DRAFT

Total Maximum Daily Load for Eutrophication in the Lower Charles River Basin, Massachusetts

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November, 2005

EXECUTIVE SUMMARY

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

This interim report presents several components of an ongoing total maximum daily load (TMDL) study for the Charles River Basin 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 Basin and characterization of the pollutant sources to the Basin.

Additional elements, yet to be completed, that will be included in the final TMDL report are: (1) development of a water quality target for the Basin that is consistent with attaining the applicable Water Quality Standards; (2) determination of the Basin's pollutant assimilative capacity (or pollutant loading capacity); and (3) allocations of allowable pollutant loadings distributed among the contributing sources. The final TMDL report will address additional TMDL regulatory requirements including seasonal variation and the margin of safety.

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).

2. **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 and five counties. This TMDL report addresses the lower portion of the river, which is referred to as the Basin 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 Charles River Basin or Basin (Figure 1-1). The Basin 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 Basin 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 Basin downstream of the Boston University (BU) Bridge (Lower Basin). The Lower 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 Basin (MADEP 2000, Breault et al. 2002). Water depths range from 6 to 12 feet in the Basin upstream of the BU Bridge and 9 to 36 feet in the Lower Basin.

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

The entire Charles River Basin 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 Basin. The remaining 40 square miles drain directly into the Basin 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 Basin. See Figure 1-1 for the locations of the tributary watersheds and the combined sewer drainage areas. The Basin is in the heart of a highly urbanized area, bordered directly by the municipalities of Boston, Cambridge, Watertown, and Newton.

The Basin 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 Basin. As a result, the Basin provides an ideal setting for a variety of recreational activities in and along the Basin, 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 extensive water quality data available for the Basin, the Massachusetts Department of Environmental Protection (MADEP) has included the Basin 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, low dissolved oxygen, and noxious aquatic plant listings as well as associated water clarity impairments such as turbidity and taste, odor and color. The noxious aquatic plants listing refers to excessive algae biomass in the Basin. It is believed that increased nutrient loads to the Basin are causing the excessive algal biomass, which in turn causes the low dissolved oxygen levels.

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 Basin is undergoing cultural eutrophication. Cultural eutrophication is the process of producing excessive plant life because of excessive pollutant inputs from human activities. In the Basin, 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 Basin 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.

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 Basin 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 blue-green algae species in the Lower Basin.

1.3 Applicable Water Quality Standards

1.3.1 Designated Uses

The applicable Massachusetts Water Quality Standards identify the Charles River Basin as a Class B water that is designated to support aquatic life and recreational uses. According to the MAWQS (MADEP 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 Basin 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 Basin 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 (MADEP 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 MADEP 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 MADEP 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 MADEP 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 Charles River Basin are predominantly urban. The four major tributary watersheds to the Basin are as follows: Stony Brook (8,393 acres), Muddy River (4,005 acres), Laundry Brook (3,038 acres), and Faneuil Brook (1,151 acres). The four watersheds have relatively large drainage areas accounting for approximately 72 percent of the Basin'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 (Weiskel et al. 2005). Figure 2-1 depicts the land use types in the Charles River Basin.

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

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**
Stony Brook	**8,393**	**HD, MF, UO, F**
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

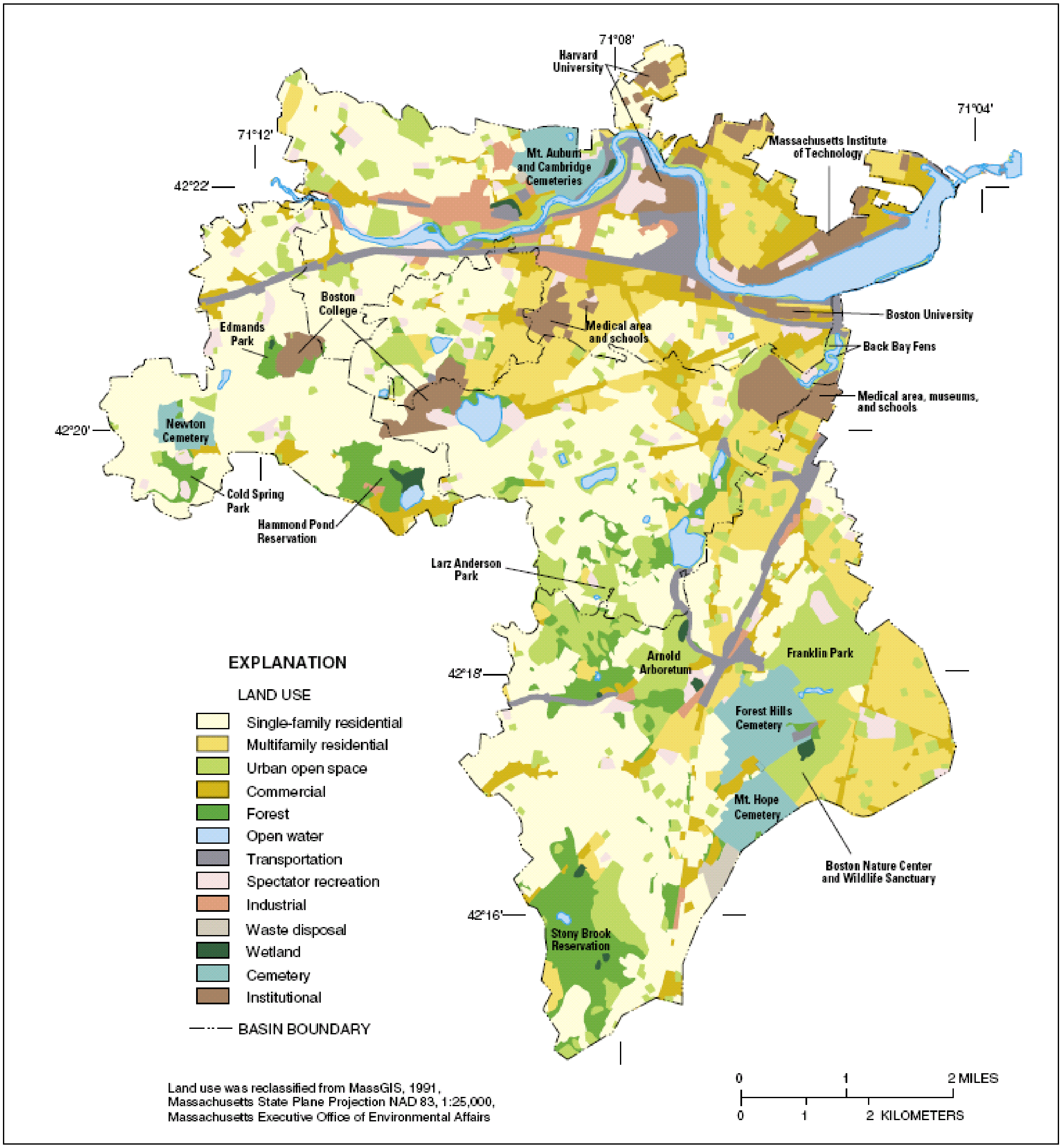

Figure 2-1. Land use types in the Charles River Basin (Weisekl et al. 2005).

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 Basin. 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 watershed is identified as "urban land." Soils classified as urban land tend to be near the river in areas that have been filled to eliminate tidal marshes and mud flats (Zarriello and Barlow 2002). Since the Basin is in such a highly urbanized area, much of the area is impervious because of paving. Based on a previous modeling effort in the Basin, 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). The average annual maximum temperature is 59 °F and the average annual minimum temperature is 43.6 °F. Days with maximum temperatures of 90 °F 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 Charles River Basin 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 Basin. Daily average river flow data entering the Basin 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 Basin.

Of particular interest is the summer period when growth conditions for algae are optimal. The low flows that occur in the Basin during the summer period favor algal growth because of the associated increase in water residence time. The impounded Lower 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 Basin 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 Basin 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 Lower 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 Lower Basin through the New Charles River Dam results in a portion of the Lower 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 Lower 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 that occurs approximately once every 10 years (7Q10 flow) and the calculated residence times are also shown in Table 2-2. Low flows, at or near the 7Q10 flow value, have occurred in the Basin 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 Lower Charles River Basin (July 1-September 30)

Year	Average Daily Flow At Watertown Dam (cfs)	Water Residence Time	
		Lower Basin without stratification (days)	Lower 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 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 Basin 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 Basin were higher than shown in Table 2-2 because of the runoff from the tributary streams and drainage systems that directly enter the Basin below Watertown Dam.

The effect on water residence time of the Basin 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 Basin 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 Lower Basin exceed 70 days even when the Basin is vertically stratified. As evidenced by the high chlorophyll *a* concentrations measured in the Lower Basin for each of the monitoring seasons (1998 through 2004) (see Section 3.2.1), the water residence times in the Lower 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 Charles River Basin, 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 Charles River Basin 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 Charles River Basin 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 Charles River Basin 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 Basin, and 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 Basin. 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. 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. 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 Basin. 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.

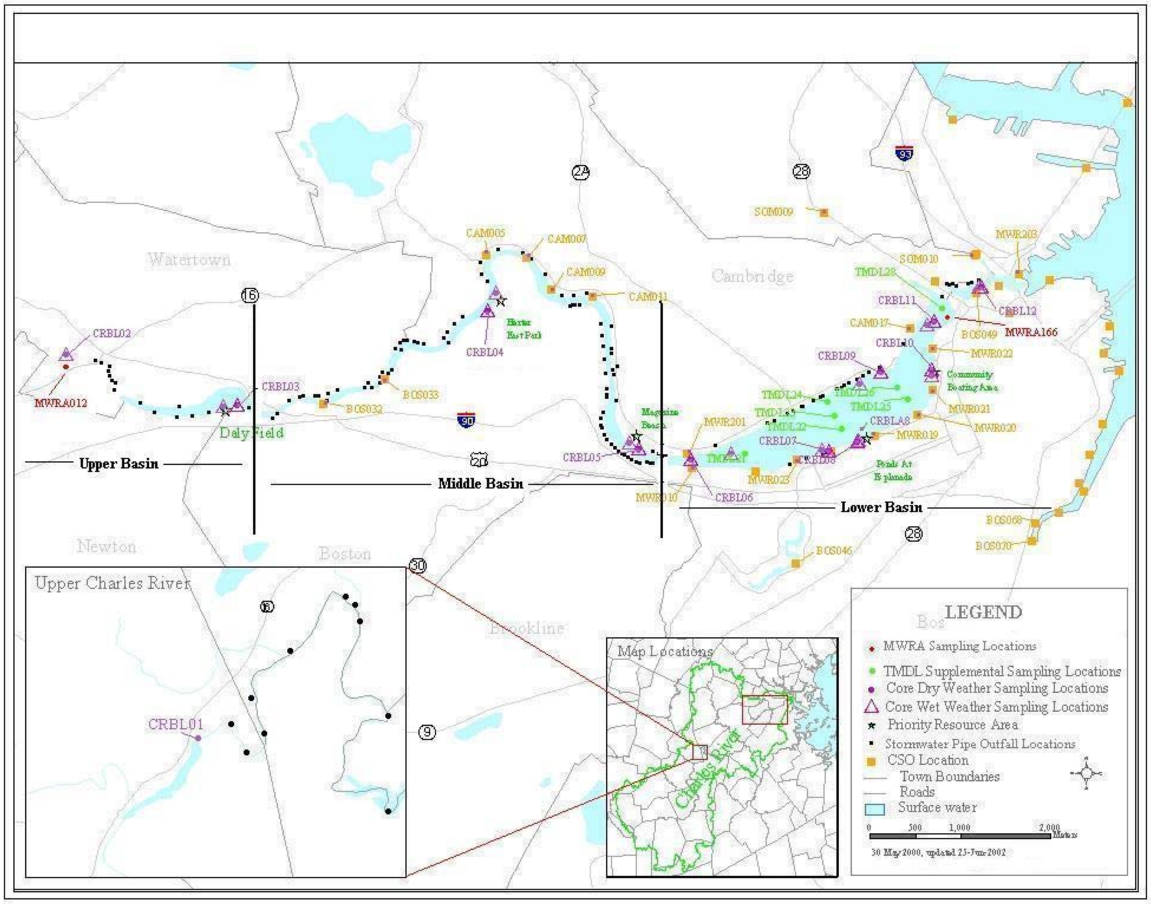

Figure 3-1. Location of the EPA and MWRA monitoring stations in the Charles River Basin.

CRWA and MWRA Water Quality Data

The CRWA and the MWRA also routinely sample the Basin for several water quality parameters. CRWA has sampled four locations in the Basin quarterly, while MWRA has conducted intensive sampling of the Basin 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 Lower Basin (station 166) and (2) at the Watertown Dam, the upstream boundary of the Basin (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 Charles River Basin that have contributed substantially to the current understanding of water quality conditions of the Basin. These investigations include (1) an examination of the extent and effects of salt water intrusion into the Basin 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 Charles River Basin. 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).

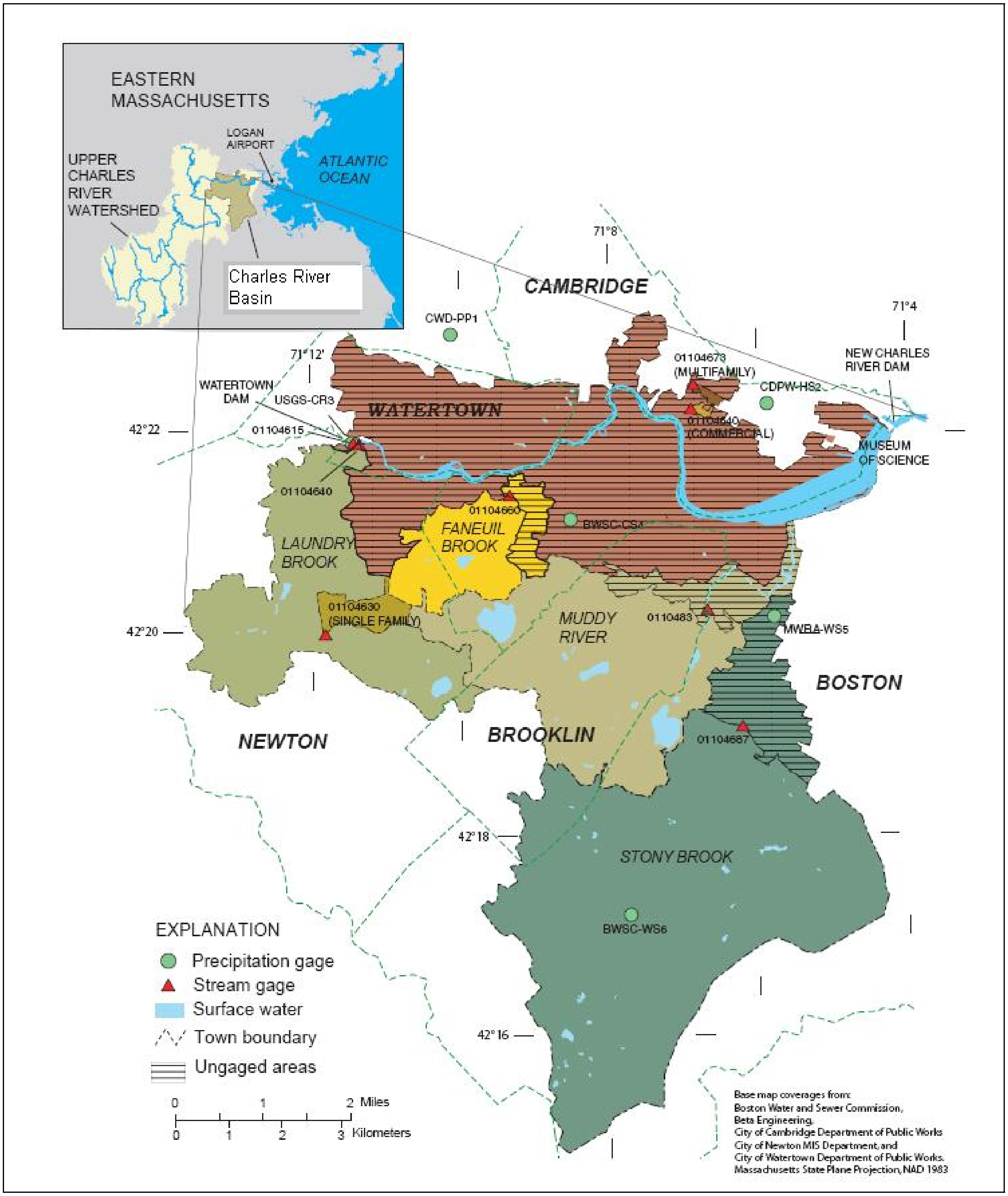

Figure 3-2. Location of the USGS water quality monitoring stations.

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 Charles River Basin 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.

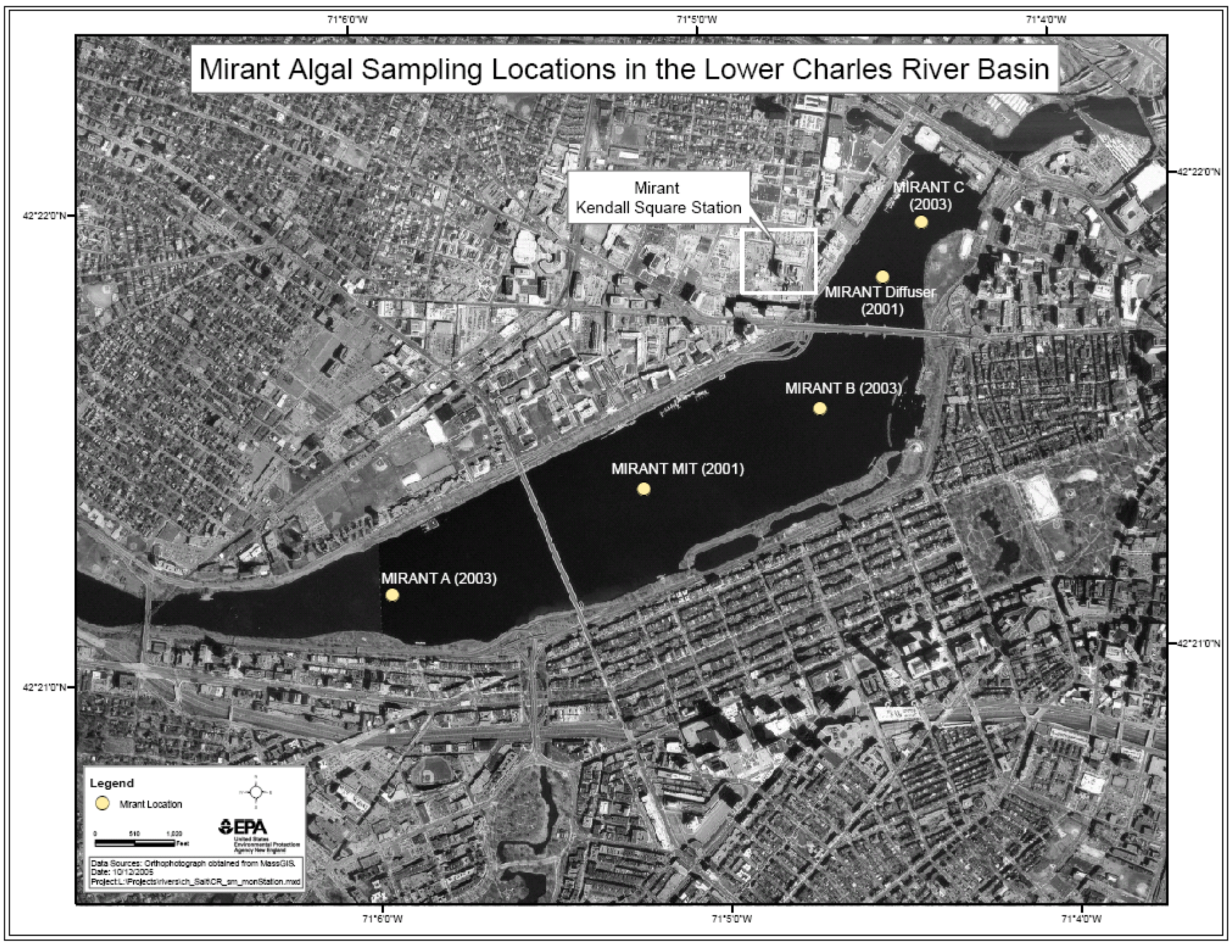

Figure 3-3. Locations of Mirant algal sampling locations in the Charles River Basin.

3.2 Current Water Quality Conditions and Data Analysis

3.2.1 Trophic Condition Assessment for the Basin

This portion of the water quality analysis focuses primarily on parameters associated with the trophic state of the Charles River Basin, 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 Charles River Basin that identify the Basin'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 Lower 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 Basin*

Trophic Status	Peak Range (µg/l)	Lower 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	Lower 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 2003a.
[b]Means are geometric annual means (log 10), except peak chlorophyll *a*.
[c]Based on data collected by the EPA and MWRA from the Lower Charles River Basin, 1998-2004.

To characterize the Basin'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 Basin (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 the lower boundary, the Lower Basin 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 pheophytons in the laboratory, while the MWRA chlorophyll *a* samples were analyzed using a fluorometric method and were corrected for pheophytons. For this report, EPA's chlorophyll *a* data have been corrected for pheophytons using the MWRA's pheophyton 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 Basin.

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 Basin 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 Basin, to characterize varying conditions in the Basin. The Upper Basin is between Watertown Dam and Daly Field; the Middle Basin is between Daly Field and the BU Bridge, and the Lower Basin 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. 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 affected for short periods of time during rain events and are not considered representative of longer term ambient conditions in the Basin. Considering the extended periods of dry-weather conditions that typically occur in the Basin during the summer seasons, the dry-weather data are thought to be more useful for evaluating the trophic status. Including the wet-weather data in the statistics presented in Tables 3-4 through 3-6 would indicate higher levels of TP, slightly lower chlorophyll *a* and lower Secchi depth measurements.

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

	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
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 Charles River Basin

	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 Charles River Basin

	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 (1.0)	0.7 - 1.8 (1.4)	0.8 - 1.7 (1.2)	0.8 - 1.7 (1.2)	1.0 - 2.2 (1.5)	0.7 - 1.6 (1.3)	0.7 - 1.8 (1.3)
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 Charles River Basin 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 as the algal community cycles through growth and death phases and varies 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 Basin 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 Basin during each year of EPA's Core Monitoring Program. In contrast, chlorophyll *a* concentrations in the Upper Basin are consistently less, and are not indicative of regularly occurring algal bloom conditions. Mean chlorophyll *a* values in the Upper Basin 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 Basin. The shorter water residence time or higher flushing rate in the Upper Basin 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 Basin are largely a function of the chlorophyll *a* levels coming over the Watertown Dam, which are typically much lower than levels in the Lower Basin.

The TP concentrations summarized in Table 3-5 are also indicative of eutrophic conditions throughout the Basin 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 Basin 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 Basin 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 Basin. However, water clarity in the Lower Basin is still low and indicates eutrophic conditions given that maximum Secchi depths rarely exceeded 1.8 meters. Although Secchi depths in the Basin 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 Lower Basin (MWRA station 166) and (2) at the Watertown Dam, the upstream boundary of the Basin (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 90th 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 Charles River Basin

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 Charles River Basin

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 Charles River Basin

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 Lower 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.

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 Lower 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 Basin 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 Basin. 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 Basin also indicate eutrophic conditions. Dissolved oxygen data collected during the summer period when chlorophyll *a* levels were elevated in the Basin 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 Basin 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 and chlorophyll *a* data from the Charles River Basin for July 30, 2002

EPA Monitoring Station	Dissolved Oxygen mg/l	Dissolved Oxygen Percent Saturation	Chlorophyll *a* µg/l
CRBL03	8.8	110	6.9
CRBL06	11.1	136	33.3
CRBL12	12.7	160	43.5
CRBL09	13.5	168	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 Basin, diurnal dissolved oxygen variations typically range between 1 and 5 mg/l.

Although the Basin 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 Lower Basin becomes stratified. The stratification of the Lower 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 Lower 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 Basin, pH values frequently exceed the upper limit of the range (6.5 to 8.3) allowed in the Massachusetts Water Quality Standards (2000). 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 Basin

Seasonal Algal Trends and Limiting Factors

Algal growth is primarily a function of nutrient availability, light, and temperature (Chapra 1997). Of all the nutrients that are required by algae (i.e., carbon, oxygen, nitrogen, phosphorus, silica, sulfur, and iron), phosphorus and nitrogen are typically in limited supply. The relative amounts of phosphorus and nitrogen in aquatic systems determine which nutrient limits 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).

Based on measured amounts of nitrogen and phosphorus in the Basin, phosphorus is consistently 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 Basin (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 Basin.

Although phosphorus appears to be more limiting than nitrogen, other water quality data from the Basin 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 Basin 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 Basin, 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 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 Basin. Consequently, phosphorus, rather than light, typically becomes the limiting factor on 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. Decreases in phosphorus and increases in bloom severity also coincide with declines in river flow, which increases the water residence time in the Lower Basin 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 reductions in TP and water color are 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 Basin 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 Basin (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.

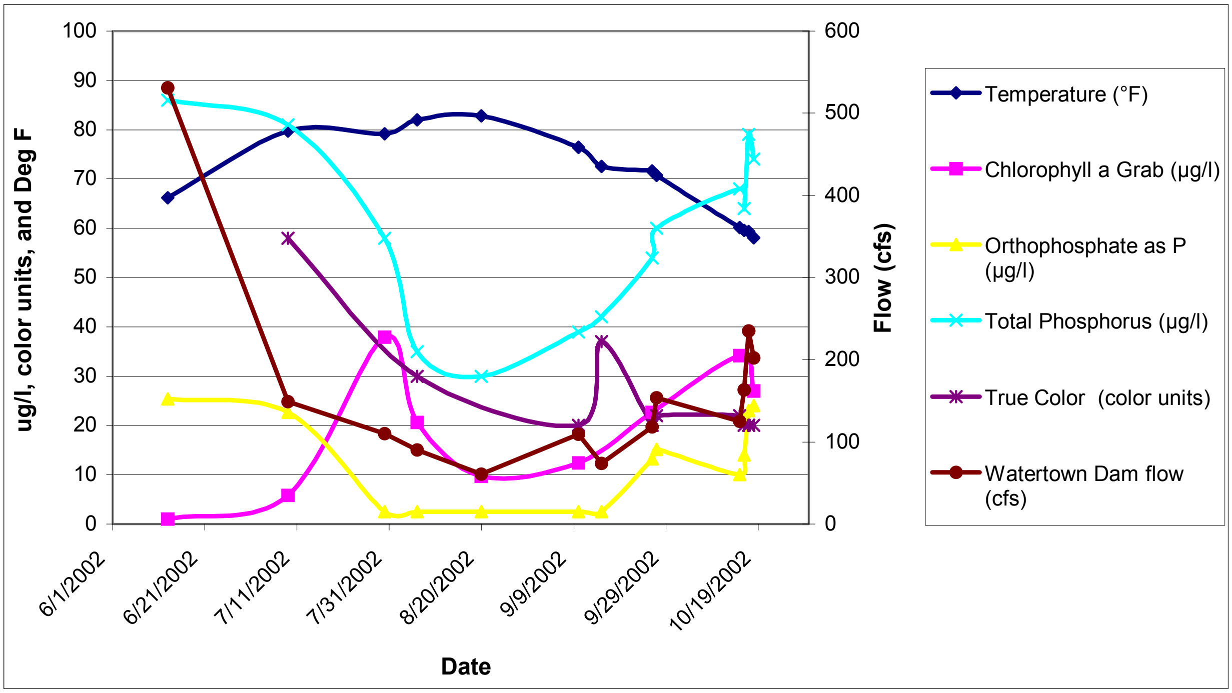

Figure 3-4. Recreational season 2002 water quality data for the Charles River Basin.

Figure 3-4 illustrates the portion of the summer when phosphorus becomes the limiting factor to algae growth in the Basin. 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 Basin, 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 Basin.

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 (Lower 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 Basin 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 Basin, algal blooms typically become a water quality concern in late July through October.

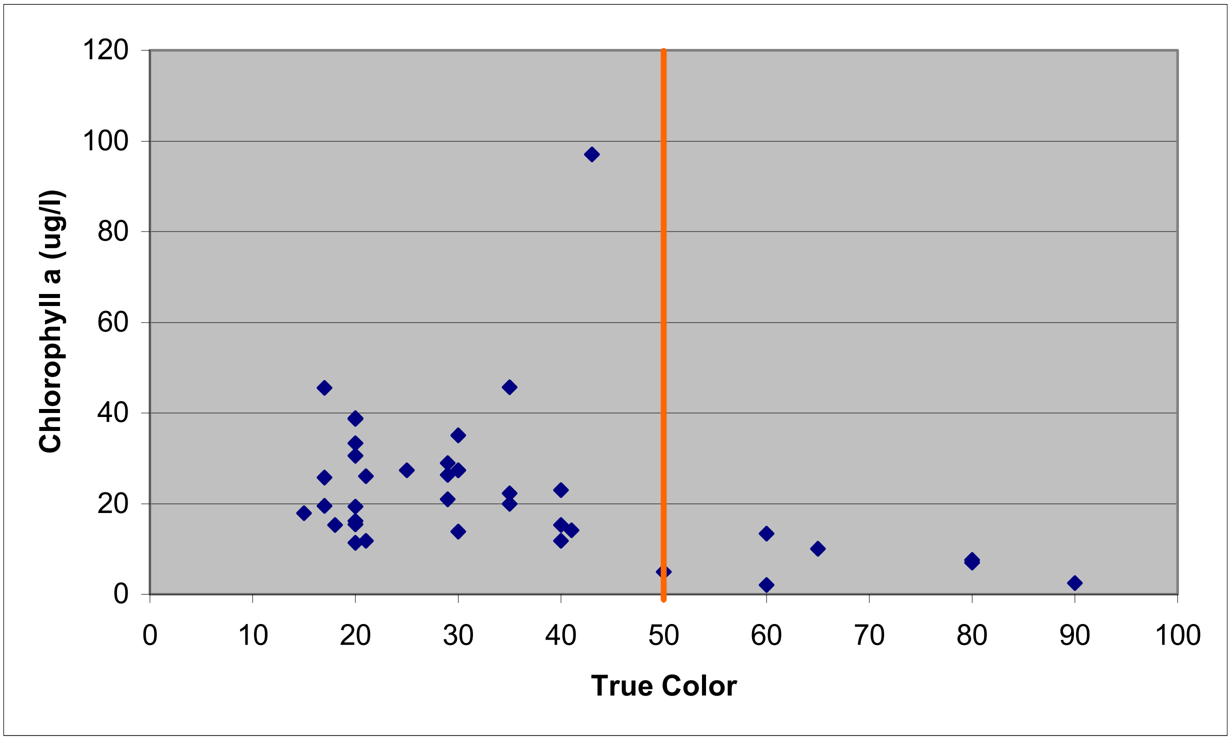

Figure 3-5. Chlorophyll *a* versus true color in the Lower Charles River Basin (EPA station CRBL11 1999-2004).

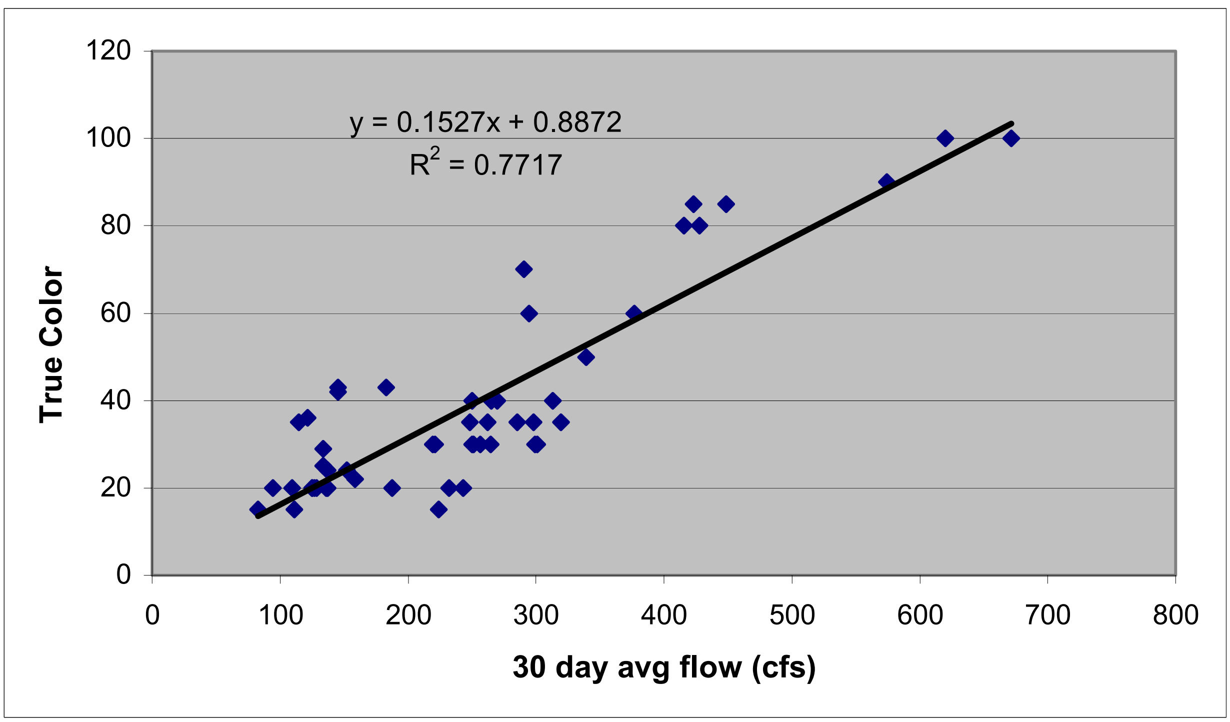

Figure 3-6. True color versus flow at the Watertown Dam (EPA station CRBL02 1999-2004).

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 "blue-greens." The blue-greens are considered to be bacteria (Cyanobacteria) with a photosynthetic pigment, chlorophyll. Many blue-greens, particularly the troublesome species, can "fix" nitrogen. While other algae must obtain their nitrogen from ammonium or nitrate in the water, the blue-greens can use atmospheric nitrogen that dissolves in water. Furthermore, some of the most troublesome blue-greens 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 blue-greens. Zooplankton are 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 blue-greens: Anabaena, Aphanizomenon, and Microcystis, are commonly associated with problems in fresh water lakes (Mattson et. al. 2003). All three genera have been identified in samples collected from the Lower Charles River Basin (USEPA 2002, Mirant 2001 and 2003).

Figures 3-7, 3-8, and 3-9 present the limited algal taxonomic data collected from the Lower 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 blue-green 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 Lower Basin during late July and again in late September/early October. During the beginning of early October 2004, a very severe blue-green bloom moved into the Basin from the upper watershed, resulting in reports from the public. Unfortunately, algal samples were not collected from the Basin during this event. However, during the bloom in the upper watershed, the MADEP collected and analyzed samples from the upper Charles River Watershed that had blue-green (Oscillatoria) cell counts of over 200,000 cells/ml (Beskenis 2005).

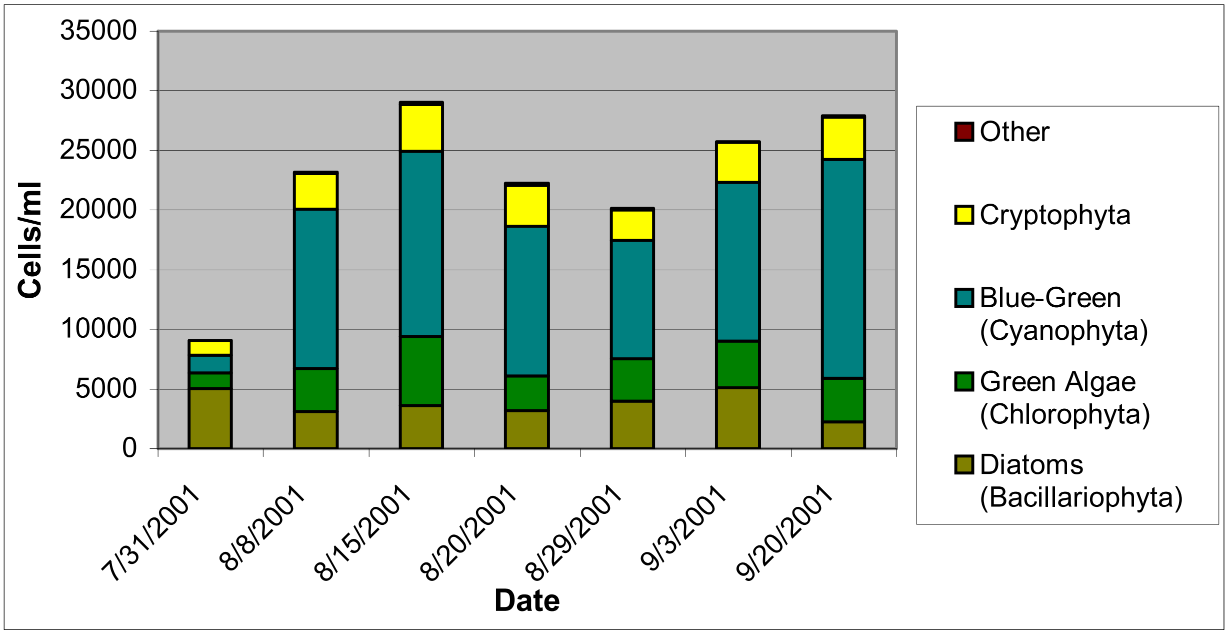

Figure 3-7. 2001 phytoplankton cell counts in the Lower Charles River Basin (Mirant MIT station).

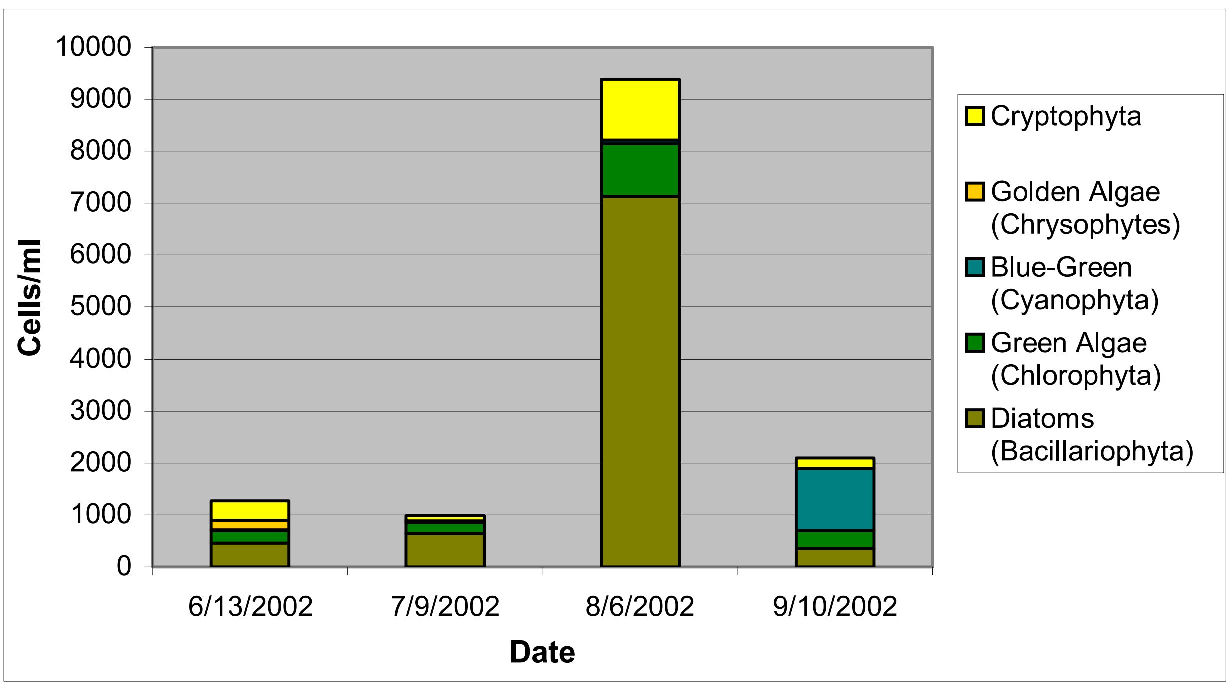

Figure 3-8. 2002 phytoplankton cell counts in the Lower Charles River Basin (EPA station CRBL11).

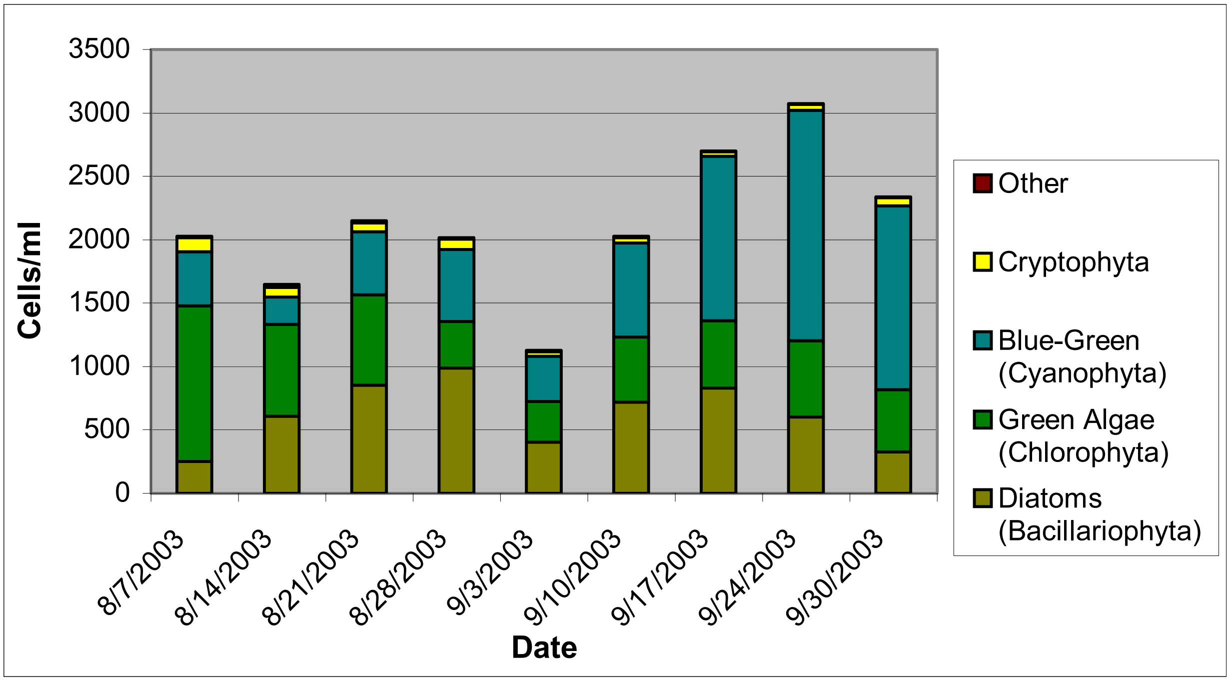

Figure 3-9. 2003 phytoplankton cell counts in the Lower Charles River Basin (Mirant station C).

3.2.3 Other Important Water Quality Characteristics of the Basin

Spatial Variability in Water Quality of the Lower Basin

Water quality data collected in the Lower Basin 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, bacteria, and typically chlorophyll *a*) 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 Basin 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 Basin is used intensively for both contact and non-contact recreational uses.

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 Lower Basin.

The improving trend in water quality conditions beginning at BU Bridge is explained by the change in morphology of the Basin. Downstream from the BU Bridge, the Basin widens and deepens. As a result, the Basin functions more like a lake than a river. The greater volume of the Lower 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 Basin 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 Lower 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) in the Basin occur 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 Lower 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 Basin. The USGS observed that salt water enters the Basin primarily by way of the boat locks at the New Charles River Dam and migrates upstream into the Lower 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 Lower 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 Lower Basin to stratify (Breault et al. 2000b). The stratification in the Lower 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 Basin 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 Lower 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 Basin 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 Lower 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 Lower 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 Basin 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 Basin fails to fully support the designated recreational and aquatic life uses as required in the Massachusetts Surface Water Quality Standards (314 Code of Massachusetts Regulations (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 Basin.

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 Lower 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 Basin do not support Massachusetts aquatic life standards. Algae blooms contribute to the dissolved oxygen problem in the Basin 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.

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). These numeric criteria are the basis for issuing numerous NPDES permits with phosphorus effluent limitations for facilities that discharge to the Lake Champlain Basin.

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 Lower Basin to the results of user-perceived aesthetic impairments to chlorophyll *a* measurements strongly suggests that the water quality of the Basin is aesthetically impaired. Summer season (July 1 – October 31) chlorophyll *a* data collected at EPA monitoring stations located in the Lower 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 Lower 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 Lower 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 Lower Basin are believed to reflect the improved water quality conditions that typically occur in the downstream-most segment of the Lower Basin.

Water Clarity Impairments

Secchi disc depths measured in the Basin 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 clarity criterion is in a narrative form, 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 Lower 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 Basin focuses mainly on phosphorus loadings to the Basin as well as potential thermal pollution. This section of the report provides a general overview of the types and magnitudes of the various pollutant sources in the Basin. 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 or industrial facility outfall. Nonpoint source pollution represents diffuse sources such as runoff from various land uses including parking lots, roads, and lawns.

There are no nonpoint sources of pollution in the Basin because the entire Basin falls under a municipal separate storm sewer systems (MS4) permit (see Section 3.4.1). Therefore this section focuses solely on point sources of pollution. There may be some nonpoint sources 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 point source to the Basin (see Section 3.4.1).

Specific loading estimates for individual sources are not provided in this document, but have been developed 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*, prepared by Tetra Tech, Inc. and Numeric Environmental Services (2005).

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 Charles River include stormwater runoff, illicit sanitary sewage discharges, combined sewer overflows (CSOs), and the discharge from the upstream watershed at Watertown Dam (including wastewater treatment plant effluent).

There are 72 major stormwater drainage system outfalls and 12 CSOs in the Basin. Figure 3-10 shows the locations of the major stormwater outfalls and all of the potentially active CSO outfalls in the Basin (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 Basin watershed areas).

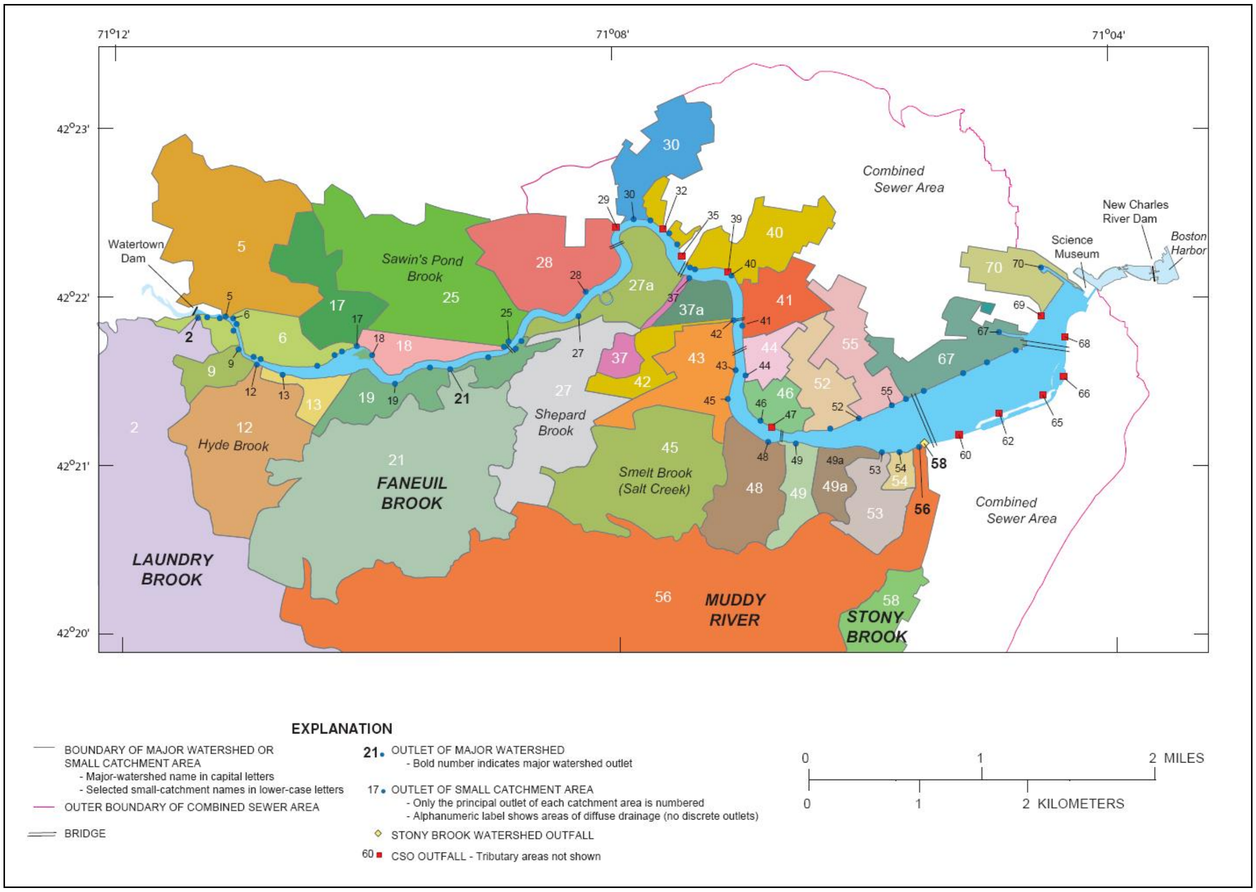

Figure 3-10. Watershed and CSO outlets for the four major tributary watersheds and small watershed areas of the Charles River Basin (Weiskel et al. 2005).

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

Stormwater System Runoff

Stormwater systems cover the entire Basin and, therefore, are a possible point source contributor of phosphorus to the Basin. Stormwater discharges are generated by runoff from urban land and impervious areas such as paved streets, parking lots, and rooftops during precipitation events, and these discharges often contain high concentrations of pollutants that can eventually enter nearby waterbodies. Most stormwater discharges are considered point sources and require coverage by a NPDES permit.

Under the NPDES stormwater program, operators of large, medium, and regulated small 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 Basin is the city of Boston.

Phase II requires a select subset of small MS4s to obtain an NPDES stormwater permit. 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 a UA that are so designated by NPDES permitting authorities, case by case (USEPA 2000b). The 5 remaining cities in the Basin are all regulated as Phase II MS4 areas. These cities include Brookline, Cambridge, Newton, Somerville, and Watertown. Therefore, because of the highly urban nature of the watershed, the entire Basin is subject to the MS4 NPDES permits.

Stormwater runoff represents a significant source of phosphorus to the Basin. There are many stormwater drainage systems that collect and transport drainage/runoff from the 40 square miles of a highly urbanized watershed contributing directly to the Basin. Pollutants, such as phosphorus, that have accumulated on watershed surfaces are readily transported to the Basin 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 Basin'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 Basin 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. This might further increases the overall stormwater pollutant load by erosion and flooding (Schueler 1987). Although stormwater is typically associated with storm or rainfall events, this section discusses dry-weather pollutant loads associated with the stormwater system as well.

From 1999 to 2000 the USGS conducted a study to estimate non-CSO pollutant loadings to the Basin. All non-CSO pollutant loads are subject to the MS4 permits in the Basin. This investigation addressed dry- and wet-weather sources to the Basin with the exception of CSOs and has provided insight into the magnitude and relative importance of pollutant sources to the Basin.

The study involved continuous flow monitoring and many dry- and wet-weather water quality sampling events of the major Basin tributary drainage systems (Laundry Brook, Faneuil Brook, Muddy River, and Stony Brook), three smaller systems that drained relatively homogeneous land use types (single family residential, multifamily-residential, and commercial), and the Charles River at Watertown Dam, the upstream boundary of the Basin. The three land use subbasins are important in characterizing the pollutant sources to the Basin because they are the dominant land uses in the Basin, representing approximately 60 percent of the watershed, and contribute much of the runoff to the stormwater system. The Basin is dominated by single-family and multi-family residential land uses and the eastern part of the Basin and areas closest to the River contain a large amount of commercial area (Zarriello and Barlow 2002). Human activities, such as the use of fertilizer and the discharge of untreated sewage, on these land uses can increase nutrient concentrations in the River and its tributaries.

Continuous flow monitoring was conducted at 8 locations, which accounts for 95 percent of the entire watershed area draining to the Basin. Figure 3-11 shows the locations of the USGS flow and water quality monitoring stations. Water quality sampling involved 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 lass 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).

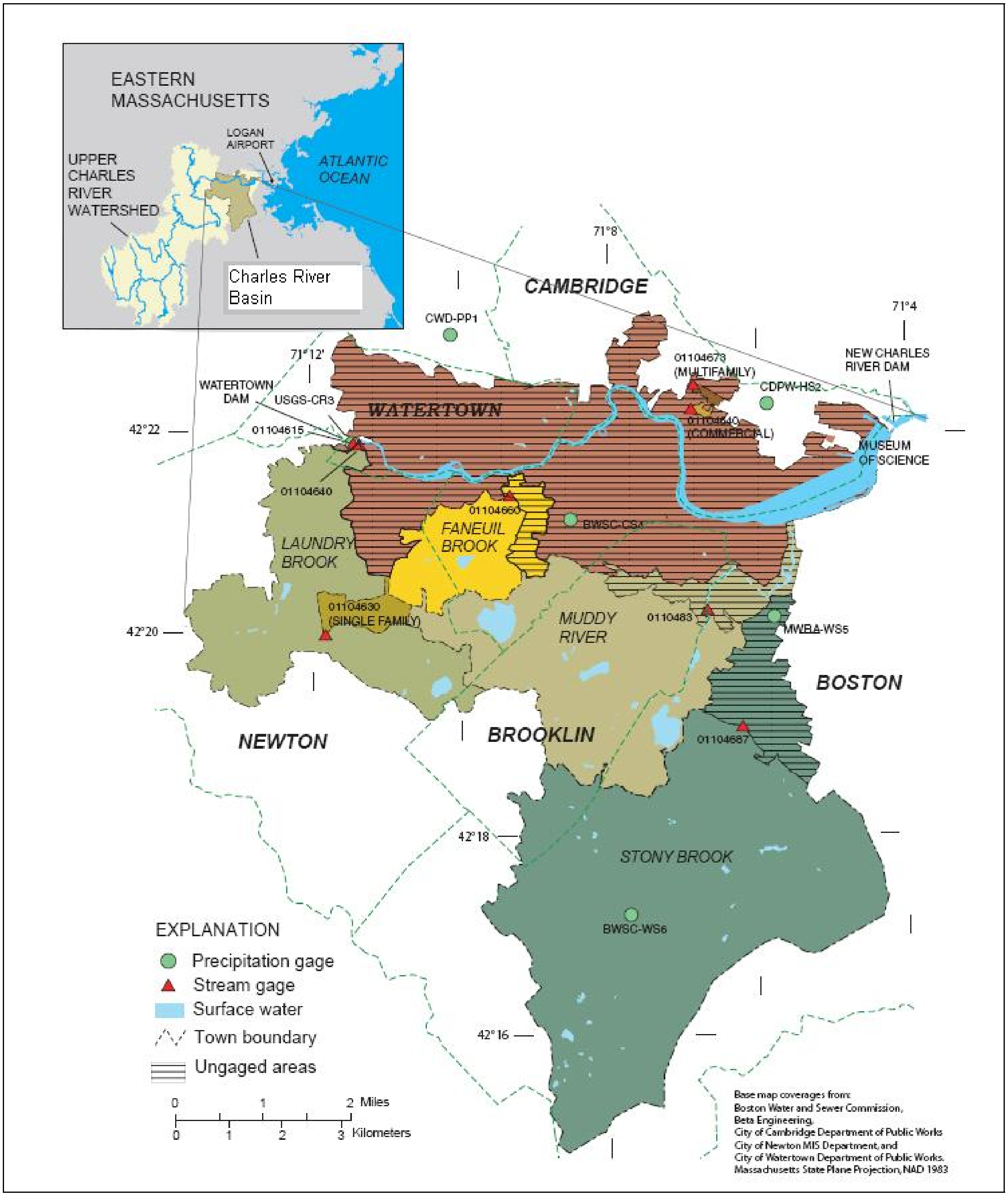

Figure 3-11. Locations of the USGS flow and water quality stations in the Charles River Basin (Zarriello and Barlow 2002).

As part of the overall effort to quantify pollutant loadings to the Charles River Basin, 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 Basin. The models were developed to estimate total dry-weather and wet-weather flow entering the Basin 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 Basin during water year 2000 (October 1, 1999 to September 30, 2000) (Table 3-11).

Table 3-11. Non-CSO dry-weather, wet-weather, and total pollutant loads to the Charles River Basin 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	251754	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 3-11 summarizes the annual (water year 2000) contributions of dry-weather loadings (base flow), wet-weather loadings (stormwater runoff), and total non-CSO loadings (i.e., combined wet and dry) of phosphorus and other pollutants relevant to this TMDL study from the major inputs (the upper watershed, Laundry Brook, Faneuil Brook, Muddy River, and Stony Brook) and the remaining drainage area served by smaller systems (including the three land use 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 runoff, 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 Basin 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 Basin 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 Basin 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 and its relatively large nutrient load can become an important source of phosphorus to the Basin during the critical summer growing season when algae are phosphorus limited.

The results of the USGS wet-weather monitoring is summarized in Table 3-12. These concentrations represent the quality of these discharges that occurred during discreet rain events and consisted primarily of stormwater runoff. 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 3-12. Stormwater event mean concentrations for select drainage areas to the Charles River Basin (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 Use Type Drainage										
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 3-12 (Budd and Meals 1994). As indicated, nutrient concentrations measured in stormwater discharges to the Basin are many times higher than those measured in undeveloped forested watersheds. Therefore, the amount of nutrients generated from the Basin's immediate watershed per unit area is likely to be several times higher than that from an undeveloped watershed (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.

The elevated stormwater phosphorus concentrations and the magnitude of stormwater runoff volume entering the Basin from the surrounding watershed make stormwater runoff 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 Basin. To illustrate the relative importance of pollutant sources during rain events, the USGS estimated flow volumes and pollutant loadings to the Basin using specific rain events known by the MWRA as the 3-month and 1-year design storms. For example, the 3-month design storm is 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 Basin (Breault et al. 2002).

Illicit Discharges

Illicit discharges are releases of untreated waste into drainage systems that result in direct discharges of raw sewage to receiving waterbodies. 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 Basin (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 considered continuous and discharge during both dry- and wet-weather conditions. Illicit discharges are likely to increase pollutant concentrations of stormwater discharges because of the flushing-out of solids that were previously deposited in the drainage systems during low-flow dry-weather conditions.

The discharge of untreated wastewater to the Basin 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 Basin. The extent of illicit discharges to the Basin is currently unknown because substantial portions of the drainage systems that discharge to the Basin 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 Basin. For example, the BWSC reports, as of May 2005, that over 900 illicit discharges to the Basin 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 Basin, EPA estimates that illicit discharge removal work has resulted in the removal of over 1 million gallons per day of untreated wastewater to the Basin (Walsh-Rogalski 2005).

The magnitude of illicit discharges identified and removed from the Basin to date indicates that illicit discharge have represented an important source of nutrients to the Basin 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 Basin. This amount of phosphorus represents approximately 20 percent of the estimated total phosphorus load discharged to the Basin for water year 2000 (see Table 3-11). 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 Basin 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 Basin communities continue to investigate the Basin's drainage systems to identify and eliminate illicit discharges.

Combined Sewer Overflows

A portion of the drainage area surrounding the Basin in Boston and Cambridge is served by a combined sewer system (Figures 1-1 and 3-10). 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 Basin, bypassing the WWTF. Presently, there are 12 CSO outfalls to the Basin including the outlet of the Stony Brook system (MWR023) and the Cottage Farm CSO treatment facility (MWR201). The Cottage Farm facility provides screening and disinfection for its CSO discharges. The locations of the outfalls are depicted in Figure 3-10.

Table 3-13 presents the CSO activation frequency, annual CSO volumes and nutrient loads for the 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 a significant source of phosphorus and nitrogen to the Basin during 2000, accounting for approximately 16 percent and 30 percent of the estimated total phosphorus and nitrogen loads, respectively.

Table 3-13. CSO flows and nutrient loads 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*			
	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	1,235.2	2	0.8	9.4	330.5
CAM007	5	1.17	13.7	483.3	1	0	0.0	0.0
CAM009	10	0.33	3.9	136.3	1	0.1	1.2	41.3
CAM011	2	0.16	1.9	66.1	0	0	0.0	0.0
CAM017	1	0.27	3.2	111.5	2	1.2	14.1	495.7
BOS049	0	0	0.0	0.0	Eliminated	0	0.0	0.0
MWR010	1	0.88	10.3	363.5	Eliminated	0	0.0	0.0
MWR018	2	2.94	34.5	1,214.6	2	0.5	5.9	206.6
MWR019	2	0.35	4.1	144.6	2	0.1	1.2	41.3
MWR020	1	0.03	0.4	12.4	1	0.1	1.2	41.3
MWR023	32	111.83	1312.3	46,198.4	0	0	0.0	0.0
MWR201	21	547.45	6424.2	226,158.4	7	26.7	313.3	11,030.1
Total		**668.4**	**7843.5**	**276,124.3**		**29.5**	**346.2**	**12,186.8**

*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.

Upstream Watershed Load at Watertown Dam

The upstream watershed draining over the Watertown Dam represents the largest source of phosphorus to the Basin at approximately 80 percent of the total annual load for water year 2000 (Breault et al. 2002) (see Table 3-11). The 268 square mile watershed encompasses land area in 31 communities and is drained by numerous tributary streams and rivers (CRWA 2005). Figure 3-12 shows some of the important features of the upstream watershed, including community boundaries and locations of major WWTF discharges.

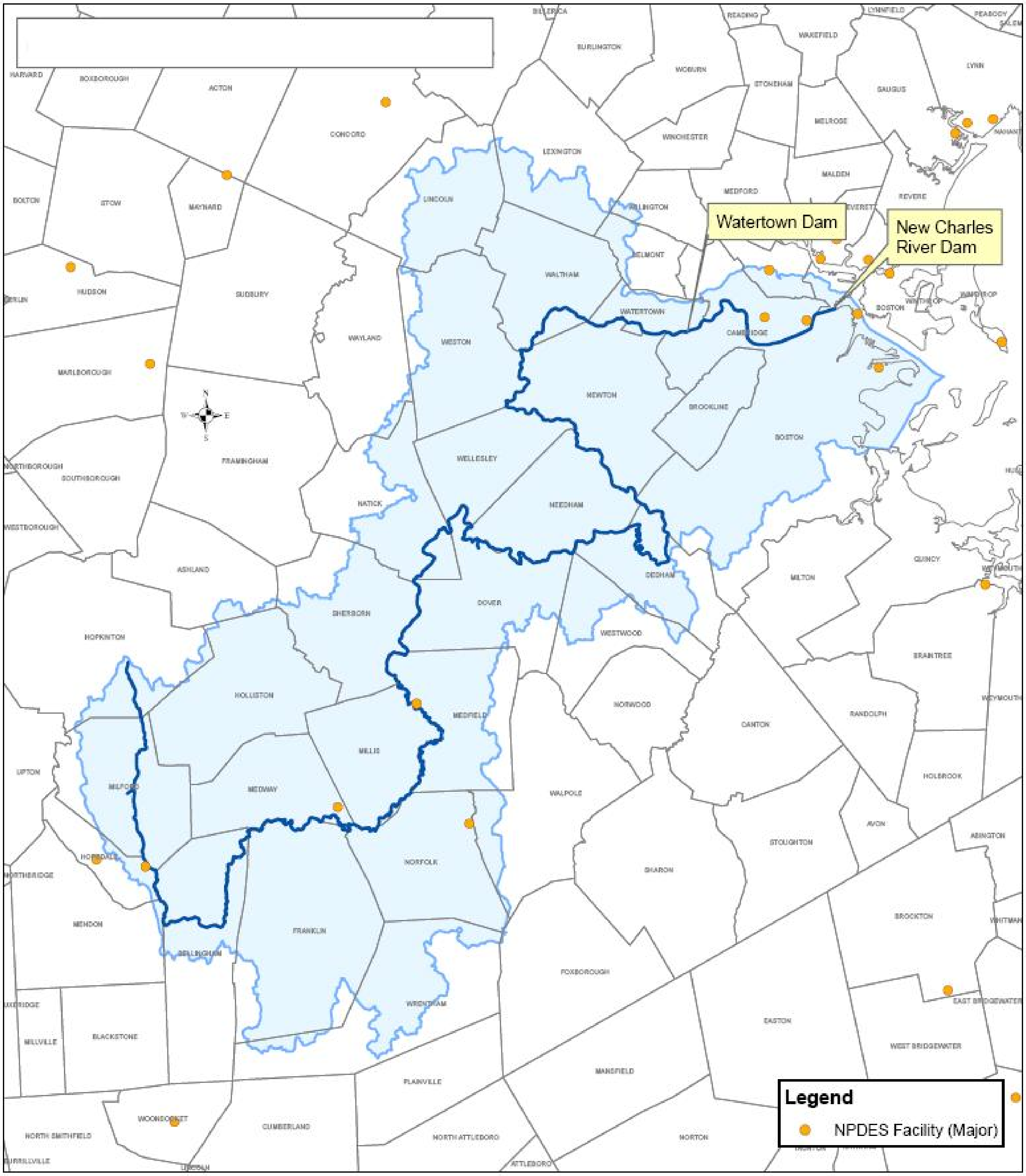

Figure 3-12. Community boundaries and NPDES facilities (WWTFs) in the upper watershed.

Sources of phosphorus from the upstream watershed include WWTF discharges, stormwater runoff, illicit discharges, and natural sources (e.g., adjacent wetland areas, groundwater inflow, and runoff from undeveloped areas). Presently, there is insufficient information available for the entire upstream watershed to quantify the individual contributions of all these sources as they enter the Basin at Watertown Dam. Even though phosphorus loads have been estimated for the WWTFs in the upper watershed, it is not currently possible to determine for a given time, how much of the load at Watertown Dam originated from the WWTFs. The dynamics associated with the fate and transport of phosphorus in the upper watershed has not been studied. Therefore, little is known about overall phosphorus attenuation and retention times as phosphorus moves downstream through the watershed. Nevertheless, ample flow and phosphorus data exist at Watertown Dam to quantify the overall phosphorus load to the Basin. Therefore, for the TMDL analysis, the upstream watershed is being treated as single source.

Figure 3-13 summarizes the annual phosphorus loading to the Basin at the Watertown Dam for the years 1998 to 2002. The TP load for 2000 differs from the estimated TP load reported by the USGS for water year 2000 (Table 3-11). 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).

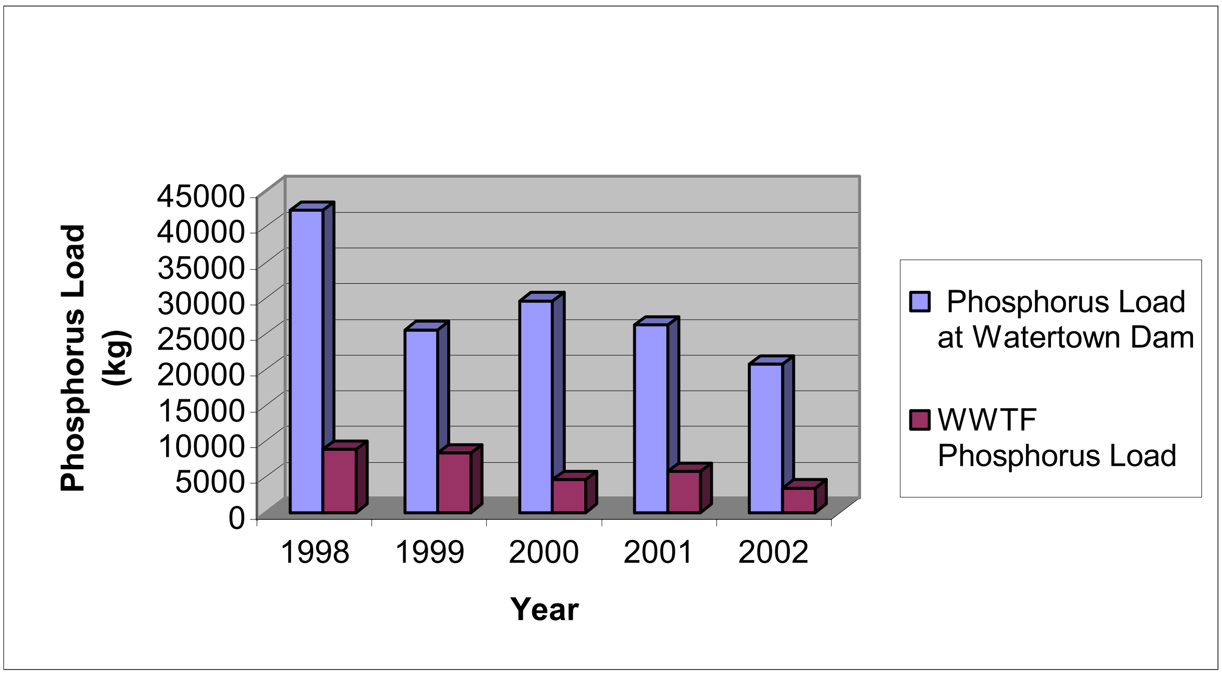

Figure 3-13. WWTF annual phosphorus load compared to phosphorus load at Watertown Dam.

Also shown in Figure 3-13 are the TP loads discharged by WWTFs located in the upper Charles River watersheds (CRWA 2005). 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 (CRWA 2004). 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. More recently, EPA and MADEP 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 the Charles River during the summer growing season.

Figure 3-13 illustrates that the phosphorus load discharged by the WWTFs since 2000 has decreased substantially. 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 3-14 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 3-14. 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 Basin. It is probable that some of the phosphorus discharged by the upstream WWTFs is attenuated as it flows downstream to the Basin. In a river system, such as the Charles, it is possible for pollutants (like phosphorus) to have long travel or retention times, possibly taking many years to reach the Basin (Hoffmann et al. 1996).

Based on the phosphorus loadings at Watertown Dam, there does not appear to have been an obvious effect on the annual phosphorus loading due to the reductions at the WWTFs. This may be due to the relationship between river flow volume, which varies annually and seasonally based on rainfall, and phosphorus loading at Watertown Dam. Figure 3-14 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 nonpoint sources are critical to TP concentrations. 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 Basin over a seasonal or annual basis.

A close examination of phosphorus concentrations and flow data during dry- and wet-weather conditions indicate that wet-weather and high-flow conditions strongly influence phosphorus concentrations entering the Basin. Based on an examination of phosphorus and flow data collected during extended dry-weather low-flow periods in July and August of 1999 and 2002 (before and after the WWTF upgrades), it cannot be determined whether phosphorus concentrations entering the Basin at Watertown Dam during dry-weather low-flow conditions have declined after the WWTF upgrades were implemented.

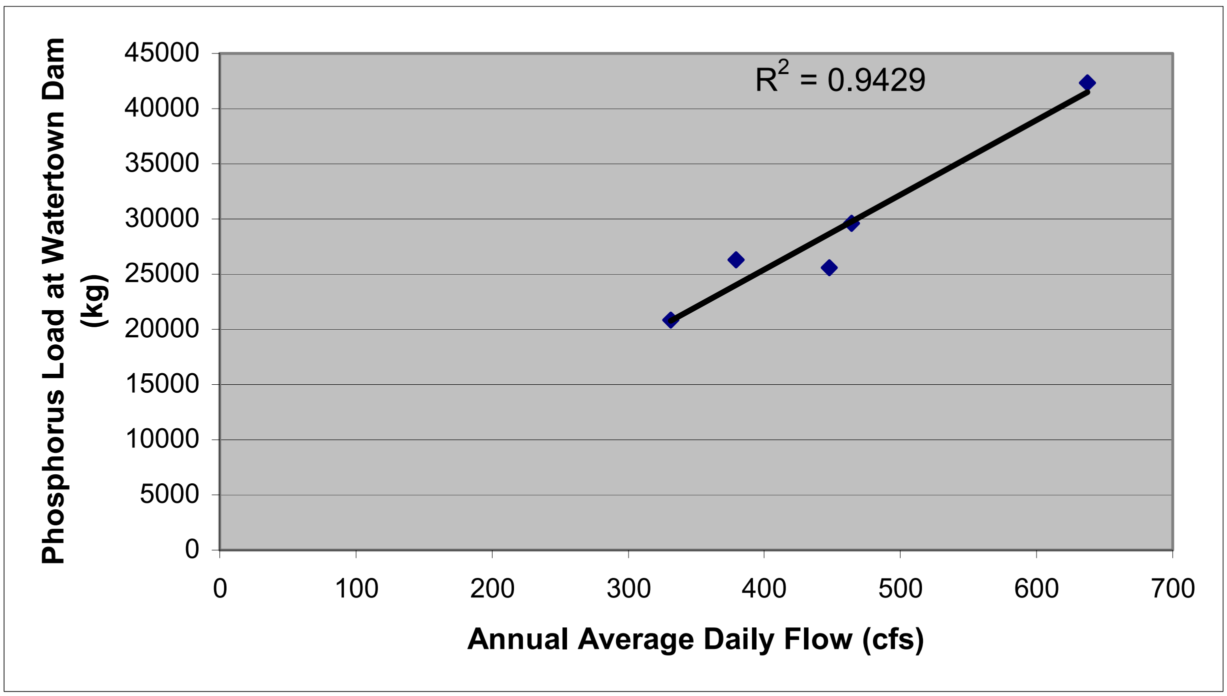

Figure 3-14. Annual flow versus total phosphorus load at Watertown Dam.

The phosphorus loading from the upstream watershed consists of many sources and represents the largest source of phosphorus to the Basin. Presently, there is insufficient information to provide reasonable estimates of the contributions of the various sources to the total phosphorus load entering the Basin at Watertown Dam. Therefore, as discussed above, the upstream watershed is being treated as a single source in this TMDL analysis. 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.

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 blue-green species in the Lower Basin. An increase in river temperatures, potentially because of the thermal discharge from the Kendall Square Station facility, is a concern for controlling algal levels in the Lower Basin. Additionally, there is a concern for the potential shift in the algal community to include more undesirable blue-greens that favor higher temperatures.

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 Basin.

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 Lower 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 (USEPA 2004).

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 3-15 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.

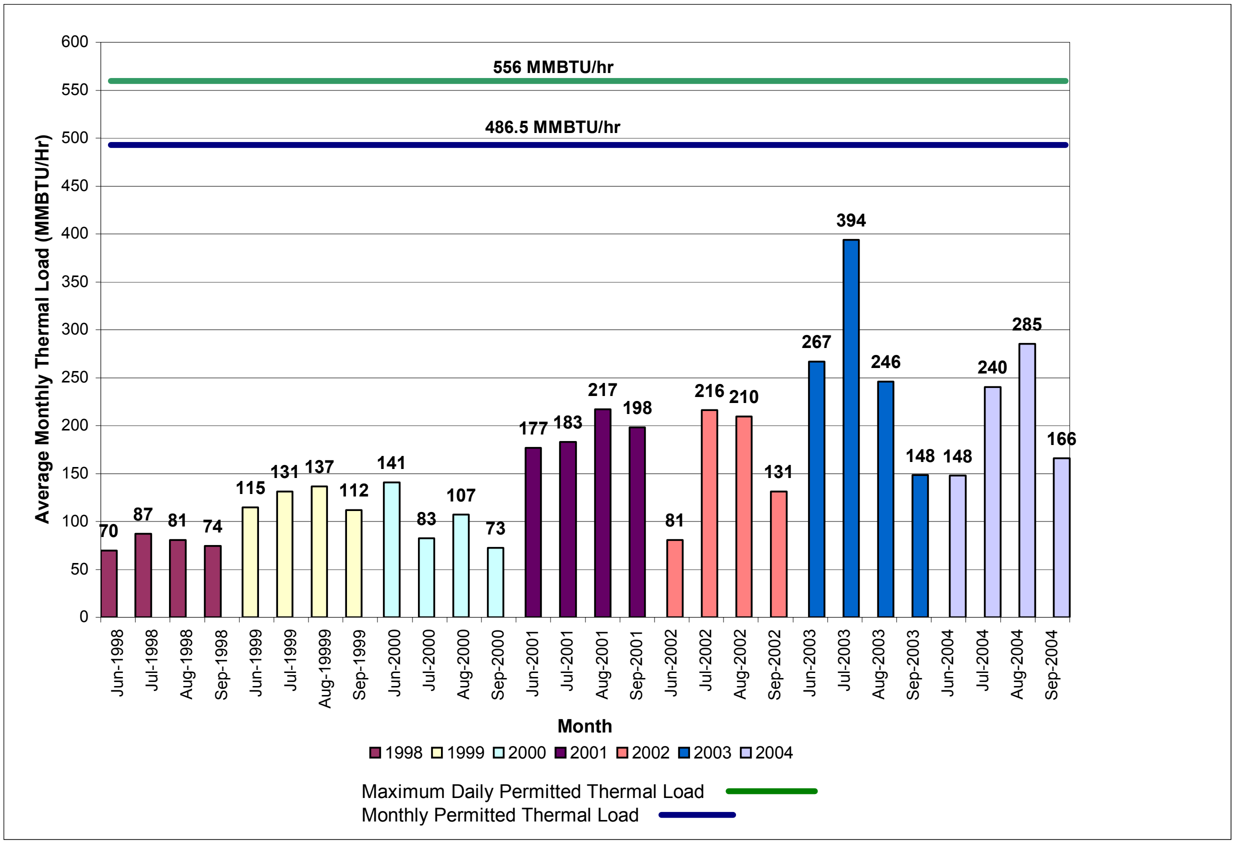

Figure 3-15. Thermal load discharged to the Charles River Basin from Kendall Square Station.

The upgraded facility has the capacity to further increase the thermal load to the Lower Basin and raise river temperatures (USEPA 2004). 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 Lower Basin. For example, on August 18, 1999 river temperatures in the downstream portion of the Lower Basin were observed to be at least 4 ºF higher than temperatures in the upstream portion of the Lower 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 Lower Basin by several degrees F. 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 3-16). 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) to an average of 1.67 day $^{-1}$ at 20 ºC. In the higher temperature range, growth rates for the blue-green species *Anacystis nidulans* varied from 2.64 day $^{-1}$ at 25 ºC to an average of 4.4 day $^{-1}$ at 30 ºC and to 11.0 day $^{-1}$ at 40 ºC.

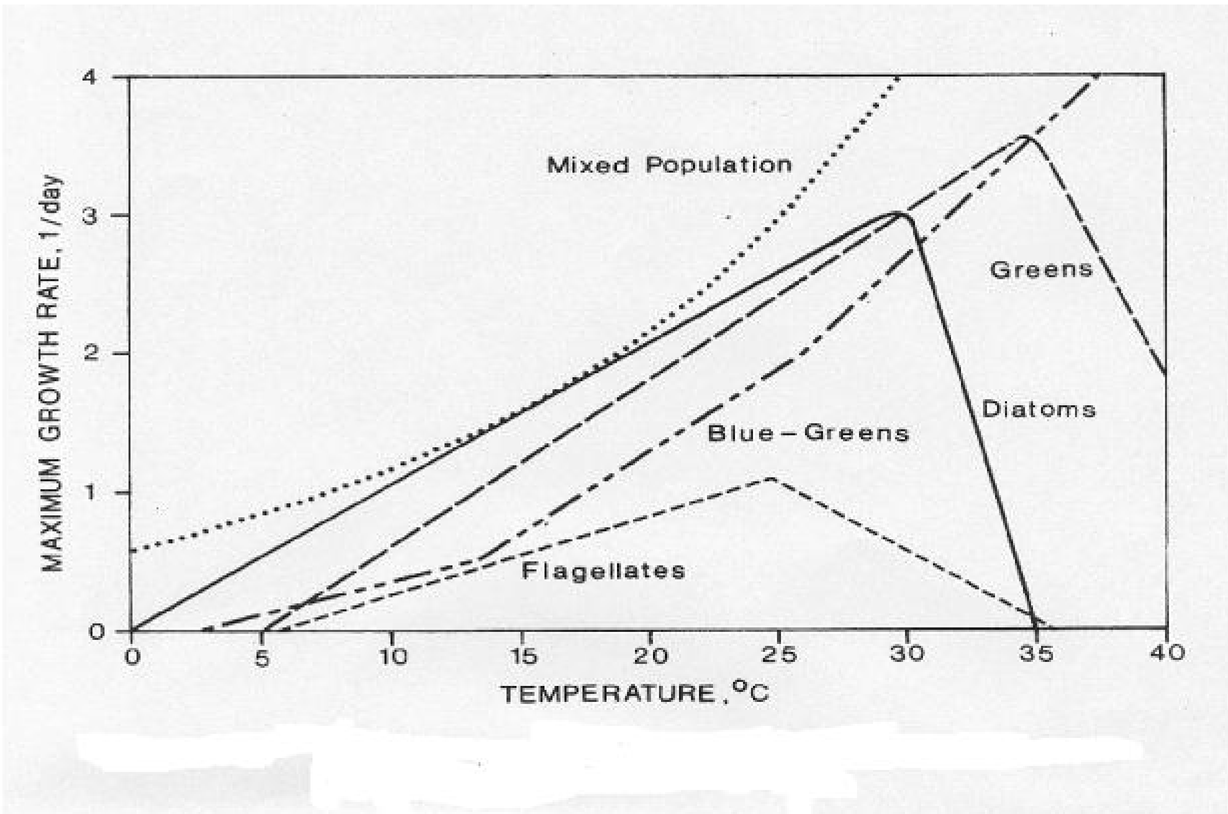

Figure 3-16. Temperature-growth curves for major algal groups from Canale and Vogel, 1974.

Charles River Basin Algal and Temperature Data

During the summer of 2002 EPA conducted algal analyses to document species composition in the Lower 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 Lower 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 Lower 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 3-15 summarizes the upstream and downstream 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 Lower 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 3-15. Relative percent differences in algal counts between the upstream and downstream portions of the Lower Basin

Date	Lower Basin –Upstream (cells or units per ml)					Lower 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	9,951	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[c]	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[b]														
8/7/2003	A	78	2,507	3.1	78.0	B&C[d]	403	2,088	19.3	80.8	2.8	416.7	-16.7	16.2
8/14/2003	A	150	1,601	9.4	79.5	B&C[d]	248	1,383	17.9	82.9	3.4	65.3	-13.6	8.6
8/21/2003	A	351	1,991	17.6	78.7	B&C[d]	510	2,186	23.3	82.9	4.2	45.3	9.8	5.7
8/28/2003	A	168	1,618	10.4	75.0	B&C[d]	472	2,147	22.0	78.1	3.1	181.0	32.7	11.6
9/3/2003	A	281	1,425	19.7	71.0	B&C[d]	390	1,156	33.7	72.5	1.5	38.8	-18.9	14.0
9/17/2003	A	373	1,659	22.5	71.9	B&C[d]	1,426	2,938	48.5	74.6	2.7	282.3	77.1	26.1
9/24/2003	A	176	1,278	13.8	69.7	B&C[d]	1,801	3,084	58.4	71.7	2.0	923.3	141.3	44.6
9/30/2003	A	314	1,607	19.	67.4	B&C[d]	1,339	2,325	57.6	68.9	1.5	326.4	44.7	38.1

[a]A ppositive 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
[d]Represents average of data from Mirant stations B and C

The results do not indicate a clear trend with respect to temperature across the three years. The magnitude of the blooms in the Lower 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 Lower Basin.

The trend of improving water quality in the downstream direction of the Lower Basin usually applies to chlorophyll *a*. The dry-weather chlorophyll *a* data collected by EPA (1998 to 2002) at monitoring stations CRBL06 (upstream – 400 meters downstream of BU Bridge) and CRBL11 (downstream – 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 Lower 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 Lower 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 Basin.

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 Lower 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 Lower 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 Basin during critical periods of the growing season (i.e., mid to late summer). The water quality model will be used during the allocation simulations to further evaluate the relative contribution of thermal pollution from the Kendall discharge to the excessive algae levels in the Lower Basin.

4 TECHNICAL ANALYSIS

While the summary of annual nutrient loadings for the major inputs to the Basin provide a useful overview of the magnitude and the possible relative importance of the nutrient sources entering the Basin, more detailed information on the timing and delivery of the nutrients to the Basin 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 Basin has been developed to simulate the cause and effect relationship between pollutant loadings and algal growth in the Basin. 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 2005).

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 Basin 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 Basin through the 72 storm drain outfalls and 12 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 2005).

5 TMDL ANALYSIS

6 IMPLEMENTATION

7 PUBLIC PARTICIPATION

8 FOLLOW-UP MONITORING AND EVALUATION

9 REFERENCES

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