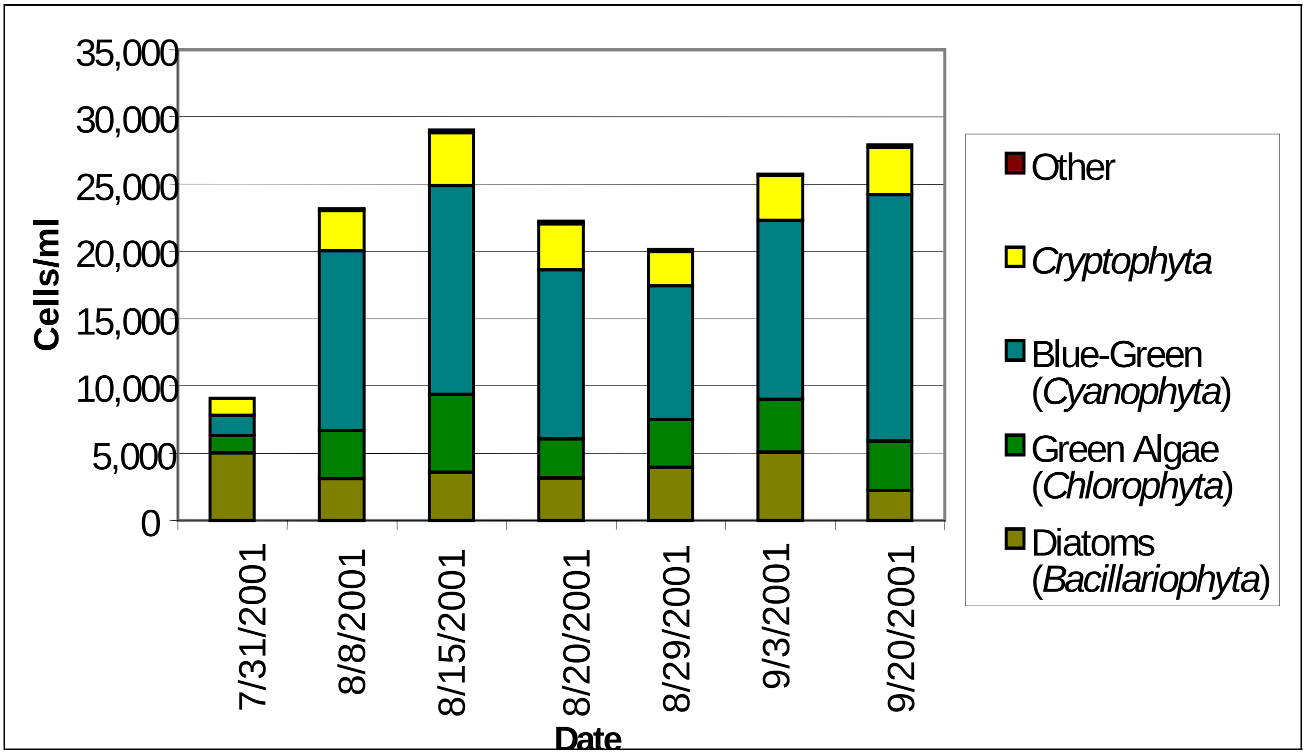

Figure 3-9. 2001 phytoplankton cell counts in the Charles River Basin (Mirant MIT station)

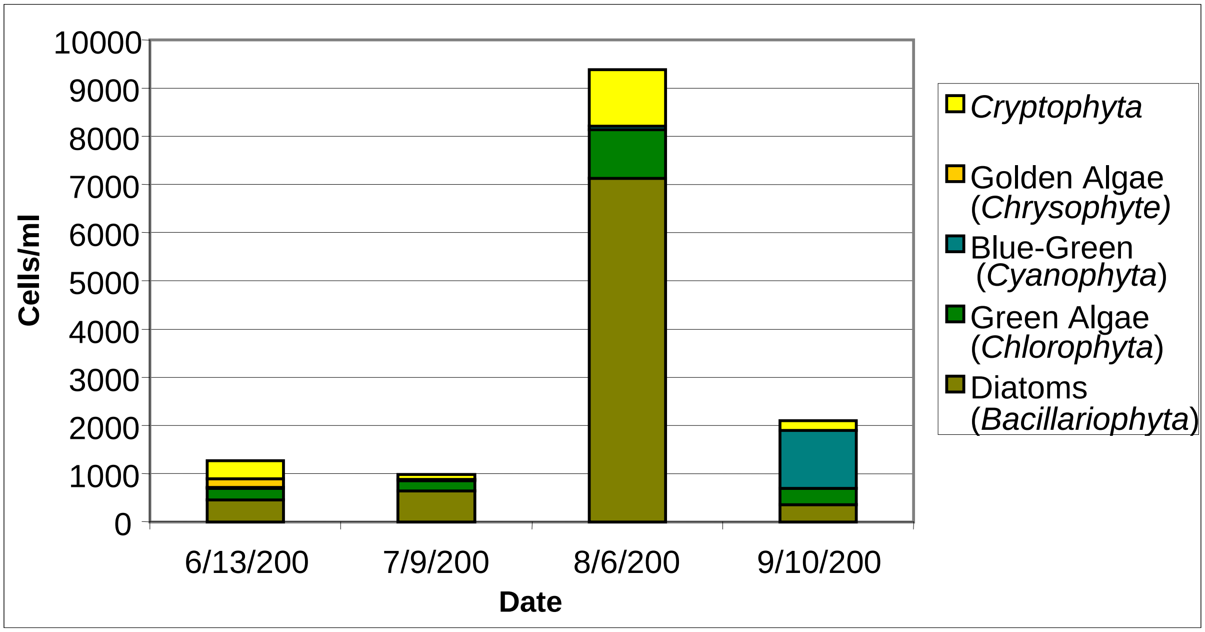

Figure 3-10. 2002 phytoplankton cell counts in the Charles River basin (EPA station CRBL11)

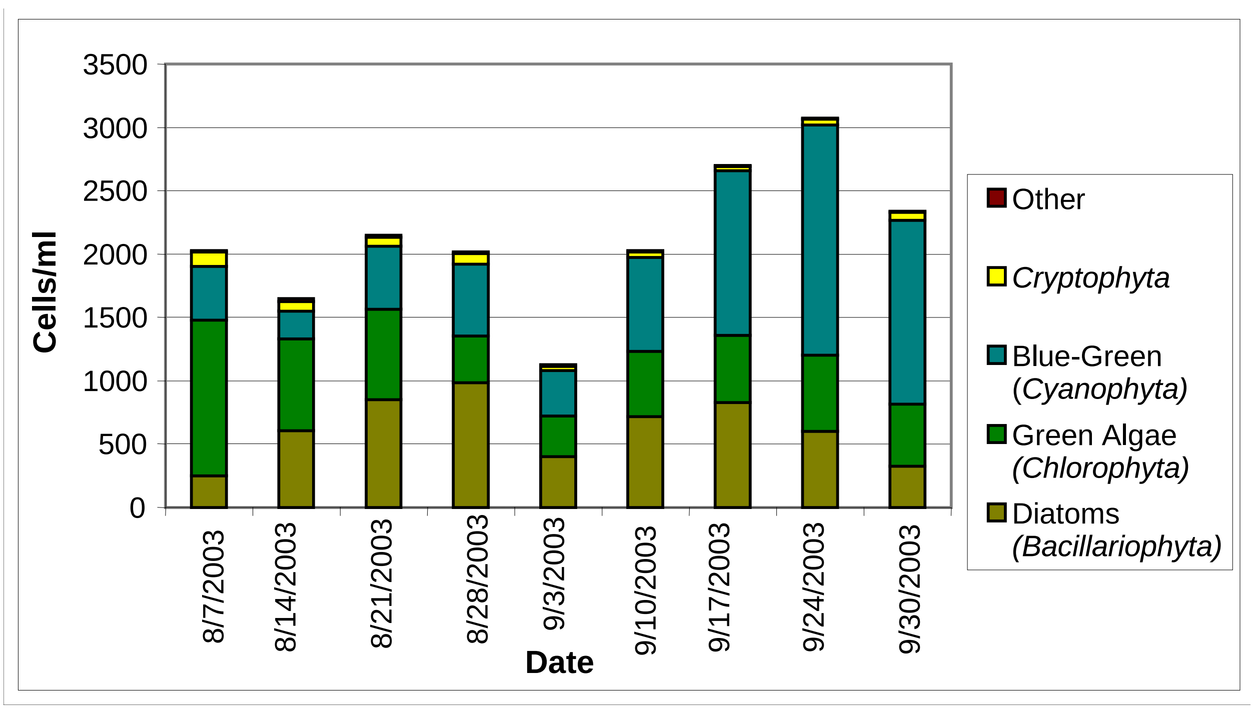

Figure 3-11. 2003 phytoplankton cell counts in the Charles River basin (Mirant station C)

3.2.3 Other Important Water Quality Characteristics of the Lower Charles River

Spatial Variability in Water Quality of the Basin

Water quality data collected in the Lower Charles River reveal important characteristics that are common to impounded and stratified systems. First, the data show that water quality progressively improves starting at the BU Bridge and moving downstream. EPA data for several parameters (e.g., Secchi depth, solids, and bacteria) collected at stations located between the BU Bridge and the Museum of Science (CRBL06, 07, A8, 09, 10, and 11) indicate progressively improved water quality the further downstream one moves from the BU Bridge. The best water quality observed in the Lower Charles regularly occurred at station CRBL11, located between Longfellow Bridge and the Museum of Science. It is important to note that this lower portion of the Lower Charles River is used intensively for both contact and non-contact recreational uses. While, the downstream water quality is typically better than further upstream in the Lower Charles, water quality impairments still exist because of excessive algae levels.

The improving trend in water quality conditions between the BU Bridge and the Museum of Science is demonstrated by EPA Secchi depth data collected on the same dates at monitoring stations CRBL06 (400 meters downstream of BU Bridge) and CRBL11 (between Longfellow Bridge and the Museum of Science). The results show that Secchi depths at CRBL06 were never higher than the corresponding values at CRBL11. The Secchi depth at CRBL11 was on average 48 percent or 1.4 feet greater than the corresponding value at CRBL06, indicating that the water clarity downstream of Longfellow Bridge was consistently better than the upstream portion of the Basin.

The improving trend in water quality conditions beginning at BU Bridge is explained by the change in morphology of the Lower Charles River. Downstream from the BU Bridge, the Lower Charles River widens and deepens. The greater volume of the Basin causes flow velocities to decline and travel times (residence times) to increase, which in turn increases sedimentation rates. Using a mean summer (July – September) flow in the Charles River at the Watertown Dam of 229 cfs, the water residence time in the Lower Charles downstream from BU Bridge is approximately 19 days. A travel time for a parcel of water to pass through the 2.6 miles of the Basin provides ample opportunity for suspended particulate matter to settle out of the water column. Detailed mapping of sediment thickness in the Basin by the USGS shows that the greatest accumulations of soft sediments (thickness of 3 to 5 feet) occur in the downstream most portion of the Lower Charles between the Longfellow Bridge and the Museum of Science (Breault et al. 2000a).

Salt Water Intrusion and Stratification

Another important water quality characteristic of the Basin is the intrusion of salt water from Boston Harbor. The USGS conducted an intensive monitoring program to track the temporal and spatial variability of salt water entering the Lower Charles River. The USGS observed that salt water enters the Lower Charles River primarily by way of the boat locks at the New Charles River Dam and migrates upstream into the Basin along the bottom of the river. The USGS reports that the amount of salt entering the Basin is directly proportional to the number of openings of the boat locks at the Dam. Also, the USGS produced an empirical model that calculates the salt mass entering the Basin based primarily on the number of boat lock exchanges (Breault et al. 2000b). Subsequent monitoring of salinity in the Basin by EPA during the summer of 2002 showed the same seasonal trend of increasing salt water in the Basin during the summer season when the frequency of boat passages between the Charles River and Boston Harbor is highest.

Because salt water has a higher density than fresh water, the salt water settles to the bottom of the water column, inhibits vertical mixing, and causes portions of the Basin to stratify (Breault et al. 2000b). The stratification in the Basin is very stable, resulting in very low exchanges between the lower salt water layer and the upper fresh water layer. As a result, the bottom layer, downstream of Harvard Bridge, tends to have very low dissolved oxygen levels during the summer, typically between 0 and 3 mg/l (Breault et al. 2000b, USEPA 2002). Without vertical mixing to replenish dissolved oxygen, oxygen in the bottom layer is readily depleted from the oxidation of organic matter in the water column and the sediments (i.e., sediment oxygen demand). Algal blooms contribute to the low dissolved oxygen problem in the Lower Charles River through algal respiration and the decomposition of dead algae that have settled to the bottom. High chlorophyll *a* concentrations and the associated algal biomass observed in the Basin help to explain why the bottom sediments of the Basin, as measured by the USGS, are high in organic content (Breault 2003).

Benthic Phosphorus Cycling

The mechanism for phosphorus release from sediment under anoxic conditions is well known since the work of Mortimer (1941). In the presence of oxygen, iron exists as Fe(III) oxide particulates that strongly sorb phosphate and, therefore, prevent it from diffusing from the sediment bed. Under anoxic conditions the Fe(III) rapidly reduces to Fe(II), which is soluble and, therefore, cannot sorb phosphate. As a result, the phosphate is released to the water column. In many eutrophic lakes and impoundments the release of nutrients from the benthic sediments is often an important source of nutrients for algal growth. This does not appear to be the case, however, in a portion of the Basin where the very stable stratification that occurs during the summer essentially traps benthic nutrients in the bottom water layer. Nutrient and chlorophyll *a* data collected during 2002 at the surface and above and below the pycnocline (i.e., top of salt water layer) indicate that there is very little transfer of pollutants from the bottom higher salinity layer to the upper water column. The data indicate that the upper water column, above the salt water layer, is well-mixed, and that the bottom salt water layer contains very high levels of nutrients. During the August and September 2002 period, when algal growth was at its peak in the Lower Charles River and also limited by the availability of phosphorus, TP in the bottom salt water layer was as high as 1,620 µg/l (approximately 37 times higher than TP in the upper water column). Furthermore, almost all of the phosphorus measured in the bottom layer was orthophosphate, the form that algae can readily use. In effect, the stratification caused by the salinity gradient is helping to prevent nutrients from mixing into the upper water column where they could further fuel algal blooms.

The very high levels of nutrients in the lower water column (salt water layer) are due, in part, to the release of nutrients from the bottom sediments. Results of the USGS sediment study indicate that the sediments in the Basin are high in organic carbon and phosphorus content (Breault

2003). USGS's measurements of nutrient flux rates (amount of nutrients released from sediments) from the Basin's sediments showed that the rates are substantially higher under anoxic (absence of oxygen) conditions than under oxic (presence of oxygen) conditions (Breault and Howes 1999). For example, orthophosphate flux rates were up to 197 times higher during anoxic conditions when compared to rates measured under oxic conditions. On average, orthophosphate flux rates in the Basin were 200 µg m^{-2} day^{-1} and 15,100 µg m^{-2} day^{-1} for oxic and anoxic conditions, respectively. Without stratification, benthic phosphorus fluxing from just the area that is typically under the salt wedge would contribute approximately 0.17 kg/day (60 kg/yr) if the sediments are oxic or 12.4 kilograms (kg)/day (4500 kg/year) if the sediments are anoxic.

3.3 Water Quality Impairments

Water quality problems common to eutrophic waters include poor aesthetic quality, low dissolved oxygen in the hypolimnion (bottom waters), and undesirable alterations to species composition and the food web (Chesapeake Bay Program 2001). The high chlorophyll *a* values and low Secchi depths observed in the Lower Charles River are indicative of excessive amounts of algae. Excessive algae results in poor aesthetic quality due to reduced water clarity and a green-brown coloration. Additionally, excessive amounts of algae and/or the presence of noxious algae species may further impair contact recreational uses (e.g., swimming, kayaking, sail boarding) because of bad odors and skin irritations. Excessive algae can also cause very high supersaturated dissolved oxygen levels and fluctuating pH in the surface water and contributes to low dissolved oxygen in the bottom waters. As a result, the Lower Charles River fails to fully support the designated recreational and aquatic life uses as required in the Massachusetts Surface Water Quality Standards (314 CMR 4.00)(2000) (Refer to Section 1.4 for specific water quality standards). The following is a summary of the impairments related to excessive algal biomass in the Lower Charles River.

Dissolved Oxygen Impairments

Very low dissolved oxygen levels, typically between 0 and 3 mg/l, have been regularly measured during the summers in the bottom waters of the Basin (downstream of Harvard Bridge) (Breault et al. 2000b, USEPA 2002). Such low dissolved oxygen levels are not meeting the Massachusetts water quality criterion of 5 mg/l and will not sustain a healthy and balanced aquatic community. Therefore, the dissolved oxygen concentrations in the Lower Charles River do not support Massachusetts's aquatic life standards. Algae blooms contribute to the dissolved oxygen problem in the Lower Charles River through algal respiration and the decomposition of dead algae that have settled to the bottom. Algal activity has also resulted in high supersaturated dissolved oxygen levels in the surface layer of the Basin, which could contribute to gas bubble disease in fish (USEPA 1986).

Aesthetic Impairments

There are a limited number of references in the literature concerning the relationship between specific chlorophyll *a* levels and aesthetic impacts. Some of the more informative studies involve the analysis of simultaneously collected water quality and user-perception data. The results of three "user-perception" based studies are summarized below to provide general information concerning the relationship between the magnitude of chlorophyll *a* values and perceived aesthetic impairments because there are no numeric criteria for aesthetic impairments. Note that these values were used only as supporting information for assessing the aesthetic impacts of chlorophyll *a*. The actual chlorophyll *a* target applied in this TMDL is presented in Section 5.1.

Smeltzer (1992) presents the results of a study conducted by the Vermont Water Resources Board to develop eutrophication standards for Lake Champlain from user survey data. Results from this study indicated that over 50 percent of the respondents found that enjoyment of the lake was impaired when chlorophyll *a* levels were 8 – 11.9 µg/l. The frequency of this response increased to approximately 90 percent when chlorophyll *a* concentrations were greater than 20 µg/l. Vermont ultimately used the results of the user perception study as the basis for adopting numeric phosphorus criteria for Lake Champlain into the Vermont Water Quality Standards (VTWRB 1996).

As part of a plan to develop numeric water quality criteria, the Vermont Department of Environmental Conservation conducted a similar analysis applying user-perception and water quality data collected from 60 inland lakes. The results indicate that between 40 percent and 60 percent of the respondents found water quality to be aesthetically impaired when chlorophyll *a* was 10 – 20 µg/l (VTDEC 2002). Finally, Walker and Havens (1995) summarize the following results of another user-perception based study conducted on 21 reservoirs in South Africa by Walmsley.

Chlorophyll *a* (µg/l)	Nuisance Value
0 – 10	No problems encountered
10 – 20	Algal scums evident
20 – 30	Nuisance conditions encountered
>30	Severe nuisance conditions encountered

A comparison of the high chlorophyll *a* levels regularly observed in the Basin to the results of the user-perceived aesthetic impairments to chlorophyll *a* measurements discussed above, strongly suggests that the water quality of the Lower Charles River is aesthetically impaired. Summer season (July 1 – October 31) chlorophyll *a* data collected at EPA monitoring stations located in the Basin were analyzed to evaluate the frequency at which certain levels of chlorophyll *a* were exceeded. The data review showed that 100, 40, and 21 percent of 42 sampling events conducted by EPA had chlorophyll *a* concentrations at one or more stations in the Basin that were greater than 20 µg/l, 30 µg/l, and 40 µg/l, respectively (EPA Data 1998-2004). An analysis of the MWRA summer season data collected at station 166 located at the downstream end of the Basin (just upstream of the Museum of Science) found that 55 percent, 25 percent, and 13 percent of 121 sampling events had chlorophyll *a* concentrations that were greater than 20 µg/l, 30 µg/l, and 40 µg/l, respectively. The lower frequencies of observed elevated chlorophyll *a* concentrations at station 166 compared to data from the entire Basin are believed to reflect the improved water quality conditions that typically occur in the downstream-most segment of the Basin.

Water Clarity Impairments

Secchi disc depths measured in the Lower Charles River frequently do not attain the Massachusetts clarity criterion for the designated uses of aquatic life and recreation. Secchi depth is an indication of water clarity and represents the depth at which a small black and white disc lowered into the water column can be seen from the water surface. Although the criteria addressing clarity are in a narrative form (see criteria for solids and color and turbidity in Table1-1) , Massachusetts uses a Secchi depth of four feet (1.2 meters) to assess attainment of the primary contact recreation use (MAEOEA 2003). Based on a review of the EPA Secchi depth data collected at sampling stations CRBL06 (downstream of the BU Bridge), CRBL07 (downstream of the Harvard Bridge), and CRBL11 (between the Longfellow Bridge and the Museum of Science), only 17, 61, and 80 percent of the observations, respectively, attained the four-foot criterion. Suspended algae in the water column are partially responsible for the poor water clarity because of light absorption and light scattering in the water column (Wetzel 1983).

pH Impairments

Based on EPA's Core Monitoring data, there were numerous measured exceedances of Massachusetts's pH criterion in the Basin. The observed pH often exceeded the 8.3 criterion value during times when chlorophyll *a* levels were high in the Basin. Continuous monitoring of pH and dissolved oxygen show that the pH exceedances coincide with supersaturated dissolved oxygen conditions, which indicates that algal photosynthesis is consuming carbon dioxide from the water and causing the pH to rise. It is common for eutrophic lakes to have high pH values. Supersaturated oxygen conditions, which often occur in the upper layer of the Basin, result in little or no free carbon dioxide. Under these conditions, pH often increases due to the low bicarbonate concentrations and lack of carbonates caused by the absence of free carbon dioxide (Reid 1961). Therefore, a reduction in algal biomass should result in a reduction of the pH levels in the Basin.

3.4 Pollutant Sources

The identification of pollutant sources to the Lower Charles River focuses mainly on phosphorus loadings to the Lower Charles River as well as a consideration of the extent of thermal pollution as a possible contributor to algal blooms. This section of the report provides a general overview of the types and magnitudes of the various pollutant sources in the Lower Charles River watershed. Pollutant sources are divided into point and nonpoint sources. Point source pollution typically represents those sources generated by a discrete discharge such as a wastewater treatment plant, stormwater drainage system, or industrial facility outfall. Nonpoint source pollution represents diffuse sources that enter the river such as groundwater recharge and overland runoff from various land covers and uses. However, stormwater that is collected and discharged to receiving waters by way of piped or channelized conveyance systems (i.e., drainage systems) is considered a point source of pollution.

There are relatively few nonpoint sources of nutrient pollution that discharge directly to the Lower Charles River and its direct tributaries. Most of the watershed area surrounding the Lower Charles River is highly urbanized with extensive piped drainage systems. In fact, a large portion of the drainage system networks serving the Lower Charles River watershed are covered by a general NPDES permit for municipal separate storm sewer systems (MS4s) (see Section 3.4.1). There are nonpoint sources of nutrients in the upstream watershed above the Watertown Dam, however, those sources have not been specifically identified at this time and the phosphorus load at Watertown Dam is being treated as a single source to the Lower Charles River that is composed of both point and nonpoint sources (see Section 3.4.1).

Specific loading estimates for each individual sources that discharge directly to the Lower Charles River are not provided in this document, but have been developed for many sources for use in the water quality model. The methodology for developing the loading estimates is discussed more fully in the model documentation report, *A Hydrodynamic and Water Quality Model for the Lower Charles River, Massachusetts* (Tetra Tech, Inc. and Numeric Environmental Services 2006).

3.4.1 Phosphorus Sources

Anthropogenic and natural sources of phosphorus are ubiquitous throughout the Charles River watershed. Phosphorus is a natural component of soil and organic matter (e.g., vegetation and fecal matter) and is present in many commercially available products that are commonly used (e.g., fertilizers and some detergents). Thus, phosphorus enters the river in a variety of ways. The major source categories of phosphorus to the Lower Charles River include stormwater (from both overland runoff and piped drainage systems), illicit sanitary sewage discharges, combined sewer overflows (CSOs), and discharges into the upper watershed above the Watertown Dam from similar sources, with the exception of the CSOs, as well as discharges from several wastewater treatment plants.

There are 72 major stormwater drainage system outfalls and 13 CSOs in the Lower Charles River watershed. Figure 3-12 shows the locations of the major stormwater outfalls and all of the potentially active CSO outfalls discharging directly in the Lower Charles River (Weiskel et al. 2005). Also shown are the tributary drainage areas for the stormwater outfalls and the overall drainage area served by CSOs. Only a portion of the Laundry Brook, Muddy River, and Stony Brook watersheds are depicted because of their relatively large size (see Figure 1-1 for the entire watershed areas). Table 3-11 presents the stormwater and CSO outfall numbers that discharge directly to the Lower Charles and their associated areas and land use types.

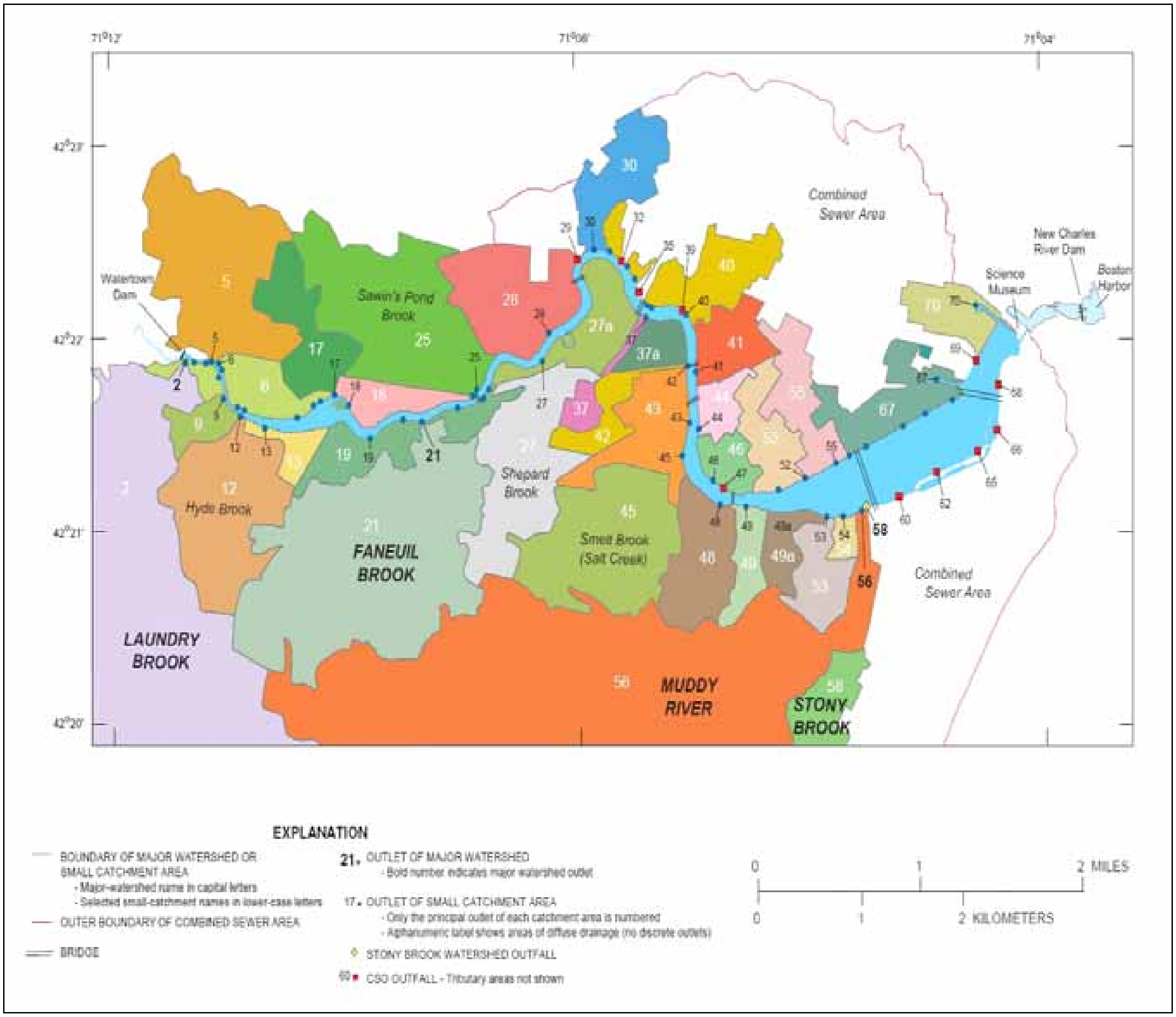

Figure 3-12. Watershed and CSO outlets for the four major tributary watersheds and small watershed areas of the Lower Charles River (Weiskel et al. 2005)

Note that major watersheds are only partly shown (see Figure 1-1 for full areal extent of the major watersheds).

Table 3-11. Drainage area characteristics of watershed and CSO outfalls in the Lower Charles River watershed (Weiskel et al. 2005)

Major Watershed or Small Catchment Area[ab]	Principal Outlet Identifier	Drainage Area (acres)	Dominant Land Uses[c]
Laundry Brook	**2**	**3,038**	**HD, MD, F**
Watertown West local drainage	6	153	HD, UO, C
Watertown Sq. Drain	5	560	HD, UO
Newton West local drainage	9	71	HD, C
Hyde Brook	12	439	HD, UO
Newton East local drainage	13	58	HD, T, R
Watertown Central local drainage	17	205	HD, I
Watertown East local drainage	18	97	T, R
Brighton local drainage	19	190	HD, T, C
Faneuil Brook	**21**	**1,151**	**HD, MF, C**
Sawins Pond Brook	25	579	HD, I
Shepard Brook	27	414	I, MF, UO
Soldier's Field Local Drainage	27a	169	R, T
Mt. Auburn Cem. local drainage	28	311	UO, T
CSO (CAM 005)	29	---	---
Sparks St. local drainage	30	194	MD, UO, HD
CSO (CAM 007)	32	---	---
Harvard Square local drainage	40	231	MF, UO, C
CSO (CAM 009)	35	---	---
No. Harvard Street local drainage	37	56	HD, UO
Harvard Bus. School Local drainage	37a	72	UO, MF, C
CSO (CAM 011)	39	---	---
North Putnam Ave. local drainage	41	132	HD, T
Western Ave. local drainage	42	92	HD, T, C
Cambridge Street local drainage	43	218	T, C, I
Riverside local drainage	44	68	MF, C
Smelt Creek	45	494	MF, HD, C
Magazine Beach local drainage	46	76	MF, R, UO
CSO (MWR 201; Cottage Farm)	47	---	---
Halls Pond Drain	48	227	C, HD, MF, UO
St. Mary's Street Drain	49	91	HD, C
Boston University local drainage	49a	81	MF, UO, C
Cambridgeport local drainage	52	144	MF, C, UO
Muddy River Conduit	53	135	C, MF, UO
Bay State Rd. local drainage	54	31	C, T
MIT West local drainage	55	172	C, MF, UO
Muddy River	**56**	**4,005**	**HD, MF, UO**
Stony Brook	**58**	**8,393**	**HD, MF, UO, F**
MIT East local drainage	67	199	C, UO, T
CSO (MWR 018)	60	---	---
CSO (MWR 019)	62	---	---
CSO (MWR 020)	65	---	---
CSO (MWR 021; Closed)	66	---	---
CSO (MWR 022; Closed)	68	---	---
CSO (CAM 017)	69	---	---
Lechmere local drainage	70	120	C, MF

[a]Note that major watershed areas are in bold font.

[b]Data for combined sewer overflow (CSO) catchment areas are not included because of the active sewer-separation projects occurring in these watershed areas. For current status of the Charles River CSO projects, see Massachusetts Water Resources Authority website (www.mwra.state.ma.us/).
[c]HD = High-density single-family residential; MD = Medium-density single-family residential; F = Forest; UO = urban open space; C = commercial; T = Transportation; R = Spectator or participant recreation; I = Industrial; MF = Multi-family residential; --- = Not Available
Source: Weiskel et al. 2005

Stormwater Drainage Systems

Stormwater drainage systems cover most of the Charles River watershed and, therefore, are a point source contributor of phosphorus to the Lower Charles River. Stormwater discharges are generated by rainfall from urban land and impervious areas such as paved streets, parking lots, and rooftops during precipitation events, and these discharges contain pollutants that can eventually enter nearby waterbodies. Many stormwater discharges in the Charles River watershed are considered point sources and require coverage by an individual or general NPDES permit.

Under the NPDES stormwater program, operators of large, medium, and regulated small Municipal Separate Storm Sewer Systems (MS4s) require authorization to discharge pollutants. The Stormwater Phase I Rule (55 FR 47990; November 16, 1990) requires all operators of medium and large MS4s to obtain an NPDES permit and develop a stormwater management program. Medium and large MS4s are defined by the size of the population in the MS4 area, not including the population served by combined sewer systems. A medium MS4 has a population size between 100,000 and 249,999. A large MS4 has a population of 250,000 or more. The only Phase I MS4 in the Lower Charles River watershed is the city of Boston.

Phase II requires a select subset of small MS4s to obtain an NPDES stormwater permit. In Massachusetts, EPA has issued a statewide general permit and MS4 facilities obtain permit authorization from EPA by filing an approved notice of intent. A small MS4 is any MS4 not already covered by the Phase I program as a medium or large MS4. The Phase II Rule automatically covers all small MS4s in urbanized areas (UAs), as defined by the Bureau of the Census, and also includes small MS4s outside an UA that are so designated by NPDES permitting authorities, case by case (USEPA 2000c). Four of the five cities located in the Lower Charles River watershed below the Watertown Dam as well as all of the communities located in the upper watershed above the dam are regulated as Phase II MS4 areas. The cities below Watertown Dam that are regulated by the MS4 permit include Brookline, Cambridge, Newton, and Watertown. The portion of the city of Somerville in the Lower Charles River watershed is completely drained by combined sewers (discussed below) and, therefore, is not regulated by the MS4 NPDES permit. All 31 communities in the upstream watershed have separate storm sewer systems that are either entirely or partially subject to the Phase II MS4 permit regulations (Table 3-12). Also, the Massachusetts Highway Department (MassHighway), the Massachusetts Turnpike Authority, and the Massachusetts Department of Conservation & Recreation (DCR) are subject to the Phase II MS4 stormwater permit regulations, as is any other state or federal facility with a separate storm sewer system within the identified UAs.

Table 3-12. Municipalities and agencies in the watershed with separate storm sewer systems that are either entirely of partially subject to Phase II MS4 permit regulations

MS4 Entirely Subject to Phase II MS4 Permit Regulations	MS4 Partially Subject to Phase II MS4 Permit Regulations
Arlington, Belmont, Boston, Brookline, Lexington, Newton, Waltham, Watertown, Wellesley, Weston, Massachusetts Turnpike Authority	Ashland, Bellingham, Dedham, Dover, Franklin, Holliston, Hopedale, Hopkinton, Lincoln, Medfield, Medway, Milford, Millis, Natick, Needham, Norfolk, Sherborn, Walpole, Wayland, Westwood, Wrentham, Mass Highway, Mass Department of Conservation and Recreation

Stormwater represents a significant source of phosphorus to the Lower Charles River. There are many stormwater drainage systems that collect and transport drainage from the 40 square miles of a highly urbanized watershed contributing directly to the Lower Charles River. Pollutants, such as phosphorus, that have accumulated on watershed surfaces are readily transported to the Lower Charles River by way of the stormwater drainage systems and/or overland flow during rain events. Given the level of urbanization and the extent of impervious cover (e.g., streets and parking lots), the Lower Charles River's watershed has lost much of its natural capacity to absorb rainfall and remove pollutants by filtering the runoff through vegetative cover and the soil matrix. Thus, the concentrations of pollutants in stormwater discharges to the Lower Charles River have become elevated. Also, urbanized watersheds generate substantially more runoff volume than undeveloped watersheds because of the greater extent of impervious cover (and less opportunity for infiltration) in urbanized watersheds. The higher concentrations and the greater volumes of stormwater associated with the urban watershed results in much greater amounts of phosphorus entering the river (i.e., phosphorus loading) than would come from a naturally vegetated watershed. Also, the higher storm flows might further increase the overall stormwater pollutant load because of erosion and flooding (Schueler 1987).

From 1999 to 2000 the USGS conducted a study to estimate non-CSO pollutant loadings to the Lower Charles River. This investigation addressed dry- and wet-weather sources to the Lower Charles River with the exception of CSOs and has provided insight into the magnitude and relative importance of pollutant sources to the Lower Charles River.

The study involved continuous flow monitoring and many dry- and wet-weather water quality sampling events of the major tributary drainage systems to the Lower Charles River (Laundry Brook, Faneuil Brook, Muddy River, and Stony Brook), three smaller systems that drained relatively homogeneous land cover types (single family residential, multifamily-residential, and commercial), and the Charles River at Watertown Dam, the upstream boundary of the Lower Charles River. The three land- cover monitoring stations are useful for characterizing the pollutant sources to the Lower Charles River because they are representative of the most prevalent land cover in the Lower Charles River watershed together representing approximately 60 percent of the watershed, and contribute much of the storm water to the drainage systems. The Lower Charles River watershed is dominated by single-family and multi-family residential land cover and the eastern part of the watershed and areas closest to the river contain a large amount of commercial area (Zarriello and Barlow 2002). Human activities increase nutrient concentrations in the river and its tributaries because of the increase in impervious cover, use of fertilizers, and the presence of illicit sanitary discharges that occur within these land cover types.

Continuous flow monitoring was conducted at 8 locations, which accounts for 95 percent of the entire watershed area draining to the Lower Charles River. Figure 3-13 shows the locations of the USGS flow and water quality-monitoring stations. Water quality monitoring consisted of monthly dry-weather sampling and wet-weather sampling for up to 9 storm events at each of the flow gaging locations.

Dry-weather samples were collected on days that had less than 0.1 inches of precipitation during the previous 72 hours as measured at USGS's rain gage at the Charles River at Watertown. Storm event sampling consisted of collecting flow-weighted composite samples that were used to estimate storm event mean concentrations (EMCs) for each of the contaminants (Breault et al. 2002).

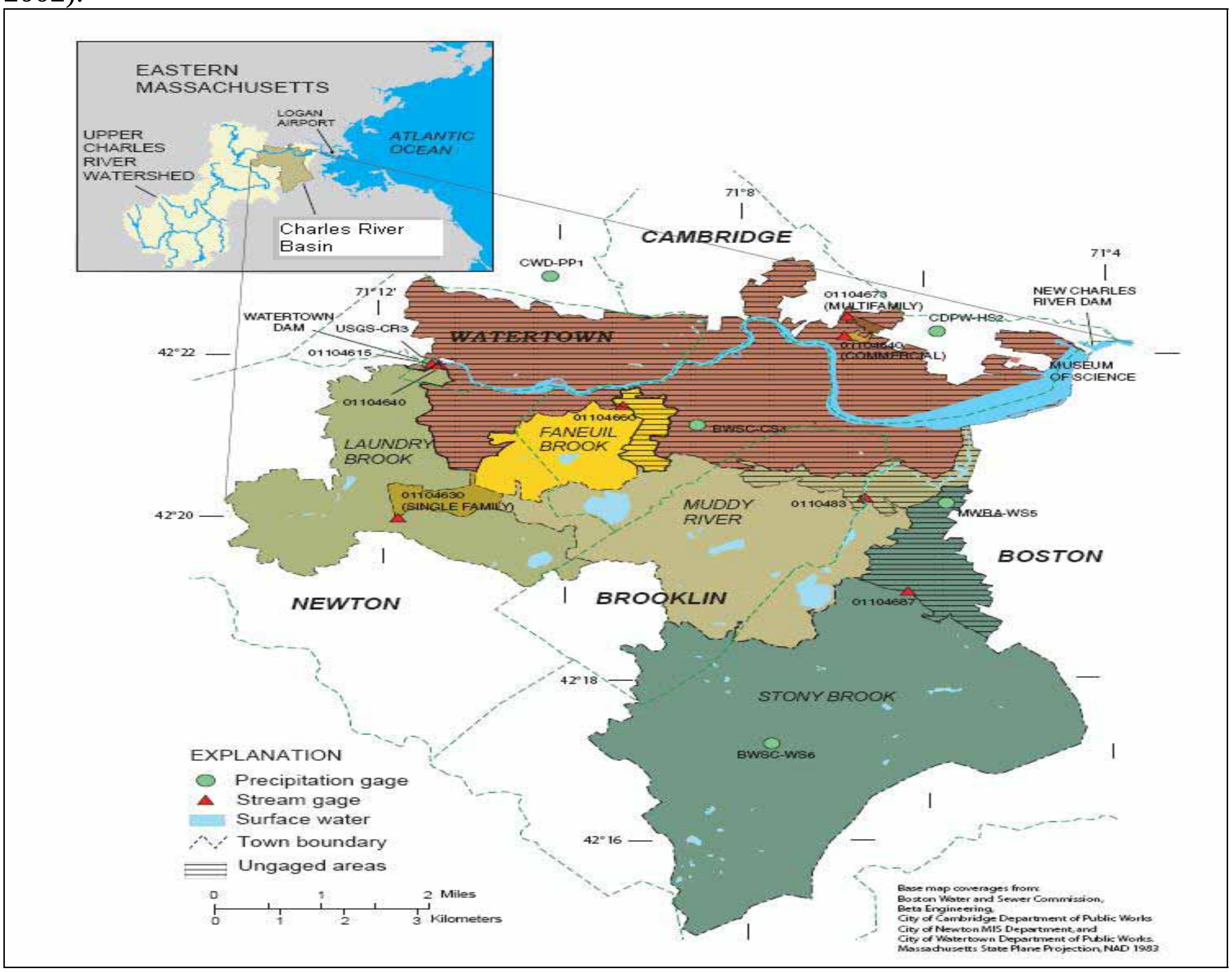

Figure 3-13. Locations of the USGS flow and water quality stations in the Lower Charles River watershed (Zarriello and Barlow 2002)

As part of the overall effort to quantify pollutant loadings to the Lower Charles River, the USGS also developed hydrologic (rainfall-runoff) models using the Storm Water Management Model (SWMM) for separate stormwater and tributary drainage systems that discharge to the Lower Charles River. The models were developed to estimate total dry-weather and wet-weather flow entering the Lower Charles River from the tributary drainage systems. The SWMM models of the USGS gaged subwatersheds, Laundry Brook, Faneuil Brook, and the three land use watersheds, were calibrated using the continuous flow data from the monitoring program described above. For the Stony Brook and Muddy River systems, an existing SWMM model developed by the Boston Water and Sewer Commission (BWSC) and provided by Metcalf and Eddy, Inc. was used by the USGS to estimate flow volumes (Zariello and Barlow 2002).

The USGS used the flow estimates from the models together with the pollutant monitoring and flow monitoring data to estimate the total non-CSO pollutant loads discharged to the Lower Charles River during water year 2000 (October 1, 1999 to September 30, 2000) in both wet- and dry-weather conditions (Table 3-13).

Table 3-13. Non-CSO dry-weather, wet-weather, and total pollutant loads to the Lower Charles River for water year 2000 (October 1, 1999 – September 30, 2000) (Breault et al. 2002)

Subwatershed	Condition	Total Phosphorus		Total Nitrogen		Dissolved Solids		Suspended Solids		Total Discharge	
		kg	%	kg	%	kg	%	kg	%	MCF	%
Charles River at Watertown Dam	Dry-Weather	22,929	91.4	366,649	90.9	67,036,774	93.0	1,265,623	95.5	10,648	95.5
Laundry Brook	Dry-Weather	64	0.3	1,590	0.4	199,410	0.3	2004	0.2	26	0.2
Faneuil Brook	Dry-Weather	88	0.4	1,999	0.5	240,176	0.3	10,513	0.8	17	0.1
Muddy River	Dry-Weather	320	1.3	7,241	1.8	895,814	1.2	18,093	1.4	96	0.9
Stony Brook	Dry-Weather	1,487	5.9	20,756	5.1	3,082,170	4.3	19,634	1.5	288	2.6
Other Drainage Area	Dry-Weather	210	0.8	4,945	1.2	615,480	0.9	9,606	0.7	73	0.7
	Dry-Weather Total	25,099	100	403,181	100	72,069,825	100	1,325,473	100	11,148	100
Charles River at Watertown Dam	Wet-Weather	11,420	68.0	174,569	76.0	23,291,552	89.6	4,833,612	80.0	4,635	86.1
Laundry Brook	Wet-Weather	318	1.9	3,547	1.5	199,462	0.8	65,020	1.1	56	1.0
Faneuil Brook	Wet-Weather	148	0.9	2,004	0.9	147,499	0.6	73,514	1.2	33	0.6
Muddy River	Wet-Weather	1,371	8.2	14,244	6.2	774,989	3.0	279,633	4.6	244	4.5
Stony Brook	Wet-Weather	2,235	13.3	21,293	9.3	801,559	3.1	541,215	9.0	201	3.7
Other Drainage Area	Wet-Weather	1,304	7.8	14,038	6.1	775,766	3.0	251,754	4.2	211	3.9
	Wet-Weather Total	16,795	100	229,695	100	25,990,828	100	6,044,747	100	5,380	100
Charles River at Watertown Dam	Total	34,349	82.0	541,218	85.5	90,328,326	92.1	6,099,235	82.8	15,283	92.5
Laundry Brook	Total	382	0.9	5,138	0.8	398,873	0.4	67,024	0.9	82	0.5
Faneuil Brook	Total	237	0.6	4,002	0.6	387,676	0.4	84,027	1.1	49	0.3
Muddy River	Total	1,691	4.0	21,485	3.4	1,670,803	1.7	297,725	4.0	340	2.1
Stony Brook	Total	3,722	8.9	42,049	6.6	3,883,730	4.0	560,849	7.6	489	3.0
Other Drainage Area	Total	1,513	3.6	18,983	3.0	1,391,246	1.4	261,360	3.5	284	1.7
	Total Non-CSO Load	41,894	100	632,876	100	98,060,653	100	7,370,220	100	16,528	100

Table 3-13 summarizes the annual (water year 2000) contributions of dry-weather loadings, wet-weather loadings (e.g., stormwater runoff), and total non-CSO loadings (i.e., combined wet and dry) of phosphorus and other pollutants relevant to this TMDL study that discharge to the Lower Charles. Loading summaries are presented for the major non-CSO inputs, the upper watershed, Laundry Brook, Faneuil Brook, Muddy River, Stony Brook, and the remaining drainage area served by smaller systems (including the three land cover areas). Depending on the location of the monitoring station and the characteristics of the contributing drainage area, the dry-weather pollutant loads were likely to include contributions from groundwater inflow, illicit discharges, treated wastewater effluent, and natural sources from the watershed. The wet-weather pollutant loads include contributions from most of the same dry-weather sources, stormwater and possibly illicit discharges that are only active during high-flow wet-weather conditions.

The upstream watershed represents the dominant source of phosphorus (as well as all other measured constituents) to the Lower Charles River on an annual basis, accounting for 91.4, 68, and 82 percent of the dry-weather, wet-weather, and total non-CSO phosphorus load, respectively. It is evident that the upstream watershed was the most important source of phosphorus to the Lower Charles River for those summers with extended periods of dry weather (e.g., 1997, 1999, and 2002). See the *Upstream Watershed Load at Watertown Dam* Section for more detail on this particular pollutant source.

Also noteworthy is the increased significance of the estimated wet-weather phosphorus load discharged directly to the Lower Charles River from the immediate tributary drainage areas. Their relative contribution of phosphorus load increased from approximately 8.6 percent of the dry-weather load to 32 percent of the total wet-weather load. Thus, stormwater from the direct tributary watershed and its relatively large nutrient load can become an important source of phosphorus to the Lower Charles River during the critical summer growing season when algae are phosphorus limited.

An estimate of the “natural” watershed phosphorus loading is provided in Table 3-14 together with the estimates of the total non-CSO load for water year 2000. A comparison of these loads illustrates the impact of anthropogenic activities on watershed phosphorus loading. The natural load was estimated by assuming the entire watershed is forested and multiplying the watershed area by a phosphorus loading export factor (0.129 kg/ha or 33.41 kg/sq. mi.) for forested areas, as determined for Massachusetts’ lakes (Mattson and Isaac,1999). As indicated, phosphorus loadings under current conditions represent an overall increase of over 300 % from forested conditions. This large relative increase is likely due to several factors including increased stormwater volume due to impervious surfaces, illicit sources, less natural filtering in the watershed, and discharges from wastewater facilities.

Table 3-14. Comparison of Charles River watershed phosphorus loadings for "natural" (forested) and current (WY2000) conditions

Watershed	Area (Sq. Mi.)	"Natural" Forested Phosphorus Load (kg/yr)	Total non-CSO Phosphorus Load, Water year 2000 (kg/yr)	Relative percent Increase in Phosphorus Loading due to anthropogenic activities %
Charles River at Watertown Dam	268.02	8,955	34,349	284
Laundry Brook	4.76	159	382	140
Faneuil Brook	1.78	59	237	299
Muddy River	6.26	209	1,691	709
Stony Brook	13.1	438	3,722	750
Other Drainage Area	10.1	337	1,513	348
Totals	**308**	**10,291**	**41,894**	**307**

The results of the USGS wet-weather monitoring are summarized in Table 3-15. These concentrations represent the quality of these discharges that occurred during discrete rain events and consisted primarily of stormwater. However, flow monitoring and dry-weather sampling conducted at these locations indicate that these discharges also include base flow consisting of groundwater infiltration and, to some extent, illicit sanitary sewage sources (see following section). The Stony Brook system did include some CSO discharges during six of the nine sampling events, which may explain why the wet-weather mean and median concentrations are higher than the other systems.

Table 3-15. Stormwater event mean concentrations for select drainage areas to the Lower Charles River (Breault et al. 2002)

Drainage System	Number of Samples[a]	Total Phosphorus (mg/l)			Total Nitrogen (mg/l)			Total Suspended Solids (mg/l)		
		Mean	Median	Range (Min - Max)	Mean	Median	Range (Min - Max)	Mean	Median	Range (Min - Max)
Land Cover Drainage, Lower Charles River Watershed										
Single Family Residential	8	0.40	0.30	(0.10 - 0.96)	3.1	2.5	(1.1 - 7.0)	92	72	(27 - 269)
Multi-Family Residential	8	0.20	0.20	(0.10 - 0.40)	2.2	1.9	(0.7 - 4.1)	34	31	(15 - 72)
Commercial	8	0.20	0.20	(0.10 - 0.30)	2.3	2.1	(0.7 - 4.2)	50	44	(18 - 110)
Major Tributary System										
Laundry Brook	9	0.20	0.20	(0.10 - 0.60)	2.6	2.0	(1.1 - 4.5)	45	33	(16 - 142)
Faneuil Brook	9	0.20	0.20	(0.10 - 0.50)	2.8	2.7	(1.1 - 4.8)	97	49	(29 - 318)
Muddy River	9	0.20	0.20	(0.10 - 0.40)	2.2	2.2	(1.2 - 3.5)	39	36	(24 - 65)
Stony Brook	9	0.40	0.40	(0.20 - 0.83)	3.3	2.6	(1.3 - 6.2)	107	104	(22 - 260)
Forested Watersheds[b]		0.015	na	(0.01 – 0.025)[c]	0.8	na	(0.5 - 1.0)[c]			

[a]Flow-weighted composite samples
[b]From *Lake Champlain Nonpoint Source Assessment* (Budd and Meals 1994)
[c]Most frequently reported

To illustrate the effects of urbanization on stormwater runoff quality, typical total phosphorus and total nitrogen concentrations for runoff from undeveloped forested watersheds are also provided in Table 3-15 (Budd and Meals 1994). As indicated, nutrient concentrations measured in stormwater discharges to the Lower Charles River are many times higher than those measured in undeveloped forested watersheds. Therefore, the amount of nutrients generated from the Lower Charles River's immediate watershed per unit area is likely to be several times higher than that from an undeveloped watershed as indicated in Table 3-14(Schueler 1987). The data show that the land use with the highest phosphorus concentration was single-family residential (as compared to multi-family and commercial). The commercial land use area had the lowest concentrations of these three types. However, when phosphorus loading is considered, this trend is reversed, with the commercial land cover generating the greatest phosphorus loading per unit area, followed by multi-family, and then by single-family residential. The loading trend is due to the percent impervious cover of the land cover categories and its relationship with stormwater volume. Table 3-16 shows estimated percent impervious values, stormwater volume yields (storm water volume per unit area), phosphorus yields (loading rates per unit area), and phosphorus concentrations for water year 2000 (WY 2000) and for the three land-cover categories. As shown, as the percent imperviousness of the land cover increases, so does the stormwater volume and phosphorus loading yields increase.

Table3-16. Lower Charles River Watershed land cover monitoring stations, percent imperviousness, stormwater volume yields, phosphorus yields and stormwater phosphorus concentrations for water year 2000 (Breault et al. 2002) and (Zarriello et. al. 2002)

Drainage System	Percent Imperviousness %	WY 2000 Stormwater Volume Yield (ft^3/mi^2)	WY 2000 Phosphorus Yield (kg/mi^2)	Stormwater Phosphorus Concentration (mg/l)		
Single Family Residential	17	17.5	200	0.40	0.30	(0.10 - 0.96)
Multi-Family Residential	73	71.0	590	0.20	0.20	(0.10 - 0.40)
Commercial	86	106.0	4,300	0.20	0.20	(0.10 - 0.30)

The elevated stormwater phosphorus concentrations and the magnitude of stormwater volume entering the Lower Charles River from the surrounding watershed make stormwater an important source of phosphorus. This is especially true for rain storms that occur during the growing season when phosphorus is limiting algal growth in the Lower Charles River. To illustrate the relative importance of pollutant sources during rain events, the USGS estimated flow volumes and pollutant loadings to the Lower Charles River using specific rain events known by the MWRA as the 3-month and 1-year design storms. For example, the 3-month design storm was an actual rain event that occurred beginning on July 20, 1982 and lasted for 30 hours with a total rainfall of 1.84 inches. For this storm, the USGS estimated that the immediate non-CSO tributary drainage areas (assuming the Stony Brook system is separated) contributed approximately 29 percent (Zariello and Barlow 2002) of the total flow volume and 43 percent of the total phosphorus load to the Lower Charles River (Breault et al. 2002).

Illicit Discharges

Illicit discharges are any discharge to a separate storm sewer that is not composed entirely of stormwater, except discharges pursuant to an NPDES permit. Many illicit discharges are caused by connections between the sanitary sewer system and the storm sewer system that results in the conveyance of pathogen-contaminated stormwater into surface waters. These connections include wastewater piping either mistakenly or deliberately connected to storm drains or indirect connections (e.g., infiltration into the storm drain system or spills collected by drain inlets (64 Fed. Reg., 68765. December 8, 1999).

The existence of illicit discharges to storm drains is well documented in many urban drainage systems, particularly in older systems that might have been combined at one time (MAEOEA 2003). Investigations conducted by several of the communities that drain to the Lower Charles River (e.g., Boston, Cambridge, Brookline, Waltham, Newton, and Watertown) found that illicit discharges are prevalent in their separate stormwater drainage systems. Examples of the types of illicit discharges found include direct connections of sanitary wastewater pipes from buildings to storm drains, direct cross-connections between the sanitary sewers and the storm drains, and sewer pipes with loose joints and/or cracks that leak wastewater into storm drains or underdrains. Many of these discharges are continuous and discharge during both dry- and wet-weather conditions. Illicit discharges are likely to increase the concentrations of pollutants (including phosphorus) in stormwater discharges because of the flushing-out of solids that were previously deposited in the drainage systems from the illicit discharges during low-flow dry-weather conditions.

The discharge of untreated wastewater to the Lower Charles River is a serious concern for controlling eutrophication since untreated wastewater typically has high concentrations of nutrients. For example, TP and TN concentrations found in raw sanitary wastewater typically range from 4 to 12 mg/l and 20 to 70 mg/l, respectively (Metcalf and Eddy, Inc. 2003). Illicit discharges, therefore, represent a concentrated source of nutrients to the Lower Charles River. The extent of illicit discharges to the Lower Charles River is currently unknown because substantial portions of the drainage systems that discharge to the river have not been investigated. However, several of the communities such as Boston, Cambridge, Brookline, and Newton have done considerable work to identify and eliminate illicit discharges to the river. For example, the BWSC reports, as of May 2005, that over 900 illicit discharges to the Lower Charles River have been eliminated in Boston's drainage systems since it began this work in 1986. Based on reports from all of the communities draining to the Lower Charles River, EPA estimates that illicit discharge removal work has resulted in the removal of over 1 million gallons per day of untreated wastewater to the Lower Charles (Walsh-Rogalski 2005).

The magnitude of illicit discharges identified and removed from the Lower Charles River watershed to date indicates that illicit discharge have represented an important source of nutrients to the river and may still. For example, assuming a TP concentration of 7 mg/l (medium strength wastewater as reported by Metcalf and Eddy 2003) the illicit discharge removal work has resulted in an annual reduction of approximately 9,500 kg (21,000 pounds) of phosphorus to the Lower Charles River. This amount of phosphorus represents approximately 20 percent of the estimated total phosphorus load discharged to the Lower Charles River for water year 2000 (see

Table 3-13). Currently, there is insufficient information to estimate how much of the total annual phosphorus load for water year 2000 can be attributed to illicit discharges. However, it is reasonable to assume that illicit discharges remain a potentially important source of nutrients to the Lower Charles River based on previous investigations that have found illicit discharges to be prevalent in drainage systems and the extent of the drainage system network that still requires investigation. Presently, the communities in the Lower Charles River watershed continue to investigate the watershed’s drainage systems to identify and eliminate illicit discharges.

Combined Sewer Overflows

A portion of the drainage area surrounding the Lower Charles River in Boston and Cambridge is served by a combined sewer system (Figures 1-1 and 3-12). A combined sewer system is a network of sewer pipes designed to collect and carry both sanitary wastewater and stormwater runoff. To protect downstream pumping and treatment facilities from flooding and washing-out treatment systems during rain storms, the combined system includes hydraulic relief structures known as combined sewer overflows (CSOs). Under normal dry-weather operation the system transports wastewater to the Deer Island WWTF, owned and operated by the MWRA. During most wet-weather conditions, a mixture of stormwater runoff and wastewater (i.e., combined sewage) is also transported to the Deer Island WWTF. However, during larger rain events the capacity of the combined system is sometimes exceeded, resulting in the discharge of combined sewage directly to the Lower Charles River, bypassing the WWTF. Presently, there are 13 CSO outfalls to the Lower Charles River including the outlet of the Stony Brook system (MWR023), the outlet of the Muddy Brook System (BOS046), and the Cottage Farm CSO treatment facility (MWR201). The Cottage Farm facility provides screening and disinfection for its CSO discharges. The locations of direct outfalls to the Lower Charles River are depicted in Figure 3-12.

Table 3-17 presents the CSO activation frequency, annual CSO volumes and nutrient loads for calendar year 2000 and the level of CSO control based on the recommended plan for the design or “typical” rainfall year used in the facility planning. The nutrient loads are based on average TP and TN concentrations (3.1 mg/l and 9.3 mg/l, respectively) determined from CSO samples collected by the MWRA (Breault et al. 2002). CSO discharges were an important source of phosphorus and nitrogen to the Lower Charles River during 2000. When compared to the available non-CSO nutrient loading data (Table 3-13), it appears that CSO loads accounted for approximately 10-20 percent of the estimated total phosphorus loads and 10-15 percent of the estimated total nitrogen loads to the Lower Charles River at that time. Note that this is a rough approximation since non-CSO and CSO data collected during the same time period are not available. The non-CSO data are for water year 2000 and the CSO data are for calendar year 2000.

Table 3-17. CSO flows and nutrient loads to the Lower Charles River for conditions in calendar year 2000 and recommended plan conditions for the typical year

CSO Outfall Number	Status for Year 2000				Recommended Plan for Typical Year[ab]			
	Activation Frequency (events/yr)	Volume (MG)	Phosphorus Load (kg)	Nitrogen Load (kg)	Activation Frequency (events/yr)	Volume (MG)	Phosphorus Load (kg)	Nitrogen Load (kg)
CAM005	8	2.99	35.1	105.3	3	0.84	9.9	29.6
CAM007	5	1.17	13.7	41.2	1	0.03	0.4	1.1
CAM009	10	0.33	3.9	11.6	2	0.01	0.1	0.4
CAM011	2	0.16	1.9	5.6	0	0	0.0	0.0
CAM017	1	0.27	3.2	111.5	1	0.45	5.3	15.8
BOS049	0	0	0.0	0.0	Eliminated	0	0.0	0.0
BOS046	2	21.96	257.3	772.0	2	5.38	63.0	189.1
MWR010	1	0.88	10.3	31.0	Eliminated	0	0.0	0.0
MWR018	2	2.94	34.5	103.5	0	0	0.0	0.0
MWR019	2	0.35	4.1	12.3	0	0	0.0	0.0
MWR020	1	0.03	0.4	1.1	0	0	0.0	0.0
MWR023	32	111.83	1,312.3	3,936.9	2	0.13	1.5	4.6
MWR201	21	547.45	6,424.2	19,272.6	2	6.3	73.9	221.8
Total		**690.4**	**8100.8**	**24,404.6**		**13.1**	**154.1**	**462.4**

[a]The typical year is the design rainfall year used by the MWRA for CSO facilities planning and is indicative of average rainfall conditions, including a number of large rain events.
[b]The recommended plan for the typical year is based on the Long Term Control Plan to abate CSOs to the Lower Charles River. Implementation of the plan is scheduled to be completed in 2013.

Upstream Watershed Load at Watertown Dam

The upstream watershed draining over the Watertown Dam represents the largest source of phosphorus to the Lower Charles River at approximately 80 percent of the total annual load for water year 2000 (Breault et al. 2002) (see Table 3-13). The 268 square mile watershed encompasses land area in 31 communities and is drained by numerous tributary streams and rivers (CRWA 2005). Figure 3-14 shows some of the important features of the upstream watershed, including community boundaries and locations of major WWTF discharges.

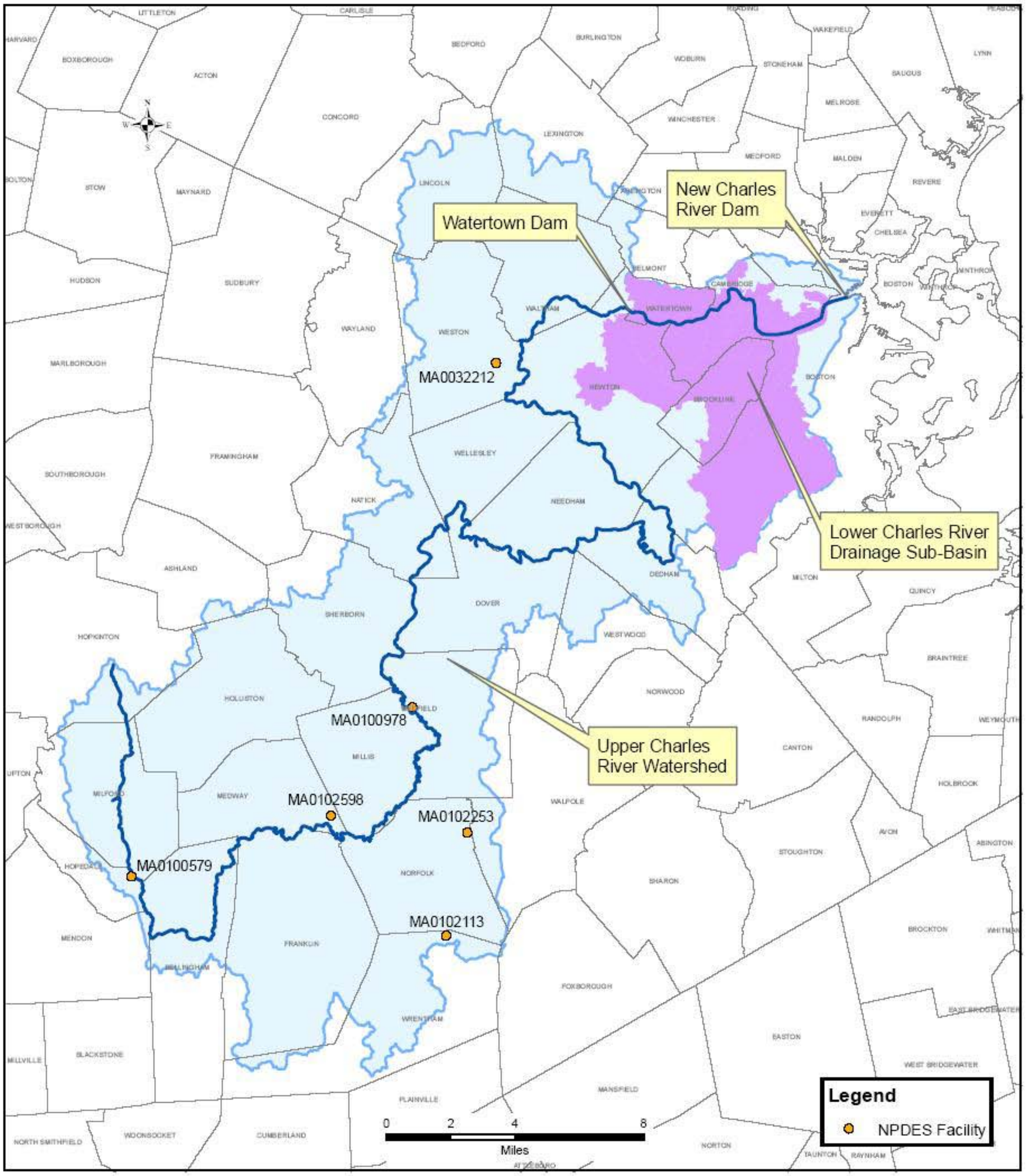

Figure 3-14. Community boundaries and NPDES facilities (WWTFs) in the upper watershed

Sources of phosphorus from the upstream watershed include six WWTF discharges, stormwater, illicit discharges, nonpoint source runoff, and natural sources (e.g., adjacent wetland areas, groundwater inflow, and runoff from undeveloped areas). The total phosphorus loading that enters the Lower Charles over the Watertown dam is very well defined, as it is based on extensive water quality monitoring conducted by the MWRA and river flow data collected by the

USGS. The water quality modeling analysis conducted for this TMDL to estimate the cause and effect relationship between nutrients and algae growth in the Lower Charles River, treats the upstream watershed as a single source (see Section 5 and the modeling analysis report, *A Hydrodynamic and Water Quality Model for the Lower Charles River Basin, Massachusetts,* Tetra Tech et. al., 2006).

Figure 3-15 summarizes the annual phosphorus loading to the Lower Charles River at the Watertown Dam for the years 1998 to 2002. The loadings are based on total phosphorus sampling conducted by the MWRA and daily river flow data collected by the USGS at Waltham and adjusted to Watertown Dam. The total phosphorus load for 2000 differs from the estimated total phosphorus load reported by the USGS for water year 2000 (Table 3-13). This difference can be partially attributed to the difference between water year 2000 (October 1, 1999 to September 30, 2000) and calendar year 2000 (January 1 to December 31, 2000).

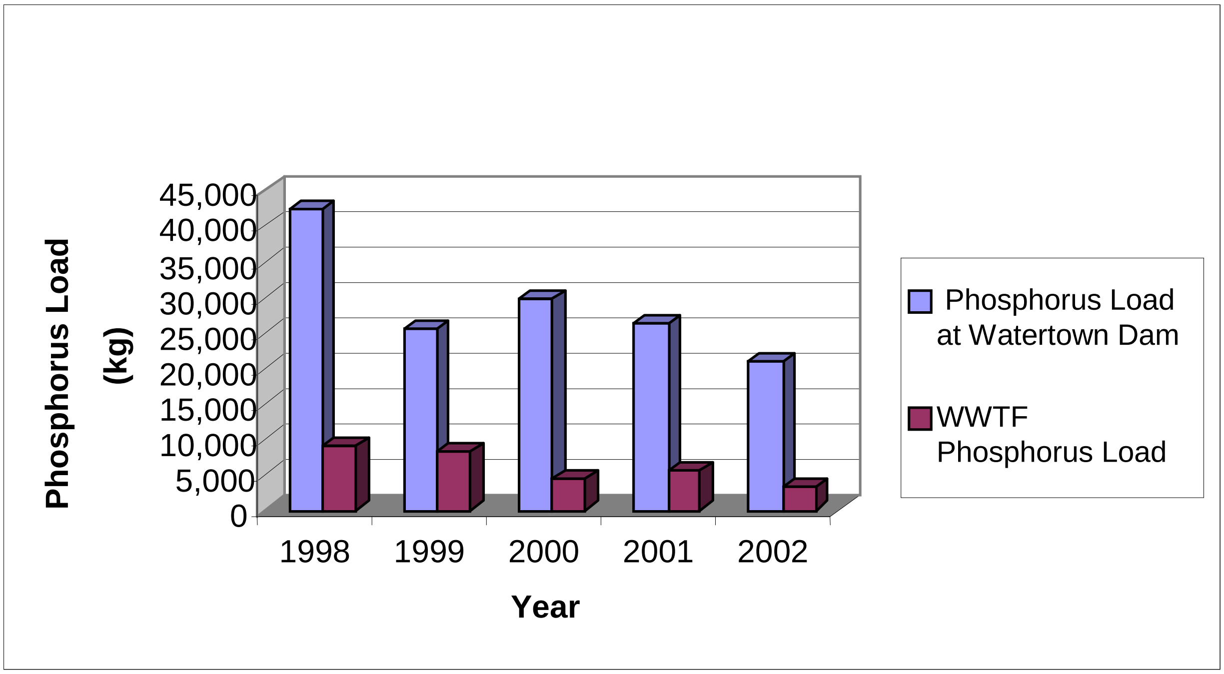

Figure 3-15. WWTF annual phosphorus load compared to phosphorus load at Watertown Dam

Also shown in Figure 3-15 are the total phosphorus loads discharged by WWTFs located in the upper Charles River watersheds (CRWA 2005). The WWTFs that discharge phosphorus to the Charles River and tributaries are identified in Table 3-18. The WWTFs discharges are continuous sources of phosphorus, have been previously identified as significant sources of phosphorus to upstream segments of the Charles River, and have strict phosphorus effluent limitations in their NPDES permits to address eutrophication-related water quality issues. During permit re-issuance in 2000, the seasonal phosphorus limits, effective April 1 to October 31, were further reduced from 1 mg/l to 0.2 mg/l (an 80 percent reduction) in order to address persistent algal problems in the upper watershed. Currently, EPA and MassDEP are in the process of issuing NPDES permits for the Charles River WWTFs that will extend phosphorus limitations from seasonal to year-round. Year-round phosphorus limits will reduce the accumulation of phosphorus in the downstream system and address excessive nutrient levels that still exist in many sections of the upper and lower Charles River during the summer growing season. Allocations for the WWTFs are presented in Section 5.2.

Table 3-18. WWTF discharges of phosphorus in the upper Charles River watershed

NPDES Number	Facility name	Location and receiving water
MA0032212	Pine Brook Country Club	Weston – Pine Brook
MA0100579	Milford WWTF	Milford – Charles River
MA0100978	Medfield WWTF	Medfield – Charles River
MA0102113	Wrentham Development Center	Wrentham – Stop River
MA0102253	MCI Norfolk-Walpole WWTF	Norfolk – Stop River
MA0102598	Charles River Pollution Control District	Norfolk – Charles River

Figure 3-15 illustrates that the phosphorus load discharged by the WWTFs has decreased substantially starting in 2000. On an annual basis, the annual phosphorus load discharged by the WWTFs has been reduced by approximately 60 percent, while on a seasonal basis (April 1 to October 31), when the 0.2 mg/l phosphorus limits are in effect, the reductions exceed 80 percent.

Table 3-19 summarizes the total and seasonal phosphorus loads at Watertown Dam as well as the phosphorus loads discharged by the upstream WWTFs. Also shown are the average flow rates of the Charles River at Watertown Dam for these periods. Relative percentages of the WWTF loads compared to the total loads at Watertown Dam are also given to illustrate the relative magnitude of phosphorus loading from the WWTFs.

Table 3-19. Charles River phosphorus loads at Watertown Dam and phosphorus loads from the upstream WWTFs

Year	Annual Mean Flow (cfs)	Annual Phosphorus Load (kg)			Seasonal Mean Flow (cfs)	Seasonal Phosphorus Load (kg) *		
		Watertown Dam	WWTF	Percent WWTF		Watertown Dam	WWTF	Percent WWTF
1998	637	42,362	8,851	21	623	22,829	4,700	16
1999	448	25,601	8,351	33	280	11,773	3,284	28
2000	464	29,632	4,633	16	416	16,590	2,159	13
2001	379	26,289	5,748	22	353	14,368	1,231	9
2002	331	20,816	3,439	17	259	10,119	828	8

*April 1 to October 31

It is difficult to determine how the reductions at the WWTFs have reduced the phosphorus loadings at Watertown Dam because of the characteristics of the upstream river system and the potential for phosphorus attenuation. The larger WWTFs contribute most of the WWTF phosphorus loadings and are located more than 40 river miles upstream from the Watertown Dam. Downstream from these dischargers, the river passes through several impounded and wetland-dominated segments before reaching the Lower Charles River. It is probable that some of the phosphorus discharged by the upstream WWTFs is delayed and attenuated as it flows downstream to the Lower Charles River. In a river system, such as the Charles, it is possible for pollutants (like phosphorus) to have long travel or retention times as it moves downstream to the mouth of the river (Hoffmann et al. 1996).

An examination of the observed phosphorus loadings at Watertown Dam, indicates that the effect reductions at the WWTFs have on the annual phosphorus loading at Watertown Dam is presently not clear. This may be due in part to the retention time of phosphorus in the upstream segments of the Charles River, which may cause the more recent load reductions to not yet be reflected in these data. Also, it appears that the presence of other phosphorus sources in the watershed may overshadow the effect of the WWTF's phosphorus load.

This becomes evident upon examination of the relationship between river flow volume, which varies annually and seasonally based on rainfall, and phosphorus loading at Watertown Dam. Figure 3-16 shows the relationship between average annual river flow and total annual phosphorus load at Watertown Dam, indicating that annual phosphorus loads at Watertown Dam are strongly correlated (R^2 = 0.94) with river flow volume. A similar strong relationship (R^2 = 0.85) was found between phosphorus loads and flow volumes on a seasonal basis, further suggesting that non-WWTF sources such as stormwater and nonpoint sources are an important component to the phosphorus loadings entering the Lower Charles River. In general, wetter years with higher flows (e.g., 1998) yield more phosphorus than low-flow dry years (e.g., 2002). As a result of the contributions from other sources, particularly those that are more prevalent during high-flow and wet-weather conditions, it is difficult to confidently isolate the effects of the treatment plant upgrades on phosphorus loading to the Lower Charles River over a seasonal or annual basis.

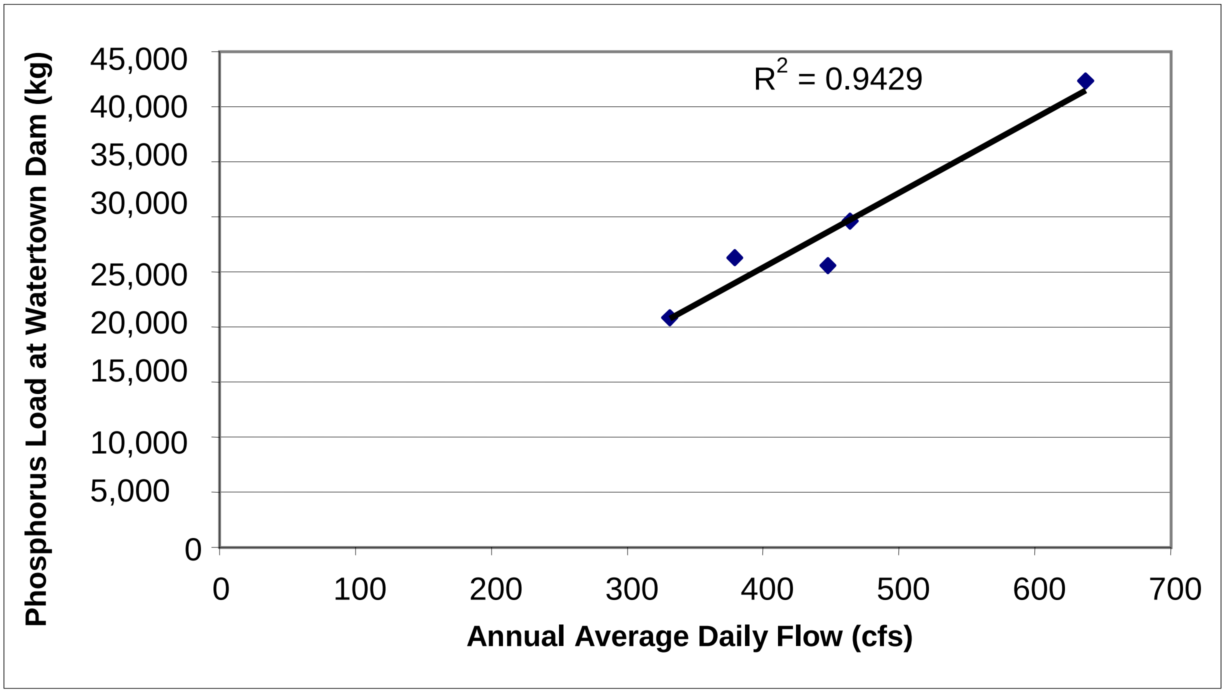

Figure 3-16. Annual flow versus total phosphorus load at Watertown Dam.

The phosphorus loading from the upstream watershed consists of many sources and collectively represents the largest source of phosphorus to the Lower Charles River. While many of the sources (e.g., stormwater, illicit discharges, and WWTFs) in the upstream watershed are controllable, and significant reductions have already been achieved at the WWTFs, other more natural sources (e.g., wetland areas bordering the river and runoff from undeveloped/undisturbed areas) may offer little opportunity for reductions. “Natural” and background phosphorus loadings are discussed above in Section 3.4.1 *Stormwater Drainage Systems* (see Table 3-14).

For this TMDL, a land cover phosphorus loading analysis has been performed to estimate the magnitude of phosphorus loading for several land cover categories that exist in the upstream watershed. The land cover loading estimates were developed by multiplying the area of each major land cover category in the upstream watershed by a phosphorus export loading factor for the corresponding land cover category. Literature values of phosphorus export factors were used initially and then were adjusted so that the total phosphorus loading from the upstream watershed matched the measured phosphorus loading at the Watertown Dam used in the TMDL analysis for the five year period, 1998-2002. Applying phosphorus loading export factors to estimate watershed phosphorus loading is a common practice used in developing TMDLs for eutrophic lakes.

As discussed further in Section 6.1 of this report, the purpose of developing land cover phosphorus loading estimates is to better understand the relative importance of phosphorus sources in the Charles River watershed, and to determine the magnitude of phosphorus reductions that will need to be achieved from the different land cover categories in order to achieve applicable Massachusetts water quality standards. Section 6.1 provides a land cover loading analysis for the entire Charles River watershed and for each watershed community and includes phosphorus load reductions by land cover category.

Figure 3-17 depicts both the literature and adjusted phosphorus loading export factors used in preparing the loading estimates for the land-cover categories. The source of the export factors is cited in the footnotes to Figure 3-17. The loading factors were directly applied using the area for the appropriate land cover categories in the upstream Charles River watershed. The estimated loadings were then adjusted to match the measured current loadings for 1998-2002. Only a minor adjustment of approximately 1 % was needed to adjust the estimated loadings derived from the literature loading export factors to match the annual average measured loading estimates for the period of 1998-2002 used in the TMDL modeling analysis.

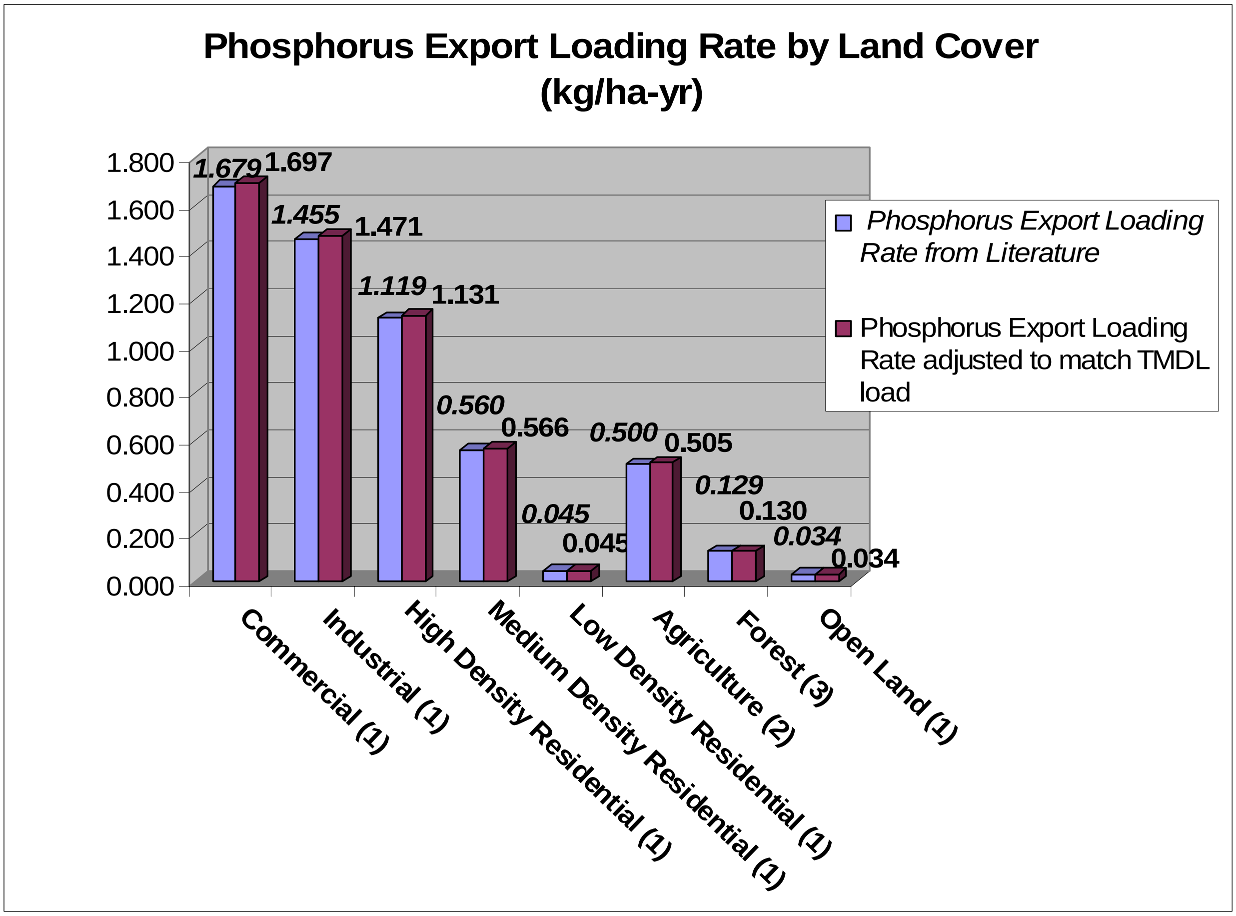

Figure 3-17. Phosphorus Loading Export Factors from literature and adjusted values for Lower Charles TMDL.

Footnotes for Figure 1.

1. Horner, Richard R., Joseph J. Skupien, Eric H. Livingston, and H. Earl Shaver. 1994. *Fundamentals of Urban Runoff Management: Technical and Institutional Issues*. Prepared by the Terrene Institute, Washington, DC, in cooperation with the U.S. Environmental Protection Agency.
2. Budd, Lenore F.and Donald W. Meals. February 17, 1994. Draft Final Report. *Lake Champlain Nonpoint Pollution Assessment.*
3. Mattson, Mark D. and Russell A. Isaac. 1999. *Calibration of phosphorus export coefficients for Total Maximum Daily Loads of Massachusetts's lakes.* Lake Reservoir. Management, 15:209-219.

Figure 3-18 illustrates the distribution of land cover in the upstream Charles River Watershed (Breault. et. al., 2002). The upstream watershed includes a drainage area of approximately 268 square miles or 69,417 hectares (171,533 acres) that drains over the Watertown Dam. Figure 3-19 presents the estimated relative contributions of phosphorus loading from the various major source categories of the upstream Charles River Watershed**.** The loadings depicted for the WWTFs represent average annual loads for the period of 1998-2002. Refer to Figure 3-18 to note that the more intense urban-type land cover categories such as commercial, industrial and high density residential areas (that make up approximately 13% of the watershed) are estimated to contribute a disproportionately large amount of the phosphorus load (~42%) to the Lower Charles River at the Watertown Dam. Figure 3-20 presents the estimated loadings for each of the source categories that correspond to the relative distributions shown in Figure 3-19.

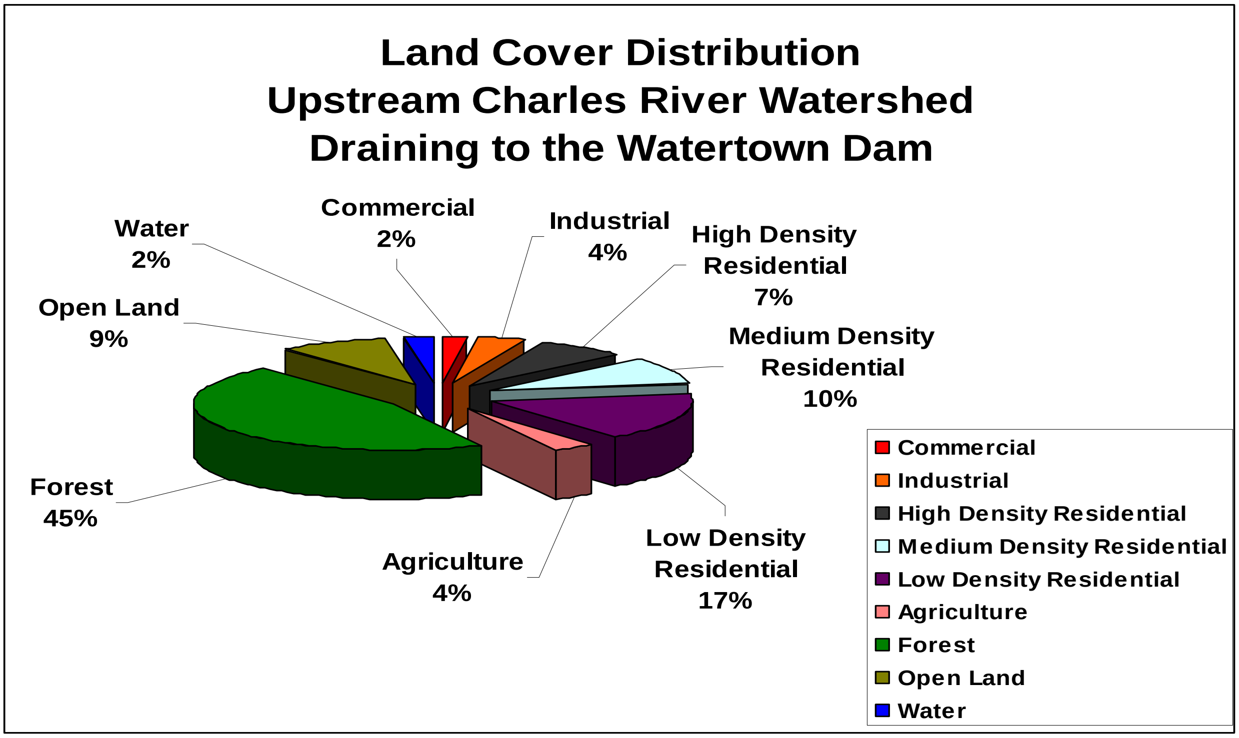

Figure 3-18. Land cover distribution, upstream Charles River watershed draining to the Watertown Dam.

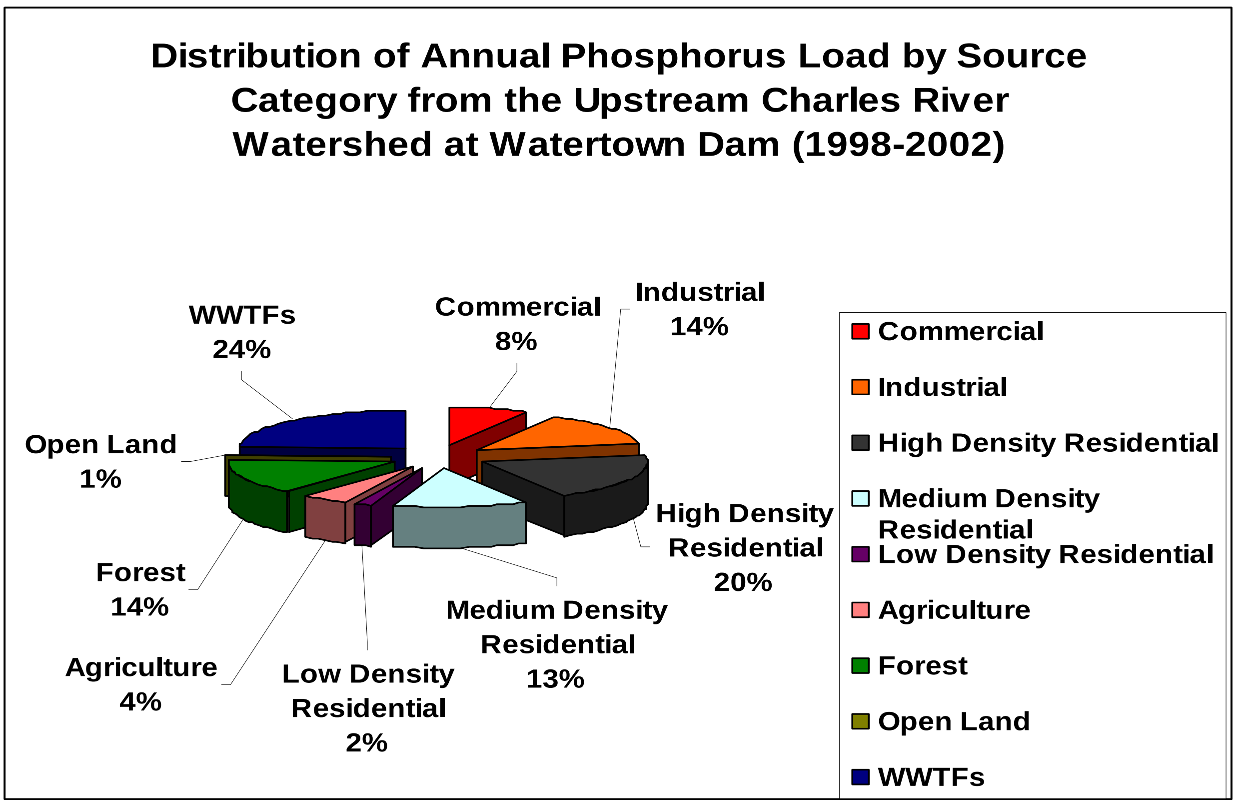

Figure 3-19. Distribution of the annual phosphorus load by source category from the upstream watershed at Watertown Dam (1998-2002).

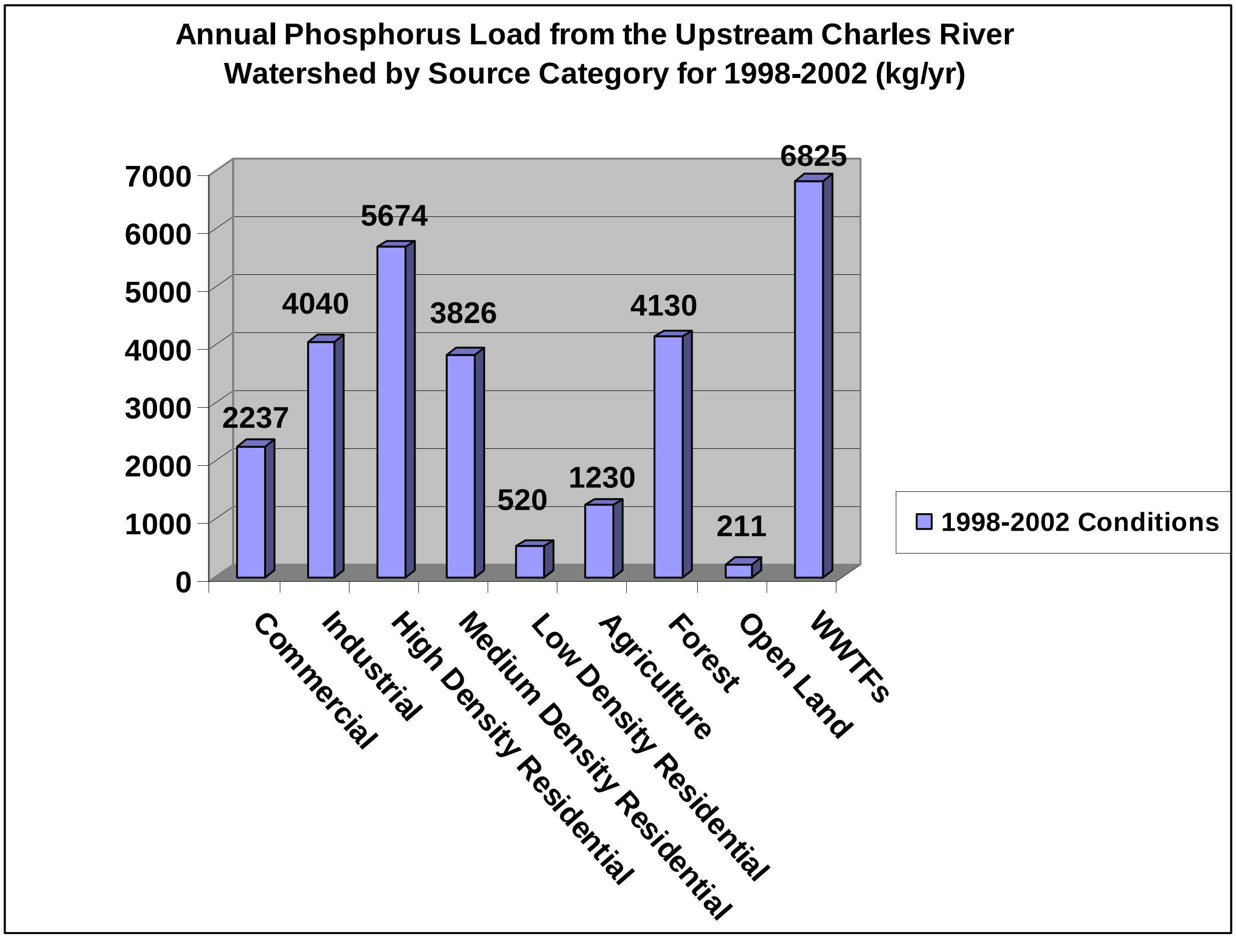

Figure 3-20. Annual phosphorus load from the upstream Charles River Watershed by source category for 1998-2002.

3.4.2 Thermal Discharge from Kendall Square Station

Heat, in the form of thermal discharge from the once-through non-contact cooling water discharge from the Kendall Square Station power generation facility (owned and operated by Mirant), is also identified as a potential pollutant of concern for contributing to excessive algal biomass and the proliferation of undesirable cyanobacteria species in the Basin. An increase in river temperatures, because of the thermal discharge from the Kendall Square Station facility, is potentially a concern for controlling algal levels in the Basin. Additionally, there is a concern for the potential shift in the algal community to include more undesirable cyanobacteria that favor higher temperatures.

It has been determined that the model used to calculate the nutrient TMDL for the Lower Charles River does not currently have the necessary resolution to determine thermal loads based on algal growth. Therefore, thermal loads are not included in this TMDL. However, heat from the power plant is still considered a potential pollutant of concern with respect to algal blooms and needs further evaluation. There is currently a lack of information necessary to determine the impact of heat on algal biomass in the Lower Charles River and to calculate an allowable thermal load based on algae. In order to evaluate heat as a potential pollutant of concern, there is a need for additional chlorophyll *a* monitoring in the Basin during critical periods when the Kendall facility has sustained discharges near its permitted thermal load. The following discussion provides the basis for considering thermal discharge from the Kendall Square Station facility to be a potential pollutant of concern for contributing to the cultural eutrophication of the Lower Charles River.

The Kendall Square Station is a fossil-fuel electrical generation facility located on the banks of the Charles River in Cambridge, Massachusetts. The facility discharges once-through non-contact cooling water to the Cambridge side of the Basin just downstream from the Longfellow Bridge. Under the existing NPDES permit the Kendall Square Station has a monthly average discharge limit of 70 million gallons per day (MGD) and a maximum daily discharge limit of 80 MGD of non-contact cooling water. The discharge temperature is limited to an increase of up to 20 °F above the water temperature at the intake and cannot exceed 105 °F (40.6°C) (USEPA 2004a).

In late 2002 and early 2003, Mirant completed an upgrade of the facility. Historically, the facility's thermal discharge during the summers has been well below the full permitted load. Starting in the summer of 2001 there was a notable increase in thermal discharge compared to the summer months of 1998 to 2000. Figure 3-21 shows the average thermal load discharged by the facility for the months of June through September for the years 1998 to 2004 (Mirant 2003 and 2005). Also shown is the allowable monthly average permitted thermal load, 486.5 Million British Thermal Units per hour (MMBTU/hr), which was considered in this TMDL. As indicated, the facility has operated well below the allowable permitted load, but starting in the summer of 2001 has increased its monthly average thermal load by approximately 92 percent over the thermal load that was discharged during the summers of 1998 to 2000. More substantial increases (approximately 135 percent) in summer thermal load discharges by the facility have occurred following the upgrade during the summers of 2003 and 2004.

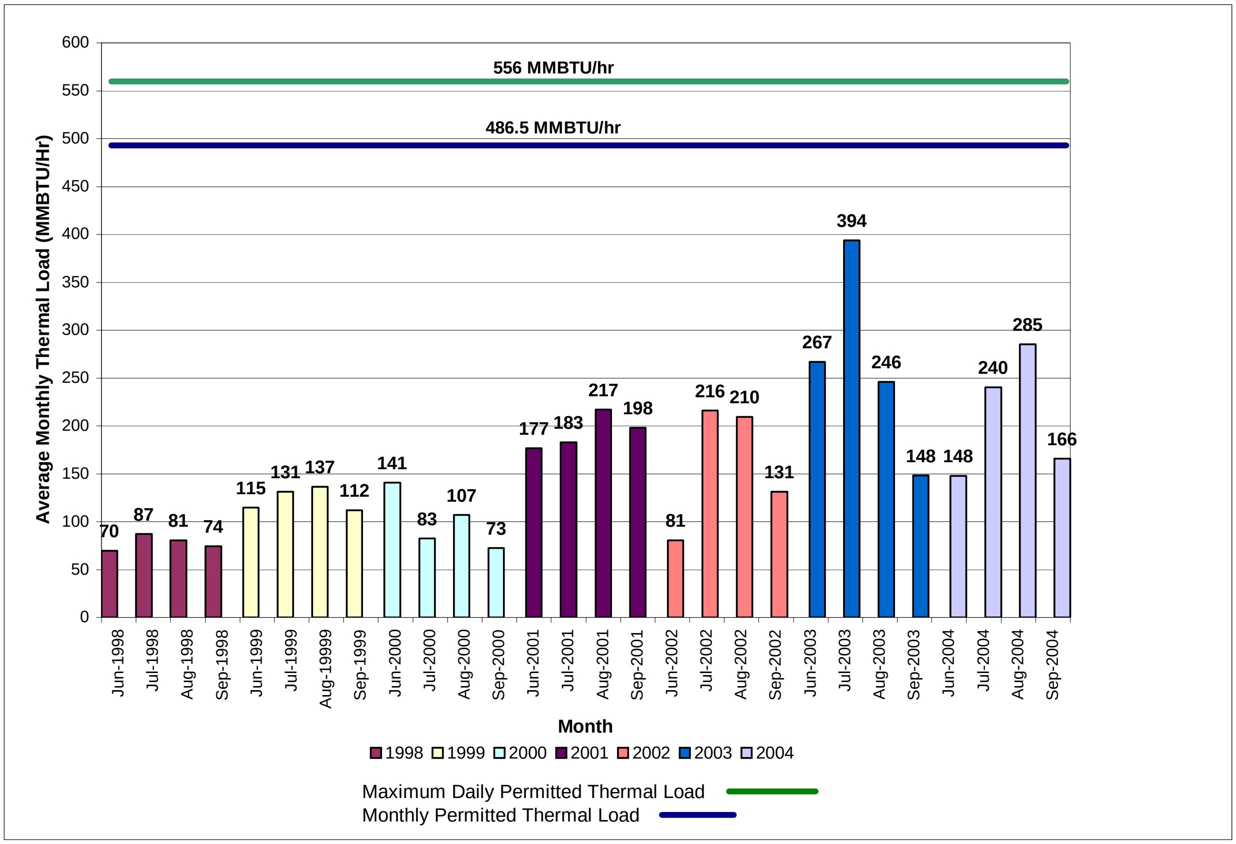

Figure 3-21. Thermal load discharged to the Charles River Basin from Kendall Square Station.

The upgraded facility has the capacity to further increase the thermal load to the Basin and raise river temperatures (USEPA 2004a). For example, assuming full permitted thermal discharge (486.5 MMBTU/hr), the river would receive more than a 500 percent increase in thermal load when compared to the actual average monthly heat load discharged during August of 1998 (81 MMBTU/hr). Based on a review of river temperature and thermal loading data provided by Mirant, it appears that the thermal discharges from the facility cause water temperatures to increase by several degrees in the downstream portion of the Basin. For example, on August 18, 1999 river temperatures in the downstream portion of the Basin were observed to be at least 4 ºF higher than temperatures in the upstream portion of the Basin. This observed increase was associated with a daily average thermal load of 250 MMBTU/hr, only 51 percent of the full monthly average permitted load of 486.5 MMBTU/hr (Mirant 2001).

Temperature Effects on Algal Growth Rates

One of the primary concerns relating to the operation of the Kendall Square Station facility and eutrophication is the relationship between temperature and algal growth. Under its existing permit, the facility has the potential to increase the temperature in the downstream portion of the Basin by several degrees F. A new final permit for the facility has been prepared by EPA,which would curtail temperature increases associated with the facility's discharge. However, the final permit is presently under appeal. Literature exists concerning the influence of temperature on phytoplankton growth. Canale and Vogel (1974) summarize the findings of numerous investigators and present temperature data and corresponding calculated specific growth rates for several species from four groups of phytoplankton (Figure 3-22). The data illustrate that growth rates for individual species vary with temperature. For example, the calculated specific growth rate for the diatom *Asterionella formosa* varied from 0.69 day $^{-1}$ at 10 degrees Celsius (ºC) (50 ºF) to an average of 1.67 day $^{-1}$ at 20 ºC (68 ºF). In the higher temperature range, growth rates for the blue-green species *Anacystis nidulans* varied from 2.64 day $^{-1}$ at 25 ºC (77 ºF) to an average of 4.4 day $^{-1}$ at 30 ºC (86 ºF) and to 11.0 day $^{-1}$ at 40 ºC (104 ºF). Note that Figure 3-22 is for illustrative purposes only. The algorithms relating water temperature and algal growth in the model for the Lower Charles River were based on values in the Chesapeake Bay Model, not those represented in Figure 3-22. Please refer to *A Hydrodynamic and Water Quality Model for the Lower Charles River, Massachusetts* (Tetra Tech, Inc. and Numeric Environmental Services 2006) for more detailed information on the parameters applied in the model.

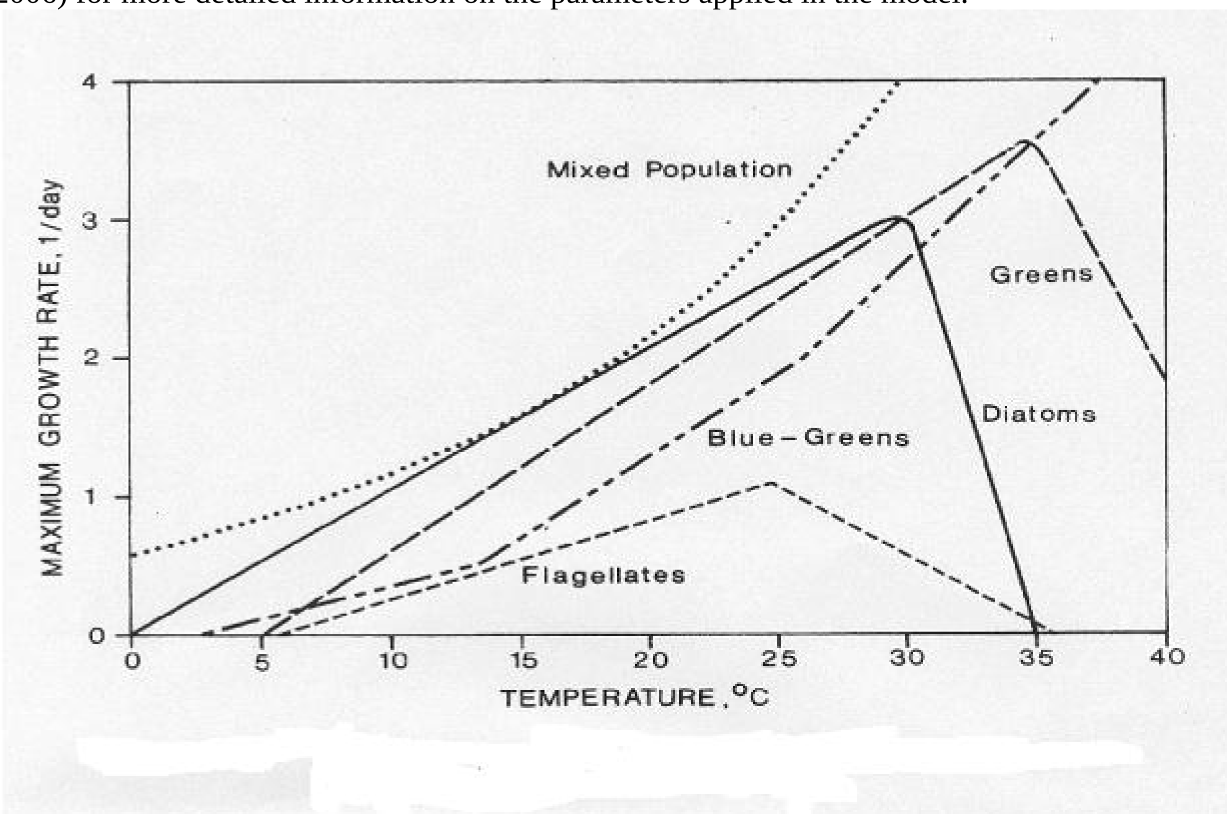

Figure 3-22. Temperature-growth curves for major algal groups from Canale and Vogel, 1974.

Charles River Basin Algal and Temperature Data

During the summer of 2002 EPA conducted algal analyses to document species composition in the Basin. The data show that the composition of the algal community shifted from predominantly diatoms in early summer to blue-greens as the summer progressed (Figure 3-8) (USEPA 2002). Other algal taxonomic data collected from the Basin by Mirant in the mid to late summer periods of 2001 and 2003 showed the same trend of increasing predominance of blue-greens as the summer progressed (Figures 3-7 and 3-9) (Mirant 2001 and 2003).

Algal and temperature data collected upstream in the Basin and downstream in the vicinity of the Kendall Square discharge were compared to identify any obvious trends between river temperature and algal cell counts. Table 3-20 summarizes the upstream and downstream cyanobacteria (blue-green) and total algal cell counts measured during the summers of 2001, 2002, and 2003. Because of the influence of other factors (i.e., water clarity, nutrient availability, and settling) that affect algal concentrations, it is virtually impossible to isolate temperature as a sole influencing factor on algal growth in natural waters (Goldman 1981). The variability of water quality in the Basin has been discussed above and generally shows improvement in the downstream direction. It is probable that environmental conditions, other than temperature, differed between the upstream and downstream stations and may have affected algal concentrations.

Table 3-20. Relative percent differences in algal counts between the upstream and downstream portions of the Basin

Date	Basin – Upstream (cells or units per ml)					Basin – Downstream (cells or units per ml)					Change in Temp. (F)	Relative Percent Difference		
	Location	Blue-Greens	Total Algae	Blue-Green %	Temp. (°F)	Location	Blue-Greens	Total Algae	Blue-Green %	Temp. (°F)		Blue-Greens	Total Algae	Blue-Green % [a]
2001[b]														
8/20/2001	MIT	12,587	22,234	56.6	78.3	Diffuser	10,515	20,356	51.7	77.8	-0.5	-16.5	-8.4	-5.0
8/29/2001	MIT	9951	20,132	49.4	77.8	Diffuser	12,629	22,377	56.4	78.7	0.9	26.9	11.2	7.0
9/3/2001	MIT	13,284	25,764	51.6	73.9 [c]	Diffuser	25,638	38,426	66.7	75.4 (1)	1.5	93.0	49.1	15.2
9/20/2001	MIT	18,341	27,885	65.8	70.4	Diffuser	8,642	16,754	51.6	71.1	0.7	-52.9	-39.9	-14.2
2002[b]														
7/9/2002	TMDL21	20	2,059	1.0	78.9	CRBL11	18	985	1.8	82.7	3.8	-10.0	-52.2	0.9
8/6/2002	TMDL21	364	9,893	3.7	80.8	CRBL11	73	9,456	0.8	84.0	3.2	-79.9	-4.4	-2.9
9/10/2002	TMDL21	1,163	4,110	28.3	74.0	CRBL11	1,195	2,137	55.9	78.8	4.8	2.8	-48.0	27.6
2003 Comparison between Mirant Stations A and B[b]														
8/7/2003	A	78	2,507	3.1	78.0	B	376	2,150	17.5	80.2	2.2	382.1	-14.2	14.4
8/14/2003	A	150	1,601	9.4	79.5	B	281	1,119	25.1	82.1	2.6	87.3	-30.1	15.7
8/21/2003	A	351	1,991	17.6	78.7	B	525	2,225	23.6	82.5	3.8	49.6	11.8	6.0
8/28/2003	A	168	1,618	10.4	75.0	B	378	2,282	16.6	77.1	2.1	125.0	41.0	6.2
9/3/2003	A	281	1,425	19.7	71.0	B	426	1,186	35.9	72.5	1.5	51.6	-16.8	16.2
9/17/2003	A	373	1,659	22.5	71.9	B	1,553	3,169	49.0	74.2	2.3	316.4	91.0	26.5
9/24/2003	A	176	1,278	13.8	69.7	B	1,834	3,199	57.3	70.9	1.2	942.0	150.3	43.6
9/30/2003	A	314	1,607	19.5	67.4	B	1,223	2,314	52.9	68.3	0.9	289.5	44.0	33.3
2003 Comparison between Mirant Stations A and C[b]														
8/7/2003	A	78	2,507	3.1	78.0	C	429	2,027	21.2	81.5	3.5	450.0	-19.1	18.1
8/14/2003	A	150	1,601	9.4	79.5	C	275	1,648	16.7	83.7	4.2	83.3	2.9	7.3
8/21/2003	A	351	1,991	17.6	78.7	C	496	2,150	23.1	83.2	4.5	41.3	8.0	5.4
8/28/2003	A	168	1,618	10.4	75.0	C	566	2,013	28.1	79.1	4.1	236.9	24.4	17.7
9/3/2003	A	281	1,425	19.7	71.0	C	355	1,125	31.6	72.5	1.5	26.3	-21.1	11.8
9/17/2003	A	373	1,659	22.5	71.9	C	1,301	2,707	48.1	75.1	3.2	248.8	63.2	25.6
9/24/2003	A	176	1,278	13.8	69.7	C	1,769	2,969	59.6	72.4	2.7	905.1	132.3	45.8
9/30/2003	A	314	1,607	19.5	67.4	C	1,454	2,336	62.2	69.5	2.1	363.1	45.4	42.7

[a]A positive percent indicates an increase in blue-green algae when traveling from the upstream station to the downstream station. A negative percent indicates a decrease.
[b]Data sources: 2001 and 2003 = Mirant; 2002 = EPA; [c]Temperature data from 9/5/01

The results presented in Table 3-18 do not indicate a clear trend with respect to temperature across the three years. The magnitude of the blooms in the Basin among these three years appeared to vary considerably, as did river flow. However, when data from individual years are examined, trends between blue-green counts and temperature become apparent for two of the years. The 2001 data (four sampling events) show higher blue-green and total algae counts at the downstream station for two of the four sampling events, which corresponded with the two highest positive increases in observed temperature. In contrast, despite the high change in temperature recorded for all three sampling events in 2002, total algae counts were lower at the downstream station for each sampling event and the blue-greens increased only slightly on one event, on September 10, 2002, when the change in temperature was 4.2 °F. The 2003 algal data set was the most extensive, consisting of eight sampling events over a two month period. For all eight sampling events the blue-green counts were significantly higher (39 percent to 923 percent) at the downstream station, while total algae counts were higher at the downstream station for five of the eight sampling events. For all eight 2003 sampling events, temperatures at the downstream station were higher than at the upstream station with temperature changes ranging from 1.5 °F to 4.2 °F.

The 2003 data are of interest for three reasons: (1) the thermal load discharged by the Kendall Square Station facility was significantly higher than the previous two summers; (2) the relative difference (i.e., increase) in blue-green counts between the downstream and upstream stations were notably higher than the relative differences of total algae between the downstream and upstream stations; and (3) the results are generally inconsistent with the typical water quality trend of improving water quality in the downstream direction that has been observed in the Basin.

The trend of improving water quality in the downstream direction of the Basin typically applies to chlorophyll *a*. The dry-weather chlorophyll *a* data collected by EPA (1998 to 2002) at monitoring stations CRBL06 (400 meters downstream of BU Bridge) and CRBL11 (between Longfellow Bridge and the Museum of Science) were compared and found that chlorophyll *a* concentrations were higher at the upstream station, CRBL06, for 72 percent (21 of 29) of the paired observations. On average, the chlorophyll *a* concentration at CRBL06 was 39 percent (or 15 µg/l) higher than the corresponding value at CRBL11 for those sampling days when CRBL06 had a higher chlorophyll *a* concentration. The 2003 algal data collected by Mirant indicate that algal levels in the upstream portion of the Basin were higher for only 38 percent (3 of 8) of the sampling events. Although increases in temperature may appear to be a primary reason for the increase in blue-green and algae levels in the downstream portion of the Basin, caution should be exercised when interpreting these results since other site-specific factors may have partially contributed to the higher levels in the downstream end of the Lower Charles River.

Every summer from 1998 to 2004, water quality monitoring of the Basin shows there have been water quality impairments related to excessive algae in the Basin, even when the power plant's thermal load was less than 20 percent of the allowable permitted load, which occurred during August 1998. Although water quality monitoring data appear to indicate that algal-related water quality problems occur in the Basin regardless of the facility's thermal discharge, the important question concerning the facility is how much the discharge has contributed or will contribute (under full permitted thermal load) to the severity of algal blooms and related water quality impairments. After considering (1) the relationship between temperature and algal growth; (2) existing documented water quality impairments in the Basin; (3) the 2003 algal data analysis; and (4) the magnitude of the potential increase in thermal load from the Kendall Square Station facility, it is reasonable to have concerns that the thermal discharge from the Kendall Square Station facility aggravates the excessive algae levels in the downstream portion of the Lower Charles River during critical periods of the growing season (i.e., mid to late summer). It is possible that the relative effect of heat load on algae can increase as other pollutant loads (e.g., nutrients) are controlled. This TMDL recommends that the Kendall Station collect additional algae, chlorophyll *a*, and nutrient data during the summer growing seasons. These data will be useful in further evaluating the relative contribution of thermal pollution from the Kendall discharge to the excessive algae levels in the Basin.

4 TECHNICAL APPROACH

While the summary of annual nutrient loadings for the major inputs to the Lower Charles River provide a useful overview of the magnitude and the possible relative importance of the nutrient sources entering the Lower Charles River, more detailed information on the timing and delivery of the nutrients to the river is needed to evaluate the effects of nutrient loadings on algal growth during the critical summer growing season. For this TMDL a water quality model of the Lower Charles River was developed to simulate the cause and effect relationship between pollutant loadings and algal growth in the Lower Charles River. The development of the model, including the estimation of pollutant loads, model set-up, and model calibration/validation, is presented in the report entitled *A Hydrodynamic and Water Quality Model for the Lower Charles River, Massachusetts* (Tetra Tech, Inc. and Numeric Environmental Services 2006).

As an overview of how pollutant loadings were estimated for input into the model, consider that continuous water quality model simulations were performed for the five-year period, beginning January 1, 1998 and ending December 31, 2002. To perform these simulations it was necessary to generate time-series pollutant loading estimates for the various sources (e.g., drainage system outfalls, CSO outfalls, and the upstream watershed) that discharged to the Lower Charles River during the five-year period. Existing hydrologic and hydraulic SWMM models of the stormwater drainage systems and the combined sewer system, developed by the USGS, BWSC, and MWRA, were used to estimate daily flow volumes that were discharged to the Lower Charles River through the 72 storm drain outfalls and 13 CSO outfalls (see Figure 3-10). Pollutant quality data collected by the USGS (Breault et al. 2002) from the storm drainage systems and CSO quality data collected by the MWRA were used with the model simulated flow estimates for calculating daily loadings for these discharges. In the upstream watershed, daily pollutant loading estimates for the five year period were calculated using USGS Charles River flow data (Waltham and Watertown Dam gages) and water quality monitoring data collected by the MWRA at Watertown Dam. For a more detailed account of how pollutant source loadings were estimated, please refer to the model documentation report (Tetra Tech, Inc. and Numeric Environmental Services 2006).

5 TMDL ANALYSIS

The TMDL is the total amount of pollutant that can be assimilated by the receiving waterbody while still achieving water quality standards. In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL must be established and thereby provide the basis to establish water quality-based controls.

A TMDL for a given pollutant and waterbody is composed of the sum of individual wasteload 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 waterbody. The TMDL components are illustrated using the following equation:

$$\text{TMDL} = \sum \text{WLAs} + \sum \text{LAs} + \text{MOS}$$

For most pollutants, TMDLs are expressed on a mass loading basis (e.g., kilograms per day).

5.1 Water Quality Target Selection

There are no numeric water quality criteria for excessive algal biomass or nutrients in the Massachusetts Water Quality Standards (see Section 1.3.2). Therefore, defining the total allowable pollutant loading, or loading capacity, for the Lower Charles River required the interpretation of applicable narrative water quality criteria to select an appropriate numeric water quality target. A surrogate water quality target was determined in order to calculate nutrient load reductions to the Lower Charles River. Chlorophyll *a* was chosen as the surrogate water quality target used to define the assimilative capacity of 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 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. Water quality monitoring of the Lower Charles River has found elevated levels of algae, as indicated by chlorophyll *a* samples, during each of the past 8 summers (1997-2004).

Typically, the algal blooms are most severe during the mid to late summer when the amount of phosphorus controls algal abundance in the Lower Charles River (see Section 3.2.2). This period of maximum algae concentrations also coincides with reductions in water color and increases in water temperature. Although phosphorus is usually the controlling or limiting nutrient in the Lower Charles River, there are times when nitrogen also limits algal growth. However, there is uncertainty surrounding the nitrogen limitation because of the fact that nitrogen limitation is often dependent on the presence of specific species of algae (information that is not available at this time). Many of the source controls that will be required to achieve the needed phosphorus reductions will also reduce nitrogen loading as well (e.g., elimination of illicit discharges and implementation of stormwater controls). Nevertheless, phosphorus reductions have been set at levels using the water quality model to meet the selected chlorophyll *a* target and result in decreased algal levels in the Lower Charles River.

A water quality model was used to provide the link between an acceptable algae level (i.e., chlorophyll *a* target) in the Lower Charles River and allowable nutrient loadings to the Lower Charles. A full description of the water quality model is described in a separate document titled *A Hydrodynamic and Water Quality Model for the Lower Charles River, Massachusetts* (Tetra Tech, Inc. and Numeric Environmental Services 2006). The Lower Charles River model was specifically developed for this TMDL to simulate algal dynamics in the Lower Charles River from Watertown Dam to Boston Harbor in response to pollutant loadings from watershed sources. The model simulates water column and sediment nutrient cycling and algae dynamics coupled with three-dimensional transport in the Lower Charles River.

The chosen chlorophyll *a* target for the Lower Charles River is site-specific. The target was derived using a weight-of-evidence approach that relied on (1) site-specific information and water quality data concerning the physical, chemical, and biological characteristics of the Lower Charles River, (2) literature values of chlorophyll *a* as it relates to the trophic classifications, and (3) the relationship between chlorophyll *a* levels and aesthetic impairments as determined from user perception studies conducted in other waterbodies. The chlorophyll *a* target is set at a level that will result in reductions in eutrophication sufficient to enable the Lower Charles River to attain all applicable Class B narrative (nutrients, aesthetics, and clarity) and numeric (dissolved oxygen in the epilimnion and pH) criteria as specified in the MAWQS for the Lower Charles River (see Section 1.3).

A seasonal average chlorophyll *a* concentration of 10 µg/l has been selected as the water quality target for the Lower Charles River. The seasonal average is defined as the mean chlorophyll *a* concentration of samples collected from the Basin between June 1 and October 31 of each year. This period represents critical conditions when algal blooms are typically most severe in the Basin and have the greatest impact on designated uses (see Section 5.3). Achieving a seasonal average chlorophyll *a* concentration of 10 µg/l will reduce algal biomass in the Lower Charles River to levels that are consistent with a mesotrophic status and will address aesthetic impacts and attain clarity standards. A waterbody that is mesotrophic has intermediate nutrient availability and biological production (USEPA 1990) without having an adverse impact on the aquatic food web (USEPA Chesapeake Bay Program 2003a). A review of available literature indicates that a mean chlorophyll *a* concentration of 10 µg/l is within the mesotrophic status or at the boundary between eutrophic and mesotrophic status (Wetzel 2001, Novotny and Olem 1994, and Vollenweider and Carekes 1980), while it is slightly above the range reported by others (Smith 1998, and Ryding and Rast 1989). See Tables 3-1 and 3-2 in Section 3.2.1 for more information on literature values. Based on the variability reported in the literature, there is not necessarily one value that is appropriate for all waters. Rather, the values are used as guidelines for selecting the chlorophyll *a* target for the Lower Charles River. Sections 5.1.1 through 5.1.3 discuss how the chlorophyll *a* target satisfies the applicable criteria and addresses other related water quality concerns for the Lower Charles River.

5.1.1 Aesthetic and Water Clarity Impacts

Excessive algae often results in poor aesthetic quality because of coloration and reduced clarity. To evaluate the high levels of algae that might be encountered during a growing season, the 90th percentile value (the value that is expected to be exceeded only 10 percent of the time) was estimated for each season at the two MWRA water quality monitoring stations (stations 012 and

166). The 90th percentile value was selected because it eliminates possible outliers from the data set, it represents an infrequent and relatively high chlorophyll *a* value, and also corresponds with Massachusetts' assessment protocol for water clarity, which states that no less than 90 percent of the measurements should exceed the minimum clarity threshold. The relationship between the seasonal mean and the seasonal 90th percentile values are illustrated in Figure 5-1. As indicated, there is a strong correlation (R^2= 0.94) between seasonal 90th percentile chlorophyll *a* and seasonal mean chlorophyll *a*. Using this linear relationship and a seasonal mean chlorophyll *a* concentration of 10 µg/l, the 90th percentile chlorophyll *a* concentration is estimated to be 18.9 µg/l.

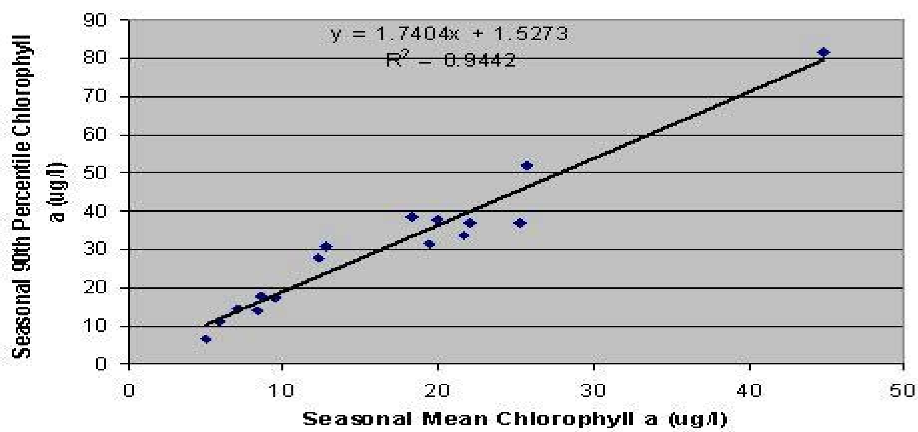

Figure 5-1. Seasonal mean chlorophyll *a* concentrations versus 90th percentile chlorophyll *a* concentrations at MWRA stations 012 and 166.

One direct way to evaluate the relationship between algae levels and aesthetic impacts is through the application of user perception-based studies as discussed in Section 3.3. Although the results of user perception-based studies are most applicable to the particular waters that are studied, the results of these studies provide valuable information for generally relating levels of algal biomass (i.e., chlorophyll *a*) to perceived aesthetic impairments. This is especially true for evaluating chlorophyll *a* targets for the Lower Charles River since a user perception-based study has not been conducted for the Lower Charles River.

Most of the studies reviewed for this TMDL indicate that chlorophyll *a* concentrations higher than 20 µg/l have consistently resulted in perceived aesthetic impairments among users (Smeltzer 1992, VTDEC 2002, Walker and Havens 1995). While some of the results from these Vermont studies indicate impairments for chlorophyll *a* levels less than 20 µg/l, it is important to exercise caution in applying these results to other waters, especially if the other waters have notably different water quality, hydrologic, and morphological characteristics than the waters where the user perception-based studies were conducted. For example, the user perception-based studies conducted in Vermont were performed primarily for lakes with relatively low color (i.e., low dissolved organic matter), while the Lower Charles River is an impounded river system with high to moderate water color. It is plausible that algal-related aesthetic impairments in clear water lakes might be more easily detected (i.e., detected at lower chlorophyll *a* levels) than in waters that naturally have moderate to high color.

Despite these differences, the MassDEP and USEPA believe that the results from these studies serve as a useful guide for the Lower Charles River because: (1) they provide general magnitudes of chlorophyll *a* concentrations that would likely cause aesthetic impairments, (2) they corroborate other supporting evidence (discussed below) that algal-related aesthetic impairments have regularly occurred in the Lower Charles River, and (3) there is an absence of a site-specific user perception-based study for the Lower Charles River. Based on the information from the user perception-based studies and considering the site-specific characteristics (e.g., high color) of the Lower Charles River, a 90^{th} percentile chlorophyll *a* value of 18.9 µg/l (based on achieving a seasonal average chlorophyll *a* concentration of 10 µg/l) is determined to be sufficient to attain narrative related aesthetic criteria.

Water clarity is another measure of aesthetic quality that is directly affected by algae. Algae both absorb and scatter light as it passes through the water column. As a result, the presence of algae reduces water clarity and lowers the observed Secchi depth. To determine whether a seasonal average target chlorophyll *a* concentration equal to10 µg/l would likely result in attaining Massachusetts' clarity standards, chlorophyll *a* and Secchi depth data from the Lower Charles River were evaluated. MassDEP assesses its clarity criteria by requiring that 90 percent of the Secchi depth observations be 1.2 meters or more. The chlorophyll *a* data were divided into two populations: (1) chlorophyll *a* values when Secchi depths were <1.2 meters and (2) chlorophyll *a* values when Secchi depths were $\geq$1.2 meters. At Secchi depth transparencies less than 1.2 meters, chlorophyll *a* (i.e., algae) levels are known to contribute to reduced clarity and non-attainment of Massachusetts' clarity criterion for primary contact recreation.

To determine whether one grab sample indicates an impairment, a new measurement is compared to the distribution of values from a population of measurements considered impaired (i.e., chlorophyll *a* measurements made when Secchi depth is less than 1.2 meters). For this analysis, only those chlorophyll *a* and Secchi depth data collected when the corresponding true color at the sampling location was 40 units or less were used because this level of color is consistent with other critical conditions when algal blooms are most likely to occur in the Lower Charles River (see Section 3.2.2). Chlorophyll *a* measurements below this distribution can be considered unimpaired with a specified level of confidence. A calculation of the one-sided prediction interval from the baseline measurements was applied. The one-sided prediction interval was calculated to determine if a new observation likely came from a different distribution than the previously collected data (Helsel and Hirsch 1992). A one-sided, rather than a two-sided, prediction interval was used because MassDEP and USEPA are interested only in the chlorophyll *a* value that is lower than chlorophyll *a* values associated with impaired conditions.

The calculation of the one-sided prediction interval relies on the mean and standard deviation of a normally distributed data set. A standard set of statistics was calculated on the chlorophyll *a* data set, which had corresponding Secchi depth transparencies less than 1.2 meters. The statistical analysis indicates the data are normally distributed. The one-sided prediction interval was calculated with a confidence level of 90 percent, meaning there is a 90 percent likelihood that the chlorophyll *a* value is associated with water quality conditions that meet the clarity criterion.

$$PI = x - t_{(\%,\, n-1)}\,(s^2 + (s^2/n))^{½}$$ (eq. 3.12 in Helsel and Hirsch 1992)

where PI = prediction interval
x = arithmetic mean = 33.3 µg/l
s = standard deviation = 9.7
n = number of observations = 38
$t_{(0.1,\ 37)}$ = critical value of Student t Distribution = 1.304

$$PI = 33.3 - 1.304(9.7^2 + (9.7^2/38))^{½}$$
$$PI = 20.5\ \mu g/l$$

Thus, at levels below 20.5 µg/l chlorophyll *a*, a single sample measurement is unlikely to cause an excursion of the clarity criterion. Conversely, a single measurement above 20.5 µg/l chlorophyll *a* is likely to represent an excursion of the clarity criterion. Comparing 20.5 µg/l chlorophyll *a* to the estimated 90th percentile chlorophyll *a* target value of 18.9 µg/l indicates, with a 90 percent confidence level, that the seasonal average chlorophyll *a* target concentration of 10 µg/l is sufficient to attain Massachusetts' clarity standard in the Lower Charles River. The difference between 20.5 µg/l and 18.9 µg/l (1.6 µg/l) represents one component of the margin of safety, which is discussed in Section 5.5.

5.1.2 Harmful Algal Blooms

As stated earlier, a goal of achieving the seasonal average chlorophyll *a* target concentration of 10 µg/l is to move the Lower Charles River from a eutrophic to mesotrophic status. A mesotrophic status for the Lower Charles River would indicate intermediate nutrient availability and biological production (USEPA 1990) without having an adverse impact from harmful algal blooms on the aquatic food web (USEPA 2000b). An analysis of patterns in algal taxonomic composition across temperate lakes of differing nutrient status conducted by Watson et al. (1997) shows 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 Lower Charles River should result in reductions in cyanobacteria (blue-green) biomass and the potential for nuisance and toxic blooms.

Algal taxonomic data and chlorophyll *a* data collected during late summer 2002 in the Lower Charles are helpful indicators as to what future water quality conditions might occur under reduced phosphorus levels for sustained periods of time. EPA's two dry-weather sampling surveys conducted on August 20 and September 10, 2002 occurred during an extensive dry-weather period when phosphorus loading from watershed sources was at a minimum. During these surveys, total phosphorus and chlorophyll *a* concentrations were relatively low for the Basin. Results of algal taxonomic analyses conducted on September 10 at USEPA stations TMDL21 and CRBL11 indicated low to moderate blue-green cell counts of 1,163 and 1,195 cells/ml, respectively. These counts correspond with chlorophyll *a* concentrations of 16 and 19 µg/l at USEPA stations TMDL21 and CRBL11, respectively. These data indicate that the 10 µg/l seasonal average chlorophyll *a* target and the associated 90th percentile of 18.9 µg/l would not result in cyanobacteria blooms. In contrast to the 2002 algal and chlorophyll *a* data, high blue-green cell counts ranging from approximately 12,000 to 19,000 cells/ml were measured by Mirant in the Basin during the months of August and September of 2001. Chlorophyll *a* concentrations from the Basin, available only for three of the 2001 surveys, were also high and ranged from 24 to 33 µg/l.

From a public health perspective, the World Health Organization (WHO) has provided the following benchmarks for blue-green cell counts that indicate potential levels of concern (WHO 2003):

- 2,000 cells/ml – Alert Level 1 for raw water supplies. It assumes that this number of cells contains enough toxin to have some adverse health effect from water consumption.
- 5,000 cells/ml – Scum can form, which concentrates toxins.
- 20,000 cells/ml – Guidance Level 1 for recreational water. Skin and eye irritation is likely from contact with the blue-green algae.

Thus, achieving a seasonal average chlorophyll *a* concentration of 10 µg/l is adequately protective from a public health standpoint as well as a water quality standpoint.

5.1.3 Dissolved Oxygen and pH

Presently, dissolved oxygen levels very rarely fall below the minimum dissolved oxygen criterion of 5 mg/l in the upper water column of the Lower Charles River. However, as a result of algal photosynthetic activity, dissolved oxygen concentrations can vary considerably during the day resulting in high super-saturated dissolved oxygen levels (see Section 3.2.1). 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 lower super-saturated dissolved oxygen concentrations.

In the hypolimnion, dissolved oxygen concentrations typically drop below 5.0 mg/l during the summer when the Lower Charles River stratifies because of the salt wedge (see Section 3.2.3). Based on model results, it appears that a reduction in algal biomass will help to increase the dissolved oxygen levels in the hypolimnion. However, it is unlikely that the dissolved oxygen levels in the hypolimnion will meet water quality criteria based on algal reductions alone. It is probable that dissolved oxygen levels will become low in the hypolimnion regardless of algae levels because of the high chemical and biochemical oxygen demand that exists in the bottom waters because of the presence of sulfides and the large reservoir of organic materials.

Similar to dissolved oxygen, pH also varies diurnally because of photosynthetic activity of algae and sometimes exceeds the maximum pH criterion of 8.3. Reductions in algal biomass associated with achieving the seasonal chlorophyll *a* target should result in smaller diurnal variations in pH and compliance with the pH criterion of 6.5 – 8.3.

5.2 TMDL

Model simulations for the period 1998-2002 were used to define existing conditions and the nutrient reductions that are needed to achieve the seasonal chlorophyll *a* average of 10 µg/l. The reductions were based on achieving an overall average seasonal chlorophyll *a* concentration of 10 µg/l using the average of the five modeled growing seasons (June 1 through October 31 of 1998-2002). The average of five growing seasons is being used to determine the TMDL instead of one growing season because the average accounts for variations between years such as hot dry summers versus summers with heavy rainfall resulting in large nutrient inputs. Using the average of five growing seasons also helps to reduce model error in predicting the necessary reductions.

5.2.1 TMDL Scenario Analyses

The model of the Lower Charles River was applied to determine the beneficial water quality impacts of nutrient load reductions. Simulations were conducted with the model to determine total phosphorus load reductions required to meet the growing season average chlorophyll *a* target of 10 µg/l. Numerous phosphorus loading scenarios were examined before choosing the best scenario for meeting the TMDL water quality target.

Daily phosphorus loadings were input to the model at 91 specific locations throughout the Lower Charles River. These inputs included the upstream watershed above Watertown Dam, harbor water intrusion through the New Charles River Dam, 12 direct CSO discharges, 73 piped stormwater drainage network outfalls, and the 4 major tributary streams (Stony Brook, Muddy River, Laundry Brook, and Faneuil Brook). The direct CSO discharges included: City of Cambridge CAM005, CAM007, CAM009, CAM011, and CAM017, City of Boston BOS049, and MWRA MWR201 (Cottage Farm CSO Treatment Facility), MWR010, MWR018, MWR019, MWR020, MWR022, and MWR021. Piped stormwater drainage network discharges included the Muddy River Conduit (including CSO BOS 046) and 72 other unmonitored outfalls. Total phosphorus loads for each source were subdivided into the various forms of phosphorus, including inorganic ortho-phosphorus, refractory particulate organic phosphorus, labile particulate organic phosphorus, and dissolved organic phosphorus.

Under existing wet-weather conditions the Stony Brook discharge includes a significant amount of CSO (MWR 023). However, for TMDL scenario modeling, the CSO phosphorus inputs were decreased based on reduction estimates by MWRA and USGS (Breault et al. 2002). Individual wet-weather CSO overflow discharge rates were also adjusted for TMDL scenario runs based on annual volumes predicted for each CSO by MWRA in their Recommended Long Term CSO Control Plan (see Section 7.1.2).

Loads of phosphorus and other water quality parameters that enter the Lower Charles River during operation of boat locks at the New Charles River Dam were not adjusted for TMDL scenario simulations. These lockages, which are most frequent during summer and fall months, bring saline water into the Lower Charles River from Boston Harbor. This harbor water intrusion, which results in establishment and upstream migration of a saline wedge in the deeper portions of the Basin during summer and fall, contributes to vertical stratification of the water column, bottom water hypoxia, and subsequent release of benthic phosphorus and nitrogen pools to bottom waters. However, due to the strength of the vertical stratification produced, most of these nutrients are currently trapped within bottom waters during the growing season.

TMDL scenario simulation results used for development of the phosphorus TMDL consisted of 5-year simulations, using existing loads for the period between 1998 and 2002 for each discharge group. Constant daily reduction factors were specified independently for each of the following nutrient sources: (1) upstream watershed above Watertown Dam, (2) non-CSO drainage areas that discharge directly to the Lower Charles River (including Stony Brook, Muddy River, Laundry Brook, Faneuil Brook, and all other non-CSO drainage areas), (3) CSO discharges. Reductions to CSO loads were applied only on days when CSOs were active. Phosphorus reductions specified for the upper watershed varied between 25 and 50 percent. Reductions for the upper watershed greater than 50% were not simulated because of concerns that higher reductions might extend beyond anthropogenic loading and into sources of natural loadings. Phosphorus reductions for non-CSO drainage areas varied between 25 and 90 percent. All CSO loads were set at the MWRA's Long Term CSO Control Plan's recommended conditions, wherein CSO event mean concentrations (EMCs) were held constant and existing condition daily CSO discharge rates were attenuated to match the Long Term Control Plan annual overflow volumes.

TMDL scenario modeling results for the photic zone (near surface) waters just upstream of the Museum of Science were selected for determining attainment of the seasonal average (June through October) target chlorophyll *a* level of 10 µg/l. Seasonal average and 90th percentile peak chlorophyll *a* predictions were calculated for each of the 5 modeled years and averaged. The Museum of Science location was selected for the TMDL analysis because it has been the most extensively monitored location in the Lower Charles River for many years. In addition, growing season model predictions of chlorophyll *a* and phosphorus at this location are highly correlated with the monitoring data for the period 1998 – 2002.

The resulting seasonal average chlorophyll *a* concentrations based on various tested total phosphorus reduction scenarios are presented in Table 5-1. The TMDL scenario modeling results indicate that the chlorophyll *a* target will be met if total phosphorus discharged in the upper watershed is reduced year round by 45 percent and all non-CSO direct inputs to the Basin are reduced by 60 percent. This scenario results in a seasonal average chlorophyll *a* level of 9.8 µg/l in the photic zone at the Museum of Science location. Section 5.2.3 provides more detail on the modeling results of the selected TMDL scenario and the associated allocations.

A seasonal modeling simulation was conducted for one of the load reduction scenarios to evaluate whether seasonal loading would be a more appropriate expression of the TMDL. The results shown in Table 5-1 for the 40% - 70% (upstream watershed – lower watershed) annual and seasonal reduction scenarios show that the applying the reductions annually results in a lower seasonal chlorophyll *a* average by approximately 0.4 µg/l. The results from these scenarios support expressing the TMDL as an annual load by showing that some of the non-growing season phosphorus load contributes to growing season algae concentrations.

Table 5-1. Sensitivity of model-predicted seasonal average chlorophyll *a* to various total phosphorus reduction scenarios

Total Phosphorus Reduction Scenario (% Reductions)		Seasonal Average Chlorophyll *a* (µg/l)
Upper Watershed	All Other Sources	
25	25	13.7
50	50	10.2
40 (seasonal)*	70 (seasonal)*	10.2
40	70	9.8
45	60	9.8 (TMDL)
45	65	9,7
50	70	8.8
50	90	7.7

*April through October

Previous modeling analysis demonstrated that settling of organic phosphorus and nitrogen to bottom sediments and subsequent bottom sediment diagenetic processes serve as a long term source of phosphorus and nitrogen to the Lower Charles River. Modeling results suggest that, following implementation of nutrient load reduction scenarios, the sediment nutrient pool and subsequent sediment nutrient releases will gradually decrease over a period of 10 or more years. However, only 5-years of this sediment nutrient "wind-down" were included explicitly in the TMDL scenario modeling. This TMDL modeling approach thus serves as an implicit margin of safety (see Section 5.5).

5.2.2 TMDL Expression

Conceptually, the allowable phosphorus loading or loading capacity for the Lower Charles River may be viewed in terms of either an annual load or a daily load. As explained below, an analysis based on annual loading is, at the model and implementation level, more productive and more realistic for specifying loading conditions that will result in attainment of applicable water quality standards. However, for purposes of adding clarity on how the allowable annual phosphorus load should be interpreted, as well as satisfying section 303(d) of the CWA, both an annual load and a maximum daily load have been established. The translation from annual loading analysis to daily loadings is based on frequency distributions of daily phosphorus loadings to the Lower Charles River, and has been conducted both for existing conditions (1998-2002), and for a future scenario under which phosphorus loadings have been reduced to levels that would result in attainment of applicable water quality standards. Daily phosphorus loading shows that achieving the allowable annual load should be accomplished by placing controls that are in effect throughout the year.

Annual Loading Analysis

As specified in 40 C.F.R. 130.2(i), TMDLs may be expressed in terms of either mass per unit time, toxicity, or other appropriate measures. From a scientific perspective, phosphorus and eutrophication are most appropriately analyzed on a seasonal or annual basis. Long-term average phosphorus loadings have been determined through modeling to be more critical to algal biomass in the Lower Charles River than short term or daily loadings, for several reasons.

First, the amount of algae in the Lower Charles River is related to climatic and nutritional conditions that occur over extended periods of time during the summer season. Excessive algal abundance does not occur instantaneously, but occurs over time as algal populations grow under favorable climatic and nutritional conditions. Second, the large volume of impounded water in the Lower Charles River and the relatively small daily inflow volumes during the growing season result in long water residence times. In effect, the large impounded river volume and long retention times allow the Lower Charles to hold pollutant loadings that have occurred over extended periods of time. The long retention times also allow algae to grow and accumulate in the system, sometimes reaching bloom conditions. Long-term averaging of nutrient loading becomes more important when dealing with an impoundment that receives highly variable and intermittent wet-weather discharges that are prevalent in the Charles River watershed. Discharges of nutrients during wet-weather events have a long term cumulative impact on algal levels in the Lower Charles because of the residence time, which allows previously discharged nutrients to remain in the Lower Charles during periods when high algal growth can occur.

Finally, river sediments act as a reservoir of nutrients that have been discharged from the watershed. Nutrients from sediments are released to the water column at various rates depending on site-specific conditions. The model was used to evaluate whether the loading capacity and allocations should be established for implementation purposes on a shorter time frame than annually. Determining the river's phosphorus loading capacity on an annual basis is consistent with the limnology of the Lower Charles River, and is most useful for calculating levels of total phosphorus necessary to realistically attain the seasonal chlorophyll *a* target. The model predicts that phosphorus loadings that discharge to the Lower Charles River throughout the year contribute to nutrient levels in the sediments of the Lower Charles. The model predicts that some of these nutrients are released during the critical growing season and are available for algal uptake.

Maximum Daily Loadings Analysis

For reasons discussed above, algal levels in the Lower Charles River are a function of long-term average phosphorus loadings and seasonal/climactic conditions. Therefore, it is not useful to specify a single maximum daily phosphorus load value for the Lower Charles River that could be used to determine what phosphorus load reductions are needed to attain applicable water quality standards throughout the growing season. Daily phosphorus loadings to the Lower Charles River are highly variable and are dependent on seasonal and climatic conditions. The algal response to phosphorus loading is also dynamic and dependent on seasonal and climatic conditions.

Conditions for algal growth in the Lower Charles are highly variable and dynamic and far from constant or steady state where a single maximum daily load value could be specified to define allowable loadings. For highly variable and dynamic conditions, multiple maximum daily load values can be used to better define allowable loading conditions. For the Lower Charles River, frequency distribution curves of daily phosphorus loading were prepared for existing and proposed TMDL conditions. The curves shown in Figure 5-2, illustrate the amount of time (frequency) that phosphorus loadings of different magnitudes have occurred and may occur in order to meet water quality standards. For example, under existing conditions the total daily phosphorus load discharged to the Lower Charles is equal to or less than 202 kg/day and 86 kg/day 90 and 50 percent of the time, respectively. For this TMDL, the allowable maximum daily load values for the 90th and 50th percentiles would be 104 kg/day and 47 kg/day, respectively. The 90th percentile daily load value under the TMDL (104 kg/day) is a 49% reduction from the 90th percentile daily load value under current conditions (202 kg/day). Similarly, the 50th percentile daily load value under the TMDL is a 45% reduction from the 50th percentile daily load value under current conditions.

The curve for TMDL conditions was generated using the water quality model and reflects conditions that are needed to achieve the water quality target for the TMDL. The curves demonstrate the high variability of phosphorus loadings to the Lower Charles River. Table 5-2 summarizes points on the curves for existing and proposed TMDL conditions. As indicated by both the curves and values in Table 5-2, there is not a single daily load value that can be used to define the phosphorus loading capacity for the Lower Charles River to address eutrophication. Maximum daily phosphorus loads consistent with the frequency distribution for the proposed TMDL conditions shown in Figure 5-2, must be achieved in order to reduce algal blooms and attain applicable water quality standards.

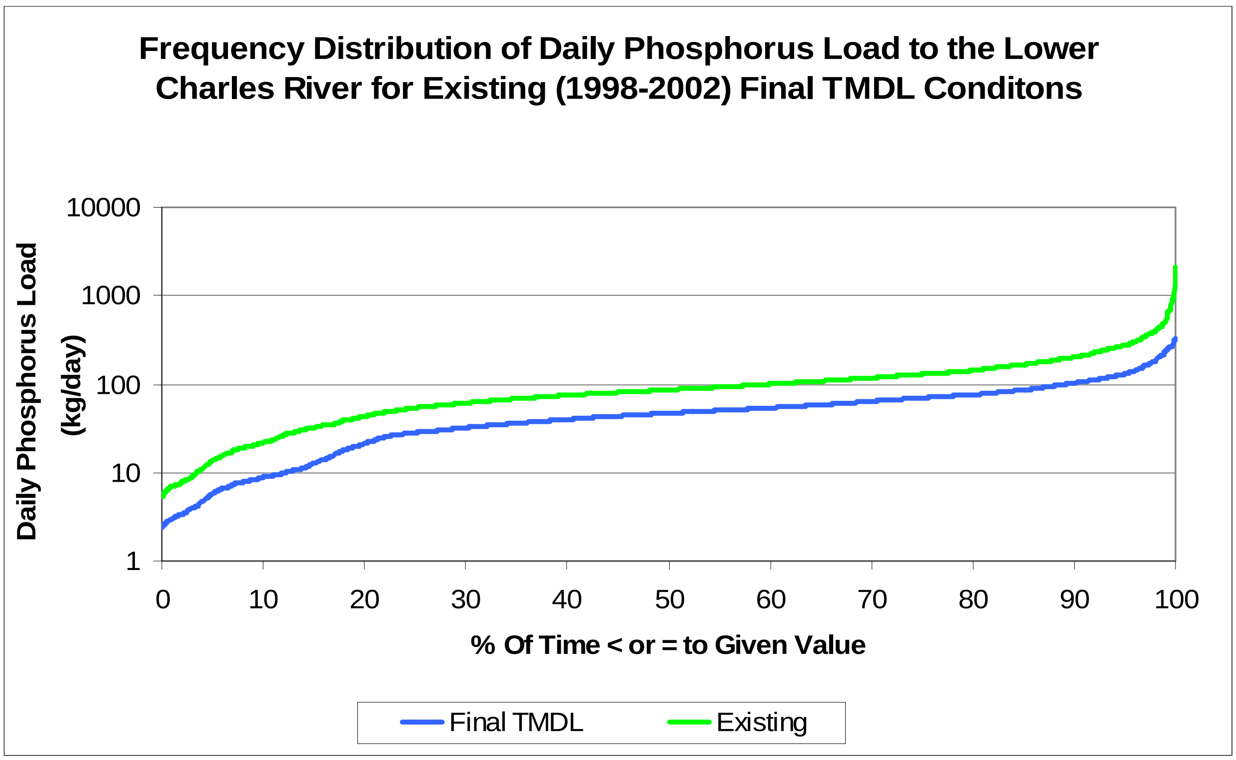

Figure 5-2. Frequency distributions of daily phosphorus load to the Lower Charles River for existing and final TMDL conditions.

Table 5-2. Frequency distribution of daily phosphorus loadings to the Lower Charles River for existing and proposed TMDL conditions

Percentage of Time ≤ or equal to Value	Existing Daily Phosphorus Load (kg/day)	TMDL Daily Phosphorus Load (kg/day)	# of days per year that must be < or equal to the corresponding TMDL daily load
10	22	9	37
25	54	28	91
50	86	47	183
75	130	70	274
90	202	104	329
99.7	914	279	364

Table 5-2 reflects the TMDL expressed as a daily load under Section 303(d) of the CWA, and may be understood as follows: In each year, there must be 37 days during which the daily phosphorus load does not exceed 9 kg/day; there may be up to 54 days (91 less 37) during which the phosphorus load is more than 9 kg/day, but does not exceed 28 kg/day; there may be up to 92 days (183 less 91) during which the phosphorus load is between 28 and 47 kg/day; up to 91 days (274 less 183) during which the load is between 47-70 kg/day; up to 55 days (329 less 274) during which the load is between 70-104 kg/day; and up to 35 days (364 less 329) during which the load is between 104-279 kg/day. Thus, Table 5-2 presents a TMDL during which there is a total maximum daily load applicable to each day of the year. Precisely which days fall into each category is not relevant, so long as the appropriate TMDL is achieved for the appropriate number of days.

5.2.3 TMDL Results and Allocations

Most pollutant sources to major tributary watersheds that discharge to the Lower Charles River have been grouped together for allocations rather than provide hundreds of source-specific allocations (e.g., by specific stormwater outfalls). For setting aggregate allocations, drainage systems and nonpoint sources have been grouped together because (1) the scale (e.g., tributary watershed area) of the aggregate allocations reflect the same scale for which the best available source data (e.g.,water quality monitoring and flow measurements) are available, (2) there is limited detail currently available to separate point and nonpoint sources, (3) there is potentially high variability associated with the quality of wet- and dry-weather discharges from smaller individual drainage systems, and (4) there is unknown and unquantified contributions from illicit discharges to stormwater drainage systems which could strongly influence the quality of a discharge.

Moreover, the aggregation of sources into gross or lumped allocations is appropriate for this TMDL because the allocations are based on extensive amounts of technically sound data and information that confidently define existing loadings and the phosphorus reductions that are needed from the major source areas. While there is reasonable confidence in the magnitude of the total nutrient loadings and needed reductions to the Lower Charles River from the major source areas, the aggregate allocations acknowledge that there are limited flow and water quality data currently available for most of the individual sources that contribute nutrients to the Charles River. Many of the sources present in the Charles River watershed are characteristically highly variable and influenced, to varying degrees, by illicit sewage discharges. Establishing aggregate allocations at this time allows for a future framework where individual dischargers can collect the necessary additional information to develop effective phosphorus control plans that will collectively achieve the aggregate allocations of the TMDL.

Aggregate allocations are summarized into three broad categories: (1) upstream watershed at Watertown Dam, (2) non-CSO drainage areas that discharge directly to the Lower Charles River, and (3) CSO discharges. Individual allocations are provided for CSO discharges to the Lower Charles River and the WWTFs in the upstream watershed. The allocation for the upstream watershed at Watertown Dam includes all sources in the upstream watershed including the WWTFs, stormwater drainage systems, and nonpoint sources that eventually discharge into the Lower Charles River over the dam. The allocations for the non-CSO drainage areas in the Lower Charles River watershed include point and nonpoint nutrient sources that discharge to the major tributaries and other smaller drainage systems. Separate aggregate allocations are identified for (1) Stony Brook, (2) Muddy River, (3) Laundry Brook, (4) Faneuil Brook, and (5) all other non-CSO tributary drainage systems in the Lower Charles River watershed. The remaining drainage system discharges in the Lower Charles watershed are grouped together into one allocation because there are presently very little data available to characterize the loadings from individual sources.

Table 5-3 presents the total phosphorus TMDL for the Lower Charles River that will result in meeting the 10 µg/l seasonal average chlorophyll *a* water quality target. As indicated, the Lower Charles River has an annual phosphorus loading capacity of 19,544 kilograms per year. The LA, WLA, and the MOS are discussed in greater detail in Sections 5.2.1, 5.2.2, and 5.5, respectively. Separate allocations are not set for phosphorus loading from future growth in the Charles River watershed. In addition to achieving the load reductions from existing sources, new loads resulting from future development projects will need to be offset in order to maintain progress towards achieving water quality goals.

Table 5-4 presents the existing 90th percentile total phosphorus concentrations during the growing season as well as the predicted concentrations based on the TMDL for each of the 5 modeled years and the 5-year average. Table 5-5 presents the existing 90th percentile seasonal average chlorophyll *a* concentrations as well as the predicted concentrations based on the total phosphorus reductions. Note that the total phosphorus reductions required by this TMDL result in an average chlorophyll *a* concentration of 9.8 µg/l during the growing season, which meets the seasonal average TMDL target of 10 µg/l for chlorophyll *a*.

Table 5-3. Total phosphorus TMDL for the Lower Charles River

Source	Existing Load (1998-2002) (kg/year)	WLA (kg/year)	LA (kg/year)	TMDL (kg/year)	% Reduction
Upstream Watershed at Watertown Dam[a]	28,925	15,109	0	15,109	48
CSOs[b]	2,263	90[c]	0	90[c]	96
Stony Brook Watershed	5,123	1,950	0	1,950	62
Muddy River Watershed	1,549	590	0	590	62
Laundry Brook Watershed	409	155	0	155	62
Faneuil Brook Watershed	326	125	0	125	62
Other Drainage Areas	1,455	550	0	550	62
Explicit Margin of Safety	-	-	-	979	
TOTAL	40,050	18,565	0	19,544	54

[a]The gross allocation for sources in the upstream watershed includes all point and nonpoint sources in the upstream watershed. See Table 5-7 for individual allocations for the WWTFs

[b]See Table 5-6 for individual CSO allocations

[c] This value represents an estimate that would be needed under 1998-2002 conditions. The TMDL however is based on a typical year and compliance with the approved long-term control plan LTCP. Individual Wasteload Allocations for each CSO based on the LTCP can be found in Table 5-6.

Table 5-4. Existing and reduced seasonal (June – October) total phosphorus concentrations for the five modeled years

Modeled Year	Existing Total Phosphorus Concentrations (mg/l)		TMDL Total Phosphorus Concentrations (mg/l)	
	90th Percentile	Seasonal Average	90th Percentile	Seasonal Average
1998	0.153	0.092	0.080	0.046
1999	0.120	0.063	0.051	0.026
2000	0.097	0.067	0.044	0.029
2001	0.092	0.059	0.034	0.022
2002	0.067	0.042	0.028	0.016
5-Year Average	0.106	0.065	0.047	0.028

Table 5-5. Existing and reduced seasonal (June – October) chlorophyll *a* concentrations for the five modeled years

Modeled Year	Existing Chlorophyll a Concentrations (µg/l)		TMDL Chlorophyll a Concentrations (µg/l)	
	90th Percentile	Seasonal Average	90th Percentile	Seasonal Average
1998	36.4	23.2	19.8	12.3
1999	32.9	24.9	15.7	11.2
2000	33.3	24.2	14.7	10.7
2001	30.4	22.9	13.3	9.2
2002	22.5	15.3	9.6	5.7
5-Year Average	31.1	22.1	14.6	**9.8**

Load and Wasteload Allocations. As stated previously, TMDLs determine the amount of a pollutant that a water body can safely assimilate without violating the water quality standards. Both point and non-point pollution sources are accounted for in a TMDL analysis. EPA regulations require that point sources of pollution (those discharges from discrete pipes or conveyances) subject to NPDES permits receive waste load allocations (WLA) 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 load allocations (LA) 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, 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.

5.2.4 Load Allocation

Both nonpoint sources of phosphorus and unregulated stormwater drainage systems exist throughout the Charles River watershed. The major nonpoint source categories that contribute phosphorus to the Lower Charles River are diffuse overland runoff and groundwater recharge to the Charles River and tributaries. Also, there are many stormwater drainage systems in the Charles River 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 such as in Dover, Sherborn, and Millis.

As discussed previously, the level of information available for this TMDL is suitable for quantifying total phosphorus loadings from large watershed areas (e.g., the upstream watershed, Stony Brook, Muddy River, etc.) that 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 watershed areas to the regulated and non-regulated stormwater source categories within the watershed areas. As a result, this TMDL is not specifying LAs because at present the phosphorus load contribution from nonpoint sources and non-regulated point sources of stormwater cannot be distinguished from the load contribution from regulated point sources. Consequently, nonpoint sources and unregulated stormwater discharges are combined with the regulated stormwater discharges and are identified as WLAs (see Section 5.2.5).

While phosphorus loading data are limited for almost all individual sources in the contributing watershed, a land cover phosphorus loading analysis has been conducted to characterize the relative importance of sources in the watershed using land cover data layers and literature information on phosphorus export values for different land cover categories. This analysis was conducted to determine the magnitude of phosphorus reductions that will be needed from different source areas and to provide guidance for carrying out the implementation plan and to help prioritize clean-up actions. The results of this analysis are presented in Section 6.1, the implementation plan.

5.2.5 Wasteload Allocation

NPDES regulated point sources in the Charles River Watershed that contribute phosphorus loading to the Lower Charles River include combined sewer overflows (CSOs), wastewater treatment facilities (WWTFs), and a variety of stormwater sources. . The vast majority of the Charles River watershed is comprised of communities that are subject to the Phase I and 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.

Much of the existing anthropogenic nutrient load that enters the Lower Charles River is related to storm water drainage system discharges from urbanized areas that discharge directly to the Basin and to the river in the upstream 268 square mile watershed. Water quality monitoring of both dry and wet-weather drainage system discharges to the Lower Charles show that the quality of these sources are highly variable and are likely to be contaminated with illicit sources of sewage. 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. It should be noted that the WLA values are estimates that can be refined in the future as more information about the MS4s, illicit discharges, and land use-specific loadings become available

CSOs

The MWRA, and the communities of Boston and Cambridge have a number of active CSOs that discharge at various frequencies during wet-weather conditions to the Charles River Basin. CSO discharges represent a point source of pollution to the Basin (including nutrients) that requires WLAs. The implementation of a CSO abatement program for the Charles River Basin is well underway and is proceeding in accordance with an approved Long Term Control Plan. The development of the Long Term Control Plan was required by Massachusetts and EPA regulations and a Federal Court Order issued by the Federal District Court in Boston, Massachusetts. The implementation of the plan, through completion, is also required by the court order.

Table 5-6 identifies the WLAs for each CSO to the Lower Charles River based on using the “typical” rainfall year. The “typical” rainfall year was used during development of the Long Term Control Plan, which will be used as the basis for NPDES permits for CSOs. Therefore, CSO phosphorus WLAs are based on the “typical” rainfall year. Table 5-6 presents loadings for recent conditions for year 2004 and the WLAs that are consistent with the Long Term Control Plan.

Table 5-6. Phosphorus WLAs for CSOs to the Lower Charles River

	2004 Conditions for Typical Year[a]			Long Term Control Plan for Typical Year[b]		
CSO Outfall Number	**AF[c] (events/yr)**	**Volume (MG)**	**P[d] Load (kg)**	**AF (events/yr)**	**Volume (MG)**	**WLA P Load (kg)**
BOS032	Eliminated	0.00	0.00	Eliminated	N/A	N/A
BOS033	Eliminated	0.00	0.00	Eliminated	N/A	N/A
CAM005	4	1.62	19.01	3	0.84	9.86
CAM007	3	0.71	8.33	1	0.03	0.35
CAM009	5	0.18	2.11	2	0.01	0.12
CAM011	0	0.00	0.00	0	0.00	0.00
BOS028	Eliminated	0.00	0.00	Eliminated	N/A	N/A
BOS042	Eliminated	0.00	0.00	Eliminated	N/A	N/A
BOS046	10	5.66	66.32	2	5.38	63.04
BOS049	0	0.00	0.00	Eliminated	N/A	N/A
CAM017	1	2.09	24.53	1	0.45	5.28
MWR010	0	0.00	0.00	0	0.00	0.00
MWR018	1	0.73	8.57	0	0.00	0.00
MWR019	1	0.18	2.11	0	0.00	0.00
MWR020	1	0.10	1.17	0	0.00	0.00
MWR021	Eliminated	0.00	0.00	Eliminated	N/A	N/A
MWR022	Eliminated	0.00	0.00	Eliminated	N/A	N/A
MWR201[e]	16	117.08	1,373.90	2	6.30	73.93
MWR023	21	32.36	379.74	2	0.13	1.53
Total		**160.71**	**1885.79**		**13.14**	**154.1**

[a]The typical year is the design rainfall year used by the MWRA for CSO facilities planning and is indicative of average rainfall conditions including a number of large rain events.
[b]The implementation of the Long Term Control Plan for the Charles River is scheduled to be completed in 2013. Certain components of the plan affecting other receiving waters will be completed by 2015.
[c]AF = Activation frequency
[d]P = Phosphorus
[e]MWR201 represents the Cottage Farm CSO Treatment Facility, which provides screening and disinfection

Sources in the Upstream Watershed

An aggregate WLA is assigned to all sources in the upstream watershed that contribute phosphorus to the Lower Charles at Watertown Dam. The reason for assigning a WLA to the phosphorus load at Watertown Dam is that currently there is insufficient information available to apportion the total loading at Watertown Dam between NPDES regulated point sources and non-regulated stormwater and nonpoint sources.

The allocation for the load coming from the upstream watershed includes the sum of loads from all sources that contribute phosphorus to the Lower Charles River over the Watertown Dam including the WWTFs located in the upstream watershed. The phosphorus allocation for the load at Watertown Dam implicitly takes into account the attenuation of phosphorus loading from the

WWTFs as well as other sources that exist far upstream. There currently is not enough information available to explicitly define at any given time, particularly during the growing season, how much of the total loading from the upstream watershed at Watertown Dam is from the WWTFs or any other specific source.

Nutrient loads are attenuated as they travel through the aquatic systems in the upstream watershed as a result of several natural processes including nutrient cycling in plants and sediments and sedimentation. For the purpose of this TMDL, it is not critical to understand the specific details of these processes in the upstream watershed. The net effect of upstream attenuation is indirectly accounted for in the technical analysis used to develop the TMDL, as it relies on the use of daily loadings for a five year period (1998-2002) at Watertown Dam to calculate allowable annual loadings. By using such a long period that spans several years and a wide range of climatic and hydrologic conditions, the effects of upstream attenuation is reflected in the loadings at Watertown Dam. Also, hydraulic travel times in the upstream watershed, the time for flow to move from the upper reaches in the upstream watershed to the Watertown Dam, are substantially lower than the five year period used in the TMDL analysis.

Individual WLAs for the six WWTFs that contribute phosphorus to the Charles River are presented in Table 5-7. The WLAs are consistent with the allowable phosphorus loading specified in the existing NPDES permits for four of the facilities that require year-round treatment for phosphorus (Milford, Medfield, Wrentham Development Center, and Pine Brook Country Club). The year round treatment includes growing season (April–October) total phosphorus limits of 0.2 mg/l (0.1 mg/l for the Pine Brook Country Club), and non-growing season (November–March) total phosphorus limits of 1.0 mg/l. Existing permits for the other two facilities, Charles River PCD and MCI Norfolk–Walpole, have growing season total phosphorus limits of 0.2 mg/l but do not yet include non-growing season limits.

The WLAs for these two facilities include reductions in permitted non-growing season phosphorus loadings based on including non-growing season total phosphorus limits of 1.0 mg/l into the permits. Non-growing season reductions in phosphorus loading are reflected in the WLAs for these two facilities because the discharge of phosphorus, particularly phosphorus associated with particulate matter, can be stored in depositional areas within the downstream system as sediments. Depositional areas are often in impoundments such as the Lower Charles River where conditions are favorable for algal growth. Phosphorus discharged during the non-growing season and stored in benthic sediments has the potential to be released later during the growing season and contribute to eutrophication-related impairments in the Lower Charles, as well as in other impoundments located in the upstream watershed. Environmental conditions during the growing season such as higher water temperatures, lower dissolved oxygen levels, and higher retention times due to low-flow conditions, cause release rates (fluxing) of nutrients from the sediments to the water column to increase.

A total phosphorus effluent limit of 1.0 mg/l at the WWTFs during the winter will effectively remove most of the particulate-bound phosphorus in the discharge. As a result, only dissolved phosphorus is discharged by the WWTFs to the Charles River during the non-growing season. Since plant growth and nutrient uptake is minimal during this time of the year, the dissolved phosphorus is carried downstream out of the system to Boston Harbor before the onset of the next growing season.

Table 5-7. WLAs for WWTF discharges of phosphorus in the Charles River watershed

NPDES Number	Facility name	WLA (Apr–Oct) kg	WLA (Nov.-Mar.) kg	WLA Total kg/yr
MA0032212	Pine Brook Country Club	0.5	3.4	3.9
MA0100579	Milford WWTF	697	2,458	3,155
MA0100978	Medfield WWTF	246	869	1,115
MA0102113	Wrentham Development Center	74	259	333
MA0102253	MCI Norfolk-Walpole WWTF	78	277	355
MA0102598	Charles River Pollution Control District	888	3,486	4,364

A separate TMDL to address nutrients in the upper watershed is currently underway and is scheduled to be completed in late 2007. This upper Charles River TMDL will evaluate the impact of nutrient loading from WWTFs on eutrophication in the upper watershed and will also include individual nutrient allocations for each facility.

As discussed above in Section 3.4, a land cover phosphorus loading analysis for the upstream Charles River watershed was prepared to provide more information on phosphorus sources in the watershed. Section 6.1 presents the land cover phosphorus loading analysis developed in part to estimate the magnitude of phosphorus loading reductions that are needed to meet the allowable phosphorus loadings in the TMDL for the entire watershed. Land cover phosphorus loadings and reductions are presented in Section 6.1 for each community in the Charles River watershed.

Summary of Allocation for Sources to the Upstream Watershed and Tributary Streams.

For reasons discussed above, all allocations addressing nutrient loads from regulated stormwater sources, illicit sources, unregulated stormwater sources, and nonpoint sources in this TMDL are expressed as WLAs. Table 5-8 summarizes the various source categories that in total account for the existing phosphorus loads and the WLAs for the upstream watershed, direct tributary streams, and other drainage systems that discharge directly to the Lower Charles River. As indicated in Table 5-8, the allowable contribution from illicit discharges is set equal to zero kg phosphorus per year. Illicit discharges are prohibited and must be eliminated.

Table 5-8. Summary of WLAs and contributing source categories for the upstream watershed, direct tributary streams, and other drainage systems that discharge directly to the Lower Charles River

Geographic Source Area	Existing Load (1998-2002) (kg/year)					WLA (kg/year)	
	Illicit discharges	Regulated stormwater	Unregulated stormwater	Nonpoint sources	Total	Illicit discharges	Other Sources[1]
Upstream Watershed at Watertown Dam[1]	?	?	?	?	28,925	0	15,109
Stony Brook Watershed	?	?	?	?	5,123	0	1,950
Muddy River Watershed	?	?	?	?	1,549	0	590
Laundry Brook Watershed	?	?	?	?	409	0	155
Faneuil Brook Watershed	?	?	?	?	326	0	125
Other Drainage Areas	?	?	?	?	1,455	0	550

[1] Other sources include NPDES regulated stormwater discharges, unregulated stormwater discharges, and nonpoint sources.

5.3 Seasonality and Critical Conditions

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 annual basis, thus accounting for seasonality.

Phosphorus reductions were based on achieving an overall average seasonal chlorophyll *a* concentration of 10 µg/l by using the average of model results for the five growing seasons (June 1 through October 31 of 1998-2002). The TMDL model simulation consisted of a continuous five-year simulation for the period of January 1, 1998 to December 31, 2002. The average of five growing seasons is being used to determine the TMDL instead of one growing season because the average accounts for variations between years such as hot dry summers versus summers with heavy rainfall resulting in large nutrient inputs. The goal of this TMDL is to meet the chlorophyll *a* water quality target during the growing season because this represents critical conditions when algal blooms are typically most severe in the Lower Charles River and have the greatest impact on designated uses. By accounting for critical conditions, the TMDL makes sure that water quality standards are maintained for infrequent occurrences, and not only for average conditions. Also, the development of this TMDL for the critical conditions has set allowable phosphorus allocations at levels that will protect water quality throughout the year from algal blooms and ensure that eutrophication-related water quality standards will be met year round.

The TMDL model was used to provide a frequency distribution of allowable daily phosphorus loading (see Section 5.2.2) as estimations of allowable maximum daily loads to the Lower Charles. Combining the frequency distribution of allowable daily loads with the allowable annual load, essentially specifies that phosphorus controls should be in place throughout the year in order to meet both the allowable annual load and the seasonal chlorophyll *a* target of 10 µg/l.

5.5 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 (USEPA 1991): (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 analysis, the MOS is both explicit and implicit.

An explicit MOS of 5 percent of the targeted TMDL was reserved to account for any uncertainty in the TMDL. An additional explicit MOS is provided in the TMDL analysis by selecting the loading scenario, 45% and 60 % phosphorus reductions from the upstream and downstream watersheds, respectively, which results in achieving a seasonal average chlorophyll *a* concentration of 9.8 µg/l (2 % lower than the target).

The implicit MOS was included through the selection of the seasonal chlorophyll *a* target and the associated 90th percentile chlorophyll *a* concentration needed to meet water clarity standards, selecting low flow periods for TMDL development, and accounting for only a portion of sediment “wind-down”. Details on the implicit MOS are discussed below.

Based on the seasonal mean chlorophyll *a* target of 10 µg/l, the 90^{th} percentile chlorophyll *a* concentration for the Lower Charles River is 18.9 µg/l, which is determined to be sufficient to attain the narrative aesthetic criteria. In addition to calculating the 90^{th} percentile chlorophyll *a* for the Lower Charles River, a one-sided prediction interval (PI) with a 90 percent confidence level was calculated using chlorophyll *a* data collected when Secchi depth was less than 1.2 meters (based on MassDEP’s clarity assessment criteria) and when corresponding true color was 40 units or less. The PI was calculated as 20.5 µg/l, meaning that a chlorophyll *a* sample below 20.5 µg/l is not likely to cause an excursion of the clarity criterion. Comparison of the 20.5 µg/l PI to the 90^{th} percentile chlorophyll *a* target value of 18.9 µg/l indicates, with a 90 percent confidence level, that the seasonal average chlorophyll *a* target of 10 µg/l is sufficient to attain Massachusetts’ clarity standard in the Lower Charles River. The difference between 20.5 µg/l and 18.9 µg/l represents a portion of the implicit margin of safety since meeting the 18.9 µg/l 90^{th} percentile chlorophyll *a* concentration should also result in meeting the clarity criterion. See Section 5.1.1 for more detail on how the 90^{th} percentile chlorophyll *a* concentration and PI were calculated.

Another portion of the implicit MOS is based on the Charles River's flow data. Daily flow data from the USGS flow gage at the Charles River at Waltham were used to develop a time series plot of daily flows during the period between September 30, 1980 and September 30, 2004 (Figure 5-3). The plot shows that the 5-year period (January 1, 1998 through October 30, 2002) used for the Lower Charles River modeling had some of the lowest flow summers of the 23-year record.

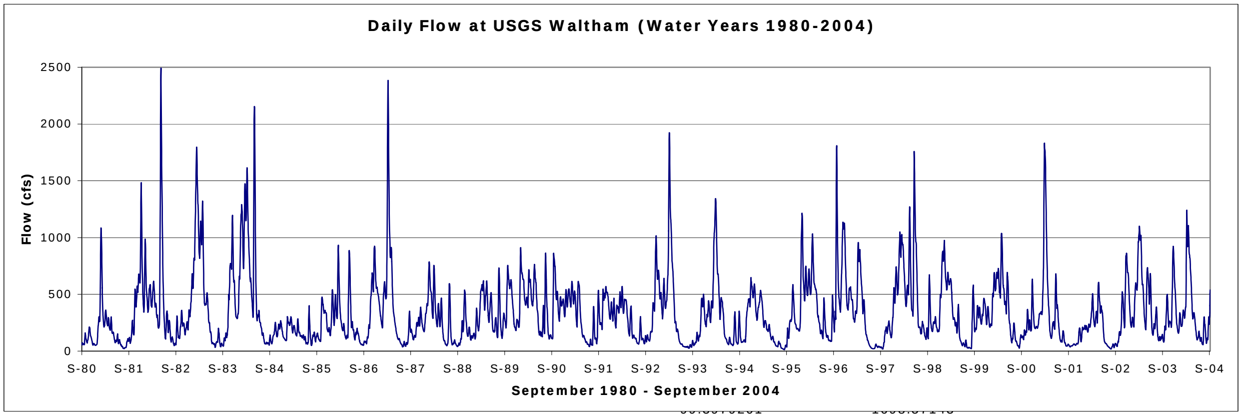

Figure 5-3. Daily flow data for the Charles River at Waltham from September 30, 1980 – September 20, 2004.

Weekly average flows, developed using the daily flow data, were used to create flow-frequency plots for the 23-year record and the 5-year modeling period (Figures 5-4 and 5-5). Figure 5-4 presents the flow duration curve for all flows measured at the USGS gage during the stated time period. Figure 5-4 presents only those flows below 250 cfs in order to highlight low flow periods. Figure 5-4 demonstrates that low flow weeks (those with flows less than 100 cfs) during the modeling period were up to 10 cfs lower than the 23 year record. These low flow weeks generally occurred during the summer growing seasons. These lower than average summertime flows included in the modeling period resulted in water residence times that are greater than typically occur during the growing season based on the 23 year period as a whole. The increased residence times have the potential to allow more algae to grow and accumulate in the Lower Charles River

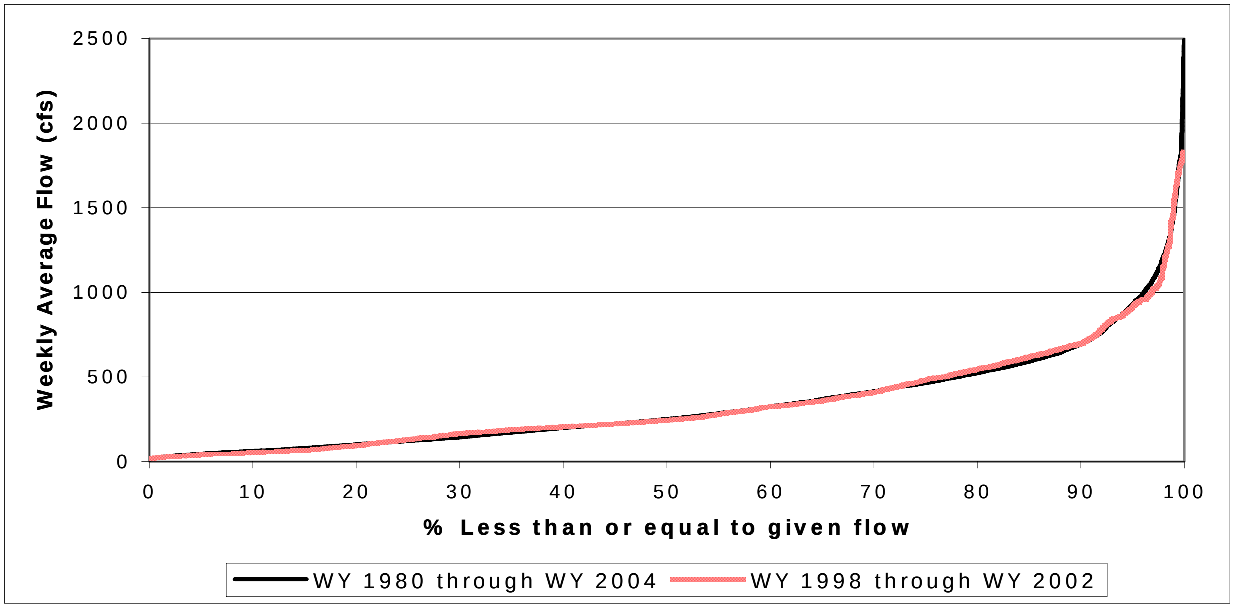

Figure 5-4. Flow duration curve for the Charles River at Waltham for water years 1980 through 2004 and 1998 through 2002.

Figure 5-5. Flow duration curve for low flows at the Charles River at Waltham for water years 1980 through 2004 and 1998 through 2002.

The flow characteristics presented in Figures 5-3 and 5-4 suggest that use of the 5-year modeling period chosen for the TMDL analysis to attain the chlorophyll *a* target represents an implicit margin of safety because of the greater frequency of low flow events that occurred during the modeling period compared to the overall record. Most of these lower flow events occurred during the summer growing season during periods of low rainfall. Less rain generally results in higher water temperatures and greater sunlight intensity because of less cloud cover. These conditions are favorable for algal growth and combined with increased water residence times associated with the lower flow periods, have the potential for more algae to accumulate in the Lower Charles. The implicit margin of safety is reflected in the modeled load reductions needed to attain the chlorophyll *a* target during the modeled period as opposed to what would likely be needed for less critical conditions (less sunlight, lower temperatures and water residence times) that is indicated from the whole 23 year flow record.

The final implicit MOS is related to the release of nutrients from the sediments. With the reduction of nutrients to the Lower Charles over time, fluxes of dead algae and particulate organic phosphorus, carbon, and nitrogen to bottom sediments in the Charles River Basin will be reduced. Sediment diagenesis and subsequent release of the inorganic byproducts of these organic forms from the bottom sediments will continue. This will result in a gradual decrease of sediment pools of phosphorus, carbon, and nitrogen, and hence gradual decreases in fluxes of these nutrients from bottom sediments to the water column. The model used in this TMDL study has shown that, because of this "wind-down" of bottom sediment nutrient releases, subsequent availability of these nutrients for algal growth in the photic zone of the upper water column will also decrease slowly over time.

Model predictions for the TMDL nutrient reduction scenarios were made over a 5-year period into the future, with sediment release wind-down also occurring over that period. Beneficial impacts of nutrient reductions on water column nutrient levels and algal control would continue to increase compared to existing conditions, following the 5-year period of each scenario. Since quantification of nutrient control benefits was limited to only 5-years into the future, this modeling assumption is conservative and constitutes an implicit margin of safety.

6 IMPLEMENTATION

The TMDL analysis has determined that large reductions in nutrient loading to the Lower Charles River are needed to reduce algal biomass in the Lower Charles and attain the related Massachusetts Water Quality Standards. This section of the report identifies the components of an implementation plan for reducing nutrient loadings to the Lower Charles River to meet the TMDL. 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 Lower Charles River over the long term.

The water quality-hydrodynamic model used to estimate the nutrient loading capacity for the Lower Charles River and the necessary reductions in nutrient loading was reviewed by a technical committee that included a panel comprised of water quality and modeling experts (Expert Panel). The Expert Panel concluded that the model is suitable for use in developing the nutrient TMDL and for outlining an implementation plan for addressing cultural eutrophication in the Lower Charles River. Because of the complexity of the system being modeled, the inherent difficulties in modeling phytoplankton, and the overall accuracy of the modeling predictions, the Expert Panel recommended that the model be used to guide implementation activities in an adaptive management approach, which allows for an implementation process that is implemented in stages over time.

Achieving the Lower 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 algal blooms in the Lower Charles River.

As indicated in Section 5.2, allowable nutrient loadings are specified as WLAs in terms of both loadings and relative percent reductions. For this TMDL, emphasis is placed on the relative percent reductions for the purpose of guiding implementation activities.

Aggregate WLAs for the Lower Charles River were established for sources that contribute phosphorus loads to the (1) the upstream watershed at Watertown Dam, (2) Laundry Brook, (3) Faneuil Brook, (4) Muddy River, (5) Stony Brook, and (6) all other non-CSO tributary drainage systems that discharge directly to the Lower Charles River. Individual allocations were established for the CSO discharges and WWTFs. Sources contributing phosphorus to the major tributaries to the Lower Charles (Laundry Brook, Faneuil Brook, Muddy River, and Stony Brook) received separate aggregate allocations because there are extensive water quality and flow monitoring data available to group these sources on a tributary basis. In contrast, the remaining drainage system discharges to the Lower Charles (other non-CSO tributary drainage systems) are grouped together into one allocation because there are presently very limited data available to characterize the sources that make up this group.

The aggregation of sources into gross or lumped allocations is consistent with the level of information available for this TMDL. While there is reasonable confidence in the overall magnitude of the total nutrient loadings to the Lower Charles River from the identified major tributary source 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 most of the sources, and many of the drainage system sources are influenced, to varying degrees, by illicit sewage discharges.

Based on the magnitude of phosphorus reductions called for in this TMDL, a watershed-wide implementation plan is called for. This plan requires the control of and/or elimination of several nutrient sources to the Charles River including stormwater runoff from drainage systems, illicit discharges to stormwater drainage systems, and CSOs. TMDL implementation-related tasks are presented in Table 6-4. The MassDEP working with the watershed communities, 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.

Table 6-1. TMDL implementation tasks

Task	Responsible Organization
Writing TMDL	USEPA and MassDEP
TMDL Public Meeting	MassDEP and USEPA
Response to Public Comment	MassDEP
Organization, contacts with volunteer groups	MassDEP and CWRA
Development of comprehensive stormwater management programs including identification and implementation of BMPs	Charles River Watershed Communities and other relevant NPDES permit holders
Illicit discharge detection and elimination	Charles River Watershed Communities with CRWA, MWRA, and BWSC
Identification of leaking sewer pipes and sanitary sewer overflows	Lower Charles River Watershed Communities
CSO abatement	MWRA, Boston, Brookline, and Cambridge
Inspection and upgrade of on-site sewage disposal systems as needed	Homeowners, CRWA and Charles River Watershed Communities (Boards of Health)
Organize implementation; work with stakeholders and local officials to identify remedial measures and potential funding sources	MassDEP, CRWA, and Charles River Watershed Communities
Organize and implement education and outreach program	MassDEP, CRWA, and Charles River Watershed Communities
Apply for funding opportunities (e.g., grants and loans)	CRWA, Charles River Watershed Communities, and planning agencies with guidance from MassDEP
Inclusion of TMDL recommendations in Executive Office of Environmental Affairs (EOEA) Watershed Action Plan	EOEA
Surface Water Monitoring	USEPA, MWRA, MassDEP, and CRWA
Provide periodic status reports on implementation of remedial activities	Charles River Watershed Communities, CRWA, MWRA, and other relevant NPDES permit holders

6.1 Phosphorus Loading by Land Cover and Community

A land cover phosphorus loading analysis has been prepared for the Charles River watershed. The purpose of developing land cover phosphorus loading estimates is to better understand the relative importance of phosphorus sources in the Charles River watershed, and to determine the magnitude of phosphorus reductions that will need to be achieved from the different land cover categories in order to achieve applicable Massachusetts water quality standards. The following figures and tables were prepared to provide insight into the distribution of average annual phosphorus loading to the Charles River among several land cover categories that are present in the Charles River Watershed.

Loadings are apportioned to watershed areas according to major land cover groupings. Consolidated loadings are also presented for groupings of the WWTFs and CSOs that exist in the watershed. The distribution of phosphorus loading by land cover is an estimate based primarily on loading export factors from the literature and the area of land cover for each category present in the Charles River watershed. The loadings for WWTFs are reasonable accurate estimates as they are based on frequent discharge monitoring and flow data from the WWTFs. The CSO loading estimate is coarser than the WWTF estimate, as it is based on CSO model predictions and overall CSO quality data.

The estimated loadings by land cover were first derived from literature export factors and then adjusted to match the total phosphorus loadings estimated for the Lower Charles River Phosphorus TMDL. Export factors represent an estimate of the amount of pollutant load that is discharged from a unit area of land cover (hectare) per year (One hectare is equal to 10,000 square meters or 2.47 acres). Export factors differ from event mean concentrations (EMCs), which are often used to characterize stormwater sources, because they account for the total load being discharged from the source area. EMCs indicate only the concentration or strength of the source and do not represent the amount or loading of a pollutant from the source. It is possible to have a source area that has a relatively high EMC but a low export factor because the area does not generate much flow. When dealing with water quality problems caused by eutrophication it is critical to have an understanding of the overall loading and its impacts on water quality.

The TMDL loading estimates were derived using water quality monitoring and flow data and the results of hydrologic modeling of portions of the watershed. Loadings from the WWTFs are based on actual discharge flows and discharge monitoring data and permit limits. The TMDL existing loading estimates are presented as annual average phosphorus loading for the years of 1998-2002. These years represent a variety of hydrologic conditions that include low, high, and average flow periods. Using the land cover loading analysis, loads to meet the TMDL for phosphorus are also presented for the entire watershed and for each contributing community that has land that drains to the Charles.

Figure 6-1 depicts both the literature and TMDL adjusted phosphorus loading export factors used in preparing the loading estimates for the land-cover categories. The source of the export factors are cited in the footnotes to Figure 6-1. It is worth noting that the highest export factors are associated with land covers that typically have the highest percentages of impervious cover. Table 6-2 presents a comparison of the literature values of phosphorus export loading rates and the percent imperviousness typical of the different land cover categories in Massachusetts. The percentages of impervious area for the various land cover categories presented in Table 6-2, noted as directly connected impervious area (DCIA), were derived by Mass GIS. As indicated in Table 6-2, the relationship between percent impervious cover and phosphorus export loading rate is particularly evident for the urban/suburban land covers. The land covers with the higher percent imperviousness (i.e., commercial, industrial, and high density residential) also have the higher phosphorus export loading rates. Areas with high impervious cover generate more surface runoff than areas with lower percent impervious cover and also offer less opportunity for ground cover and the soil matrix to intercept and filter pollutants from runoff. The increased runoff volume and decreased pollutant attenuation caused by impervious surfaces results in increased pollutant loading.

Table 6-2. Phosphorus export loading rates and percent directly connected impervious area by land cover

Land Cover	Phosphorus export loading rate (kg/h-yr)	TMDL Adjusted Phosphorus export loading rate (kg/h-yr)	Percent directly connected impervious area[1] (%)
Commercial	1.679	1.697	77
Industrial	1.455	1.471	65-66
High Density Residential	1.129	1.131	35-46
Medium Density Residential	0.560	0.566	19
Low Density Residential	0.045	0.045	15
Agriculture (crop land)	0.500	0.505	3
Forest	0.129	0.130	2
Open Space	0.034	0.034	2-6

[1]Brian R. Brodeur, MassGIS Watershed Tools, Massachusetts Executive Office of Environmental Affairs 2001, 2003

The loading factors were directly applied using the area for the appropriate land cover categories in the Charles River watershed. The estimated loadings were then adjusted to match the measured current loadings for the1998-2002 period used in the TMDL modeling analysis Only a minor adjustment of approximately 1 % was needed to adjust the estimated loadings derived from the literature loading export factors to match the annual average TMDL loading estimates for the period of 1998-2002.

Figure 6-2 illustrates the distribution of land cover in the Charles River Watershed based on MassGIS (1999). The entire watershed includes a drainage area of approximately 305 square miles or 79,100 hectares (195,400 acres). Areas served by combined sewers in the lower watershed are not included in this analysis because much of the runoff-related loadings from these areas are conveyed out of the watershed to the Deer Island WWTF. CSO discharges to the Charles that result from rainfall on these areas have been accounted for separately in the CSO loadings analysis.

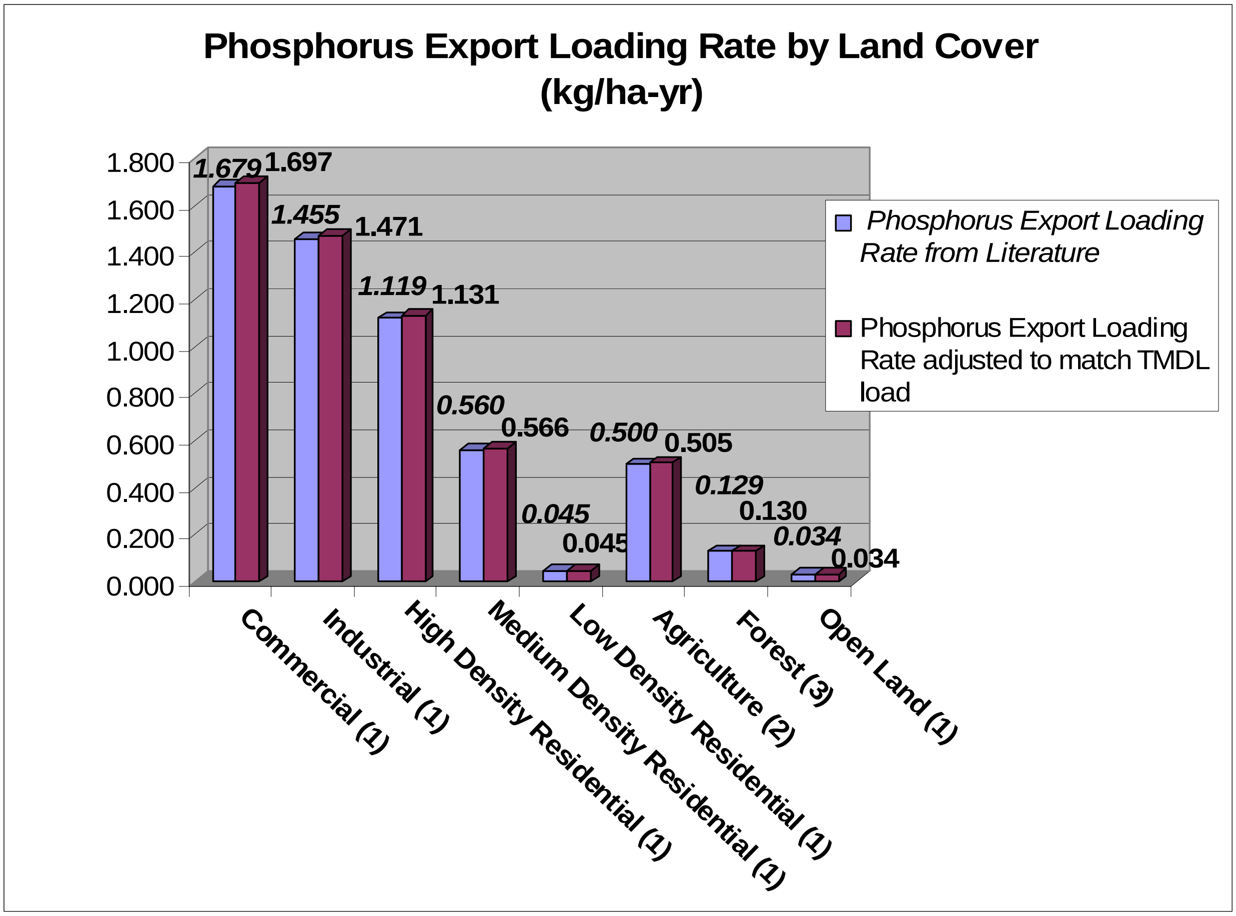

Figure 6-1. Phosphorus Loading Export Factors from literature

Footnotes for Figure 1.

1 Horner, Richard R., Joseph J. Skupien, Eric H. Livingston, and H. Earl Shaver. 1994. *Fundamentals of Urban Runoff Management: Technical and Institutional Issues*. Prepared by the Terrene Institute, Washington, DC, in cooperation with the U.S. Environmental Protection Agency.

2 Budd, Lenore F.and Donald W. Meals. February 17, 1994. Draft Final Report. *Lake Champlain Nonpoint Pollution Assessment.*

3 Mattson, Mark D. and Russell A. Isaac. 1999. *Calibration of phosphorus export coefficients for Total Maximum Daily Loads of Massachusetts's lakes.* Lake Reservoir. Management, 15:209-219.

Figure 6-3 presents the estimated relative contributions of phosphorus loading from the various major source categories of the Charles River Watershed**.** The loadings depicted for the POTWs and the CSO represent average annual loads for the period of 1998-2002. Refer to Figure 6-2 to note that the more intense urban-type land cover categories such as commercial, industrial and high density residential areas (that make up approximately 20% of the watershed) are estimated to contribute a disproportionately large amount of the phosphorus load (~50%) to the Charles River. Figure 6-4 presents the estimated loadings for each of the source categories that correspond to the relative distributions shown in Figure 6-3.

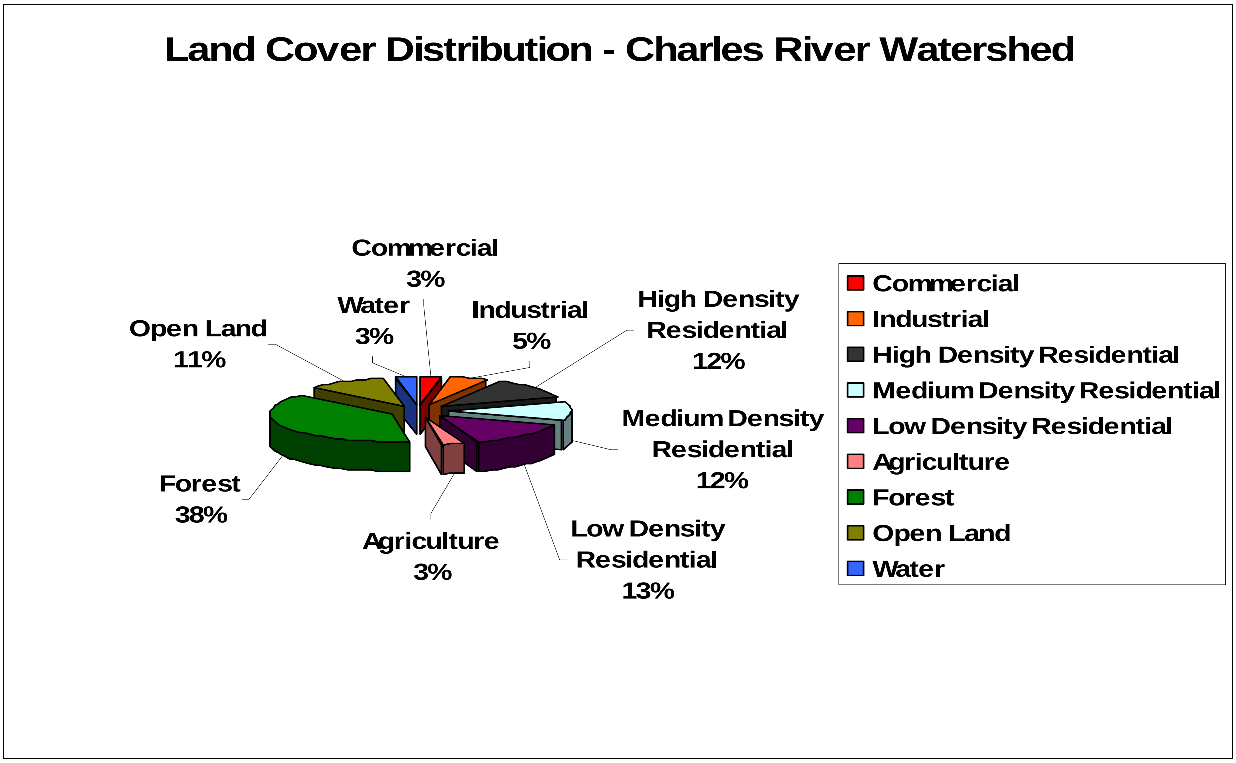

Figure 6-2. Land Cover Distribution of the Charles River Watershed

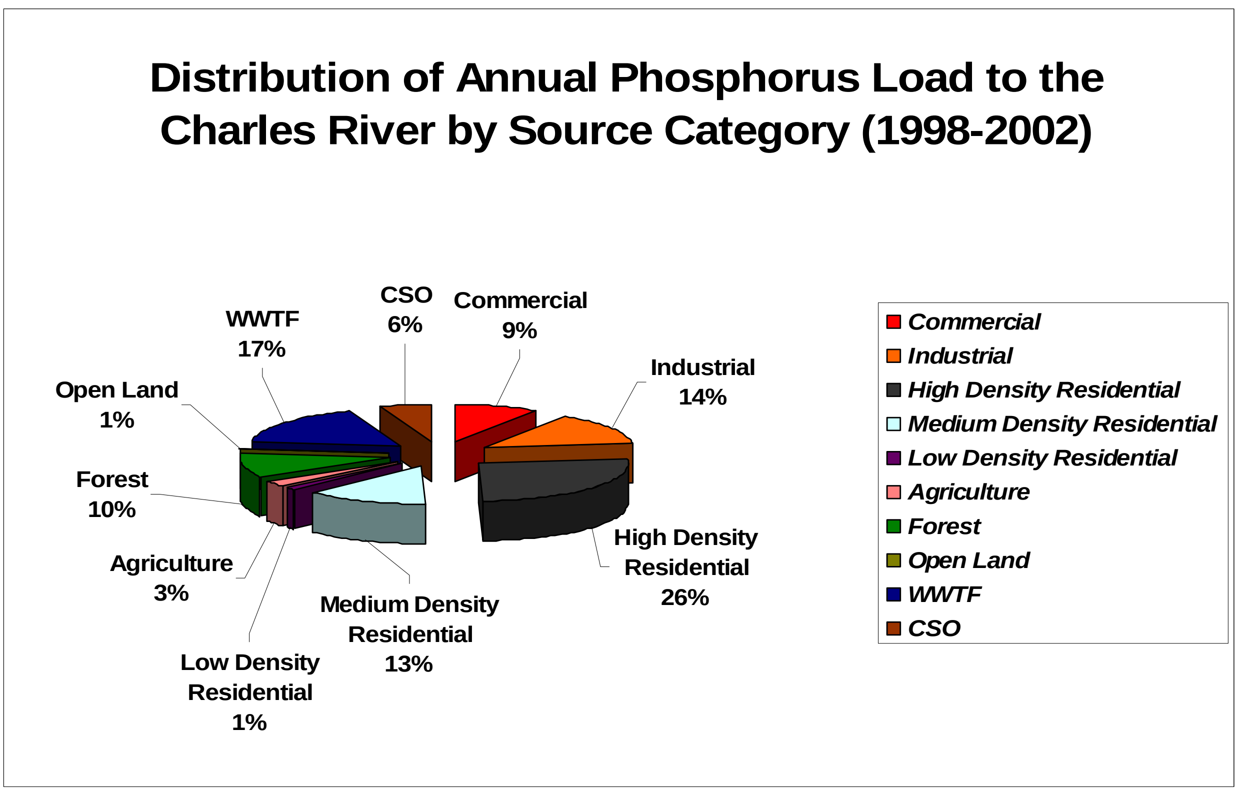

Figure 6-3. Distribution of estimated phosphorus load by source category with actual load from WWTFs for 1998 -2002.

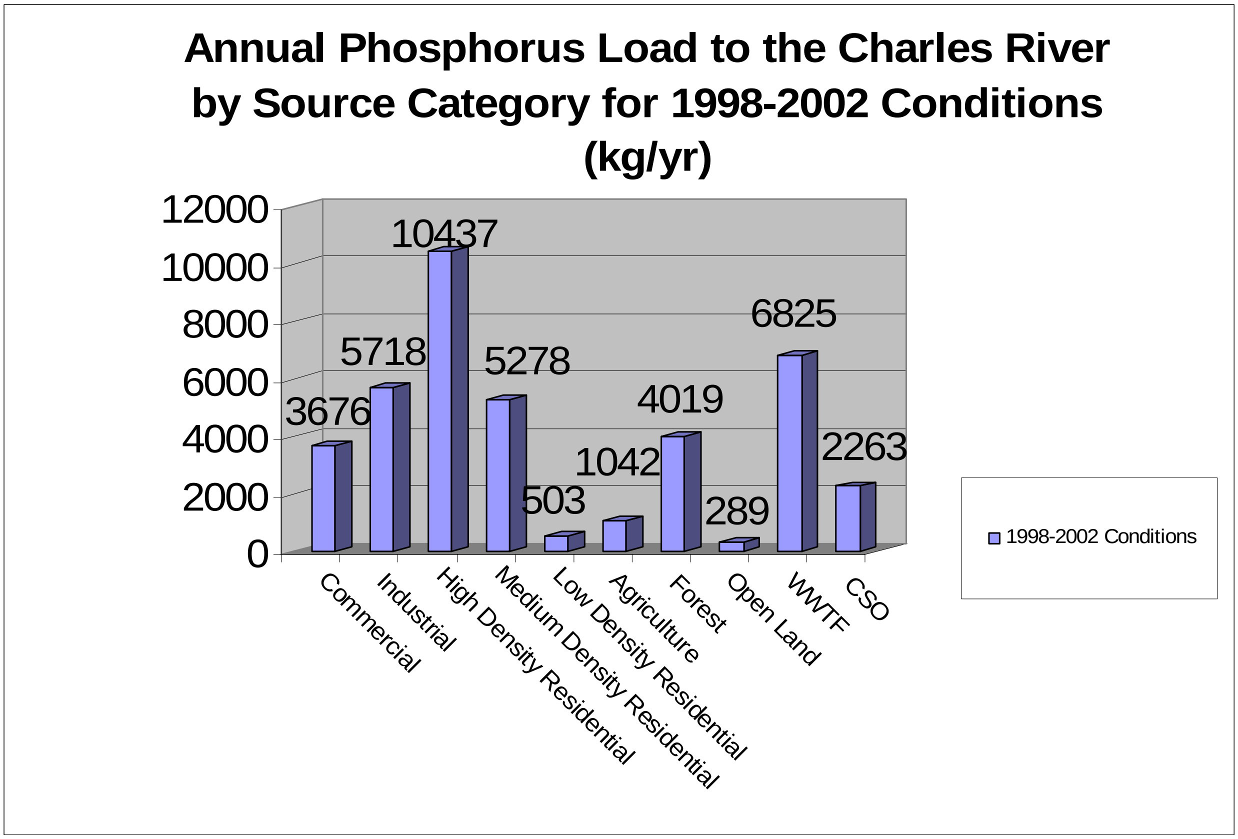

Figure 6-4. Annual average phosphorus loading by source category to the Charles River.

Figure 6-5 represents phosphorus loadings to the Charles River by source for the 1998-2002 period and a phosphorus load reduction scenario where the loadings are reduced to match the TMDL target load. As indicated, the TMDL load reduction scenario assigned varying load reductions according to land cover and to the WWTFs and CSOs. The load reductions used for the WWTFs reflect recent reductions resulting from issuance of NPDES permits to the facilities. The CSO reductions reflect reductions that will be achieved through implementation of the accepted long-term control plan for CSOs to the Charles River. The cumulative load reduction shown would achieve the water quality goal of the TMDL. Table 6-3 shows the percent reductions assigned to each source category. For the purpose of this analysis, phosphorus load reductions were not considered for forested areas. Figure 6-6 shows the new distribution of loading to the Charles River by source category that would result if this TMDL scenario were fully implemented.

Table 6-4 presents average annual phosphorus loading for the land cover categories for each community. All land area in the Charles River watershed is included in the analysis because no matter where phosphorus is discharged it can persist and become available for algal growth in downstream receiving waters even after long periods of time (e.g., years). The long residence time of phosphorus in the Charles River system is another reason why a five-year averaging period has been used for evaluating phosphorus loading in the Charles River. Allowable loadings consistent with the phosphorus load reductions in the TMDL are also shown. The same reductions as shown in Table 6-3 were applied to the land cover category for each community. These results provide an indication of the magnitude of reductions that are needed for each community. Communities that have more intense urban development and higher amounts of impervious cover are likely to be larger contributors of phosphorus to the Charles than communities that have more vegetated and natural cover. Consequently, larger phosphorus reductions will likely be needed in those communities that have more impervious cover.

In summary, the land-cover loading analysis is intended to provide general guidance as to the relative importance of broad source categories for contributing phosphorus to the Charles River. The magnitude of the loading estimates for each of the land-cover categories is based on general information (land cover categories and literature based phosphorus export loading rates) and may very well not be accurate 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 much 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.

As discussed below in section 6.2.1, this TMDL 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.

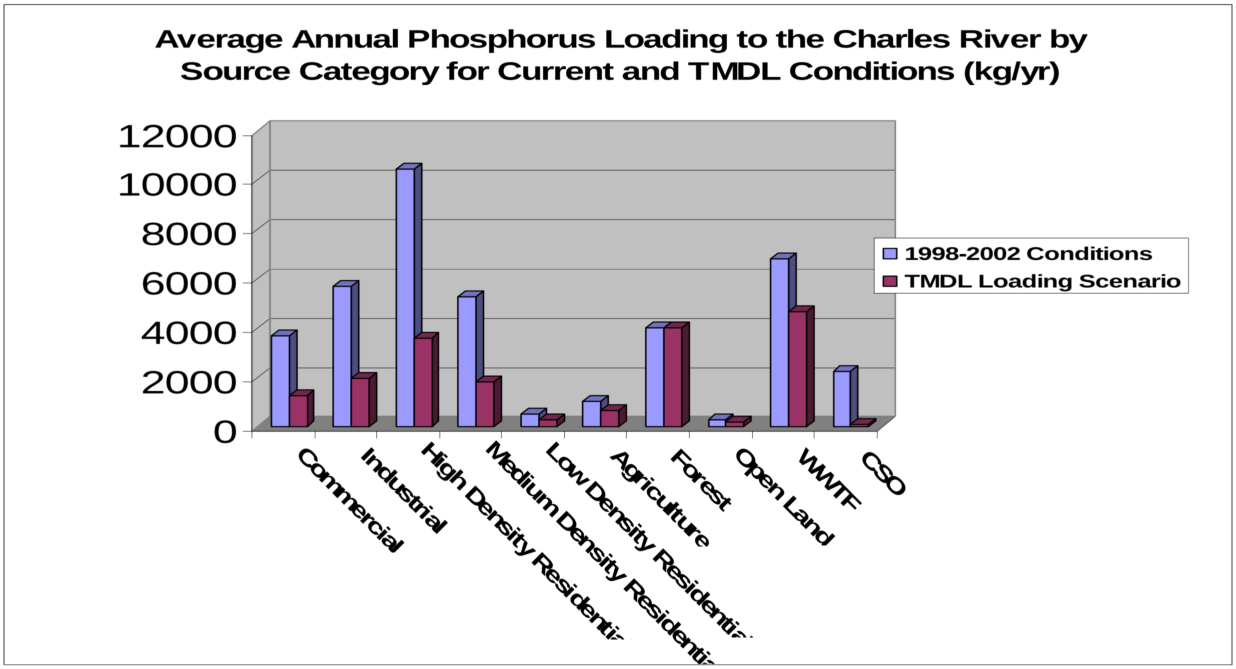

Figure 6-5. Average annual phosphorus loading to the Charles River by source category for current and post-TMDL conditions.

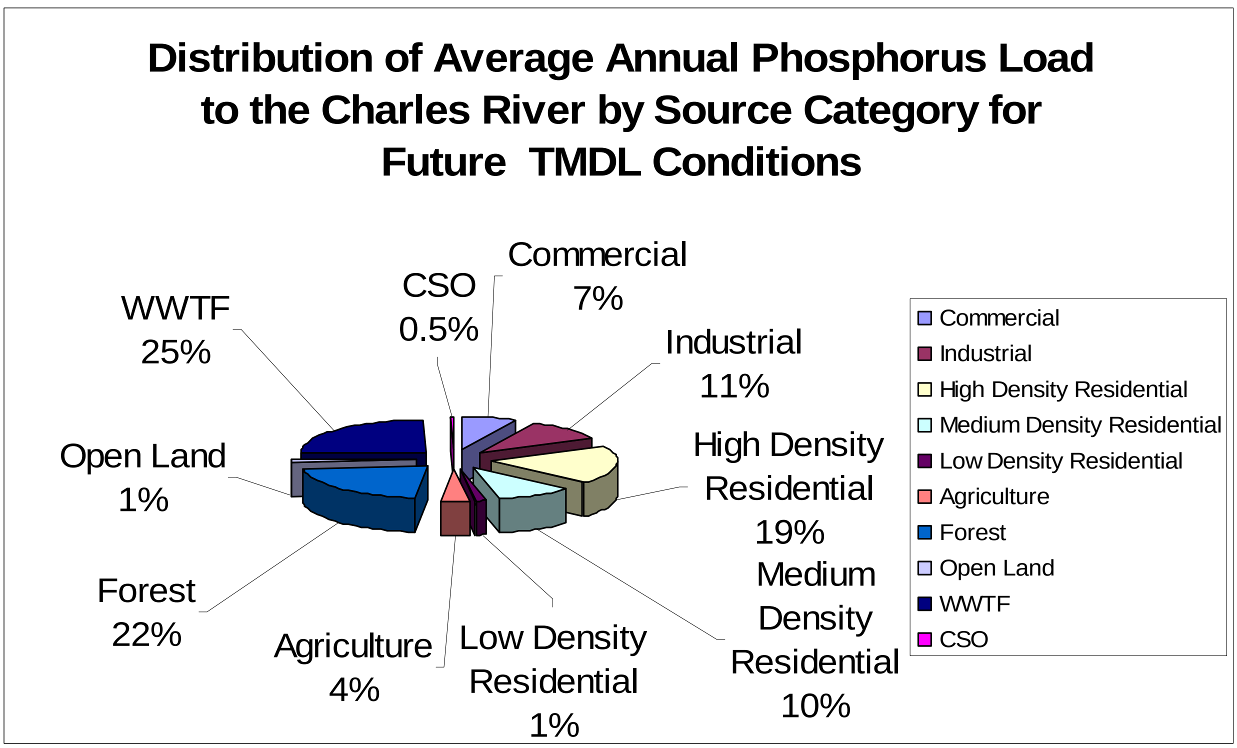

Figure 6-6. Distribution of phosphorus load to the Charles River by source category for TMDL

Table 6-3. Average annual phosphorus loading to the Charles River for current and future -TMDL conditions (kg/yr)

Grand Total Charles River Watershed	Commercial	Industrial	High Density Residential	Medium Density Residential	Low Density Residential	Agriculture	Forest	Open Land	WWTF	CSO	Total
Drainage Area (ha)	2,166	3,888	9,225	9,324	11,068	2,061	30,820	8,421	n/a	n/a	76,974
1998-2002 Loading (kg/yr)	3,676	5,718	10,437	5,278	503	1,042	4,019	289	6,825	2,263	40,050
TMDL Loading (kg/yr)	1,268	1,972	3,600	1,820	276	672	4,018	187	4,663	90[a]	18,565
Percent Reduction	65%	65%	65%	65%	45%	35%	0%	35%	32%	96%	53.6%

[a]This value represents an estimate that would be needed under 1998-2002 conditions. The TMDL however is based on a typical year and compliance with the approved long-term control plan LTCP. Individual Wasteload Allocations for each CSO based on the LTCP can be found in Table 5-6.

Table 6-4. Land cover area and annual phosphorus loadings to the Charles River from communities in the Charles River watershed

Charles River Watershed Community	Commercial	Industrial	High Denisty Residential	Medium Density Residential	Low Density Residential	Agriculture	Forest	Open Land	Total	Percent Reduction Required
Arlington										
Drainage Area (ha)	0.2	5.0	77.3	0.0	0.0	0.0	0.0	10.1	92.67	
1998-2002 Loading (kg/yr)	0.4	7.4	87.5	0.0	0.0	0.0	0.0	0.3	95.60	
TMDL Loading (kg/yr)	0.1	2.5	30.2	0.0	0.0	0.0	0.0	0.2	33.08	**65.4%**
Ashland										
Drainage Area (ha)	2.0	0.0	7.1	60.9	3.8	13.0	70.6	2.7	160.08	
1998-2002 Loading (kg/yr)	3.5	0.0	8.1	34.5	0.2	6.5	9.2	0.1	61.98	
TMDL Loading (kg/yr)	1.2	0.0	2.8	11.9	0.1	4.2	9.2	0.1	29.44	**52.5%**
Bellingham										
Drainage Area (ha)	58.8	212.0	134.2	240.0	212.2	57.1	1,315.9	245.0	2,475.25	
1998-2002 Loading (kg/yr)	99.8	311.7	151.9	135.9	9.7	28.8	171.6	8.4	917.81	
TMDL Loading (kg/yr)	34.4	107.5	52.4	46.9	5.3	18.6	171.6	5.4	442.09	**51.8%**

Charles River Watershed Community	Commercial	Industrial	High Denisty Residential	Medium Density Residential	Low Density Residential	Agriculture	Forest	Open Land	Total	Percent Reduction Required
Belmont										
Drainage Area (ha)	7.2	10.0	105.1	0.9	30.5	0.0	99.9	96.5	350.10	
1998-2002 Loading (kg/yr)	12.3	14.7	118.9	0.5	1.4	0.0	13.0	3.3	164.07	
TMDL Loading (kg/yr)	4.2	5.1	41.0	0.2	0.8	0.0	13.0	2.1	66.40	**59.5%**
Boston										
Drainage Area (ha)	587.1	541.5	2,556.5	43.4	20.2	7.4	688.2	1,444.0	5,888.27	
1998-2002 Loading (kg/yr)	996.4	796.4	2,892.4	24.6	0.9	3.7	89.7	49.6	4,853.77	
TMDL Loading (kg/yr)	343.7	274.7	997.6	8.5	0.5	2.4	89.7	32.0	1,749.04	**64.0%**
Brookline										
Drainage Area (ha)	135.9	10.0	588.2	209.4	254.8	42.9	157.0	357.1	1,755.51	
1998-2002 Loading (kg/yr)	230.7	14.8	665.5	118.5	11.6	21.7	20.5	12.3	1,095.54	
TMDL Loading (kg/yr)	79.6	5.1	229.5	40.9	6.3	14.0	20.5	7.9	403.81	**63.1%**
Cambridge										
Drainage Area (ha)	123.1	126.9	205.7	0.0	0.0	0.0	3.1	181.7	640.42	
1998-2002 Loading (kg/yr)	208.9	186.6	232.7	0.0	0.0	0.0	0.4	6.2	634.84	
TMDL Loading (kg/yr)	72.0	64.3	80.3	0.0	0.0	0.0	0.4	4.0	221.09	**65.2%**
Dedham										
Drainage Area (ha)	42.8	195.8	116.1	289.2	219.5	21.1	816.5	151.4	1,852.42	
1998-2002 Loading (kg/yr)	72.6	287.9	131.4	163.7	10.0	10.7	106.5	5.2	787.90	
TMDL Loading (kg/yr)	25.1	99.3	45.3	56.5	5.5	6.9	106.5	3.4	348.27	**55.8%**
Dover										
Drainage Area (ha)	6.7	0.0	0.0	154.7	738.0	166.3	2,052.6	216.1	3,334.44	
1998-2002 Loading (kg/yr)	11.3	0.0	0.0	87.6	33.6	84.0	267.6	7.4	491.55	
TMDL Loading (kg/yr)	3.9	0.0	0.0	30.2	18.4	54.2	267.6	4.8	379.11	**22.9%**

Charles River Watershed Community	Commercial	Industrial	High Denisty Residential	Medium Density Residential	Low Density Residential	Agriculture	Forest	Open Land	Total	Percent Reduction Required
Foxborough										
Drainage Area (ha)	0.0	0.0	0.0	0.0	1.6	0.0	4.2	0.0	5.75	
1998-2002 Loading (kg/yr)	0.0	0.0	0.0	0.0	0.1	0.0	0.5	0.0	0.62	
TMDL Loading (kg/yr)	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.58	**5.2%**
Franklin										
Drainage Area (ha)	87.5	351.2	110.5	1,455.0	597.6	119.8	2,966.7	600.3	6,288.59	
1998-2002 Loading (kg/yr)	148.6	516.4	125.0	823.5	27.2	60.6	386.8	20.6	2,108.72	
TMDL Loading (kg/yr)	51.2	178.1	43.1	284.0	14.9	39.1	386.8	13.3	1,010.58	**52.1%**
Holliston										
Drainage Area (ha)	74.6	104.5	89.5	687.4	616.1	122.8	2,790.9	347.3	4,833.18	
1998-2002 Loading (kg/yr)	126.6	153.7	101.2	389.1	28.0	62.1	363.9	11.9	1,236.61	
TMDL Loading (kg/yr)	43.7	53.0	34.9	134.2	15.3	40.0	363.9	7.7	692.78	**44.0%**
Hopedale										
Drainage Area (ha)	9.4	11.7	0.0	59.0	32.0	3.9	134.9	22.5	273.38	
1998-2002 Loading (kg/yr)	15.9	17.1	0.0	33.4	1.5	2.0	17.6	0.8	88.26	
TMDL Loading (kg/yr)	5.5	5.9	0.0	11.5	0.8	1.3	17.6	0.5	43.09	**51.2%**
Hopkinton										
Drainage Area (ha)	3.6	31.6	0.0	76.4	215.9	10.8	487.3	30.8	856.31	
1998-2002 Loading (kg/yr)	6.1	46.4	0.0	43.2	9.8	5.4	63.5	1.1	175.63	
TMDL Loading (kg/yr)	2.1	16.0	0.0	14.9	5.4	3.5	63.5	0.7	106.14	**39.6%**
Lexington										
Drainage Area (ha)	87.3	107.3	36.0	273.3	150.1	29.1	443.4	137.3	1,263.96	
1998-2002 Loading (kg/yr)	148.2	157.9	40.8	154.7	6.8	14.7	57.8	4.7	585.62	
TMDL Loading (kg/yr)	51.1	54.4	14.1	53.4	3.7	9.5	57.8	3.0	247.06	**57.8%**

Charles River Watershed Community	Commercial	Industrial	High Denisty Residential	Medium Density Residential	Low Density Residential	Agriculture	Forest	Open Land	Total	Percent Reduction Required
Lincoln										
Drainage Area (ha)	7.0	0.9	7.8	7.0	693.1	146.5	1,244.9	117.5	2,224.70	
1998-2002 Loading (kg/yr)	11.8	1.3	8.9	3.9	31.5	74.0	162.3	4.0	297.81	
TMDL Loading (kg/yr)	4.1	0.4	3.1	1.4	17.3	47.7	162.3	2.6	238.87	**19.8%**
Medfield										
Drainage Area (ha)	25.8	62.3	69.3	390.7	480.4	95.3	1,580.2	226.0	2,929.97	
1998-2002 Loading (kg/yr)	43.9	91.6	78.4	221.1	21.8	48.2	206.0	7.8	718.74	
TMDL Loading (kg/yr)	15.1	31.6	27.0	76.3	12.0	31.1	206.0	5.0	404.08	**43.8%**
Medway										
Drainage Area (ha)	38.2	54.6	40.3	500.3	672.0	208.0	1,244.2	255.1	3,012.75	
1998-2002 Loading (kg/yr)	64.8	80.3	45.7	283.2	30.6	105.1	162.2	8.8	780.62	
TMDL Loading (kg/yr)	22.4	27.7	15.7	97.7	16.7	67.8	162.2	5.7	415.88	**46.7%**
Mendon										
Drainage Area (ha)	9.5	0.1	0.0	3.2	15.5	4.4	40.9	4.6	78.17	
1998-2002 Loading (kg/yr)	16.1	0.2	0.0	1.8	0.7	2.2	5.3	0.2	26.49	
TMDL Loading (kg/yr)	5.5	0.1	0.0	0.6	0.4	1.4	5.3	0.1	13.48	**49.1%**
Milford										
Drainage Area (ha)	80.3	328.9	270.7	647.7	243.4	3.1	1439.1	265.2	3,278.42	
1998-2002 Loading (kg/yr)	136.4	483.7	306.3	366.6	11.1	1.6	187.6	9.1	1,502.33	
TMDL Loading (kg/yr)	47.0	166.8	105.6	126.4	6.1	1.0	187.6	5.9	646.52	**57.0%**
Millis										
Drainage Area (ha)	23.7	81.4	22.1	328.9	385.4	303.2	1,749.1	271.6	3,165.42	
1998-2002 Loading (kg/yr)	40.2	119.8	25.0	186.1	17.5	153.2	228.1	9.3	779.31	
TMDL Loading (kg/yr)	13.9	41.3	8.6	64.2	9.6	98.8	228.1	6.0	470.52	**39.6%**

Charles River Watershed Community	Commercial	Industrial	High Denisty Residential	Medium Density Residential	Low Density Residential	Agriculture	Forest	Open Land	Total	Percent Reduction Required
Natick										
Drainage Area (ha)	33.5	71.7	171.1	587.9	370.6	72.8	939.1	195.4	2,442.11	
1998-2002 Loading (kg/yr)	56.9	105.4	193.6	332.8	16.9	36.8	122.4	6.7	871.53	
TMDL Loading (kg/yr)	19.6	36.4	66.8	114.8	9.2	23.7	122.4	4.3	397.26	**54.4%**
Needham										
Drainage Area (ha)	66.0	200.5	674.8	504.7	456.3	47.3	1,038.4	231.1	3,219.09	
1998-2002 Loading (kg/yr)	112.0	294.9	763.4	285.7	20.8	23.9	135.4	7.9	1,643.96	
TMDL Loading (kg/yr)	38.6	101.7	263.3	98.5	11.4	15.4	135.4	5.1	669.45	**59.3%**
Newton										
Drainage Area (ha)	202.3	216.4	2,393.5	525.0	59.1	0.9	545.4	673.7	4,616.36	
1998-2002 Loading (kg/yr)	343.3	318.3	2,708.0	297.1	2.7	0.5	71.1	23.2	3,764.12	
TMDL Loading (kg/yr)	118.4	109.8	934.0	102.5	1.5	0.3	71.1	14.9	1,352.46	**64.1%**
Norfolk										
Drainage Area (ha)	26.4	101.5	1.7	581.2	600.8	103.9	2,114.1	358.1	3,887.66	
1998-2002 Loading (kg/yr)	44.8	149.3	1.9	329.0	27.3	52.5	275.6	12.3	892.80	
TMDL Loading (kg/yr)	15.5	51.5	0.7	113.5	15.0	33.9	275.6	7.9	513.48	**42.5%**
Sherborn										
Drainage Area (ha)	4.5	3.9	1.8	10.0	768.5	280.6	2,023.7	156.9	3,249.90	
1998-2002 Loading (kg/yr)	7.7	5.7	2.0	5.6	35.0	141.8	263.9	5.4	467.07	
TMDL Loading (kg/yr)	2.6	2.0	0.7	1.9	19.1	91.5	263.9	3.5	385.21	**17.5%**
Somerville										
Drainage Area (ha)	0.0	26.6	0.4	0.0	0.0	0.0	0.0	0.0	27.02	
1998-2002 Loading (kg/yr)	0.0	39.2	0.4	0.0	0.0	0.0	0.0	0.0	39.62	
TMDL Loading (kg/yr)	0.0	13.5	0.1	0.0	0.0	0.0	0.0	0.0	13.66	**65.5%**

Charles River Watershed Community	Commercial	Industrial	High Denisty Residential	Medium Density Residential	Low Density Residential	Agriculture	Forest	Open Land	Total	Percent Reduction Required
Walpole										
Drainage Area (ha)	0.0	0.0	0.0	1.6	134.2	8.6	372.4	58.8	575.73	
1998-2002 Loading (kg/yr)	0.0	0.0	0.0	0.9	6.1	4.3	48.6	2.0	61.96	
TMDL Loading (kg/yr)	0.0	0.0	0.0	0.3	3.3	2.8	48.6	1.3	56.33	**9.1%**
Waltham										
Drainage Area (ha)	158.1	501.1	1,010.2	298.6	53.0	32.6	709.2	541.1	3,304.02	
1998-2002 Loading (kg/yr)	268.3	737.0	1,143.0	169.0	2.4	16.5	92.5	18.6	2,447.21	
TMDL Loading (kg/yr)	92.5	254.2	394.2	58.3	1.3	10.6	92.5	12.0	915.64	**62.6%**
Watertown										
Drainage Area (ha)	104.3	125.5	478.7	0.0	0.0	11.7	12.9	212.9	946.06	
1998-2002 Loading (kg/yr)	177.0	184.6	541.6	0.0	0.0	5.9	1.7	7.3	918.14	
TMDL Loading (kg/yr)	61.1	63.7	186.8	0.0	0.0	3.8	1.7	4.7	321.74	**65.0%**
Wayland										
Drainage Area (ha)	0.0	12.6	14.4	10.7	46.8	0.7	54.1	7.8	147.18	
1998-2002 Loading (kg/yr)	0.0	18.5	16.3	6.1	2.1	0.3	7.1	0.3	50.67	
TMDL Loading (kg/yr)	0.0	6.4	5.6	2.1	1.2	0.2	7.1	0.2	22.71	**55.2%**
Wellesley										
Drainage Area (ha)	90.0	54.5	15.3	764.6	859.7	6.7	430.9	381.0	2,602.48	
1998-2002 Loading (kg/yr)	152.7	80.1	17.3	432.8	39.1	3.4	56.2	13.1	794.65	
TMDL Loading (kg/yr)	52.7	27.6	6.0	149.3	21.4	2.2	56.2	8.4	323.74	**59.3%**
Weston										
Drainage Area (ha)	13.9	143.9	10.8	373.4	1,450.2	56.2	1,500.6	418.8	3,967.81	
1998-2002 Loading (kg/yr)	23.5	211.6	12.2	211.4	66.0	28.4	195.7	14.4	763.18	
TMDL Loading (kg/yr)	8.1	73.0	4.2	72.9	36.1	18.3	195.7	9.3	417.60	**45.3%**

Charles River Watershed Community	Commercial	Industrial	High Denisty Residential	Medium Density Residential	Low Density Residential	Agriculture	Forest	Open Land	Total	Percent Reduction Required
Westwood										
Drainage Area (ha)	10.6	48.4	7.0	89.2	284.3	35.0	390.4	69.7	934.41	
1998-2002 Loading (kg/yr)	17.9	71.1	7.9	50.5	12.9	17.7	50.9	2.4	231.32	
TMDL Loading (kg/yr)	6.2	24.5	2.7	17.4	7.1	11.4	50.9	1.5	121.77	**47.4%**
Wrentham										
Drainage Area (ha)	45.8	146.0	8.6	149.9	402.2	49.7	1,359.3	133.2	2,294.55	
1998-2002 Loading (kg/yr)	77.7	214.7	9.7	84.8	18.3	25.1	177.2	4.6	612.13	
TMDL Loading (kg/yr)	26.8	74.1	3.4	29.3	10.0	16.2	177.2	3.0	339.84	**44.5%**
Charles River Watershed										
Drainage Area (ha)	2,166.2	3,888.4	9,224.7	9,324.2	11,067.9	2,061.1	30,820.3	8,421.3	7,6974	
1998-2002 Loading (kg/yr)	3,676.3	5,718.3	10,437.0	5,277.6	503.4	1,041.6	4,018.5	289.4	3,0962	
TMDL Loading (kg/yr)	1,267.9	1,972.3	3,599.7	1,820.3	275.6	671.9	4,018.0	186.7	1,3812	**55.4%**
Percent Reduction Required	65.0%	65.0%	65.0%	65.0%	45.0%	35.0%	0.0%	35.0%	55.4%	

6.2 Implementation Strategy Components

The implementation plan focuses on three major groups of nutrient sources: (1) stormwater runoff (Section 6.2.1), (2) illicit discharges in drainage systems (Section 6.2.2), and (3) CSO discharges to the Lower Charles River (Section 6.2.3). Phosphorus load reductions for WWTFs are not specifically addressed in this section because phosphorus reductions have already been accomplished through issuance of the NPDES permits for these facilities. Since 2000 the permitted phosphorus load for the WWTFs in the Charles River watershed has been reduced by more than 80%.

6.2.1 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 by the United States Census Bureau and are subject to the Stormwater Phase II Final Rule. In addition, Boston is subject to the Stormwater Phase I Final Rule.

The NPDES permits which EPA has issued in Massachusetts to implement the Phase I and 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 I or 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, bit 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.

A list of the municipalities in Massachusetts regulated by the Phase II Rule, as well as the Notices of Intent for each municipality can be viewed at http://www.epa.gov/region01/npdes/stormwater/ma.html.

Charles River Watershed

Estimates of pollutant loads have been calculated based on dry- and wet-weather water quality monitoring data, hydrologic data, the results of calibrated hydrologic/hydraulic models of the drainage and combined sewer systems, land cover data, and phosphorus loading export factors. Based on available information, the vast majority of the anthropogenic nutrient loading that contributes to the eutrophication of the Lower Charles River is related to the drainage systems that discharge directly to the Lower Charles and to the Charles River upstream of the Watertown Dam. Therefore, addressing stormwater drainage system discharges will be critical to reducing nutrient loads to the Lower Charles River.

Stormwater discharges represent a major source of nutrients to the Lower Charles River and the current level of control is inadequate to meet this TMDL's water quality goals for nutrients. Comprehensive stormwater management programs must be developed throughout the watershed to reduce nutrient loadings from stormwater to the Lower Charles River. Initially, the owners of regulated municipal drainage systems (communities, Mass Highway, DCR, and MassTurnpike Authority) 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.

The NPDES stormwater permitting program will be the primary mechanism for applying the implementation plan and achieving the necessary reductions from the permitted separate storm sewer systems. Most municipal stormwater discharges are regulated under the NPDES Phase I and II MS4 permitting programs (see Section 3.4.1). All municipal owned drains in the entire Lower Charles River watershed below the dam are regulated by Phase I and II MS4 permits. All of the communities above Watertown Dam are either all or partially regulated by the Phase II MS4 permit.

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 NPDES 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. As discussed above, there is extensive knowledge concerning the presence of nutrient sources to drainage systems including illicit sewage discharges (discussed in Section 6.1.2) and stormwater runoff. 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 Lower Charles River.

This latter point is particularly relevant for the Lower Charles River nutrient TMDL because the TMDL analysis demonstrates the need for very large overall nutrient load reductions and because the allocations for sources contributing to the nutrient loads from the upstream watershed and the direct tributary watersheds are only coarsely defined. It is likely that implementation activities to achieve algal-related water quality goals in the Lower Charles River will take many years. The plan will require ongoing monitoring efforts to identify, characterize, and prioritize sources; eliminate illicit sources in a 308 square mile watershed; and optimize stormwater management plans through iterative cycles of implementation and evaluation.

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 CSOs and 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.

The development and implementation of comprehensive storm water management programs throughout the Charles River watershed will be necessary to achieve the phosphorus reduction and water quality goals of this TMDL. The management program should accomplish the following tasks: (1) characterize the drainage areas that contribute to discharges requiring permit coverage under the Permittee’s jurisdiction; (2) implement a comprehensive Illicit Discharge Detection and Elimination (IDDE) program; (3) prioritize source areas for control; and (4) include the necessary 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 on these tasks 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 - Follow IDDE Regional protocol for the Charles River watershed (See Section 6.2.2):
    - 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 shall 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 will 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 working on 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). Diverting storm water runoff from impervious areas for groundwater recharge using infiltration practices is also highly recommended. 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.

Pilot Studies

There is currently limited information available on the overall effectiveness of some of the newer technologies available to the Charles River watershed. Conducting comprehensive pilot studies on stormwater management in the Charles River watershed is one potential option to collect useful information on the effectiveness of newer and innovative watershed nutrient controls. Pilot studies can be used to evaluate the effectiveness of various non-structural and structural BMPs that will be actually be implemented in the Charles River watershed. The results of the studies could be used to refine stormwater management programs and develop enhanced SWMPs. Prior to initiating any pilot studies, EPA and MassDEP should carefully evaluate project needs and design criteria. For pilot studies to be effective, the results should be transferable among the watershed communities. Therefore, all pilot studies must be well-designed and have consistent study and monitoring approaches.

Permittees could be given the option of participating in needed pilot studies within the watershed or selected area, once they have completed the source monitoring and drainage area characterizations. In order to maintain a reasonable rate of progress in reducing nutrient loading to the Charles, the pilot studies should address high-priority drainages systems that, in total, comprise approximately 20% of the participating community’s total contributing drainage area

Examples of a structural and non-structural BMP that could be evaluated in these pilot studies are discussed below and include infiltration and bioretention/filtration practices, as well as high-efficiency street sweeping.

Example of Infiltration Practices as a Structural Stormwater BMP

Stormwater infiltration practices consist of a variety of means to divert stormwater into the ground. Implementation of these BMPS typically involves the conveyance of runoff from impervious areas to locations and/or structures where the runoff is allowed to seep into the ground. Surface and sub-surface practices have been widely and successfully implemented in various parts of the country. Use of infiltration practices in the Charles River watershed is particularly desirable because these practices are extremely effective at removing many pollutants in runoff including phosphorus and bacteria and can help replenish base-flow in streams. These practices also help to reduce peak runoff flows, which contribute to accelerated stream bank erosion and the destabilization of smaller stream channels. Reducing stream channel erosion and scouring also helps to reduce internal sediment and phosphorus loadings to downstream surface waters. Finally, widespread use of infiltration practices in the watershed may also help to increase the pollutant assimilative capacity of free flowing segments of the Charles River as well as tributary streams.

Surface infiltration practices such as basins and infiltration swales allow water to be temporarily stored while it infiltrates into the ground. Generally surface infiltration practices are more desirable if ample surface areas are available because they are less expensive to construct and easier to maintain. In some cases, runoff from impervious areas may be simply diverted to open and wooded areas for groundwater recharge providing soils are suitable. Sub-surface practices may consist of chambers, trenches and galleys that are constructed under the ground surface (i.e., in right-of ways or under parking lots) to temporarily store runoff for infiltration into the surrounding soils. Subsurface practices are an option when limited surface area is available or subsurface soils are more suitable for infiltration practices than surface soils. It is particularly important to provide pre-treatment to remove as much sediment as possible in the runoff before discharging to subsurface infiltration units. Sediment loadings to infiltration storage units can lead to clogging of the infiltration surface resulting in reduced performance or failure. In all cases, infiltration practices require well-drained soils to be effective.

A review of hydrologic soil classifications for the Charles River watershed prepared by the U.S. Natural Resources Conservation Service (NRCS) indicates that the soils covering almost half of the watershed consist of moderately well-drained to extremely well drained soils (type A and B soils). Such soils are typically well suited for applying infiltration practices. The State of Maryland, which has considerable experience on using infiltration practices, allows their application to only type A and B soils. The infiltration rates in type C and D soils are considerably lower and have been found to be more prone to failure. The extent of coverage of type A and B soils in the Charles River watershed indicates infiltration practices may be very promising for addressing several stormwater runoff-related water quality impairments including as discussed further below, reducing phosphorus loading. Figure 6-7 depicts the distribution of type A and B soils in the Charles River Watershed and Table 6-5 summarizes the presence of all of hydrologic soil groups and their relative presence in the watershed.

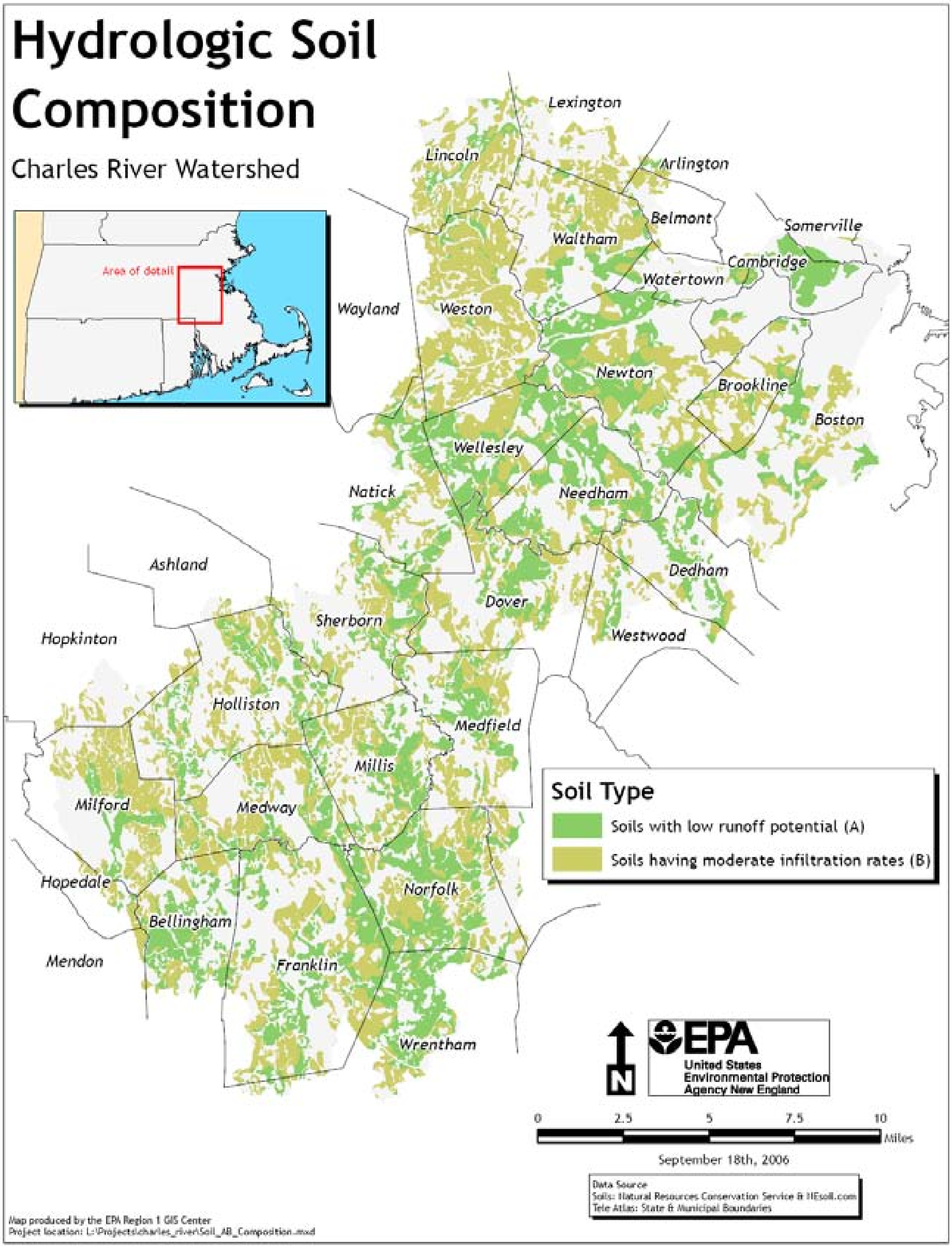

Figure 6-7. Distribution of Hydrologic Type A and B Soils in the Charles River watershed

Table 6-5. Summary of hydrologic soils in the Charles River watershed

Hydrologic Codes	Sq. Meters	Acres	% of Total
NO VALUE	248,380.25	61.35	0.0
A	168,749,406.28	41,699.08	20.9
B	211,257,256.23	52,202.74	26.2
C	174,944,872.89	43,229.72	21.7
C/D*	40,970,437.91	10,123.98	5.1
D	88,876,439.09	21,961.87	11.0
Unclassified	97,839,624.92	24,176.60	12.1
Water	22,804,842.64	5,635.19	2.8
X	572,716.67	141.53	0.1
Total	**806,015,596.63**	**199,170.71**	**100.00**

Hydrologic soil definitions

A. Soils with low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well drained to excessively well-drained sands or gravels.
B. Soils having moderate infiltration rates even when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well drained to well drained soils with moderately fine to moderately coarse textures.
C. Soils having slow infiltration rates even when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures.
D. Soils with high runoff potential. Soils having very slow infiltration rates even when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material.
C/D.* Dual hydrologic group for bedrock controlled soils. Use group C if bedrock is fractured and D if unfractured

Infiltration practices may offer high removal efficiencies for phosphorus, because essentially all of the phosphorus in the runoff that is infiltrated is removed (filtered) as it passes through the surface vegetative layer and the soil matrix. Also, the storage of runoff flows for infiltration allows for additional removal of phosphorus through sedimentation of particulate bound phosphorus. Ultimately, it is the amount of runoff that is treated by infiltration practices that determines how much phosphorus can be removed. The infiltration rate of the soils and the size of the infiltration area are the primary factors that determine how much of the annual runoff volume will be infiltrated. Typically, infiltration practices are designed to include a diversion structure that will divert runoff to the BMP based on a design flow or volume equivalent to the capacity of the infiltration system. In many cases, the infiltration area and rate will limit how much runoff can be treated at a site.

A stormwater BMP modeling analysis has been conducted to illustrate the potential benefits of infiltration practices for treating storm runoff. The P8 Urban Catchment Model (P8-UCM) was used to simulate (1) the amount of runoff that could be captured for recharge from impervious cover; (2) the amount of phosphorus that could be captured by infiltration practices sized to store varying amounts of runoff from impervious areas; and (3) the amount of runoff and phosphorus that could be captured using infiltration practices for two typical land cover categories, commercial and high density residential. The analyses demonstrates that infiltration practices can cumulatively, over the long term (i.e., annually), capture substantial amounts of runoff and phosphorus, even if only relatively small amounts of runoff are captured for each storm event.

The P8-UCM model is a hydrologic/ BMP model that predicts the generation and transport of stormwater runoff pollutants and pollutant removal efficiencies for a variety of BMPs. The model uses hourly time-series rainfall data and computes the build-up and wash-off of pollutants on impervious surfaces based on the number of dry-days between rain events and the intensity of the rainfall. The model simulates five groupings of dust and dirt particles according to size and estimates a pollutant's loading based on the pollutant's association with the different particle sizes. BMP pollutant removal performance in the model is based primarily on the settling of particulate matter, which is calculated by applying settling velocities to the different particle classes. The model has been calibrated using stormwater data collected under the National Urban Runoff Program (NURP) and is consider to be suitable to use without site-specific data for making relative comparisons.(Walker, 1990), (EPA, 1997).

First, the model was used to evaluate how much groundwater recharge could potentially be accomplished by diverting different amounts of runoff from a completely impervious drainage area (100% impervious) to an infiltration-type BMP. Hourly rainfall data collected at the Ward Street Headworks in Boston for the 1998-2002 period were used in the simulations. These data are consistent with the rainfall data used in the modeling conducted for this TMDL to estimate pollutant loadings from CSOs and the watershed areas that drain directly to the Lower Charles. During this period a total of 351 rain events occurred and the average annual rainfall was 44.43 inches.

Multiple simulations were performed for two scenarios to evaluate recharge and phosphorus removal: (1) the infiltration rate is based on hydrologic soil group A (0.6 inches/hr); and (2) the infiltration rate is based on hydrologic soil group B (0.4 inches/hr). A drainage area of 10 ha (24.69 acres) with a depression storage of 0.025 inches was used in each simulation. Runoff generated from the 10 ha impervious area was diverted to an offline infiltration practice that was sized to temporarily store a specific amount of rainfall from the area (e.g., 0.1, 0.2, 0.4, 0.6, 08, 1.0, 1.2 inches…) Figure 6-8 illustrates the cumulative percent runoff volumes captured for infiltration practices assuming type A and B soils. As indicated, storing relative small amounts of runoff for infiltration provides for a relatively large capture of total runoff volume for the 1998-2002 period. For example, an infiltration practice sized to store just 0.2 inches of rainfall from an impervious area is estimated to capture 31.8 and 27.3 percent of the total runoff volume from that area assuming type A and B soils, respectively. Storing 1.0 inch of rainfall for infiltration would capture 73.9 and 66.8 percent of the total runoff for the same period, assuming type A and B soils, respectively.

Cumulative percent capture of phosphorus was also simulated for these scenarios and is presented in Figure 6-9. Percent capture of phosphorus for a given rainfall/runoff storage volume is always higher than the corresponding percent capture of runoff volume because of the effect of sedimentation that occurs in the BMP. The results indicate that infiltration practices are very promising for removing phosphorus from impervious areas. For example, an infiltration system in type A soils designed to divert and temporarily store just 0.2 inches of rainfall/runoff from an impervious area is estimated to capture 44 percent of the total phosphorus load generated from that area for the 1998-2002 period. The same system in type B soils would capture approximately 41 percent of the total phosphorus load.

P8-UCM simulations were also performed to estimate the phosphorus capture of different sized infiltrations systems for treating runoff from typical land-cover categories prevalent in the Charles River watershed. Instead of using a drainage area that is 100% impervious, phosphorus loading and removal efficiencies were modeled for two land cover categories, commercial and high-density residential, which are estimated to be significant sources of phosphorus to the Charles River. Prior to simulating the phosphorus removal performance of infiltration practices, the model was first used to adjust the phosphorus loading from these two land cover categories to match their respective adjusted phosphorus export loading rates discussed above in Section 6.1. This was accomplished to ensure that the estimated phosphorus loading from these land covers were consistent with the estimated loadings for the TMDL.

Table 6-6 summarizes the drainage area characteristics for these land cover categories that were used in the p8-UCM for this analysis. The percent impervious values are based on typical percent impervious values as determined by MassGIS (Broduer, 2006). The percent impervious value for the commercial category is taken directly from the estimates conducted by MassGIS, while the percent impervious value of 40% used for the high density residential category is an average of the MassGIS typical percent impervious values for multi-family and high-density residential covers. In this analysis and the analysis discussed in Section 6.1, multi-family and high density residential land covers were combined into one category identified as high density residential. The pervious runoff curve number (CN) used to estimate runoff from pervious areas is representative of grassed cover in fair hydrologic condition (Walker, 1990).

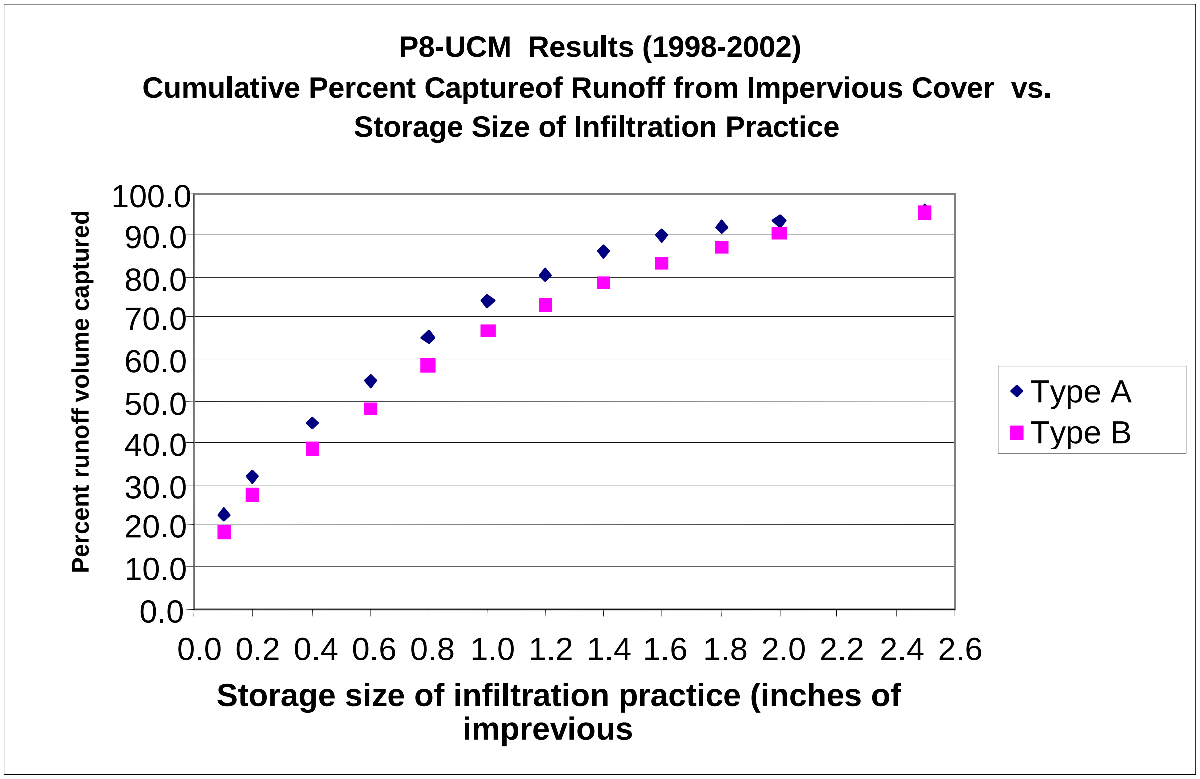

Figure 6-8. Performance of an infiltration system for capturing runoff from an impervious area

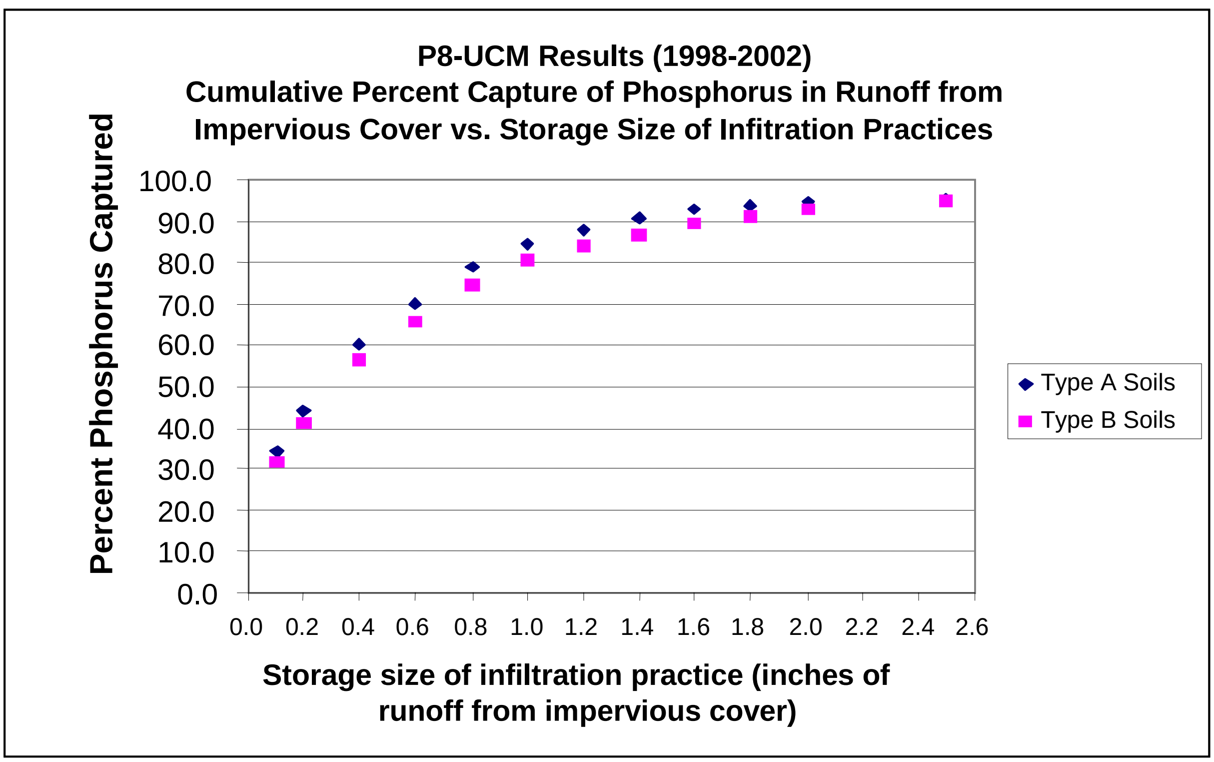

Figure 6-9. Performance of an infiltration system for removing phosphorus in runoff from an impervious area

Table 6-6. Drainage area information for P8-UCM infiltration practice modeling

Land Cover	Adjusted phosphorus export loading rate (kg/ha-yr)	% Impervious	Pervious CN	Soil Type	Infiltration Rate (in/hr)
Commercial	1.696	77	49	A	0.6
High-density residential	1.131	40	49	A	0.6

Similar to the impervious cover analysis discussed above, several P8 UCM simulations were performed where runoff from a 10 ha (24.69 acre) drainage area is diverted to an infiltration practice that is sized to temporarily store a range of rainfall runoff volumes from the impervious portion of the drainage area. Figures 6-10 and 6-11 presents the modeling results for the typical commercial and high density residential drainage areas, respectively. As indicated, infiltration practices offer great potential to achieve large phosphorus reductions and to capture substantial amount of runoff for recharge. For both the typical commercial and high density residential areas, the modeling indicates that storing approximately ½ inch of runoff from the impervious portions of the areas would effectively capture approximately 65 % of the total phosphorus load generated from these areas for the 1998-2002 period.

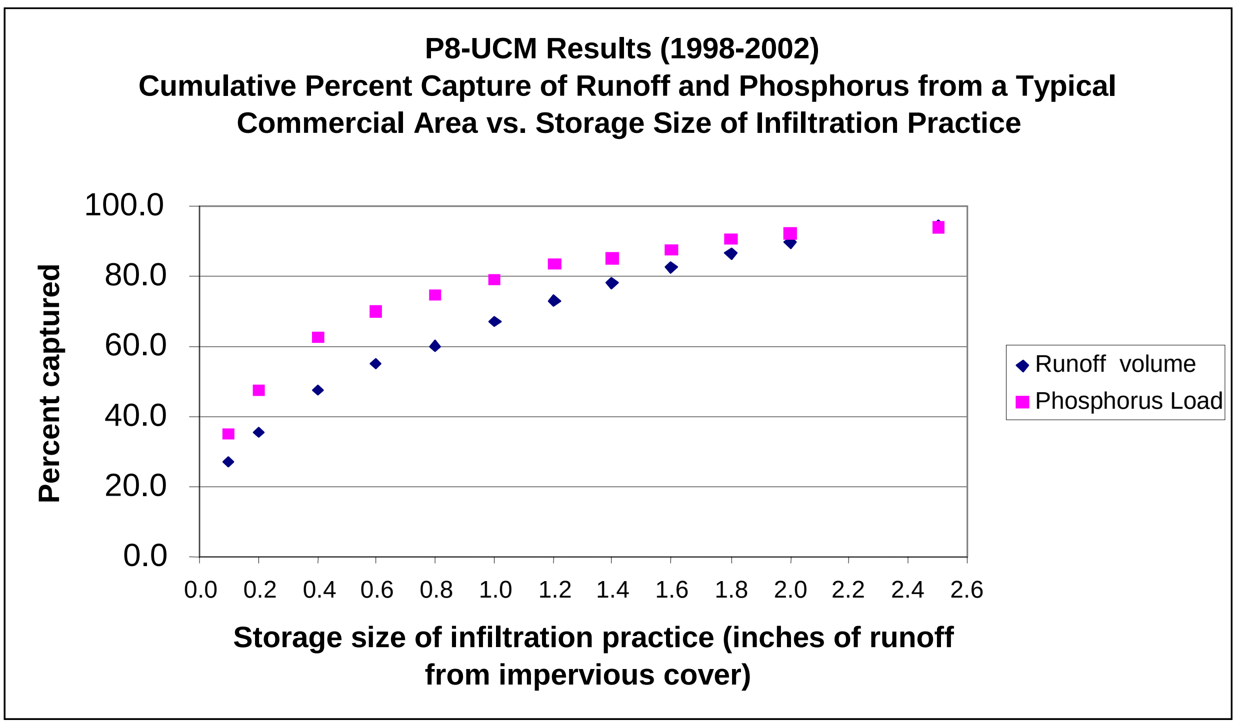

Figure 6-10. Performance of an infiltration system for treating runoff from a typical commercial area

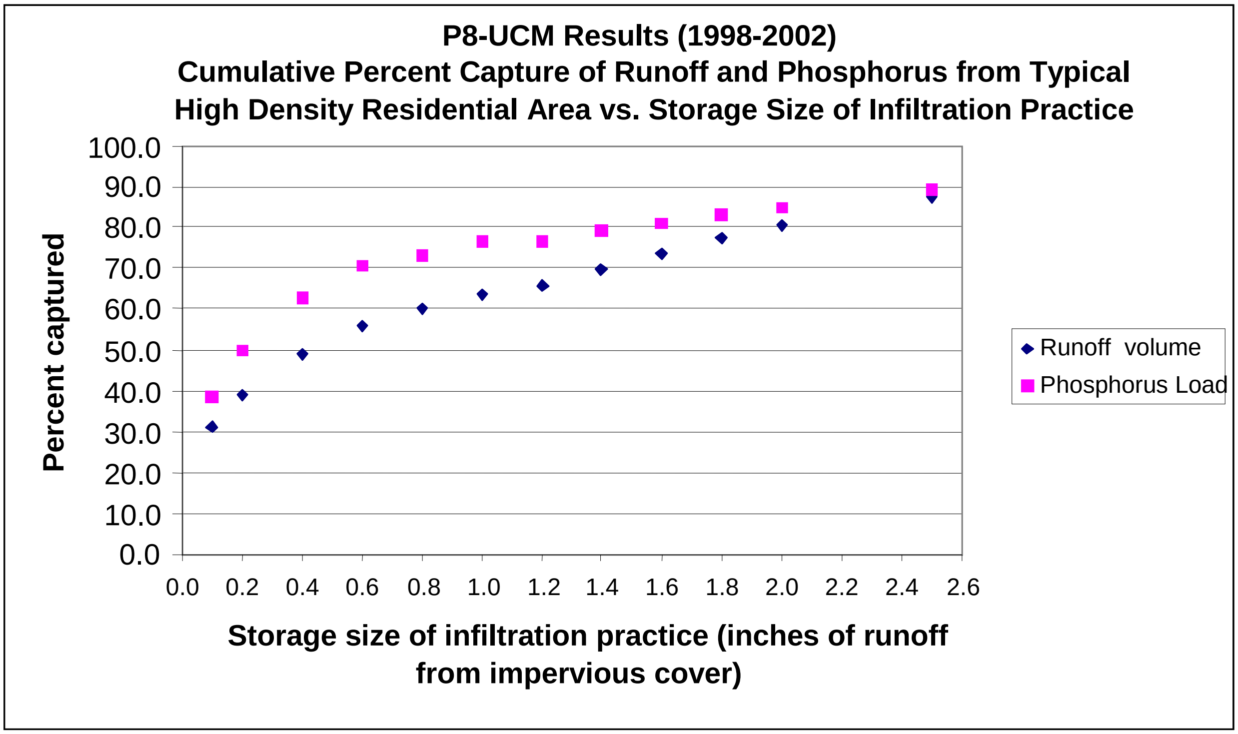

Figure 6-11. Performance of an infiltration system for treating runoff from a typical high density residential area

Example of Bioretention/filtration Practices as a Structural Stormwater BMP

Bioretention/filtration practices use a filter media and vegetation to treat stormwater runoff. These BMPs are natural looking structures that temporarily store runoff from impervious areas for filtration and uptake by vegetation. Depending on the existing soil conditions underlying the BMP, treated runoff can be either collected by and underdrain system located below the filter media or infiltrated into the underlying soils. The discharge from underdrain systems is directed to downstream BMPs (i.e., for flood control), conveyance systems or receiving waters. The filter media typically consists of a specific mixture of sand and an organic compost material that maintains an acceptable hydraulic conductivity while absorbing and filtering pollutants in the runoff. A certain amount of storage also takes place in the void spaces of the media and depending on the design and site conditions surface storage can also be achieved. Thus, these practices also help to reduce peak runoff flows, which contribute to accelerated stream bank erosion and the destabilization of smaller stream channels. Reducing stream channel erosion and scouring also helps to reduce internal sediment and phosphorus loadings to downstream surface waters. Vegetation can be planted on the surface of the practice, which can further remove pollutants and provide an attractive aesthetic environment. Also, the surface vegetation can help prevent clogging and failure of the practice. Figure 6-12 a-d show examples of vertical cross-sections of a bioretention/infiltration/filtration practices (Tetra Tech, 2001).

Recent research conducted on the performance of bioretention/filtration practices shows these practices to be very effective at removing pollutants in stormwater runoff. Cumulative long term performance of bioretention/filtration practices are believed to be comparable to the results shown for infiltration practices above making this type of BMP highly desirable for the Charles River watershed. The practices can be constructed in a variety of shapes to conform to existing site conditions in highly urbanized areas such as along the edges of parking lots and in parking lot islands. Because of the underdrain system, these practices can be constructed in locations where poorly drained soils exist and still provide high pollutant removal efficiencies.

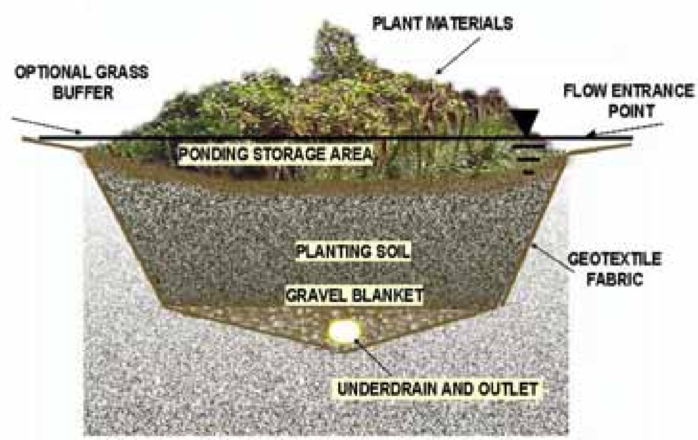

Figure 6-12(a). Bioretention Facility (Source: Tetra Tech, Inc. 2001. The Bioretention Manual, Prince George's County. Maryland, July 2001)

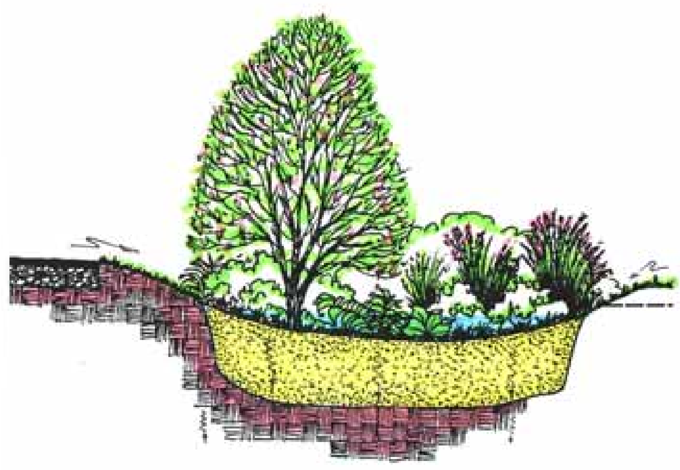

Figure 6-12(b). Infiltration/Recharge Facility (enhanced infiltration) (Source: Tetra Tech, Inc. 2001. The Bioretention Manual, Prince George's County. Maryland, July 2001)

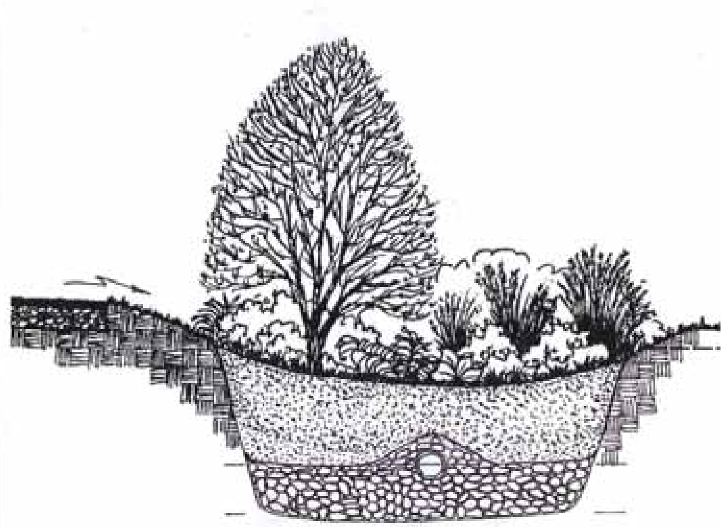

Figure 6-12(c). Infiltration/Filtration/Recharge Facility (Source: Tetra Tech, Inc. 2001. The Bioretention Manual, Prince George's County. Maryland, July 2001)

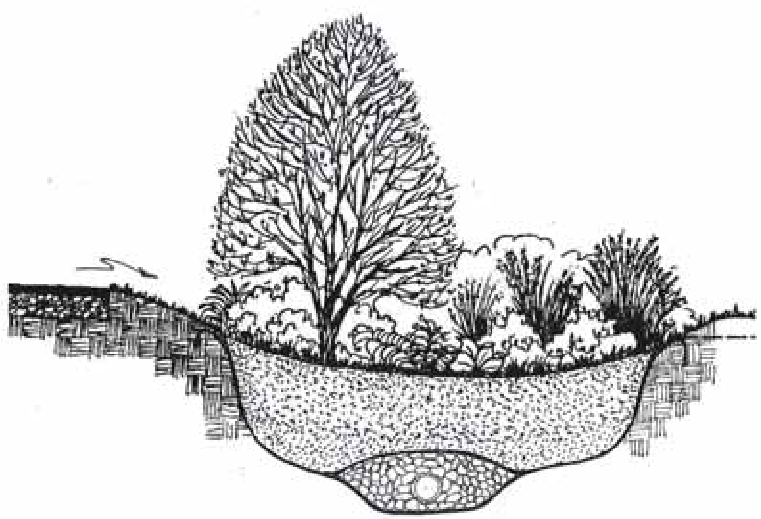

Figure 6-12(d). Biofiltration (filtration only)Facility (Source: Tetra Tech, Inc. 2001. The Bioretention Manual, Prince George's County. Maryland, July 2001)

Example of Street Sweeping as a Non-Structural BMP

In many urban areas options for structural BMPs are extremely limited because of space limitations. Street sweeping using newer high-efficiency sweeping technologies represents a promising practice for reducing nutrient loading in stormwater runoff from developed areas of the Charles River watershed. Municipal and private street sweeping programs need to be evaluated with the intention of reducing potential stormwater pollutant loadings. Sweeping program evaluations should investigate the use of high-efficiency sweeper technologies, increased sweeping frequencies, and targeting high pollutant source areas.

Improvements in sweeper technologies have resulted in the availability of high-efficiency street sweepers that are capable of collecting small particle sizes (<100 microns) from paved surfaces. Removal of these smaller particles from paved surfaces is critical for reducing stormwater pollutant loadings (including phosphorus loadings) from streets and parking lots, as most of the pollutant load in stormwater is associated with these very small particle sizes (Pitt et al. 2004). Investigations conducted by Sartor and Boyd (in Walker et al. 1999) on street dirt characteristics have shown that most particulates found on street surfaces are in the fractions of sand and gravel, while only approximately 6 percent of particles are in the silt and clay soil size (i.e., < 63 microns). However, it is the silt and clay size particles that were found to contain over half of the phosphorus and 25 percent of other pollutants (Walker et al. 1999).

With respect to nutrients, the collection of the fine-sized particles from paved surfaces by high-efficiency sweeping has the benefit of removing these pollutants before they become incorporated into stormwater. Phosphorus associated with suspended sediments in stormwater presents a serious challenge for treatment. In general, the efficiency of many structural controls at removing the smaller sized particles is limited. Also, depending on the BMP design and the operation and maintenance protocols, there are concerns that some structural BMPs may become a source of nutrients to receiving waters as accumulated pollutants removed by BMPs are later released during subsequent storm events.

It is likely that mechanical broom type sweepers are most commonly used in the watershed at present. These types of sweepers are capable of collecting coarse-sized sediments and litter, but the high-efficiency sweepers are more efficient at collecting the smaller particle sizes that are most associated with nutrients. Furthermore, mechanical broom sweepers might make the finer particles and associated phosphorus more available for washoff during rain events. Studies by Pitt and Sutherland (in Walker et al. 1999) indicated that a significant portion of the larger dirt particle sizes picked up by these sweepers are not easily transported by rainfall and that removal of these particles tends to expose the smaller sheltered particles for transport. The results of monitoring studies conducted in the late 1970s and early 1980s to evaluate the effectiveness of mechanical broom sweepers did not find them to be very effective in reducing stormwater pollutant loads (Center for Watershed Protection 1999).

Recently an investigation of the relative performance of two types of street sweepers (mechanical broom and high-efficiency vacuum type sweepers) was conducted by the USGS in conjunction with the City of New Bedford, Massachusetts (Breault et al. 2005). The results of four sweeping experiments (two for each type of sweeper) clearly show that the vacuum sweeper was about three times more efficient than the mechanical broom sweeper. With respect to picking up silt and clay sized particles, the vacuum sweeper was three and six times more efficient than the mechanical broom sweeper. The results from the USGS sweeping experiments are presented in Table 6-7.

Table 6-7. Results of street sweeper efficiency experiments with a Pelican Series P mechanical sweeper and a Johnston 605 Series 605 vacuum sweeper

Particle size	Mechanical Sweeper Experiment		Vacuum Sweeper Experiment	
	1a	1b	2a	2b
	Sweeper Efficiencies (%)			
Gravel	38	31	86	94
Coarse Sand	40	18	62	93
Fine Sand	9	11	38	75
Very Fine Sand	9	10	31	93
Silt and Clay	13	13	39	81
Weighted Average	31	20	60	92

Source: Breault et al. 2005

An evaluation of the City of New Bedford's street sweeping program also indicates promising results for using street sweeping to reduce phosphorus loading from urban areas. New Bedford is highly committed to its street sweeping program, sweeping year round to reduce the loading of solids into its combined sewer system. The City, which owns two mechanical sweepers and two high-efficiency vacuum sweepers, is now relying mostly on using the high-efficiency vacuum sweepers. The sweeping program covers an approximately 19-square mile (mi^2) urbanized area. In 2004, the City was estimated to collect around 3,800,000 kg of street dirt and debris from approximately 10,700 swept curb-miles. Using street dirt particle size and pollutant characteristics collected by the USGS from New Bedford, removal of this quantity of street dirt represents an estimated removal of approximately 3,100 kg of phosphorus or approximately 160 kg/mi^2 from New Bedford's streets.

To put this in perspective, the total (dry and wet) estimated non-CSO phosphorus loading from the direct tributary drainages to the Lower Charles River (totaling approximately 40 mi^2) in water year 2000 was approximately 7,500 kg or roughly 190 kg/mi^2 (not including the upstream watershed). Considering just wet-weather conditions, the estimated non-CSO phosphorus loading from the direct tributary drainages to the Lower Charles River in water year 2000 was approximately 5,400 kg or roughly 135 kg/mi^2. It is not likely that all of the phosphorus picked up by the New Bedford street sweepers would have been transported into receiving waters (if the system was not combined, but separated). As discussed above, the larger particle sizes (i.e., gravel, coarse sand, and fine sand) are not readily transported by rainfall. Even so, if only the fine-sized particles are used in the estimate (very fine sand, silt and clay), New Bedford's street sweeping program successfully removed over 1,400 kg or 75 kg/mi^2 of phosphorus that would be considered to be readily available for transport by rainfall from its streets in 2004.

Such phosphorus removals by the street sweeping program in New Bedford indicate that the regular use of high-efficiency sweepers has promise for reducing stormwater phosphorus loading to the Lower Charles River. Assuming for a moment that all factors such as street dirt characteristics, dirt accumulation rates, and street surface conditions are equal between New

Bedford and the greater Boston areas surrounding the Lower Charles River, and that all of the fine-sized particles collected by the street sweepers would become part of the stormwater phosphorus load, the potential reduction in stormwater phosphorus loading to the Lower Charles River by a similar sweeping program in the Boston area can be evaluated. For example, the removal of phosphorus associated with only fine-sized particles (the particle sizes that are believed to account for most of the pollutant load in stormwater runoff) from the New Bedford information is compared to the estimated stormwater phosphorus load from the urban watershed draining directly to the Lower Charles River. The phosphorus load associated with only fine particle sizes removed per unit area from street surfaces in New Bedford represents approximately 56 percent (100 * 75 kg per mi^2/135 kg per mi^2) of the estimated stormwater phosphorus load per unit area discharged directly to the Lower Charles River (not including the upstream watershed).

The purpose of extrapolating the New Bedford information to the Lower Charles River is not to define the exact street sweeping programs that are needed for the Charles River. At present, there is not sufficient information to provide such detail. The objective for providing the above estimates are merely to illustrate the potential that dedicated street sweeping programs using high-efficiency sweepers might have for reducing stormwater pollutant loadings to the Lower Charles River.

For stormwater management in urban/suburban areas, this TMDL implementation plan emphasizes development of street sweeping programs using high-efficiency street sweepers. While there are numerous investigations that document the capability of the high-efficiency sweepers to pick up fine particle sizes, less is known about the specifications for an optimal program design that will most efficiently reduce nutrient loading using the high-efficiency sweepers. Trial sweeping programs conducted in selected high priority drainage areas to evaluate various sweeping frequencies are recommended. The implementation and monitoring of high-efficiency street seeping programs will be necessary to evaluate the relative improvement in stormwater quality that might be achieved from more intensive high-efficiency sweeping programs versus other BMPs.

6.2.2 Management of Illicit Discharges to Stormwater Drainage Systems

Both dry- and wet-weather water quality monitoring of stormwater drainage system discharges to the Lower 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. Past and on-going investigations of stormwater drainage systems that discharge to the Lower Charles River show 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.

As discussed in Section 3.4.1, illicit discharges of sewage to the Lower Charles River through the stormwater drainage system represent a substantial source of nutrients that contributes to 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 Lower Charles River. Since illicit discharges are associated with the stormwater drainage systems, Phase I and II MS4 permits are also the vehicles for implementation of controls on illicit discharges.

In the past, cursory surveys of drainage system outfalls to the Lower Charles River were conducted to identify potential illicit discharges. While some egregious illicit discharges were identified through these surveys, many drains were identified as "clean" (i.e., free of illicit discharges). However, subsequent monitoring and investigations found that many of the so called "clean" drains were contaminated with numerous illicit discharges. Past experience with stormwater drainages systems discharging to the Lower Charles River, clearly shows that the cursory "end of pipe" surveys are not sufficient for evaluating the presence of illicit discharges. A lot of work has been done regarding illicit discharges to stormwater drainage systems in the watershed and has shown that almost all storm drains have some level of contamination.

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.

A protocol for illicit discharge detection and elimination (IDDE) has been developed by EPA New England (USEPA 2004b). The protocol provides a plan, available to all Charles River watershed communities, to identify and eliminate illicit discharges (both dry- and wet-weather) to their separate storm sewer systems. Implementation of the protocol outlined in the guidance document satisfies the IDDE requirement of the NPDES program. A modified version of the IDDE protocol is provided in the Appendix. Note that the protocol in the Appendix was originally developed to address illicit discharges of indicator bacteria to the watershed. However, this protocol is adequate for identifying illicit nutrient discharges as well. The original protocol has been modified to be applicable to illicit nutrient discharges. This implementation plan recommends that all communities and other regulated entities that have stormwater drainage system discharges to the Lower Charles River (i.e., all communities in the Charles River watershed) develop IDDE programs that are consistent with the Charles River IDDE protocol. 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 USEPA)

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

Several steps are currently underway to address illicit discharges to the Lower Charles River. The EPA, MassDEP, CRWA, USGS, and several municipalities in the Lower Charles River watershed have been active in the identification and mitigation of these sources. For example, between 1986, when the BWSC's Illegal Sanitary Connection Remediation Program started, and the end of 2004, a total of 931 illegal connections were identified and 893 were corrected. BWSC continues to work in its storm drainage systems that discharge to the Lower Charles River and has since identified and eliminated many more illicit discharges to the Lower Charles. Other municipalities including Cambridge, Newton, Waltham, and Brookline have also begun to eliminate illicit discharges to the Lower Charles. EPA estimates that over one million gallons per day of illicit discharges to the Charles River have been removed in the last decade. Despite this progress, most drainage systems to the Lower Charles River have not been fully investigated. Based on experience with existing IDDE programs in the watershed and ongoing monitoring efforts discussed below, many illicit discharges to the Lower Charles River remain active.

In November 2004 EPA issued administrative orders to several communities in the watershed based on data that those communities still had illicit discharges to the Lower Charles River or its tributaries. EPA withdrew one of the orders as a result of amendments to that community's stormwater management plan and its development of a comprehensive IDDE program. Another community is close to amending its stormwater management plan to address these concerns, at which point its order will also be withdrawn.

These communities are being asked to address their illicit discharges in a two-phase approach. Under phase one, the communities will address known connections or known problem areas. Under phase two, the communities will conduct a comprehensive examination of their stormwater drainage systems that would seek to identify any sanitary sources of pollution to the drainage systems at any point and remove all discharges by May 1, 2008.

For over a decade, Roger Frymire, a watershed advocate, has systematically searched the shoreline of the Lower Charles River for bacterial sources of pollution. Since the illicit sources of bacteria are also the likely illicit sources of nutrients, Mr. Frymire's work is relevant to this implementation plan for nutrients. Starting in 2002 and continuing through 2005, Mr. Frymire has consistently sampled several-hundred storm drain outfalls in the Lower Charles for fecal coliform bacteria during both dry- and wet-weather events. EPA's Regional Laboratory, located in Chelmsford, Massachusetts, performs all the fecal coliform bacteria analysis for Mr. Frymire's on-going targeted monitoring efforts. Mr. Frymire has performed the sampling in accordance with approved sampling protocols presented in approved Quality Assurance Project Plans (QAPPs) (Mystic River Watershed Association QAPP and Clean Charles Core Monitoring QAPP). These Charles River Hot Spot Data (2002 –2005) have become a critical source of information for finding and prioritizing episodic bacterial discharges. As a result of Mr.

Frymire's investigative and targeted monitoring work, a number of stormwater outfalls are considered a "high" priority for additional investigation and remediation.

In addition to the on-going work noted above, in January of 2005 MassDEP negotiated an enforcement (consent) order with the City of Waltham for failure to handle repeated sewer overflows/discharges and non-reporting of sewer overflows into its storm sewer lines. This enforcement order requires the City to create an action plan on how to meet the state Clean Water requirements. In fiscal year 2006, the City requested and received a state commitment for $650,000 in State Revolving Funds (SRF) to conduct a comprehensive sewer system evaluation and wastewater management plan study.

The detection and elimination of illicit discharges to the Charles River is a high priority for 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. Mr. Frymire's on-going and targeted bacteria monitoring during the last several years has resulted in greater community awareness and action. Some illicit discharges in the watershed have been completely removed and wet-weather bacterial concentrations have been reduced dramatically.

6.2.3 CSO Abatement

The MWRA, and the communities of Boston and Cambridge have a number of active CSOs that discharge at various frequencies during wet-weather conditions to the Lower Charles River. CSO discharges represent a source of pollution to the Lower Charles (including nutrients) and are already targeted for control. The implementation of a CSO abatement program for the Lower Charles River watershed is well underway and is proceeding in accordance with an approved Long Term Control Plan. The development of the Long Term Control Plan was required by a Federal Court Order issued by the Federal District Court in Boston, Massachusetts. The implementation of the plan, through completion, is also required by the court order.

Reductions in CSO discharges through upgrades at the Deer Island WWTF and ongoing implementation of the Long Term Control Plan by the MWRA, Boston, Brookline, and Cambridge have already resulted in large reductions in pollutant loadings from CSOs to the Lower Charles River. Further implementation of the plan involving extensive sewer separation work is scheduled to be completed by 2013 and will make CSOs a very minor source of nutrients to the Lower Charles River (approximately one-half of one percent of the total targeted phosphorus load).

Table 6-8 presents a summary of estimated CSO discharge volumes and phosphorus loads for several conditions: (1) baseline (1994), (2) 2003, (3) 2004, and (4) completion of the Long Term Control Plan. The estimates are based on model simulations using the "typical rainfall year" and system conditions that are representative of work completed at that time, or for the Long Term Control Plan condition. As indicated, implementation of the plan has resulted in CSO discharge volumes and loading reductions of 44 percent in 2003 when compared to baseline conditions of 1994. Additional abatement work completed in 2004 increased the overall CSO related reductions from baseline conditions to 59 percent. Completion of the Long Term Control Plan will represent a 98 percent reduction in CSO pollutant load by 2013.

Table 6-8. Estimates of CSO flows and nutrient loads for various conditions using the "typical rainfall year"

	Baseline Conditions (1994) for Typical Year[a]			2003 Conditions for Typical Year[a]			2004 Conditions for Typical Year[a]			Long Term Control Plan for Typical Year[b]		
CSO Outfall Number	AF[c] (events/yr)	Volume (MG)	P[d] Load (kg)	AF (events/ yr)	Volume (MG)	P Load (kg)	AF (events/yr)	Volume (MG)	P Load (kg)	AF (events/yr)	Volume (MG)	P Load (kg)
BOS032	4	3.17	37.20	0	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	N/A	N/A
BOS033	7	0.26	3.05	0	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	N/A	N/A
CAM005	6	41.56	487.70	6	1.76	20.65	4	1.62	19.01	3	0.84	9.86
CAM007	1	0.81	9.51	4	1.10	12.91	3	0.71	8.33	1	0.03	0.35
CAM009	19	0.19	2.23	9	0.30	3.52	5	0.18	2.11	2	0.01	0.12
CAM011	1	0.07	0.82	2	0.07	0.82	0	0.00	0.00	0	0.00	0.00
BOS028	4	0.02	0.23	0	0.00	0.00	Eliminated	0.00	0.00	Eliminated	0.00	0.00
BOS042	0	0.00	0.00	0	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	N/A	N/A
BOS046	2	5.25	61.52	2	2.03	23.79	10	5.66	66.32	2	5.38	63.04
BOS049	1	0.01	0.12	0	0.00	0.00	0	0.00	0.00	Eliminated	0.00	0.00
CAM017	6	4.72	55.39	3	2.31	27.11	1	2.09	24.53	1	0.45	5.28
MWR010	16	0.08	0.94	0	0.00	0.00	0	0.00	0.00	Eliminated	0.00	0.00
MWR018	2	3.18	37.32	2	1.28	15.02	1	0.73	8.57	0	0.00	0.00
MWR019	2	1.32	15.49	2	0.45	5.28	1	0.18	2.11	0	0.00	0.00
MWR020	2	0.64	7.51	2	0.13	1.53	1	0.10	1.17	0	0.00	0.00
MWR021	2	0.50	5.87	0	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	N/A	N/A
MWR022	2	0.43	5.05	0	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	N/A	N/A
MWR201[e]	18	214.10	2512.41	24	161.79	1898.56	16	117.08	1373.90	2	6.30	73.93
MWR023	39	114.60	1344.80	24	45.00	528.06	21	32.36	379.74	2	0.13	1.53
Total		**390.98**	**4587.16**		**216.22**	**2537.25**		**160.71**	**1885.79**		**13.14**	**154.1**

[a]The typical year is the design rainfall year used by the MWRA for CSO facilities planning and is indicative of average rainfall conditions including a number of large rain events.
[b] The implementation of the Long term Control Plan for the Charles River is scheduled to be completed in 2013. Certain components of the plan affecting other receiving waters will be completed by 2015.
[c]AF = Activation frequency
[d]P = Phosphorus
[e]MWR201 represents the Cottage Farm CSO Treatment Facility, which provides screening and disinfection.

Details regarding CSO projects by community can be found at: www.mwra.state.ma.us/03sewer/html/sewcso.htm. In addition, MWRA's 2004 Annual Progress Report on its Long Term Combined Sewer Overflow Control Plan can be found at: www.mwra.state.ma.us/annual/csoar/2004mwracsoar.pdf

6.3 Keeping the Lower Charles River TMDL Model Active

It is recommended that the hydrodynamic and water quality model used to develop the nutrient TMDL for the Lower Charles River be kept "active" as part of the implementation plan. Keeping the model active would require the continuation of calibration and validation of the model on a long-term basis. The model can be used on an ongoing basis, in conjunction with water quality monitoring required by the implementation plan, to evaluate the effect of phosphorus load reductions on the Lower Charles River.

In an adaptive management approach, such as the approach outlined for implementation of this TMDL, load reductions are implemented and the effect on the receiving water quality is evaluated, followed by possible further reductions. This process is repeated until water quality goals are met. If external phosphorus loads were the only driver of water quality this approach would be relatively straightforward and feasible. However, water quality also responds to other factors such as climate. Climate can affect watershed characteristics such as flow and temperature. For example, for the period 1998-2001, the highest chlorophyll *a* concentrations were observed in 1999, which was also the year of the lowest external phosphorus loading during that particular time period. Therefore, it is possible that if loading reductions were implemented in a particular year, the chlorophyll *a* concentrations could be higher in a following year, not reflecting the decreased phosphorus loading. The model could be used to simulate the new and old loading scenarios, which would allow the user to evaluate progress associated with reduced pollutant loadings versus impacts associated with climatic conditions. Therefore, keeping the model active and up to date is worth further consideration.

6.4 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 (MassDEP 2000b) available on line at http://mass.gov/dep/water/resources/nonpoint.htm. 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.

7 REASONABLE ASSURANCE

Reasonable assurances that the TMDL will be implemented include both application and enforcement of current regulations, availability of financial incentives, and the various local, state, and federal programs for pollution control. Stormwater NPDES permit coverage is designed to address illicit sewage and stormwater discharges from municipal 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 EPA through Federal and State Clean Water Acts depending on the severity of the impact. Enforcement of regulations controlling nonpoint source discharges includes local enforcement of the state Wetlands Protection Act and Rivers Protection Act and various local regulations including zoning regulations. Financial incentives include federal funding available under the Clean Water Act (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 EPA.

A summary of many of MassDEP's tools and regulatory programs to address nutrient sources is presented below.

7.1 Overarching Tools

7.1.1 Massachusetts Clean Water Act

The Massachusetts CWA (MGL Chapter 21, sections 26-53) provides MassDEP with specific and broad authority to develop regulations to address both point and nonpoint 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 these programs are described below. The Massachusetts CWA can be found at the following web site: www.mass.gov/legis/laws/mgl/gl-21-toc.htm.

Surface Water Quality Standards (314 CMR 4.0)

The MAWQS assign designated uses and establish water quality criteria to meet those uses. Waterbody 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 waterbody classification for the Lower Charles River is Class B and the MAWQS can be found at www.mass.gov/dep/water/laws/regulati.htm#wqual.

Ground Water Quality Standards (314 CMR 6.0)

These standards 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 groundwater quality criteria necessary to sustain the designated uses and/or maintain existing groundwater quality.

The Massachusetts Ground Water Quality Standards can be found at www.mass.gov/dep/water/laws/regulati.htm#gwp.

Rivers 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 groundwater; to provide flood control; to prevent storm damage; to prevent pollution; to protect land containing shellfish; to protect wildlife habitat; and to protect 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 nutrient sources close to waterbodies. More information on the Rivers Protection Act can be found on MassDEP's web site at www.mass.gov/dep/water/laws/laws.htm.

Surface Water Discharge Permitting Program Regulations (314 CMR 3.0)

The 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. 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 Surface Water Discharge Permitting Program Regulations can be found at www.mass.gov/dep/water/laws/regulati.htm.

7.1.2 Tools to Address CSOs

CSO Program/Policy

Massachusetts, in concert with EPA Region 1, has established a detailed CSO abatement program and policy. CSO discharges are regulated by the Commonwealth in several ways. Like any discharge of pollutants, CSOs must have an NPDES/Massachusetts Surface Water Discharge Permit under federal and state regulations. Municipalities and districts seeking funding for wastewater treatment, including CSO abatement, must comply with the facilities planning process at 310 CMR 41.00. Entities obtaining funding or exceeding specific thresholds must also comply with the Massachusetts Environmental Policy Act (MEPA) regulations at 301 CMR 11.00. Each of these regulations contains substantive and procedural requirements. Because both MEPA and facilities planning require the evaluation of alternatives, these processes are routinely coordinated.

As discussed in Sections 3.4.1 and 6, the MWRA, and the communities of Boston and Cambridge have a number of active CSOs that discharge occasionally during wet-weather conditions to the Lower Charles River. The CWA requires that CSO comply with technology and water quality based requirements. The implementation of a CSO abatement program for the Lower Charles River is well underway and is proceeding in accordance with an approved Long Term Control Plan. The development of the Long Term Control Plan was required by a Federal Court Order issued by the Federal District Court in Boston, Massachusetts. The implementation of the plan through completion is required by the court order and will result in the elimination of most CSO discharges. Already, substantial reductions in CSO discharges and associated pollutant loadings to the Lower Charles have occurred as a result of extensive sewer separation work and other CSO control projects implemented by MWRA and the communities of Boston, Brookline, and Cambridge.

7.1.3 Additional Tools to Address Stormwater

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 programs, the Massachusetts CWA (MGL Chapter 21, sections 26-53), the Wetlands Protection Act (MGL Chapter 130, Section 40), the state surface and ground water quality standards, and the various permitting programs previously identified.

Federal Phase I and II Stormwater Permits

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). 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, EPA and MassDEP have 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 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 permittee's 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 on many storm water discharges, in particular in segments with high bacteria levels 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/dep/water/wastewater/stormwat.htm. A full list of Phase II communities in MA can be found at http://www.mass.gov/dep/brp/stormwtr/stormlis.htm

The MassDEP Wetlands Regulations (310 CMR 10.0)

The DEP Wetlands regulations (310 CMR 10.0) direct issuing authorities to enforce the DEP 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 bacteria removal. A stormwater handbook was developed to promote consistent interpretation of the Stormwater Management Policy and Performance Standards: Volume 1: Stormwater Policy Handbook and Volume 2: Stormwater Technical Handbook can be found along with the Stormwater Policy at http://www.mass.gov/dep/water/laws/policies.htm#storm.

7.2 Financial Tools

7.2.1 Nonpoint Source Control Program

MassDEP has established a nonpoint source program and grant program to address nonpoint source pollution sources statewide. MassDEP 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 CWA 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 (CZM) on the implementation of the section 6217 program. That program outlines both short and long term strategies to address urban areas and stormwater, marinas and recreational boating, agriculture, forestry, hydromodification, and wetland restoration and assessment. The CZM section 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. The program also provides high priority points to those projects designed to address TMDL recommendations. In 2005 approximately $5 million in EQIP funds were available to address water quality goals through the application of structural and non-structural BMPs.

Massachusetts, in conjunction with EPA, also provides a grant program to implement nonpoint source BMPs that address water quality goals. The section 319 funding provided by EPA is used to apply necessary implementation measures and provide high priority points for projects that are designed to address section 303(d)-listed waterbodies and to implement TMDLs. For example, since 2002 MassDEP has funded 68 projects and awarded approximately $10.2 million through section 319 to address stormwater and bacteria related impairments.

Specifically in the Charles River watershed, since 2001 MassDEP has issued section 319 grants totaling $449,720 (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 from Plymouth Road in Bellingham and to Cold Spring Brook in Wellesley. In addition, MassDEP has provided a grant to the CRWA to collect data and develop a mathematical model for future TMDL development to address nutrient-related water quality impairments in the upper watershed.

The section 319 program also provides additional assistance in the form of guidance. MassDEP 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.

Finally, it should be noted that similar approaches for implementing other TMDLs to address water quality impairments caused by the same type of source categories (e.g., illicit sources and stormwater runoff) that contribute nutrients to the Lower Charles River are being successfully applied elsewhere.

For example, the Neponset River Watershed Bacteria TMDL, approved by EPA in 2002, was developed to address widespread bacterial contamination caused primarily by illicit discharges and stormwater runoff from drainages systems serving urban/suburban areas. The recommended implementation activities outlined in that TMDL are similar to the implementation strategy for the Lower Charles River nutrient TMDL. Since the time of approval of the Neponset TMDL, MassDEP worked closely with a local watershed group (Neponset River Watershed Association) to develop a section 319 project to implement the recommendations of the TMDL. The total project cost was approximately $472,000 of which $283,000 was provided through federal section 319 funds and the additional 40 percent was provided by the watershed association and two local communities. Although the project is not yet completed, the communities and watershed association have worked closely together to identify illicit discharges requiring removal, identify high priority stormwater sources, and install several new structural BMPs (enhanced wetland and bioretention cells) to reduce stormwater pollutant inputs into Pine Tree Brook, which is impaired. Additional BMPs are being evaluated for future implementation at this time.

Another example is the Shawsheen River Watershed Bacteria TMDL, which was used as the basis to obtain a state grant to identify and prioritize specific drainage system discharges for remediation.

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

7.2.2 State Revolving Fund

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 MassDEP has issued loans totaling over $258 million for the planning and construction of CSO facilities. Also since that time, the SRF has issued loans of more than $11.6 million to address stormwater pollution and another $44.4 million has been distributed to 142 municipal governments statewide to upgrade and replace failed Title 5 systems (for failing septics). These programs all demonstrate the state's commitment to assist local governments in implementing the TMDL recommendations.

7.3 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 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, EPA, MWRA, and the CRWA will be used to monitor progress in improving reducing algal blooms and improving water quality (see Section

9). Moreover, MassDEP recommends that the existing water quality model of the Lower 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 MassDEPs goal to work closely with 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 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.

8 FOLLOW-UP MONITORING AND EVALUATION

Post TMDL monitoring will include seasonal ambient monitoring of the Lower Charles River for nutrients and chlorophyll *a* and source area monitoring throughout the watershed to both prioritize sources for more intensive controls and to evaluate the effectiveness of control strategies outlined in the implementation plan.

Initially, EPA and MWRA will continue their current ambient monitoring programs for the Lower Charles River. The annually collected data from these programs will be used to assess water quality conditions and determine seasonal chlorophyll *a* concentrations. Ambient data will be used to evaluate progress in reducing nutrient loading and algal levels in the Lower Charles River toward achieving the seasonal average chlorophyll *a* target of 10 µg/l. Use of the existing water quality model in conjunction with the ambient data and source information might also be helpful for evaluating the progress of improving water quality in the Lower Charles River. The model can distinguish between the causative factors that contribute to algal levels related to nutrient loading and climatic conditions. MassDEP and EPA will investigate possible mechanisms for maintaining the water quality model for its continued use during the implementation process.

Given the long term timeframe that will be needed to implement the necessary controls in the watershed, regular long term monitoring of the Lower Charles River will be needed to assess future water quality conditions in the Lower Charles. At present, it is uncertain how many years in the future that the EPA and MWRA monitoring programs will continue in the Lower Charles River. Frequent seasonal ambient monitoring on an annual basis is recommended during the early years of implementing the IDDE and stormwater management programs. However, once the IDDE and progressive stormwater management programs are well established, less frequent ambient monitoring should be sufficient to evaluate progress and assess water quality conditions. MassDEP's watershed five-year cycle monitoring is one existing option for conducting this future monitoring. However, MassDEP and EPA will work, in possible coordination with the MWRA, CRWA, and others, to refine the long term ambient monitoring program to best match data needs.

Dry- and wet-weather source monitoring for nutrients and other indicator parameters is needed to better characterize individual sources. Monitoring data used with more refined source area characterization (e.g., drainage area size, land use cover, percent impervious cover) can be used to prioritize all significant nutrient source areas for control activities including the elimination of illicit discharges and applying promising but untested control strategies. One possible mechanism for accomplishing this important source area monitoring will be to require it as a monitoring component in the next round of NPDES stormwater permits issued for drainage system discharges throughout the watershed.

As indicated, another component of the source area monitoring program will be to evaluate the effectiveness of control strategies for reducing nutrients. The monitoring programs used to evaluate the effectiveness of control activities will need to be designed carefully to provide sufficient information to evaluate the reductions achieved during implementation and application of BMPs. A monitoring program to evaluate the elimination of illicit discharges to a drainage system will be different than a monitoring program to evaluate the effectiveness of BMPs for a specific drainage area. MassDEP and EPA will work to develop appropriate monitoring protocols for evaluating performance of control strategies.

Following is a summary of the post TMDL monitoring process and how it ties into the implementation process:

1. Continue with current water quality monitoring programs for the Lower Charles River (EPA and MWRA)
2. Continue with MassDEP watershed five-year cycle monitoring focused on the Charles River upstream of Watertown Dam
3. Monitor source areas to prioritize control activities (e.g., IDDE and stormwater management plans)
4. Monitor selected source areas where illicit discharges have been eliminated and stormwater nutrient control strategies are being implemented
5. Analyze all pollutant source and ambient water quality monitoring data to evaluate water quality conditions in the Lower Charles River and of the effectiveness of IDDE programs and other control strategies
6. Revise and enhance control strategies including implementation of BMPs as needed based on monitoring results
7. Refine long term ambient monitoring program

9 PUBLIC PARTICIPATION:

A public meeting was held from 4 p.m. to 6 p.m. at the Elm Bank Reservation, Wellesley on March 22, 2007 to present the Lower Charles River Nutrient TMDL and to collect public comments. The public comment period began on March 7, 2007 and closed on April 20, 2007. The attendance list, public comments, and the MassDEP responses are attached as Appendix B. The final TMDL and response to all comments will be sent to U.S. EPA Region 1 in Boston for final approval.

Public Meeting Announcement Published in the Monitor	3/07/2007
Date of Public Meeting	3/22/07
Location of Public Meeting	Elm Bank Reservation 900 WashingtonStreet Wellesley, MA
Time of Public Meeting	4 P.M. to 6 P.M.

10 REFERENCES

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APPENDIX A

Charles River Illicit Discharge Detection & Elimination (IDDE) Protocol

Charles River Watershed Illicit Discharge Detection & Elimination (IDDE) Protocol
March 2006

Purpose

This document provides a common framework for Charles River watershed communities to develop and implement a comprehensive plan to identify and eliminate dry and wet weather illicit discharges to their separate storm sewer systems. Adopted from BWSC (2004) and Pitt (2004), the protocol relies primarily on visual observations and the use of field test kits and portable instrumentation during dry weather to complete a thorough inspection of the communities' storm sewers in a prioritized manner. The protocol is applicable to most typical storm sewer systems, however modifications to materials and methods may be required to address situations such as open channels, systems impacted by sanitary sewer overflows or sanitary sewer system under drains, or situations where groundwater or backwater conditions preclude adequate inspection. The primary focus of the protocol is sanitary waste, however, toxic and nuisance discharges may also be identified. EPA has established the protocol as the expected standard of practice for the Charles River watershed communities. Implementation of the protocol will satisfy relevant provisions of Minimum Control Measure No. 3 (IDDE) of the communities' NPDES Small MS4 General Permit.

Introduction

The protocol is structured into several phases of work that progress logically through elements of mapping, prioritization, investigation, removal, verification, and monitoring. Each community should assess their current IDDE Program and identify where it has or has not successfully satisfied the elements of the protocol. In modifying their IDDE Programs to become consistent with the protocol, communities may need to refine particular elements or phases of the protocol to accommodate their institutional constraints or preferences. Regardless, the rigor and comprehensive nature of the protocol must remain unchanged.

Phase I - Mapping

The goal of the requisite mapping is the comprehensive depiction of key infrastructure and factors influencing proper system operation and the potential for inappropriate sanitary sewer discharges. The required number, scale and detail of the maps should be appropriate to facilitate a rapid understanding of the system by the municipality and regulators, serve as a planning tool for the implementation and phasing of investigations, and demonstrate the extent of completed and planned investigations and corrections, and other related capital projects. To ensure legible mapping, information should be grouped appropriately and represented thematically (e.g., by color) with legends or schedules where possible. Mapping should be updated as necessary to reflect newly discovered information, corrections or modifications, and progress made. The following information and features should be considered for inclusion in the mapping:

<u>Infrastructure</u>

- Municipal storm sewer system (including inter-municipal and private connections where

available)
- Municipal sanitary sewer system (including inter-municipal connections)
- Municipal combined sewer system (if applicable)
- Thematic representation (with schedule or legend) of sewer material, size, and age
- Sewer flow direction and flow type (pressure versus gravity)
- Rim and invert elevations for select structures (for comparison with water table and vertical separation between systems)
- MWRA interceptor alignment(s) and connect point(s)
- Aerial delineations of major separate storm sewer catchment areas, sanitary sewersheds, combined sewersheds, and areas served by on-site subsurface disposal systems
- Common manholes or structures (structures serving or housing both separate storm and sanitary sewers)
- Sanitary and storm sewer alignments served by known or suspected underdrain systems
- Sewer alignments with common trench construction and major crossings representing high potential for communication due to water table
- Lift stations (public and private), siphons, and other key sewer appurtenances
- Sewersheds or sewer alignments experiencing inadequate level of service (LOS) (with indication of reason(s))
- Location(s) of known sanitary sewer overflows (SSO) (with indication of cause(s))

<u>Water Resources and Topographic Features</u>

- Waterbodies and watercourses identified by name
- Seasonal high water table elevations or sanitary sewer alignments impacted by groundwater
- Topography
- Orthophotographic overlays

<u>Operation and Maintenance (O&M), Investigations, Remediation, and Capital Projects</u>

- Alignments, dates, and thematic representation of work completed (with legend) of past illicit connection investigations (e.g., flow isolation, dye testing, closed circuit TV (CCTV), etc.)
- Locations of suspected, confirmed, and corrected illicit connections (with dates and flow estimates)
- Water quality monitoring locations with graphical indication of indicator concentrations
- Recent and planned sewer infrastructure cleaning and repair projects
- Alignments and dates of past and planned Infiltration/Inflow (I/I) investigations and sanitary sewer remediation work
- Planned capital projects relative to utility and roadway rehabilitation or replacement
- Proposed phasing of future IDDE investigations

Phase II - Drainage Area/Outfall Prioritization

Whether documented by EPA, the municipality, or others, drainage catchments or alignments with known or suspected contributions of illicit flows may have already been identified in some instances. Necessary investigation or removal procedures should proceed immediately in these areas.

Where a municipality has little or no specific knowledge of potential illicit contributions to its storm sewer system, a ranking of drainage area investigations to be undertaken in Phase III should be developed that is based on information collected during the mapping phase and through a rapid screening process that incorporates visual observations and monitoring for bacteria indicators. Priority areas identified though mapping or previous studies might include those:

- with direct discharges to critical or impaired waters (e.g., water supplies, swimming beaches);
- with inadequate sanitary sewer level of service (LOS), sanitary sewer overflows (SSOs), or the subject of numerous/chronic customer complaints;
- served by common/twin-invert manholes or underdrains;
- significantly impacted by inflow or infiltration; and
- scheduled for near-term capital improvements or studies (e.g., infrastructure improvements, paving, SSES, or I/I investigations).

The screening process is intended to rapidly establish an understanding of the potential extent and degree of illicit contributions throughout the system, especially identification of discharges of significant and immediate concern. Where not recently completed, outfalls should be visually inspected and monitored for total phosphorus and indicator bacteria during a dry- and wet-weather period. For large catchment areas, select manholes can be similarly inspected and monitored to isolate problematic subcatchments contributing to major outfalls.

In some instances, visual observations of stormwater structures will yield tell-tale signs of obvious sanitary or non-stormwater contributions. These can include discovery of inappropriate piping, solids, floatables, odors, abnormal color, or growth (e.g., greyish slimes). In addition, sanitary influence is likely where conventional indicator bacteria organism (e.g., fecal coliform bacteria, *E. coli*, or enterococci) densities are found to be significantly elevated. Data collected during this phase should be compared to monitoring data collected in Phase IV to help assess water quality improvements realized through implementation of the protocol.

Phase III - Drainage Area Investigations

1. Public notification/outreach program

Provide letter/mailer to residents and building owners located within subject drainage basin and/or sewershed notifying them of scope and schedule of investigative work, and the potential need to gain access to their property to inspect plumbing fixtures. Where necessary, notification of property owners through letter, door hanger, or otherwise will be required to gain entry. Assessors' records will provide property owner identification.

2. Field verification and correction of subarea storm sewer mapping

Adequate storm and sanitary sewer mapping is a prerequisite to properly execute an illicit discharge detection and elimination program. As necessary and to the extent possible, infrastructure mapping should be verified in the field and corrected prior to investigations. This effort affords an opportunity to collect additional information such as latitude and longitude coordinates using a global position system (GPS) unit if so desired. To facilitate subsequent investigations (see Part 5 below), tributary area delineations should be confirmed and junction manholes should be identified during this process. Orthophotographic coverages (available from previous engineering studies and such sources as MassGIS or TerraServer) will also facilitate investigations by providing building locations and land use features.

3. Infrastructure cleaning requirements

To facilitate investigations, storm drain infrastructure should be evaluated for the need to be cleaned to remove debris or blockages that could compromise investigations. Such material should be removed to the extent possible prior to investigations, however, some cleaning may occur concurrently as problems manifest themselves.

4. Dry weather criteria

In order to limit or remove the influence of stormwater generated flows on the monitoring program, antecedent dry-weather criteria need to be established. An often used rule of thumb is to wait two (2) days after cessation of a precipitation event prior to monitoring activities. This duration can be adjusted to shorter or longer periods dependent upon the relative extent, slope, and storage of the system under investigation.

5. Manhole inspection and flow monitoring methodology

Beginning at the uppermost junction manhole(s) within each tributary area, drainage manholes are opened and inspected for visual evidence of contamination after antecedent dry-weather conditions are satisfied (e.g., after 48 hours of dry-weather). Where **flow is observed**, and determined to be contaminated through visual observation (e.g., excrement or toilet paper present) or field monitoring (see Parts 5 and 6 below), the tributary storm sewer alignment is isolated for investigation (e.g., dye testing, CCTV; see Part 7 below). No additional downstream manhole inspections are performed unless the observed flow is determined to be uncontaminated or until all upstream illicit connections are identified and removed. Where **flow is not observed** in a junction manhole, all inlets to the structure are partially dammed for the next 48 hours when no precipitation is forecasted. Inlets are damned by blocking a minimal percentage (approximately 20 percent +/- depending on pipe slope) of the pipe diameter at the invert using sandbags, caulking, weirs/plates, or other temporary barriers. The manholes are thereafter reinspected (prior to any precipitation or snow melt) for the capture of periodic or intermittent flows behind any of the inlet dams. The same visual observations and field testing is completed on any captured flow, and where contamination is identified, abatement is completed prior to inspecting downstream manholes.

In addition to documenting investigative efforts in written and photographic form, it is recommended that information and observations regarding the construction, condition, and operation of the structures also be compiled.

6. Field Measurement/Analysis:

Where flow is observed and does not demonstrate obvious olfactory evidence of contamination, samples are collected and analyzed with field instruments identified in Table A-1. Measured values are then compared with benchmark values using the flow chart in Figure A-1 to determine the likely prominent source of the flow. This information facilitates the investigation of the upstream storm sewer alignment described in Part 7. Benchmark values may be refined over the course of investigations when compared with the actual incidences of observed flow sources.

In those manholes where periodic or intermittent flow is captured through damming inlets, additional laboratory testing (e.g., toxicity, metals, etc.) should be considered where an industrial batch discharge is suspected for example.

7. Isolation and confirmation of illicit sources

Where field monitoring has identified storm sewer alignments to be influence by sanitary flows or washwaters, the tributary area is isolated for implementation of more detailed investigations. Additional manholes along the tributary alignment are inspected to refine the longitudinal location of potential contamination sources (e.g., individual or blocks of homes). Targeted internal plumbing inspections/dye testing or CCTV inspections are then employed to more efficiently confirm discrete flow sources.

8. Post-Removal confirmation

After completing the removal of illicit discharges from a subdrainage area and before beginning the investigation of downstream areas, the subdrainage area is reinspected to verify corrections. Depending on the extent and timing of corrections, verification monitoring can be done at the initial junction manhole or the closet downstream manhole to each correction. Verification is accomplished by using the same visual inspection, field monitoring, and damming techniques as described above.

Since verification of illicit discharges removal is required prior to progressing downstream through the storm sewer system, consideration must be given to providing adequate staffing and equipment resources to initiate investigations in other subareas to facilitate progress while awaiting completion of corrections.

Table A-1. Field measurements, benchmarks, and instrumentation

Analyte	Benchmark	Instrumentation[1]
Surfactants (as MBAS)	>0.25 mg/L	MBAS Test Kit (e.g., CHEMetrics K-9400)
Potassium (K)	(ratio below)	Portable Ion Meter (e.g., Horiba Cardy C-131)
Ammonia (NH_3)	NH_3/K > 1.0	Portable Colorimeter or Photometer (e.g., Hach DR/890, CHEMetrics V-2000)
Fluoride (F)	<0.25 mg/L	Portable Colorimeter or Photometer (e.g., Hach DR/890, CHEMetrics V-2000)
Temperature	Abnormal	Thermometer
pH	Abnormal	pH Meter

[1]Instrumentation manufacturers and models provided for informational purposes only. Mention of specific products does not constitute or imply EPA endorsement of same.

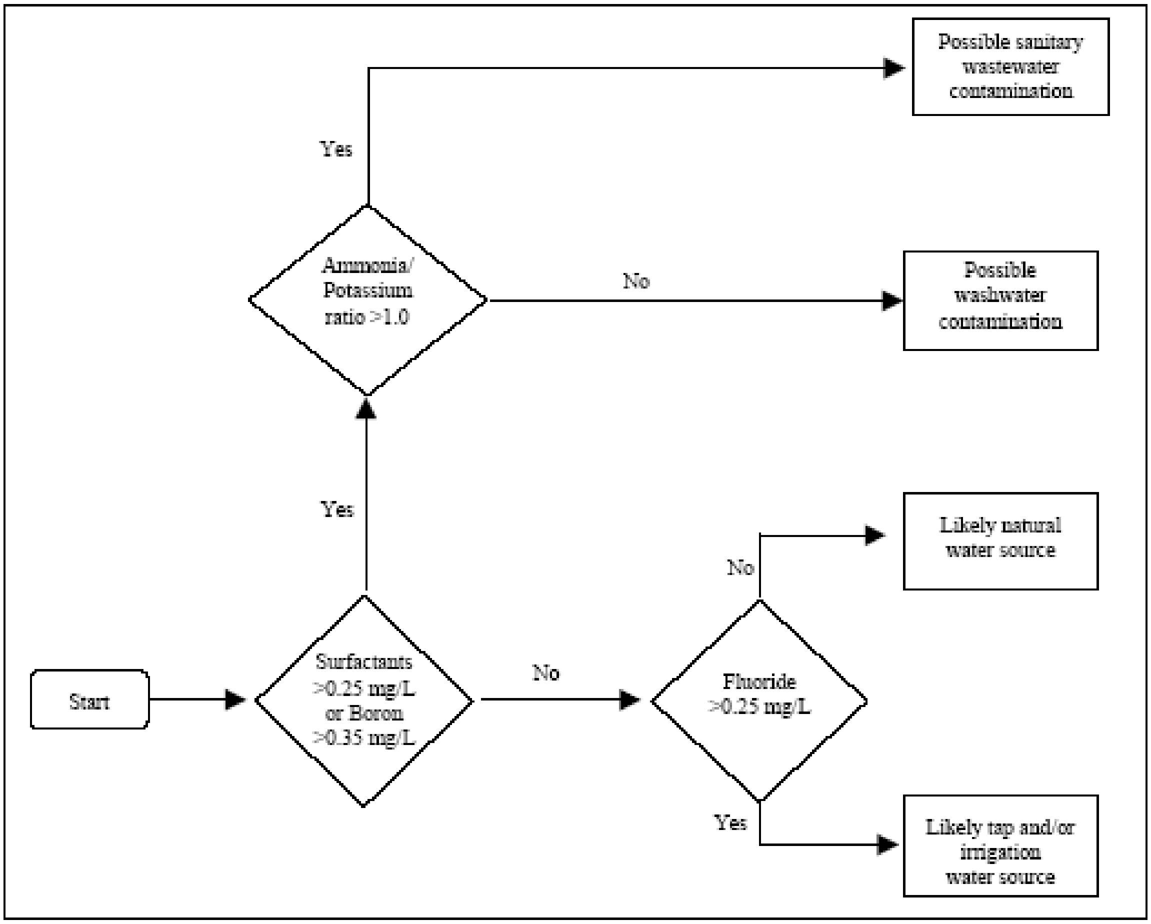

Figure A-1. Flow chart for determining likely source of discharge (Pitt 2004).

Phase IV - Outfall Monitoring

Upon conclusion of investigations and removal of identified illicit discharges, municipalities should measure program success and compliance with bacteriological water quality standards through initiation of a regular outfall monitoring program. In addition to supporting the confirmation of successful removal of illicit discharges identified during Phase III, ongoing monitoring can facilitate discovery of new illicit discharges as they occur as a result of redevelopment, infrastructure deterioration, or otherwise.

Municipalities should design and implement their program to monitor all stormwater outfalls on an annual basis during dry- and wet-weather conditions. EPA recommends analyzing grab samples for total phosphorus, fecal coliform bacteria, and either *E.coli* or enterococcus. Water quality criteria for the indicator bacteria are provided in Table A-2. Outfalls that exhibit substantially elevated densities of indicator organism should be reinvestigated using the IDDE Protocol.

Table A-2. Freshwater water quality criteria for bacteria indicator organisms (colony forming units per 100 ml of water (cfu/100ml))

Indicator	Geometric Mean	Single Sample	
Fecal Coliform[1]	200 [a]	--	[a] Geometric mean of any representative set of samples. Also, no more than 10% of the samples shall exceed 400 cfu/100ml
E. Coli[2]	126 [b]	235	[b] Geometric mean of the most recent five samples collected within the same bathing season
Enterococci[3]	33 [b]	61	

1. 314 CMR 4.00 MA - Surface Water Quality Standards - Class B Waters
2 & 3. 105 CMR 445.000 - Minimum Standards for Bathing Beaches; State Sanitary Code, Chapter VII

Program Evaluation

The ultimate success of a municipality's IDDE program will be measured through improvements in receiving water quality. Progress and success of the program can also be evaluated by tracking a variety of metrics including:

- Net or percent reduction in nutrient concentrations observed at outfalls
- Percentage of manholes/structures inspected
- Percentage of outfalls screened
- Percentage of home plumbing inspections/dye tests completed
- Percentage of pipe inspected by CCTV
- Number (and relative percentage) of illicit discharges identified through: visual inspections; field testing results; and temporary damming procedures
- Number of illicit discharges removed
- Cost of illicit discharge removals (total and average unit cost)
- Estimated flow or volume of illicit discharges removed
- Estimated flow or volume of inflow/infiltration removed
- Percentage of infrastructure jetting/cleaning completed
- Infrastructure defects identified or repaired
- Number and estimated flow of water main breaks identified or repaired

References Cited

Boston Water & Sewer Commission. 2004. *A systematic Methodology for the Identification and Remediation of Illegal Connections.* 2003 Stormwater Management Report, chap. 2.1.

Pitt, R. 2004. *Methods for Detection of Inappropriate Discharge to Storm Drain Systems. Internal Project Files*. Tuscaloosa, AL, *in* The Center for Watershed Protection and Pitt, R., *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments*: Cooperative Agreement X82907801-0, U.S. Environmental Protection Agency, variously paged. Available at: http://www.cwp.org.

Instrumentation Cited (Manufacturer URLs)

MBAS Test Kit - CHEMetrics K-9400: http://www.chemetrics.com/Products/Deterg.htm

Portable Photometer - CHEMetrics V-2000: http://www.chemetrics.com/v2000.htm

Portable Colorimeter - Hach DR/890: http://www.hach.com/

Portable Ion Meter: Horiba Cardy C-131: http://www.wq.hii.horiba.com/c.htm

Disclaimer: The mention of trade names or commercial products in this manual does not constitute endorsement or recommendation for use by the U.S. EPA.

APPENDIX B

Response to Public Comments

Public Meeting Information and Response to Comments
Nutrient TMDL for the Lower Charles Watershed

Public Meeting Announcement Published in the Monitor	3/07/2007
Date of Public Meeting	3/22/2007
Location of Public Meeting	Elm Bank Reservation 900 WashingtonStreet Wellesley, MA
Time of Public Meeting	4 P.M. to 6 P.M.

ATTENDEES

NAME	Organization
Richard Baker	Numeric, Inc.
David Taylor	MWRA
Stephen Fader	Wellesley DPW
Jeff Brandt	TRC
David Kaplan	CRWA
Bob Zimmerman	CRWA
Amy Schofield	Boston Water & Sewer
Kate Bowditch	CRWA
Catherine Daly Woodbury	Cambridge DPW
Bob Bois	Natick, MA
Rae Stiening	
Dave D'Amico	Medway DPS
Jane Madden	CDM
David Davison	Town of Needham
Kristine Chestna	Tata & Howard
Eloise Lawrence	CLF
Cynthia Liebman	CLF
Maria P. Rose	Newton DPW
Paul Hogan	MassDEP
Roger Frymire	Citizen
Rich Niles	CEI
Don Yonika	Dedham Conservation Commission
Cheri Lawless	CRPCD
John Digiacomo	Natick DPW
Jack Schwartz	MA DMF
Jenny Birnbaum	MassDEP
Richard Bock	
Robert McRae	CRPCD
Charles Aspinwall	Town of Millis
James McKay	Town of Millis
Lisa Eggleston	Eggleston Environmental
Nigel Pickering	CRWA
Bill Walsh-Rogalski	EPA
Kevin Brander	DEP/NERO
Albelee Haque	DEP/DWM
Charlie Jewell	BWSC
Henrietta Davis	Cambridge City Council

QUESTIONS AND COMMENTS RECEIVED AT THE MEETING AND RESPONSES:

QUESTION #1: Did the model look at a temperature increase of, say, 5 degrees beyond actual temperatures recorded, to see what the predictive effect would be with phosphorus effects on chlorophyll a production?

Response #1: No, the TMDL model was applied only for climatic and thermal loading conditions that occurred during the period of 1998-2002 and did not simulate the impact of projected increases in temperature. While the model includes temperature coefficients to adjust algal growth rates based on changes in temperature, the model chlorophyll *a* output did not appear to be sensitive to changes in ambient temperature for the modeling period. MassDEP and EPA believe that for these conditions algae are more sensitive to nutrient availability, which is often limited in the water column during most of the critical summer growing season (i.e., nutrient limitation).

However, during model development, MassDEP and EPA contemplated using the model to predict the impact of increased temperatures on algal growth because of the thermal discharge from Kendall Station. During the model review process, MassDEP and EPA concluded that there was not sufficient data (algal composition and species data) to support using the model to ascertain the contribution of algal biomass that would result from increased ambient temperatures caused by the full permitted thermal discharge at Kendall Station.

QUESTION #2: With respect to Phase II Stormwater Regulatory requirement controls, what do you do about Home Depot coming in with a new operation, and storing, unprotected piles of fertilizer, dried manure, and other real phosphorus generating sources from rain water runoff?

Response # 2: The Phase II program is an iterative type program, depending on public education and use of BMP's. It assumes a voluntary education and BMP application effort on the part of the public- at-large, and the permittee. We assume that public education will change peoples' behaviors in a voluntary fashion. However, as noted in Chapter 7 of the TMDL if this approach is not deemed to be effective in the future the EPA and the MassDEP may have to address this issue through other regulatory vehicles available through the Federal and State Clean Water Acts depending on the severity of the impact. As stated EPA and MassDEP have the authority to require non-regulated point source stormwater discharges to obtain NPDES permits if we determine that the stormwater discharge is a significant contributor of pollutants, or is contributing to a water quality standards violation, or where controls are needed based on the conclusions of this TMDL.

QUESTION #3: How will the agencies monitor progress in meeting the TMDL?

Response #3: Monitoring progress in meeting the TMDL will occur in two forms. Monitoring on-going pollution reduction activities and monitoring ambient water quality conditions for compliance with state standards. As to the first, the agencies will carefully track activities of on-going work such as BWSC, MRWA, and other sewered communities in their efforts to reduce and/or eliminate combined sewer overflows as well as finding and fixing illicit connections and/or finding and remediating other hotspots. We will also continue to monitor wastewater treatment facility discharges to ensure they properly adhere to their permit limits. In addition, monitoring in-stream water quality conditions over time will be important to determine the long-term effects on river water quality that result from pollution control efforts. To accomplish this the TMDL calls for EPA, MassDEP, CRWA, along with BWSC and MWRA, to continue monitoring efforts to ensure that progress toward the TMDL goals is occurring.

QUESTION #4: How long will MWRA continue to collect support data? If so, why?

Response #4: It is MassDEPs understanding that the MWRA plans to continue to collect support data into the foreseeable future in an effort to demonstrate to the ratepayers that water quality improvement progress is being made as a result of efforts by both MWRA and the communities to eliminate illicit connections. As noted in the TMDL it will take the efforts of many to continue monitoring TMDL implementation progress and the monitoring efforts of MWRA alone, although welcome, will not be sufficient by itself to monitor progress.

MassDEP believes that data collection by multiple groups will continue as it does now because it is in the interest of every community in the watershed to document that progress is being made.

QUESTION #5: How is the sediment flux situation pertaining to phosphorus in the basin best handled?

Response #5: Phosphorus fluxing from river sediments can be an important source of nutrients to the upper water column of the Charles River where algae grow. This is particularly true for slow moving sections of the river where sediments accumulate and bottom water dissolved oxygen levels are low. Phosphorus flux rates increase substantially when dissolved oxygen levels drop below approximately 2.0 mg/l. The modeling conducted for the Lower Charles accounts for phosphorus fluxing from the sediments in the Lower Charles River. The model predicts that reducing watershed phosphorus loading to the water column, will reduce over time the amount of phosphorus that is stored in the bottom sediments and released to the overlying water column. The calibrated water quality model predicts that the release of phosphorus from the bottom sediments into the upper water column, where algae grow, will decline slowly following watershed phosphorus reductions. Therefore, in general, controlling watershed nutrient loading inputs will help to reduce sediment phosphorus fluxing.

Additional attention is warranted concerning the flux of phosphorus from sediments that underlie the salt-water layer of the Lower Charles, which occurs in the deeper parts of the downstream portion of the Lower Charles. Although phosphorus flux rates from these sediments are very high because of the high phosphorus content and low dissolved oxygen levels, the density stratification caused by the salt water layer is believed to effectively trap much of the fluxed phosphorus in the lower water column. As a result, the trapped phosphorus remains in the lower water column below the photic zone where there is insufficient sunlight for algae to grow. It is important that any future activities that may disrupt the vertical stratification of Lower Charles not be allowed unless it can be assured that the phosphorus stored in these sediments will not be introduced into the upper water column during the growing season when nutrients are typically limiting growth.

QUESTION #6: We haven't heard much word from the State or the EPA regarding the future beyond the expiration of the present Stormwater Phase II Permit in 2008. Can you elaborate on this?

Response #6: The EPA is definitely planning to re-issue the Phase II permit when the present permit expires in May, 2008. The format of the re-issued Permit is expected to contain more detailed, specific requirements to address storm water management, which will hopefully be more useful for the communities to help them achieve more stormwater control progress through BMP implementation.

QUESTION #7: The BWSC permit has expired, and are there plans to renew it?

Response #7: The BWSC permit is expected to be re-issued

QUESTION #8: Why not control stormwater discharge pipe outfalls as regular discharge permits at the municipal level?

Response #8: The focus of the Phase II stormwater permit program to date has been to use an iterative approach to controlling these sources, through application of BMP's. When issuing stormwater permits in the future, the Agencies will evaluate whether imposing additional requirements in certain priority zones or areas that demonstrate special stormwater related pollution problems is appropriate. As stated in response to question #2, EPA and MassDEP have the authority to require non-regulated point source stormwater discharges to obtain NPDES permits if we determine that the stormwater discharge is a significant contributor of pollutants, or is contributing to a water quality standards violation, or where controls are needed based on the conclusions of this TMDL.

RESPONSE TO WRITTEN QUESTIONS AND COMMENTS RECEIVED DURING THE COMMENT PERIOD:

<u>By the Charles River Watershed Association, and the Conservation Law Foundation</u>

COMMENT #1: This Draft TMDL represents many years of effort and provides a clear scientific basis for the establishment of water quality controls to restore and maintain water quality in the Charles River. The data collection and modeling have been rigorous, and CRWA and CLF believe the TMDL development meets the requirements established under Section 303(d) of the Clean Water Act and the U.S. Environmental Agency (EPA) Water Quality Planning and Management Regulations. We urge EPA and the Massachusetts Department of Environmental Protection (MassDEP) to approve this Draft TMDL expeditiously so that the significant work needed to meet water quality standards in the Lower Charles River can go forward.

RESPONSE #1: Comment duly noted.

COMMENT #2: Because high phosphorous loadings are correlated with the area of impervious cover in a watershed, CRWA and CLF strongly support the inclusion in the TMDL of an offset requirement for new impervious cover and support the decision already reflected in the Draft TMDL not to include an express wasteload allocation for new growth.

RESPONSE #2: MassDEP will incorporate this concept into its non point source educational material. In addition, MassDEP will explore adding this concept to SMART GROWTH justification and guidance.

COMMENT #3: The Chlorophyll *a* Target of 10ug/l suggested in the Draft TMDL may be sufficient to meet water quality standards over the long run in the Lower Charles River. But it is suggested, that if over a certain time period, if that goal is not met, that the Chlorophyll *a* Target be reconsidered, and if necessary, lowered.

RESPONSE #3: Water quality conditions and the factors that affect them are always under review and considered as additional information becomes available. TMDLs can be revisited at any time when the agencies believe new information justifies doing so. In the case of the lower Charles, both MassDEP and EPA believe the target of a mean concentration of 10 µg/L chlorophyll *a* is a reliable and achievable target for meeting associated water quality goals and appropriately reflects varying annual and seasonal conditions.

COMMENT #4: With respect to phosphorous loading analysis, the maximum daily loading analysis, and the establishment of a frequency distribution of daily phosphorous loadings for the TMDL is a useful and practical way to allocate loading of phosphorous on a daily basis. Estimating the magnitude of phosphorous loading for several land cover categories in the upstream watershed is a valuable component of the Draft TMDL, since much of the loading comes from that upstream portion. Loading factors based upon literature values needed to be adjusted by only 1% to match loadings as predicted from the model: this proves the value of this assessment.

RESPONSE #4: Comment noted. The agencies believe that this information is useful for targeting additional community actions.

COMMENT #5: The explicit Margins of Safety (MOS) that have been included in the TMDL, reserving 5% of the targeted TMDL, and reduction targets that are predicted to bring the Chlorophyll *a* level to 2% lower than the target level, appear well designed to account for any uncertainty in the data and modeling analysis. It is important that the MOS be retained in the final approved TMDL. The final implicit MOS depends on a "wind down" or gradual reduction in phosphorous fluxes in the water column from bottom sediments. While this "wind down" is unpredictable, it seems that the MOS latitudes in the Draft TMDL are sufficient safety for any uncertainties in the data or modeling analysis.

RESPONSE #5: Comment noted. We agree with this statement.

COMMENT #6: Ongoing monitoring of instream phosphorous levels, phosphorous loading, temperature, chlorophyll *a* levels, pH, dissolved oxygen, and salinity will be critical as a phosphorous program is implemented. The *Hydrodynamic and Water Quality Model for the Lower Charles River, MA* should be kept active so that new data can be incorporated and assumptions tested. CRWA and CLF recommend adding a provision to reopen (add a reopener clause) the TMDL in light of new data, since this (the TMDL process) is a reiterative process.

RESPONSE #6: Both MassDEP and US EPA concur that documenting progress towards meeting of water quality goals through continued in-stream monitoring and reassessments will be critical for achieving the necessary phosphorus loading reductions. Additional modeling simulations may also be used in the future, after notable phosphorus loading reductions have occurred, to help distinguish progress in improving water quality of the Lower Charles as a result of the reduced loadings. It is likely that sizable phosphorus loading reductions will take several years to occur. Therefore, the Agencies do not have definite plans at present for maintaining the model and conducting future simulations. Unlike a permit, a TMDL can be reopened at any time the agencies believe new information justifies doing so. As such a re-opener clause is unnecessary.

<u>The Massachusetts Water Resources Authority</u>

COMMENT #1: The report highlights the relatively small amount of phosphorous loadings from CSOs to the Charles River. The TMDL would require a 96% reduction in phosphorous loadings from CSO discharges on an average annual basis. This amount is based on a comparison of average annual volumes in 2004, with the volume goals in the long- term CSO plan (which are federal requirements on frequency and volume, not percentage). The TMDL should recognize the court

mandated goals and estimated loadings, but not set any other reduction requirement or expectation such as percentages.

RESPONSE #1: The TMDL sets wasteload allocations (WLA) for CSO discharges to the Lower Charles that are intended to be entirely consistent with the court mandated goals and estimated loadings for these discharges. For the TMDL, the CSO WLAs were estimated assuming the court mandated control levels and using available CSO quality data and modeling results and applying the same methodology used to calculate loadings for other sources such as storm water. The TMDL presents the percent reduction for CSO phosphorus loading for general information only. MassDEP considers the WLAs for the CSOs and the court mandated goals for these discharges to be equivalent levels of control.

COMMENT #2: Whenever document refers to "Boston and Cambridge" with respect to the implementation of CSO controls in the Charles Basin, the reference should be changed to "Boston, Brookline, and Cambridge". (One exception is the first sentence of Section 6.2.3). Brookline (although it has no CSOs) is implementing a Charles R. CSO project, the Brookline Sewer Separation, necessary to achieve the level of CSO control at cottage Farm (MWR201).

RESPONSE #2: Thank you. Changes to the TMDL document have been made where appropriate.

COMMENT #3: The objective of achieving a seasonal mean of 10 ug/l may be overly ambitious. The model excludes effects such as wind (and tidal) resuspension of P and chl from bottom and marginal sediments (which in the Charles are very soft and vulnerable to resuspension). This would alter achievement of the goal. DEP might want to set 15 or 20 ug/l, or set a tiered goal, to arrive at a final goal of 10 or 15 ug/l.

RESPONSE #3: The impacts of wind are included in the circulation model, and hence also in the water quality model. In shallow areas, wind induced circulation could possibly result in re-suspension of bottom sediments and the mixing of phosphorus to the surface. This type of mixing is accounted for in the models. Also, tidal re-suspension due to saltwater intrusion moving upstream is also included in the models. As indicated above, the model predicts that the phosphorus content of bottom sediments will decline over time following reductions in watershed phosphorus loading. While implementation of controls to reduce phosphorus will take many years, MassDEP expects that the amount of phosphorus from bottom sediments that contribute to algae growth will decline.

As indicated in the implementation section of the TMDL (section 6), an iterative adaptive management approach is planned for reducing phosphorus loading to the Lower Charles. Such an approach will involve implementation of controls for the highest priority sources first followed by periodic water quality monitoring and re-assessment of water quality standards attainment.

MassDEP recognizes that the large amount of phosphorus reduction needed to achieve a seasonal chlorophyll *a* target of 10 µg/l in the Lower Charles River presents both technical and political/social challenges. However, the primary goal of the TMDL is to determine allowable pollutant loadings that will restore and protect designated uses as specified in Massachusetts Surface Water Quality Standards. The agencies have conducted careful and extensive reviews of water quality data and information related to nutrient-related water quality impacts. Based on this assessment, we have concluded that the seasonal target set for this TMDL would attain MWQS in the Lower Charles. Based on the available information, higher seasonal chlorophyll *a* mean levels of 15 or 20 µg/l would not likely attain WQS and therefore, cannot be set in the TMDL as goals.

COMMENT #4: How will the TMDL tie in with future MA water quality criteria for TP and chl? Will the seasonal objective of 10 µg/l set in the TMDL for chl-a be superseded by any criteria developed by the State or imposed on the State by EPA? Or will the chl levels set by this TMDL supersede these?

RESPONSE #4: Massachusetts considers responses to nutrients the best means of judging impacts. As such, MassDEP expects to continue to use variables such of Chlorophyll *a* to set acceptable in-stream concentrations for phosphorus rather than using a preset phosphorus value. In addition, the TMDL in effect sets a "site-specific" standard for the Lower Charles basin, which is allowed pursuant to 314 CMR 4.05(5)(c).

COMMENT #5: Executive Summary Part:

- **On page v, change "and five counties" to "in five counties."**

- **On page vii, three contributing sources in the lower watershed are identified: upstream watershed at Watertown Dam, non-CSO drainage areas, and CSO drainage areas. Are there significant industrial contributors?**

- **On page viii and anywhere else it may appear, change "needed" 96% reduction phosphorus from CSO discharges to "calculated 96% reduction based on required CSO volume reductions in the Long Term CSO Control Plan."**

RESPONSE #5: The TMDL notes that the three contributing sources are broad categories only and were not intended to be definitive of specific sources throughout the watershed. It is likely that industrial sources in the Charles River Watershed do not discharge directly to receiving waters but to municipal sewer systems. However, based on current information, direct industrial discharges are not believed to be significant contributors of phosphorus.

Other corrections duly noted and revised in the TMDL where appropriate.

COMMENT #6: The TMDL calls for TP loadings to be decreased to provide a seasonal average chl concentration of 10 µg/l. The TMDL document clearly defines what a seasonal average is, but does not identify the specific stations or regions that the average will apply to.

RESPONSE #6: The seasonal average chlorophyll *a* target of 10 µg/l applies to the entire segment between Watertown Dam and the New Charles River Dam. However, for compliance and assessment, the TMDL has focused on the water quality stations in the downstream portion of this segment just upstream of the Museum of Science (MWRA station 166 and EPA station CRBL011). These stations represent the optimal growing conditions for algae because of the large surface area and long retention times.

COMMENT #7: <u>Table 2-2</u>: There is a discrepancy between 2001 average flows and information in the sentence directly above the Table. From the data, 2001 was a high flow, not low flow, year as stated.

RESPONSE #7: After a review of the data and wording provided in the TMDL the Department did not find any discrepancy although clarification is needed. Table 2-2 provides <u>average</u> flows for each year however the statement is correct that during each of the years listed there were periods during the year that approached 7Q10 conditions in-stream. Clarification has been added to the TMDL in this regard.

COMMENT #8: <u>Table 3-11</u>: The text just before this table, on page 43, states that there are 12 CSOs in the Lower Charles River Watershed. There are actually 13 active and permitted CSO outfalls, including BOS046 to Muddy River/Back Bay Fens (see discussion under "Table 5-6," below). These are CAM005, CAM007, CAM009, CAM011, BOS049, CAM017, MWR010, MWR018, MWR019, MWR020, MWR201 (Cottage Farm), MWR023 (Stony Brook) and BOS046. Table 3-11 does not mention BOS046, BOS049, MWR023, or MWR010 (or is this the "St. Mary's St. Drain"?). Also, Table 3-11 mentions the already closed CSO outfalls MWR021 and MWR022, but does not mention the already closed outfalls BOS032, BOS033, BOS028 and BOS042. In comparison, Table 5-6 is accurate, except that it does not include BOS046. Related figures showing combined sewer outfalls (e.g. Fig. 1-1 and Fig. 3-12) should also be reviewed and adjusted, if appropriate.

RESPONSE #8: Table 3-11, Figure 1-1 and Figure 3-12 were developed by USGS under a previous evaluation. (Weiskel et al. 2005). As such the Table and Figures were not revised. This information however is certainly applicable in Section 5 and therefore appropriate corrections have been made specifically to Table 5-6.

COMMENT #9: <u>Table 3-20</u>: Are the daily measurements single points or averages for the day? If single points, what (time of day) were the samples collected and measurements made—were the times relatively consistent?

RESPONSE #9: The daily measurements listed in Table 3-20 are single measurements taken at various times throughout the day. Although we understand that algal counts can vary significantly even over the course of a single day, most samples collected on individual days varied only in the amount of time it took to collect each sample and proceed to the next station. Typically this is on the order of a few minutes. As such, we believe comparisons are representative on common days. Table 3-20 was provided to show the relative differences in total algal cell counts in comparison to cyanobacteria and differences between upstream and downstream locations on specific dates. Although the data can vary over time we believe the data clearly show a significant and consistent increase between upstream and downstream locations and that cyanobacteria comprise a significant portion of the total cell count in number of locations on the same date.

COMMENT #10: The discussion of temperature effects in part 3.4 should touch on how available light is taken into account. Were the two variables (light and temperature) autocorrelated? Are light data being collected in the additional studies?

RESPONSE #10: Sunlight duration and intensity is part of the weather data used to calculate water temperature. Data generally are available from the US Weather Bureau or from private sources, such as Cornell University, who provide it in a form that is more readily useable in a model. As such, it is collected and reported by the more extensive weather stations in the area.

COMMENT #11: <u>Section 5.2.1, page 79</u>: In the second paragraph, the list of CSOs active in the period 1998-2002 should include MWR010 and MWR022. MWR020 is listed twice.

RESPONSE #11: Thank You. Section 5.2.1 has been revised to reflect this.

COMMENT #12: <u>Section 5.2.5, page 88</u>: In the second paragraph under *CSOs*, the reference to Table 5-4 should be to Table 5-6.

RESPONSE #12: Correction made.

COMMENT #13: <u>Table 5-6</u>: For CSO outfalls that are, or will be, eliminated, the volume of discharge should be "N/A," or "Eliminated," as opposed to "0.00." This will help to distinguish these closed outfalls from outfalls that will continue to be active and permitted but will not discharge in a typical year.

- **CSO outfall MWR010 will not be eliminated under the CSO control plan (as formally recognized in Exhibit B to the Second Stipulation in the Boston Harbor Case), but will activate in storms of 5-year recurrence or longer, to provide flood control. The Annual Frequency should be "0 events/yr."**

- **BOS046, a CSO outfall that discharges to the Muddy River/Back Bay Fens, is not included in the table. Is it separately addressed with Muddy River loadings, or should it be included in Table 5-6 and other CSO tables and text references? The Annual Frequency and Volume at outfall BOS046 for 2004 system conditions were 10 events/yr and 5.66 MG, respectively. The Annual Frequency and Volume under the long term CSO control plan are predicted to be 2 events/yr and 5.38 MG, respectively.**

- **Change footnote b to "The implementation of the Long term Control Plan for the Charles River is scheduled to be completed in 2013." Certain components of the plan affecting other receiving waters will be completed by 2015. This footnote also appears with Table 6.8.**

RESPONSE #13: Corrections and suggestions noted and changes made as appropriate. BOS046 has been added to table 5-6 and changes have been made to other tables as necessary throughout the document.

COMMENT #14: <u>Section 6.2.3, page 134</u>: In the third paragraph of this section, the reduction in CSO phosphorus load from 1994 through completion of the Long Term Control Plan should be 98%, not 96%.

RESPONSE #14: Thank you. Correction was made.

COMMENT #15: <u>Table 6-8</u>: See comments for Table 5-6. Also, outfalls MWR021 and MWR022 were closed in 2000. The 2003 column should show the discharges at these outfalls as "Eliminated." Same for outfalls BOS032, BOS033 and BOS042, which were closed to CSO discharges by BWSC by the late 1990s.

RESPONSE #15: Corrections made.

COMMENT #16: <u>Section 7.1.2, page 139</u>: At the end of the next to last sentence of this section, change "…will result in the elimination of most CSOs" to "…will result in the elimination of most CSO discharges." In the last sentence, change "…as a result of extensive sewer separation work by the MWRA, and the communities…" to "…as a result of extensive sewer separation work and other CSO control projects implemented by MWRA and the communities…"

RESPONSE #16: Rewording is considered more accurate and changes have been made.

COMMENT #17: <u>Table ES-2</u>: Footnote b references Table 5-4, shouldn't it reference Table 5-6?

RESPONSE #17: Yes and in other locations; 5-5 should be 5-7. All corrections have been made.

COMMENT #18: <u>Fig. 3-1</u>: Lettering too small to see what the station numbers are and match them with text. Foldout?

RESPONSE #18: Electronic version can be expanded. Foldouts for hard copies are cumbersome.

COMMENT #19-- Throughout: Suggest changing the terms "Blue green algae" and "blue-greens," to the technically-correct and more precise "cyanobacteria." Rather than using "algae" as a catch-all term consider using "phytoplankton" or "phytoplankton and macrophytes " as appropriate.

RESPONSE #19: The distinction is noted. For the purposes of this report the terms "cyanobacteria" and blue-green have been used interchangeably. For better clarity however wording has been changed in many locations to reflect this. The term "blue-green" however was not deleted because we think more of the public is more familiar with this terminology, even if it is less technically precise.

COMMENT #20: Latin names of organisms' genus and species should be italicized.

RESPONSE #20: Duly noted and revised.

COMMENT #21: *Microcystis* is misspelled "microcystes."

RESPONSE #21: Duly noted and corrected.

COMMENT #22: Table 3-20 and in discussion, suggest reporting temperature in ^{o} Celsius, for consistency with Figure 3-22 (and science in general).

RESPONSE: Thank you for the suggestion. This issue was considered during the development of the document. Although we understand that scientific documents are generally reported this way, MassDEP and EPA decided to report the majority of temperature values in °F for two primary reasons. First, the majority of temperature data were collected in this format and easier to transcribe into the report and it would make it easier for those familiar with the data to review the report. Second, MassDEP Water Quality Standards and associated permits are also generally reported this way. In some cases however where specific scientific literature were reported and evaluated we decided to leave the information as published. In those cases data were reported in °C.

COMMENT #23: Throughout text, 'phaeophytin' is misspelled.

RESPONSE #23: Thank you. Corrections have been made.

<u>By The Boston Water and Sewer Commission:</u>

COMMENT #1: The loading analysis is based largely on a 2002 USGS study by Breault, Sorenson and Weiskel entitled "Streamflow, Water Quality and Contaminant Loads in the Lower Charles River Watershed, Massachusetts 1999-2000". Based on their analyses, Breault et al. concluded that, with the exception of fecal coliform, most of the dry weather and wet weather pollutant loads to the lower Charles originated upstream. The watershed upstream of the Watertown Dam contributed 92 percent of the total dry weather phosphorus load to the lower Charles, and 64 percent of the non-CSO wet weather phosphorus load. The TMDL mentions that a separate nutrient TMDL for upstream watershed is underway. However, the contribution of phosphorus loads from upstream sources is not currently well understood. We urge DEP to perform additional analyses of the upstream sources of phosphorus and river hydrodynamics, and expedite the development of the Upper Charles TMDL.

RERSPONSE #1: As noted the MassDEP is in the process of developing a nutrient TMDL for the upper Charles River (upstream of the Watertown Dam). In order to meet water quality goals below the Watertown Dam that TMDL must meet the loading identified in this document. Additional reductions may also be necessary to meet water quality goals in the river upstream of the Watertown dam as well. It is noted that most of the point sources have already reduced the amount of phosphorus discharged since the USGS study was conducted, and more can be done to mitigate the phosphorus loadings from non-point sources in the upper portion of the watershed. However, it is also of note that a significant amount of phosphorus generated in the upper watershed is from non-anthropogenic sources (considered natural) and cannot be removed.

COMMENT #2: The TMDL seems to do a good job of defining the problem caused by excess nutrients in the system, but falls short on identifying solutions. In particular, it seems that much of the reduction in phosphorus loads in the TMDL is directed at stormwater runoff from highly impervious surfaces in the lower basin, even though the vast majority of the annual load is from upstream, dry-weather sources. Based on the investigations by Zarriello et al, 2002 (Potential Effects of Structural Controls and Street Sweeping on Stormwater Loads to the Lower Charles River, USGS Water-Resources Investigations Report 02-4220) "only a small fraction of the load would be removed by implementation of BMP practices in the watershed below Watertown Dam. This is particularly evident for the total phosphorus load, which is dominated by upstream, dry-weather sources."

RESPONSE #2: The TMDL is calling for consistent levels of phosphorus reductions for the various land cover categories throughout the entire watershed including the upstream watershed above Watertown Dam. The USGS study and additional data analyses done for the TMDL both show that the upstream watershed, which accounts for approximately 87% of the entire watershed area, contributes most of the phosphorus load to the Lower Charles. With respect to storm water loading, impervious areas typically generate the greatest phosphorus loads primarily because these areas generate the most runoff volume. While the upstream watershed accounts for the majority of the phosphorus loading, loadings from the drainage areas that discharge directly to the Lower Charles are important and must be controlled because of their close proximity to the impaired Lower Charles and because these areas generate more phosphorus load per unit area than less developed areas elsewhere in the watershed.

For the purpose of clarification, please be aware that the characterization of the "dry weather" load coming from the upstream watershed developed by the USGS was done to best represent dry weather conditions as the loads passed over the Watertown Dam into the Lower Charles. Because of the size of the watershed and the associated long travel times of water moving through the Charles River system, some of the "dry weather load" at Watertown Dam in fact includes wet weather loads that occurred in the upper watershed. On average the USGS found that rain events occur approximately every three days in this area of Massachusetts. The travel times for flows traveling from the upper portions of the watershed to the Lower Charles exceeds three days, thus at any given time, for average conditions, flow at the Watertown Dam is likely to include wet weather loads.

MassDEP and EPA believe that eliminating illicit sanitary sources (a BMP required by the Phase 2 stormwater general permit) throughout the entire watershed represent a very important component of the implementation plan. The agencies expect that through the elimination of such sources, concentrated dry weather nutrient sources will be eliminated and wet weather loadings will be reduced. At this point, the Agencies consider this work to be high priority for all communities that drain to the Charles.

The investigation by Zarriello et al, 2002 (Potential Effects of Structural Controls and Street Sweeping on Stormwater Loads to the Lower Charles River, USGS Water-Resources Investigations Report 02-4220) provides an assessment of potential reductions associated with implementation of certain BMPs. This investigation relied on information that was readily available at the time the study was prepared. Some of this information was limited in scope and formed key assumptions on which the analysis was based. Among these was a 1999 report by Waschbusch, Selbig, and Bannerman that presented sources of phosphorus in residential storm water in Wisconsin. This study concluded that much of the phosphorus was coming from non-impervious areas and would not be available for pick-up by street sweeping or for treatment by BMPs serving impervious areas. As a result, the removal efficiencies of the BMPs evaluated were estimated to be low for phosphorus.

In contrast with the Wisconsin study, information reviewed during the preparation of the TMDL indicates that much of the phosphorus in storm water is washed off of impervious areas during rain events (Horner, et. al., 1994). Pitt theorizes that some of the phosphorus coming from pervious vegetated and non-vegetated areas eventually is carried to impervious surface where it can later be readily washed off and transported during rain events (Pitt, R.E., et. al., 2004). Also, the USGS's investigation of street sweeper efficiencies using the City of New Bedford's street sweepers (Breault et. al., 2005) show that the high efficiency sweepers are capapble of removing large amounts of phosphorus from street surfaces. Finally, more current BMP research conducted at the University of New Hampshire indicates that certain BMPs that have potential to be applied to urban settings (e.g., bioretention/filtration systems) are very effective at removing storm water pollutants.

MassDEP and EPA believe that a combination of illicit source elimination, phosphorus source controls, and implementation of non-structural and structural BMPs has the potential to achieve large reductions in annual phosphorus loadings even from already urbanized areas. However, we believe that further investigation will be needed to identify the optimal storm water management programs for various types of drainage areas. These investigations should involve detailed characterization of drainage areas, identification of illicit sources, and pilot applications of non-structural and structural BMPs.

COMMENT #3: In the same study cited above, bioretention was determined to have the lowest removal efficiency for phosphorus of the structural BMPs investigated and negative removal efficiency for fecal coliform bacteria. Given that the lower Charles also has a TMDL for bacteria, why is bioretention being suggested in the TMDL (p. 117) as a BMP "that holds great promise for removing phosphorus and other pollutants in stormwater runoff in the Charles River watershed"?

RESPONSE #3: In the cited USGS investigation, bioretention consisted of a grouping of several BMPs that collectively do not represent the bioretention/filtration BMP referred to in the TMDL report.. Some of the BMPs included in the USGS bioretention category such as dry and wet swales or vegetated filter strips are not expected to provide as high a level of treatment as the bioretention/filtration practices referred to in the TMDL document. Schematics of the bioretention/filtration facilities referred to in the TMDL are shown on pages 126 and 127 of the draft TMDL report. These include a filter medium composed of a sand/organic mixture that is effective at removing storm water pollutants including phosphorus and bacteria. MassDEP and EPA believe that the bioretention/filtration practices referred to in the TMDL will provide much greater treatment and pollutant removal efficiencies than many of the BMPs included in the "bioretention" category of the USGS report. Current research conducted at the University of New Hampshire, University of Maryland, and Villanova University have all shown very high pollutant removal efficiencies by bioreteniton/filtration practices that are similar to the type referred to in the TMDL report.

COMMENT #4: The TMDL allocation calls for a 60 percent reduction in phosphorus loads from commercial, industrial, and high density residential land use areas. Short of reducing the runoff volume itself, it is not clear how this can be effectively accomplished.

RESPONSE #4: See response to 2 above. MassDEP believes a combination of illicit source elimination, phosphorus source reduction and implementation of non-structural and structural BMPs will potentially achieve large phosphorus reductions.

COMMENT #5: There appears to be too little understanding of the influence that hydrodynamics in the lower Charles have on the algal blooms, and what opportunities might exist for better managing them. The impacts of the salt wedge and sediment flux are treated as "implicit margins of safety" in the TMDL and are not fully explored.

RESPONSE #5: The modeling for the Lower Charles TMDL include a hydro-dynamic linked water quality model. Considerable effort was invested in simulating the hydrodynamics of the lower Charles particularly as it relates to algal growth in the Basin. The primary issues concerning algal growth in the Lower Charles is ample nutrient availability and long retention times which allow algae populations to grow. All significant discharges into the Lower Charles were simulated in the model as inputs. The analysis shows that because of the large water volume present even nutrients discharged directly into the Lower Charles from tributary drainages remain in the Lower Charles for sufficiently long periods to support algal growth. This is even true for large rain events because of the pumped drawdown that occurs at the New Charles River Dam to prevent flooding.

The presence of the salt wedge was not treated as MOS in any way. The model simulated the salt wedge with the goal of simulating vertical stratification in the downstream portion of the Lower Charles. The model was determined by the review committee to accomplish this. Water quality data show that the salt wedge is effectively trapping nutrients in the lower water column and preventing them from moving into the photic zone (in the upper water column) where they would be available for uptake by algae. Destruction of the vertical stratification without sufficiently oxygenating the bottom sediments could result in the introduction of a substantial amount of phosphorus into the upper water column. Thus extreme caution is warranted involving any action that might disturb the stratification.

The implicit MOS attributed to phosphorus fluxing deals specifically with the predicted wind-down of phosphorus content in the bottom sediments as a result of reduced phosphorus loading from the watershed. Using the model, the TMDL accounted for wind-down for a ten-year period after achieving the total phosphorus reduction of 54%. Considering that complete implementation of the entire 54% phosphorus reduction will take many years to complete, and that there were little data to calibrate the sediment model, the Agencies determined that it would be premature to give credit for further reductions associated with potential reductions of phosphorus fluxing after the ten year period. Periodic water quality monitoring that will be conducted in the future to assess water quality will indirectly measure the net effect of watershed phosphorus reductions as well a reductions in nutrient fluxing.

COMMENT #6: The Charles River water residence time in the basin (that portion of the river between the B.U. Bridge and the Museum of Science) ranges from 9 to 213 days, with an average of 20 to 38 days depending on stratification. However, there is also mention in the TMDL that the level of the dam is lowered in anticipation of storm events, which should (particularly in combination with the presence of a denser salt wedge) result in more rapid discharge of the localized "flashy" freshwater runoff from storm events. This does not appear to have been addressed in the TMDL; rather the contribution of phosphorus from localized storm runoff during the summer growth period is seen as potentially significant to algal growth.

RESPONSE #6: The Massachusetts Department of Conservation and Recreation (DCR) manages the New Charles River Dam located at the mouth of the Charles River. DCR operates the Dam to protect low-lying areas along the Lower Charles from flooding during rain events. To accomplish flood protection, DCR drops the water level in the Lower Charles by pumping and gravity discharge to Boston

Harbor prior to anticipated rain events. The dropping of the water level effectively creates storage volume within the Lower Charles that effectively stores runoff during the rain event. As a result, the discharge to the Lower Charles, although flashy, does not readily pass out of the system to Boston Harbor. The large volume of the Lower Charles detains the local flows with sufficient retention time for some of the associated nutrients to be available for algal growth following the rain event.

COMMENT #7: Similarly, although the thermal impacts of the Mirant power station discharge are addressed in part, what about the effect the warmer water has on circulation of flow in the basin? In addition, how much of the freshwater storm runoff discharged from local "flashy" sources during the critical periods of algal growth merely flows over the salt wedge that is present during those times and into the harbor as it is displaced by the later runoff flow (and greater phosphorus loads) from the upstream portions of the watershed?

RESPONSE #7: The hydrodynamic model simulated the impacts of the thermal discharge from Mirant Kendall Station on the circulation of flow in the Lower Charles. Vertical stratification occurs predominantly because of the salt wedge, and the thermal plume from Mirant Kendall Station mixes into the surface layer and extends between Massachusetts Avenue Bridge and the New Charles River Dam with the highest temperatures on the Cambridge side of the River downstream from the outfall.

For typical summer time conditions, the volume of water in the salt wedge is estimated to be only between 10 and 15 percent of the water volume of the downstream portion of the Lower Charles (BU Bridge to the New Charles River Dam). As mentioned above, most of the local storm water flows do not short circuit the Lower Charles to Boston Harbor because of the substantial volume of water in this portion of the Lower Charles, which detains incoming flows (over 330 million cubic feet without accounting for the volume of the salt wedge). For example, constant flows of 500 and 1000 cubic feet per second would result in retention times of 8 and 4 days, respectively. These calculations are very conservative because they assume the duration of the flows are equal to the retention times. Also, as discussed in response to comment 6 above, additional storage volume is created when DCR drops the water level in the Lower Charles in anticipation of upcoming rain event creating greater storage times.

In any event, the models of the Lower Charles simulate the hydrodynamics of flows entering and leaving the river even during storm events. The load reduction scenarios also take this into account.

COMMENT #8: The TMDL states (p.79) that reductions in phosphorus loadings from the upper watershed greater than 50 percent were not simulated because of concerns that higher reductions might extend into natural, versus anthropogenic sources. Hence the conclusion to reduce loads in the upper watershed by 45 percent and all non-CSO direct inputs by 60 percent to get to the 9.8 ug/l chlorophyll *a* goal. However, the analysis presented in Table 3-14 indicates that phosphorus loading in the upper watershed represents a 284 percent increase over "natural" conditions due to anthropogenic activities. How would reducing it by more than 50 percent then extend into natural sources?

RESPONSE #8: Thank you for pointing out this apparent inconsistency. The final allocation scenario selected for the TMDL was based on distributing the phosphorus load reductions equitably among watershed sources and setting reduction levels that appear to be technically achievable. Please note that the same reduction rates were applied throughout the watershed for non-CSO areas (upstream watershed and downstream watershed). The overall percent reduction of 45% for the upstream watershed was calculated by applying the percent reductions for the various land cover categories shown on the bottom of Table 6-3. As indicated, a value of 65% reduction was used for the land covers that are estimated to have the higher phosphorus loading export factors (high density residential, commercial, industrial, and medium density residential). A zero % reduction was used for forested areas because it was assumed that much of the forested areas are in natural state and that it would not be realistic to call for reductions of mostly natural sources. Largely due to the large amount of forested area in the upper watershed, the net reduction was determined to be 45%. In the downstream watershed, a higher net reduction for non-CSO areas is needed because of the greater proportional amount of urban area (high phosphorus export loading factors) and the much lower proportional amount of forested area.

The statement that more than a 50% reduction was not simulated because it may extend into natural sources is based on a review of phosphorus (concentration) data collected by the MWRA at Watertown Dam (1997-2004). The intent of this review was to develop a general guideline of the maximum reduction to use for performing allocation scenarios for the upstream watershed. This exercise is independent of the values shown on Table 3-14, which were provided to give the general order of magnitude of the potential amount of increase in phosphorus loading due to anthropogenic activities.

The Watertown data analysis involved reviewing the concentration data to determine the general magnitude of phosphorus enrichment occurring in the water flowing over Watertown Dam. Data collected from minimally impacted streams in the upstream watershed by the Charles River Watershed Association were used to gauge how much higher phosphorus concentrations are at Watertown Dam. In very general terms, concentrations at Watertown Dam appear to be roughly twice that of phosphorus concentrations observed in the minimally impacted streams in the upper watershed. Thus, it was viewed that concentrations could be reduced by approximately 50 % and not call for reductions of natural sources. However, MassDEP used the results of this review as a very general guideline and ultimately relied on applying consistent and technically achievable reductions for the various source areas to achieve the chlorophyll *a* target.

COMMENT #9: As indicated above, the TMDL is not specifying how municipalities are to achieve the allocated load reductions. Therefore, the Commission and other communities should be allowed some flexibility over how to work toward them.

RESPONSE #9: MassDEP and EPA intend to allow for as much flexibility as possible provided the ultimate phosphorus reductions are achieved.

COMMENT #10: Options to reduce the sources of phosphorus in the runoff will be more limited and, aside from what can be passed on to private dischargers, many are outside of the Commission's purview; these would include increased pavement sweeping, deicing controls, and perhaps management of waterfowl, particularly in riparian areas.

RESPONSE #10: MassDEP acknowledges that at present there are many potential source areas outside of BWSC immediate jurisdiction. However, the TMDL is calling for large reductions in phosphorus loading that will likely necessitate comprehensive storm water management programs that deal with a wide range of sources including private parking lots and concentrations of waterfowl along the river. Since not all of these potential sources are currently regulated, MassDEP envisions that an iterative adaptive management process involving detailed source characterization and prioritization will help to identify the optimal solutions for achieving reductions. A goal of this process will be to identify the most cost-effective and optimal management plan to achieve the overall reductions. MassDEP expects that appropriate frameworks for implementing the necessary controls, consisting of regulatory and/or non-regulatory aspects, will become apparent once the storm water management plans are developed. MassDEP also recognizes that a coordinated and full effort from all responsible and interested parties will be required to achieve the water quality goals projected in the TMDL.