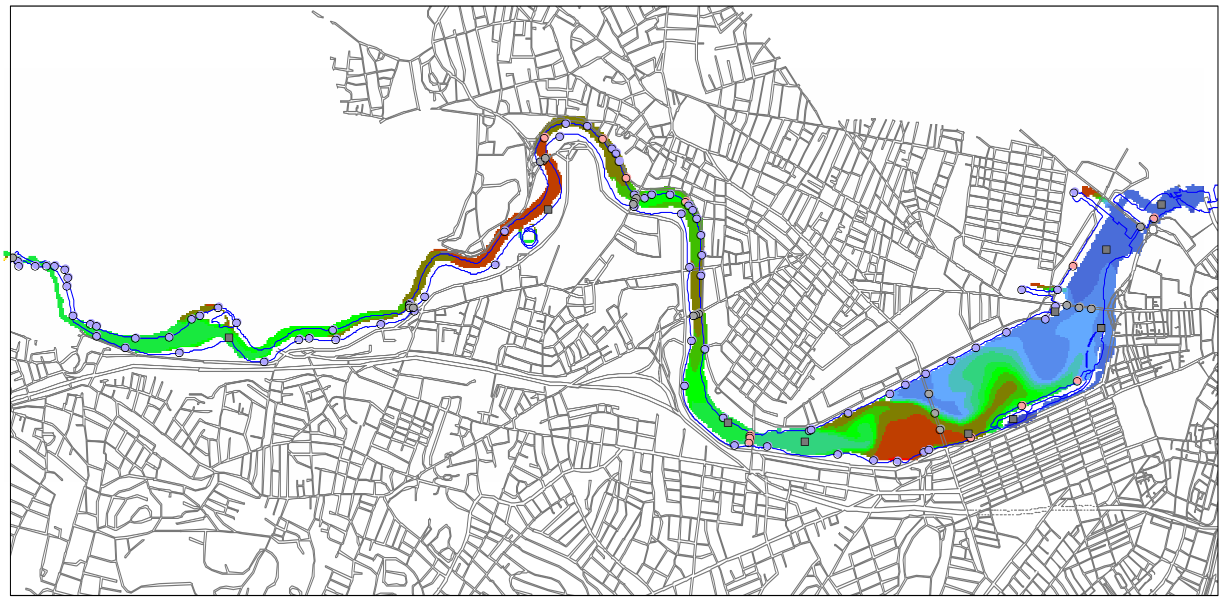
Evaluation of Stormwater Management Benefits to the Lower Charles River



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1. INTRODUCTION

The objective of this study was to assess the improvements in water quality in the Lower Charles River that have already been achieved and could be expected from the implementation of the CSO control plan developed by the Massachusetts Water Resources Authority (MWRA) and different levels of stormwater control including illicit connection removal and Best Management Practices (BMPs).

The Charles River discharges to Boston Harbor after an 80 mile travel from its headwaters in Hopkinton, Massachusetts. The discharge to Boston Harbor occurs through the New Charles River Dam, by gravity, through locks and, when needed, through a pumping station. The Lower Charles River extends from the New Charles River Dam to the Watertown Dam. It is 9 miles long and has a direct watershed area of approximately 36.6 mi^2 that is heavily urbanized, containing densely populated areas of Boston, Cambridge, Newton and Brookline. The drainage area of the Charles River upstream of the Watertown Dam is 268 mi^2.

The Lower Charles has several tributaries, which are shown in Figure 1-1. The largest tributaries are Stony Brook and the Muddy River, both of which discharge between the Boston University and Harvard Avenue Bridges. Other significant tributaries include Faneuil Brook and Laundry Brook, which discharge into the river further upstream, and the Muddy River Conduit, which conveys overflows from the Muddy River during storm events. The Lower Charles River also receives stormwater discharges from 80-some drains, and CSO discharges from 11 outfalls with varying frequency of activation. Several CSOs also discharge to Stony Brook, and hence to the Charles.

In its natural state, the Charles River experienced water level fluctuations due to the tides. In 1908, a dam was constructed where the Museum of Science is now located. This dam was replaced in 1978 with the New Charles River Dam located further downstream. The new dam creates a basin in the downstream portion of the Charles River that is maintained at an elevation of 108 feet (MDC datum). As a result, flow velocities in the pooled area of Lower Charles River are low, resulting in long residence times during dry-weather conditions.

Water quality in the Lower Charles River has been impacted by discharges from upstream, tributaries, storm drains and CSOs. The main problems have been bacteria, water clarity and dissolved oxygen in the saline wedge that exists at depth in the basin (Metcalf & Eddy, 2004; Metcalf & Eddy, 1994 a; US EPA, 2002). Several projects, as well as an intensive campaign of illicit connection removal, have helped improve water quality conditions over the past several years, particularly during dry-weather. During wet-weather, however, the Class B criterion for bacteria (200/100 mL for fecal coliform) is still regularly exceeded.

In 1997, MWRA issued a CSO Facilities Plan that includes a number of measures to decrease CSO discharges to the Lower Charles River (MWRA, 1997). Several of these measures have been implemented already.

To assess the water quality improvements that have already occurred or can be expected as the CSO control plan is fully implemented, and to estimate the further improvements that could be realized through improved stormwater management, long term simulations of fecal coliform were conducted using a two-dimensional model of the Lower Charles. The simulations covered a four-month period coincident with the recreation season: June through September. The model, previously developed for the MWRA CSO project, was used to predict the distribution of fecal coliform as a function of time over the four-month period for the following four sets of conditions:

- 1995 Conditions
- 2002 Conditions (baseline)
- CSO Recommended Plan and basic stormwater BMPs
- CSO Recommended Plan and aggressive stormwater management

To allow comparisons, these four sets of conditions were simulated with the same hydro-meteorological conditions corresponding to the *typical* year developed during the MWRA CSO Program. The *typical* year is based on 1992, with storms removed and added to achieve a close match with long term average conditions (Metcalf & Eddy, 1994 b).

Results are presented in terms of contours of hours of exceedence of the 200/100 mL fecal coliform swimming standard level, as well as plots of acres of violation of this standard as a function of time.

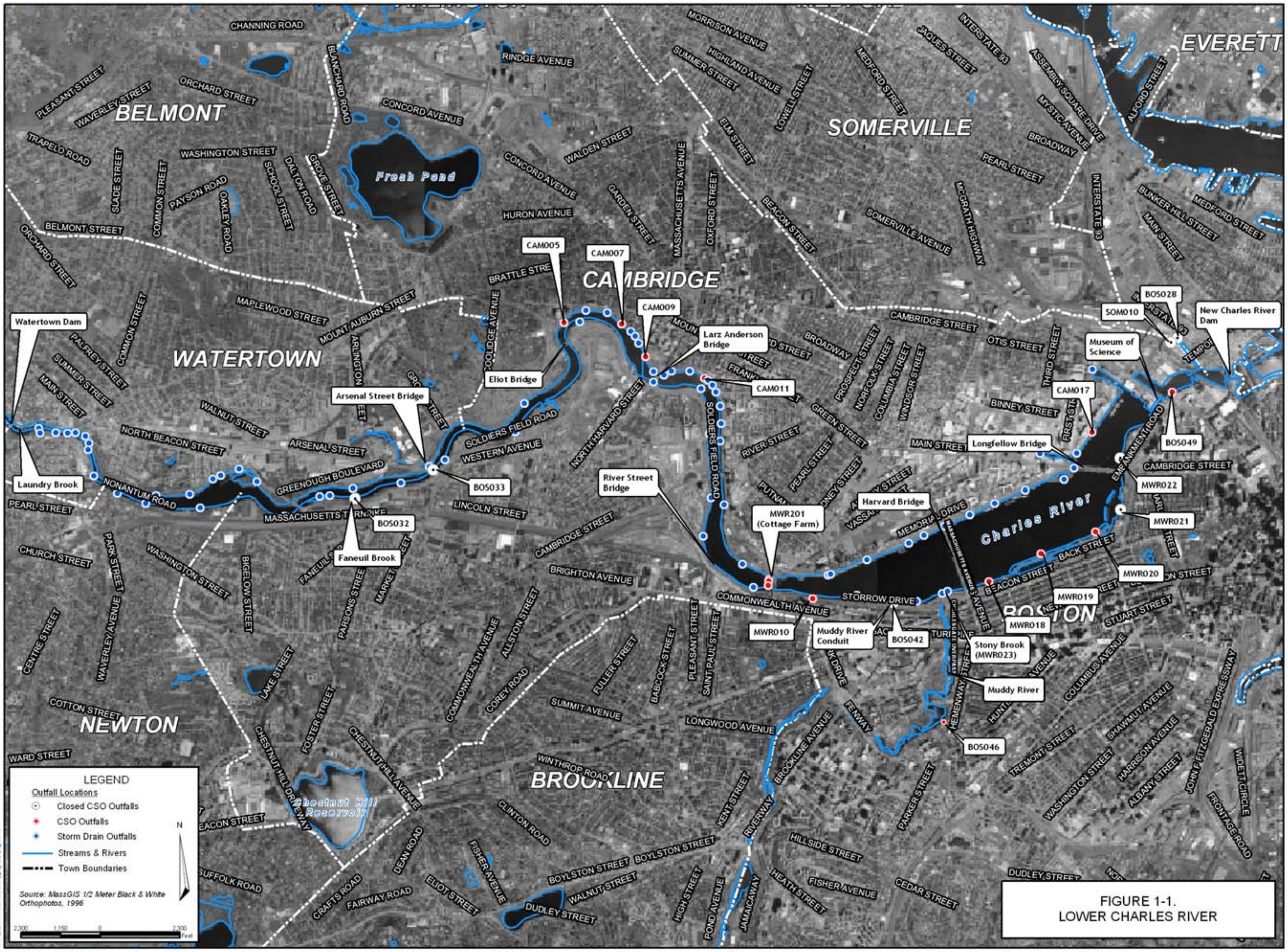

FIGURE 1-1.
LOWER CHARLES RIVER

2. APPROACH

The basic tool used in the project was a two-dimensional hydrodynamic and water quality model of the Lower Charles River, implemented with the MIKE 21 software package. Input to the model came from several sources, which are summarized in Table 2-1. These different elements are briefly described below.

Table 2-1. Summary of Charles River Model Input

	Flow	Quality
Tributaries and storm drains	Model developed by USGS using the EPA Stormwater Management Model (SWMM).	For dry weather, mean concentrations measured by USGS and, for wet weather, Event Mean Concentrations from correlations developed by USGS
CSOs	MWRA collection system model developed with the EPA Stormwater Management Model (SWMM)	Fixed fecal coliform concentration of 538,000/100 mL.
Upstream Boundary	Measurements at Waltham USGS gauging station, corrected to Watertown Dam.	Dry weather: Random concentration with mean and standard deviation based on measurements. Wet weather: Buildup/washoff model calibrated to measurements

2.1 Lower Charles River MIKE 21 Model

MIKE 21 is a two-dimensional flow and water quality model developed and marketed by the Danish Hydraulic Institute. A two-dimensional model was considered necessary to resolve the lateral variations in water quality than can be expected from shoreline discharges with little momentum. These discharges tend to produce shore-attached plumes that mix slowly across the river. Also, in the basin, the large width and low velocities will produce lateral variations.

MIKE 21 solves the depth-averaged equations for continuity, momentum and mass conservation on a rectangular grid using an Alternating Direction Implicit (ADI) numerical scheme for the hydrodynamics, and a variation of the QUICKEST scheme for advection/dispersion. The model calculates the depth-averaged velocity, water surface elevation, and fecal coliform concentrations at the center of the rectangular grid cells.

For the Lower Charles River application, a 10 m x 10 m grid was used. Bathymetry was specified based on a recent survey (Breault et al, 2000), and in the salt wedge area the bottom was set at the wedge interface elevation, at a depth of 7 m, since little transport exists across the interface.

The model was calibrated using measurements conducted by USGS during two storms in July 2000. These measurements were based on sampling at 19 locations in the Lower Charles River and at 8 locations in tributaries and storm drains (Breault et al, 2002; Metcalf & Eddy, 2002).

Some of the more important model parameters that were determined from the calibration are listed in Table 2-2. Fecal coliform die-off was calculated as a function of water temperature and salinity and light intensity using the following formula:

$$K = K_o \, \theta_S^{\,S} \, \theta_I^{\,I} \, \theta_T^{\,(T - 20)}$$

where K_o = die-off rate at 20°C, zero salinity, in the dark (day^{-1}), θ_S = salinity coefficient, S = salinity (ppt), θ_I = light intensity coefficient, I = light intensity averaged over the depth (kW/m^2), θ_T = temperature coefficient, and T = temperature (°C). For light intensity, a sinusoidal variation was assumed over the day, with a different amplitude for each month. Vertical averaging was conducted based on secchi disk depths over the length of the lower Charles measured by MWRA and EPA.

Table 2-2. Model Calibration Parameters.

Parameter		Calibrated Value
Fecal coliform die-off	Base decay rate, K_0	0.6 day^{-1}
	Temperature coefficient, θ_T	1.09
	Salinity coefficient, θ_S	1.006
	Light coefficient, θ_I	7.4
Dispersion	Longitudinal	0.01 m^2/s
	Lateral	0.40 m^2/s

A time step of 5 seconds was required for model stability and the simulations and took approximately 2 weeks to complete for the 4-month period using a 2GHz microcomputer.

2.2 Collection System Models

Three different collection system models were used to determine the discharges from the tributaries, storm drains and CSOs to the Lower Charles River.

The tributary and storm drain flows were determined using a model developed by USGS using SWMM (Zariello and Barlow, 2002). This model covered Laundry Brook, Faneuil Brook and ungaged areas. The model used the RUNOFF block of SWMM to calculate stormwater runoff and the TRANSPORT block to route flows through the drain system. TRANSPORT is a simplified routing model based on the kinematic wave approximation to the flow equations. It is appropriate for systems that are not affected by downstream restrictions.

Flows from the Stony Brook system were calculated using a SWMM model developed by Metcalf & Eddy for the Boston Water and Sewer Commission (BWSC), to design the sewer separation in the Stony Brook area. This model was subsequently recalibrated by USGS. The model uses the RUNOFF and EXTRAN blocks of SWMM. The EXTRAN block is a routing model that uses the full dynamic flow equations. As such it can simulate all the hydraulic phenomena that can affect flow in the collection system.

CSO discharges to the Lower Charles were determined using the MWRA collection system model, which was developed by Metcalf & Eddy for the CSO project (Metcalf & Eddy, 1995). This model uses the RUNOFF and EXTRAN blocks of SWMM and has been extensively calibrated with flow measurements in interceptors and at CSOs.

Stormwater quality varied between the different simulations, as described in Section 5.

2.3 Upstream Boundary Condition

A detailed description of the boundary condition applied at the Watertown Dam is provided in the Appendix, but salient features are briefly described below. The USGS monitoring data indicated that the largest concentrations anywhere in the Lower Charles River were measured at the Watertown Dam, indicating the importance of the upstream boundary as a source of contamination. It must be noted, however, that according to the collection system model, there were no CSO activations to the Charles during these storms. Therefore, for larger storms, with CSO activations, the upstream bacteria counts are probably not the highest.

Flows, as indicated in Table 2-1, were based on actual measured flows in 1992, which is the basis of the typical hydro-meteorological conditions used for the simulations. These flows were corrected from the gauging station in Waltham to the Watertown dam using correlation formulae developed by USGS and provided in the Appendix. Development of the typical hydro-meteorological conditions entailed the removal or replacement of several storms during the June-September period and the upstream flows were modified accordingly.

For fecal coliform, a buildup/washoff model similar to that implemented in the US EPA Stormwater Management Model was used. This model estimates the fecal coliform concentration at Watertown Dam based on the measured flows there. Details on the model and its calibration are provided in the Appendix.

A necessary input to the model is the dry weather concentration, upon which the wet weather component is added. Measurements by the USGS during 1999 and 2000 indicate significant fecal coliform variability at Watertown Dam during dry weather, from 40/100 mL to 5,000/100 mL. Discounting the highest value as an outlier, the average of the measurements was 195/100 mL. This value is just below the 200/100 mL value upon which the Massachusetts water quality standard is based. Using this average in the model would not reflect the frequent excursions above 200/100 mL that are observed. Therefore, the upstream boundary condition was determined using dry weather concentrations given by a random number generator with the appropriate average of 195/100 ml and standard deviation of 160/100 mL. The resulting fecal coliform concentrations during the four-month simulation period are shown in Figure 2-1.

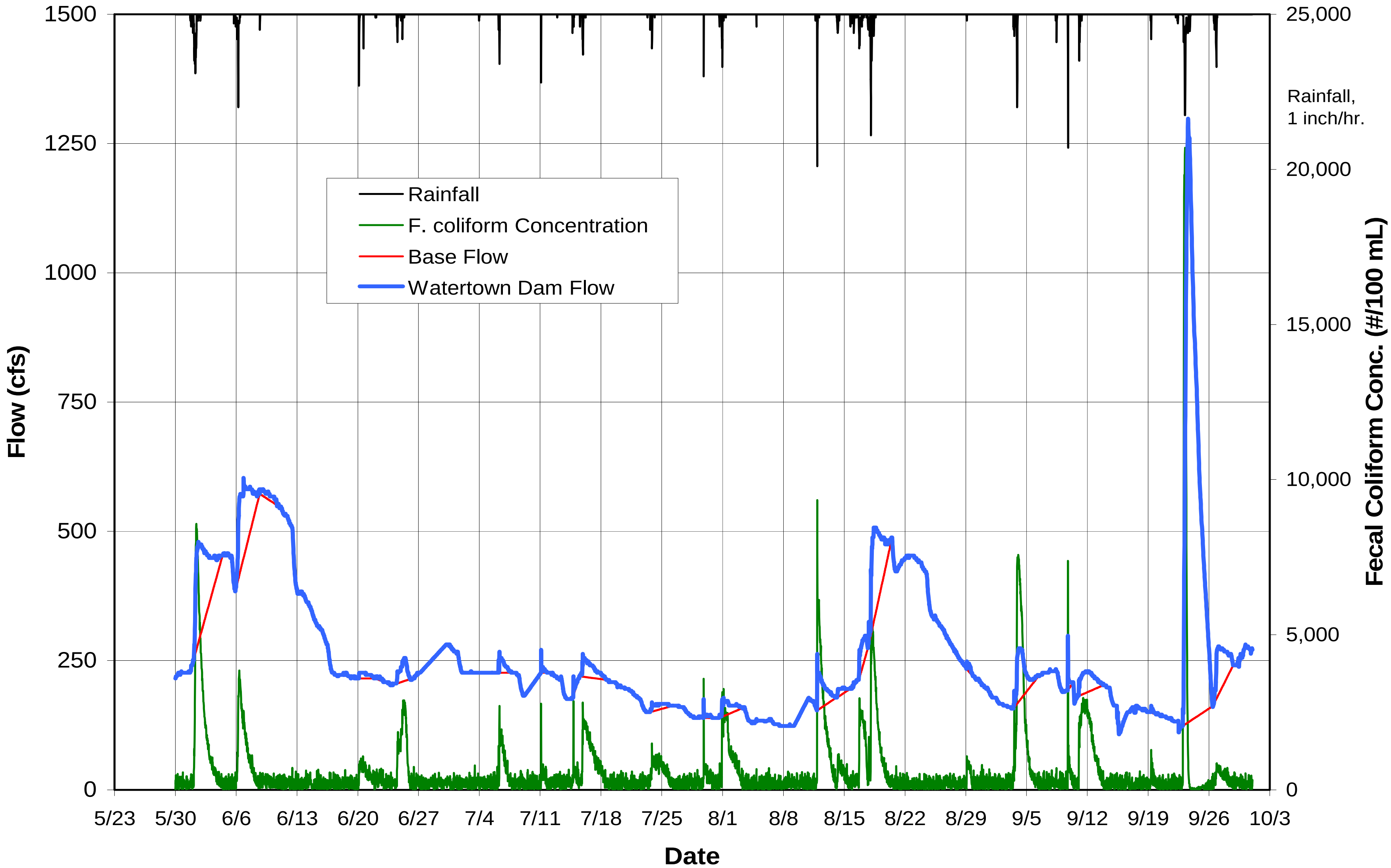

Figure 2-1. Fecal Coliform Concentrations at Watertown Dam

3. MODEL RUN CONDITIONS

The different model runs differed by the fecal coliform loadings that were applied, while flows remained essentially unchanged, except for the CSO discharges, which have a relatively small effect on flow in the river. The different conditions that were simulated are described below in some detail, as they involve a number of different components reflecting different elements of the system.

Fecal coliform concentrations levels in stormwater vary significantly from drain to drain and as a function of time during storms. For example, fecal coliform concentrations are usually higher at the beginning of wet weather events, during the so-called *first flush*. The values that were used in the different simulations are estimates based on data collected in the Lower Charles River, and elsewhere. Values at individual drains would likely deviate from those assumed, but the goal was to reproduce overall loading and illustrate the improvements that can be expected from stormwater management.

3.1 1995 Conditions

This set of conditions is representative of the system as it was prior to the CSO program. The CSO volumes calculated for the 1995 Conditions run are listed in Table 3-1. Some of the important elements of this condition are noted below:

- System Optimization Plans proposed in the early phase of the CSO program were implemented. Those include raising regulator weirs at some CSOs and blockage of several CSO outfalls.

- The Cottage Farm CSO facility had variable performance because disinfectant dosage was manual. As a result, discharge fecal coliform counts had an arithmetic average of 27,000 / 100 ml for 108 samples, and a median of 10 /100 ml (M&E, 1994). This indicates that most of the time, the facility operated correctly, but occasionally the discharge coliform concentrations were extremely high. For the analyses, a representative fecal coliform concentration of 5,000/100 ml was used.

- The Charles River discharge at Watertown was assumed to be the same as for the baseline conditions – see below. This does not account for improvements to dry weather sources that have been implemented from 1995 to 2000, because quantitative data on these improvements were not available.

- Stormwater concentrations were based on those established for the 2002 Baseline Conditions (see below) to which additional loadings were added to represent the illicit connections that were removed from 1995 to 2002. Based on records from BWSC and the City of Cambridge, it was determined that illicit connections totaling 106,000 gallons per day (gpd) were removed from the Stony Brook Conduit, 3,200 gpd was removed from the Muddy River and 83,000 gpd was removed from the Charles river in Cambridge. A fecal coliform concentration of 1×10^6 /100 mL was assumed in the effluent removed.

3.2 Baseline Conditions

This set of conditions is representative of the system in 2002. It includes a number of improvements relative to 1995 conditions, including implementation of some elements of the MWRA CSO Control Plan (MWRA, 1997). In addition, capacity increases at the Deer Island Treatment Plant have resulted in a reduction of CSO discharges to the Charles, notably at Cottage Farm. Specific conditions are:

- Increased flow capacity at the headworks due to increases of pumping and treatment capacity at Deer Island. The headwork with the most influence on overflows to the Charles River is Ward Street, whose capacity increased from 200 to 350 MGD. The corresponding reduction in CSO discharges is indicated in Table 3-1.

- Sewer relief near the CAM 5 CSO.

- Dry weather concentrations of fecal coliform in discharges to the Charles listed in Table 3-2 based on measurements conducted by USGS between July 1999 and September 2000 (USGS, 2002). These measurements indicate very high fecal coliform levels in Faneuil Brook, which can be attributed to illicit connections in this watershed. For un-monitored storm drains, the same concentration as Laundry Brook was used.

- The Charles River discharge at Watertown Dam had an average dry weather fecal coliform concentration of 195/100 ml, based on measurements conducted in 2000 by USGS - excluding one outlier of 5,000 mg/l (USGS, 2002). Added to this average were random variations with a standard deviation of 160/100 ml, also based on the USGS data.

- Stormwater concentrations were specified as constant during each storm event, equal to the Event Mean Concentration (EMC) determined by the USGS from correlations they developed. These correlations were developed between EMCs determined from measurements conducted in 2000, and several storm characteristics including antecedent conditions, duration, total depth and intensity. Different correlations were developed for the different locations listed in Table 3-2, each using the parameters found to be statistically significant. For un-monitored storm drains, the same concentration as Laundry Brook was used.

- Cottage Farm upgrade was completed in 2000. The upgrade mainly consisted of a new hypochlorite dosing system and sodium bisulfite dechorination system. As a result of these improvements, the average fecal coliform concentration of the Cottage Farm discharge decreased to 10/100 ml.

Table 3-1. CSO Volumes for Different Conditions

	Date	Rainfall Depth (inch)	Overflow Volume (MG)										
			CAM 5	CAM 7	CAM 9	CAM 11	MWR 201 Cottage Farm	MWR 10	Stony Brook	MWR 18	MWR 19	MWR 20	CAM 17
Design Storms, CSO Recommended Plan													
3-month	20-Jul-82	1.84	-	-	-	-	1.9	-	-	-	-	-	-
1-year	20-Sep-61	2.79	0.0012	-	-	-	14.8	-		0.5	0.09	0.01	0.006
June-September, Typical year													
1995 Conditions	31-May	2.24	-	-	-	-	30.36	-	6.23	-	-	-	-
	5-Jun	1.34	0.12	-	0.02	-	3.74	-	0.59	-	-	-	-
	31-Jul	0.59	0.01	-	-	-	0.38	-	0.22	-	-	-	-
	11-Aug	0.87	0.61	0.04	0.02	-	4.55	-	-	-	-	-	-
	15-Aug	2.91	0.49	0.02	0.03	-	16.48	-	3.35	-	-	-	-
	3-Sep	1.19	0.16	-	-	-	9.4	-	0.43	-	-	-	-
	9-Sep	0.57	0.36	-	0.01	-	2.04	-	-	-	-	-	-
	22-Sep	2.76	0.88	0.03	0.03	0.01	35.98	-	9.11	0.94	0.21	0.04	0.04
	26-Sep	0.74	-	-	-	-	4.94	-	2.02	-	-	-	-
	Total		2.63	0.09	0.11	0.01	107.87	-	21.95	0.94	0.21	0.04	0.04
2002 Baseline Conditions	31-May	2.24	-	-	-	-	17.1	-	6.23	-	-	-	-
	5-Jun	1.34	-	-	0.02	-	2.89	-	0.59	-	-	-	-
	15-Jul	0.5	-	-	0.01	-	-	-	-	-	-	-	-
	31-Jul	0.59	-	-	-	-	0.39	-	0.22	-	-	-	-
	11-Aug	0.87	0.24	0.07	0.03	-	4.19	-	-	-	-	-	-
	15-Aug	2.91	0.14	0.09	0.03	0.0025	10.68	-	3.30	-	-	-	-
	3-Sep	1.19	-	-	-	-	5.17	-	0.44	-	-	-	-
	9-Sep	0.57	0.15	0.04	0.02	-	1.93	-	-	-	-	-	-
	22-Sep	2.76	0.15	0.08	0.02	-	23.99	-	9.13	0.88	0.17	0.05	0.08
	26-Sep	0.74	-	-	-	-	1.96	-	2.01	-	-	-	-
	Total		0.68	0.28	0.13	0.0025	68.3	-	21.92	0.88	0.17	0.05	0.08
CSO Recom-mended Plan	31-May	2.24	-	-	-	-	6.79	-	-	-	-	-	-
	5-Jun	1.34	-	-	-	-	0.23	-	-	-	-	-	-
	11-Aug	0.87	-	-	-	-	0.27	-	-	-	-	-	-
	15-Aug	2.91	-	-	-	-	2.02	-	-	-	-	-	-
	3-Sep	1.19	-	-	-	-	0.46	-	-	-	-	-	-
	22-Sep	2.76	-	-	-	-	12.77	-	-	0.35	0.06	-	0.0008
	26-Sep	0.74	-	-	-	-	1.37	-	-	-	-	-	-
	Total		-	-	-	-	23.91	-	-	0.35	0.06	-	0.0008

Table 3-2. Dry Weather Fecal Coliform Concentrations in Discharges to the Charles

Location	Mean Fecal Coliform Concentration (#/100 mL)
Charles River at Watertown Dam	195
Single Family Use	16,000
Laundry Brook	1,800
Faneuil Brook	66,000
Multifamily Land Use	8,500
Commercial Land Use	5,100
Muddy River	550
Stony Brook	47

3.3 CSO Recommended Plan and Basic Stormwater BMPs

This scenario corresponds to full implementation of the MWRA CSO Control Plan, with the additional implementation of systematic, but basic stormwater management measures. These include significant reduction in the number of illicit connections, and basic stormwater BMPs, such as street sweeping. The corresponding pollutant loading reductions were specified by EPA based on various sources including an assessment of the benefits of stormwater BMPS conducted by USGS (Zariello et al, 2002). The specific improvements relative to baseline conditions are:

- Sewer separation in Stony Brook. This will considerably decrease CSO discharges to Stony Brook, and free up capacity at Ward Street, reducing CSO discharges to the Charles. However, stormwater discharges will increase, for which a fecal coliform concentration of 22,000/ml was used. Recent sampling by EPA at several storm drains in Cambridge from which illicit sources were removed indicate that considerably lower values can be achieved.

- Elimination of dry weather illicit connections, leading to dry weather fecal coliform concentrations of 100/100 ml. The recent EPA sampling in Cambridge – mentioned above – confirms that fecal coliform concentrations in storm drains can realistically be reduced to that level after aggressive illicit connection removal work.

- Reduction in all wet weather coliform concentrations by 15%, with further reduction of concentrations at Faneuil Brook to the same level as Laundry Brook.

- Reductions in upstream illicit connections leading to dry and wet weather fecal coliform concentration reductions of 50% and 15% respectively at Watertown Dam. Recent communications between EPA and the cities of Newton and Waltham indicate that serious illicit source problems exist upstream of Watertown Dam. EPA believes that aggressive illicit source removal would result in greater than 50% reduction at this location during dry weather.

3.4 CSO Recommended Plan and Aggressive Stormwater Management

This set of conditions represents the extreme of dry weather and wet weather stormwater quality that could occur if aggressive illicit connection removal is implemented, and all possible BMPs are applied to their fullest extent.

- Stormwater concentration of 2,000/100 ml applied throughout, instead of the EMCs developed by the USGS.

- Elimination of all dry weather illicit connections, leading to dry weather fecal coliform concentrations of 100/100 ml for drains where concentrations exceeded that value. For drains that did not exceed this value, such as Stony Brook, the original value was retained.

- Charles River discharge at Watertown during dry weather was assumed to be 50% of the baseline conditions, and the wet weather component capped at 2,000/100 ml.

4. RESULTS

The Lower Charles River is currently designated as Class B, under the Massachusetts Surface Water Quality Standards. A temporary variance allows CSO discharges until sufficient information is available to establish appropriate water quality standards and level of CSO control. A Class B_{CSO} has been requested by MWRA, which would allow short term departures from the Class B standards due to CSO discharges, but this new class has not been implemented yet.

For fecal coliform, the Massachusetts Surface Water Quality Standards establish the following conditions for Class B waters: *Fecal Coliform bacteria shall not exceed a geometric mean of 200 organisms per 100 ml in any representative set of samples, nor shall more than 10 percent of the samples exceed 400 organisms per 100 ml. This criterion may be applied on a seasonal basis at the discretion of the Division* (MADEP, 1990). Class B water are meant to be suitable for primary and secondary contact recreation.

The model calculates the distribution of fecal coliform over the entire Lower Charles River at 5-seconds intervals. As indicated previously this time step is dictated by model stability considerations rather than by the need for such a resolution. At any rate, the model results do not lend themselves to evaluation of compliance with the water quality standard, which is based on the geometric mean of a “representative” number of samples. Therefore water quality for the different scenarios was assessed by comparing calculated fecal coliform concentrations with the 200/100 mL threshold used in the standard. Because of the long duration of the simulations, the volume of model output was massive (32 Gigabytes for the 4-month simulation). Therefore, the model results were reduced in ways that would produce an overall assessment of water quality in condensed form.

4.1 Exceedence Time Contour Plots

Contour plots of the percent time that the calculated fecal coliform concentrations exceed the 200/100 ml threshold were produced. To develop these plots the number of time steps when the threshold was exceeded at each model cell was determined and divided by the total number of time steps. These contour plots for the four simulation scenarios are shown in Figures 4-1 to 4-4.

For 1995 conditions, the plot shows that the 200/100 mL threshold was exceeded most of the time in the upper portion of the Lower Charles, consistent with observations (Metcalf & Eddy, 1994 a). In the basin, however, except for the immediate vicinity of the Stony Brook and Muddy River discharges, levels were usually below the threshold. The reason is that most of the sources are upstream, and long residence times in the basin promote bacterial die-off.

For 2002 conditions, threshold exceedences were considerably reduced. In particular, the exceedence frequency in the upstream portion of the segment decreased from 90-100% to 40-60%, except for a small area near Faneuil Brook. This change is mainly attributable to the reduction of illicit connections. Reduced CSO activations at Cottage Farm improved conditions in the mid segment.

Further exceedence reductions arise for the two stormwater control scenarios, to frequencies of 10-20% for the ideal stormwater conditions.

4.2 Exceedence Areas

Another measure of water quality is the fraction of the surface area of the Lower Charles where the threshold is exceeded. This fraction is plotted as a function of time in Figure 4-5. During storms, the area exceeding the threshold increases, reflecting wet weather inputs. For 1995 conditions, however, exceedence areas remain high during dry weather because of the illicit connections. At the other extreme of the CSO Control Plan with ideal stormwater control measures, threshold exceedences still occur in conjunction with wet weather events, but the entire river is below the threshold during dry weather.

Even more concise measures of water quality conditions are provided by the total acre-days of threshold exceedence over the four-month period, and the average percent area of exceedence. These numbers, which are summarized in Table 4-1, show a dramatic improvement with implementation of the CSO Recommended Plan and stormwater control.

Table 4-1. Threshold Exceedence Statistics

	Acre-days of Threshold Exceedence	Average percent area of Threshold Exceedence
1995 Conditions	114,600	65%
2002 Conditions	60,200	34%
CSO Recommended Plan and Basic Stormwater BMPs	35,600	20%
CSO Recommended Plan and Aggressive Stormwater Management	12,200	7%

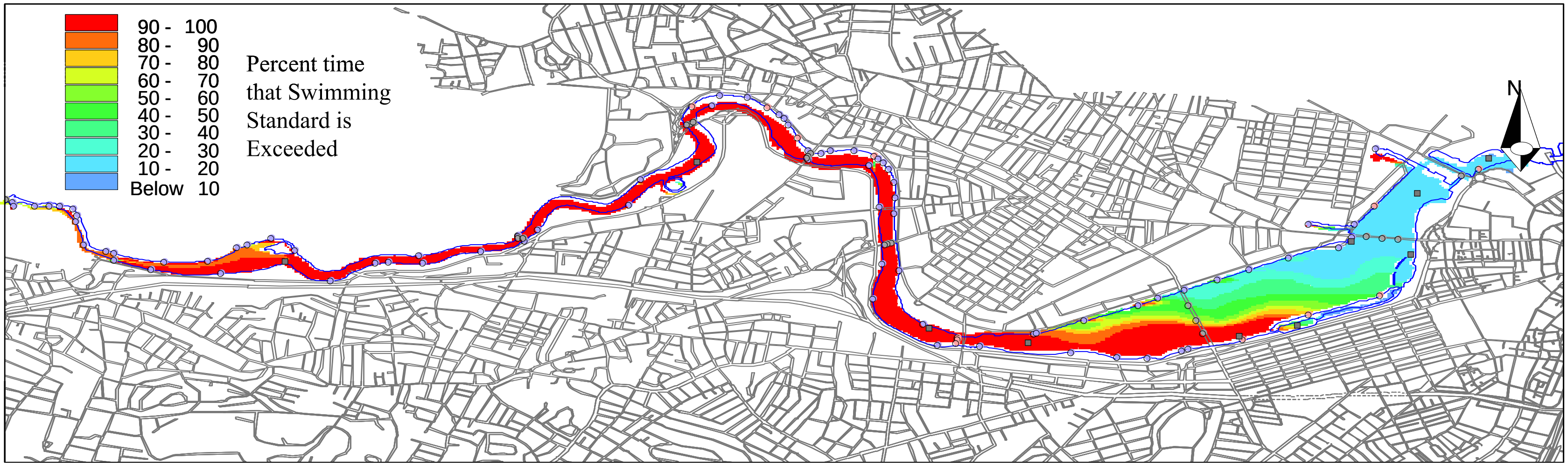

Figure 4-1. Contours of Percent time that Fecal Coliform Exceeds 200/100 mL for 1995 Conditions

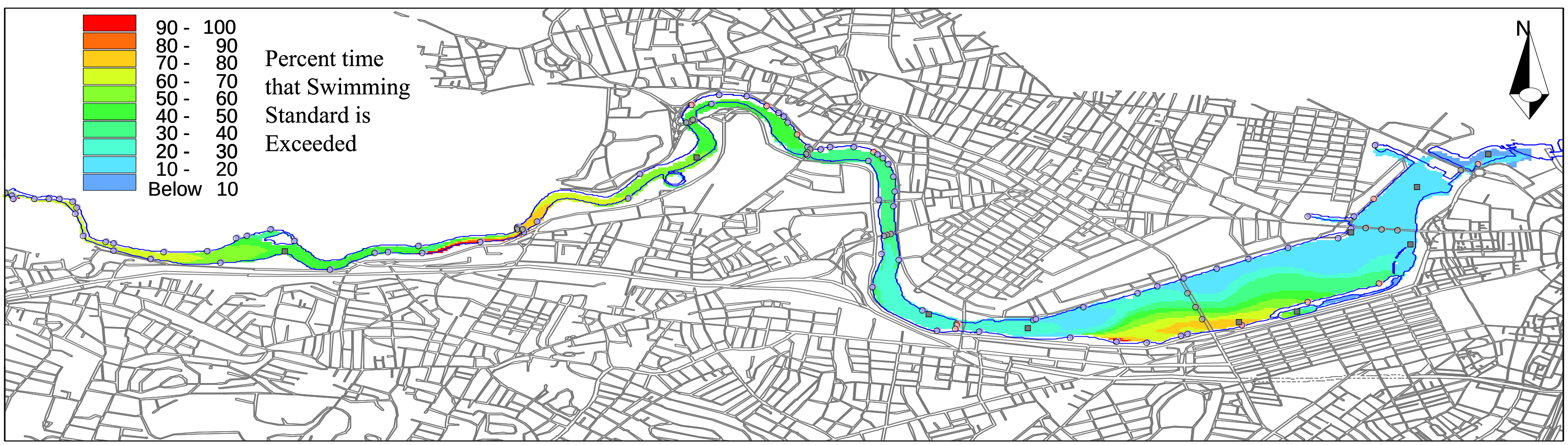

Figure 4-2. Contours of Percent time that Fecal Coliform Exceeds 200/100 mL for 2002 Conditions

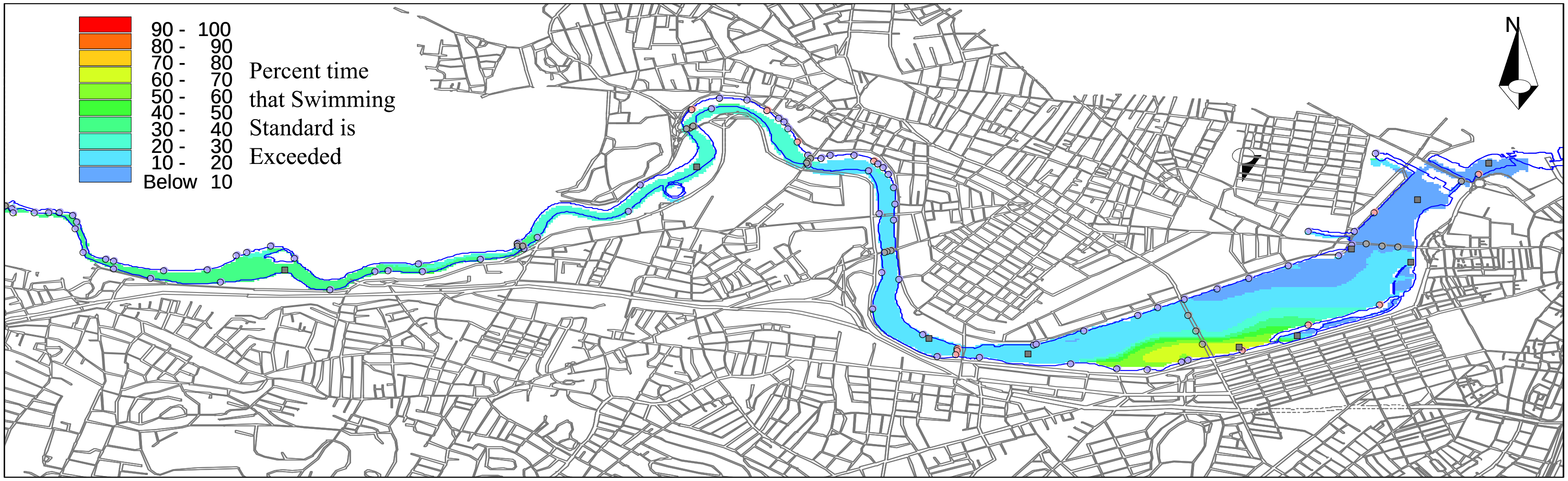

Figure 4-3. Contours of Percent Time that Fecal Coliform Exceeds 200/100 mL – CSO Control Plan + Basic BMPs

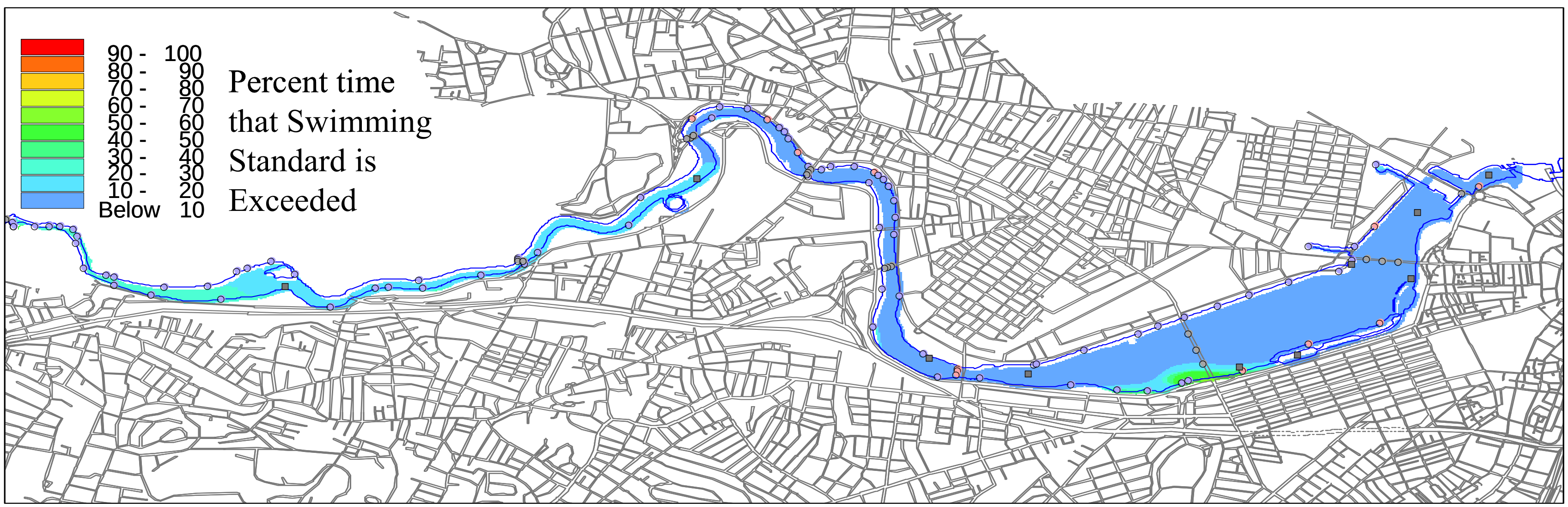

Figure 4.4. Percent Time that FC Exceeds 200/100 mL – CSO Control Plan + Aggressive Stormwater Management

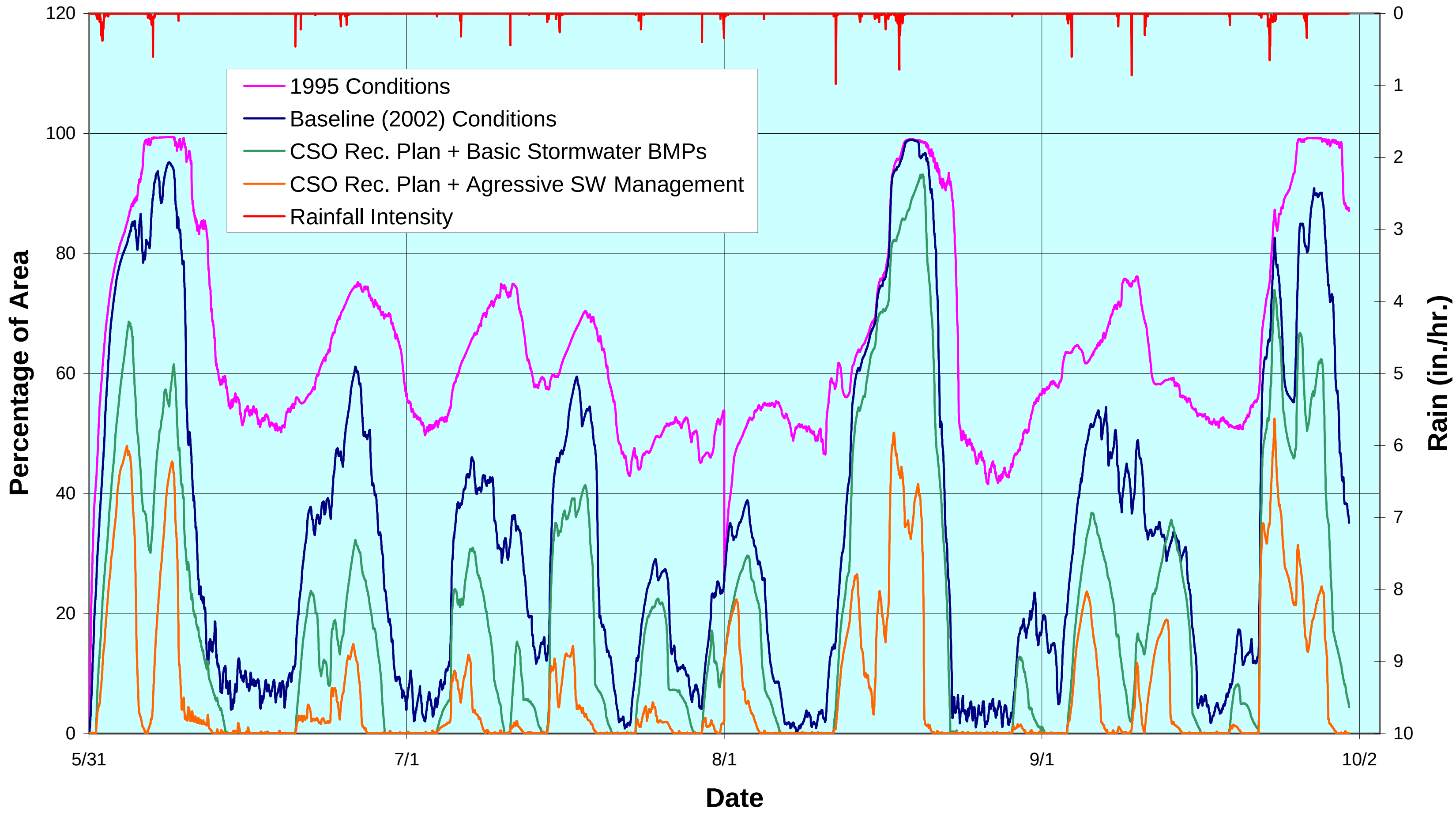

Figure 4-5. Percent of Lower Charles River Area where Fecal Coliform exceed 200/100 mL

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Appendix
Upstream Boundary Conditions Model

Upstream Boundary Condition Model

During wet weather events, flows and pollutant concentrations at the Watertown Dam increase due to upstream runoff and non-point sources. For the Lower Charles River model, both upstream flows and concentrations must be specified. Those were measured for the calibration storms and thus were be specified from the measurements, but for design storms or typical year simulations, a means of estimating upstream flow and concentrations is needed. Both the design storms (3-month and 1-year) and the typical year are based on actual events. Therefore, flows for these periods can be estimated from the USGS gauge at Waltham (No. 01104615) using the following correlation (Zariello and Barlow, 2002).

$$Q_{WD} = 6.8097\, Q_{WG}^{0.7334} \quad \text{for} \quad Q_{WG} < 450 \text{ cfs}$$
$$Q_{WD} = 3.6605\, Q_{WG}^{0.8341} \quad \text{for} \quad Q_{WG} > 450 \text{ cfs}$$

where: Q_{WD} = Flowrate at Watertown Dam (cfs)
Q_{WD} = flow at Waltham gauge (cfs)

Concentrations, however, need to be estimated. Regression formulae were developed to estimate event mean concentrations (EMC) for different pollutants at Watertown Dam, based on the rainfall depth and antecedent conditions (Breault et al, 2002). However, the bacteria counts measured at Watertown Dam during 2000 show a rapid increase followed by a drop much more rapid than the drop of flow. Thus for this modeling, which seek to predict concentrations in the river as a function of time, application of an EMC to the upstream boundary is questionable. Because the flow increase over pre-storm conditions is prolonged, the EMC is necessarily low, and this does not account for the high values observed. Using EMCs, however, is appropriate for estimation of storm or annual loadings of pollutants to the lower Charles.

Estimation of bacteria concentrations at Watertown dam for the purpose of transient water quality modeling in the Lower Charles was previously accomplished using a buildup/washoff approach (Metcalf & Eddy, 1994). This is the approach used for pollutant generation modeling in the USEPA Stormwater Management Model (SWMM) (Huber and Dickinson, 1988). In this approach, pollutants are assumed to buildup in the catchment during dry weather, and get washed off by runoff at a rate dependant on the runoff intensity. It is obviously an approximation, especially for the 265 mi^2 Charles drainage area upstream of Watertown Dam. Among other simplifications, it does not account for bacterial die-off that occurs during the travel time from upper reaches of the river. Nevertheless, the approach simulates some of the mechanisms that lead to increased concentrations in the river, and it produces simulated bacterial counts at Watertown Dam that resemble those observed. Therefore, with judicious calibration, it may be used to provide estimates of upstream water quality boundary conditions.

The previous buildup/washoff model assumed a linear buildup of pollutant during dry weather. Data from the year 2000 calibration storms suggests a decrease of the buildup rate with time, at least for bacteria. This can be justified based on bacterial die-off in the buildup. Thus, the previous model was modified to include buildup die-off:

$$\frac{dP(t)}{dt} = aA - kP(t)$$

where: P(t) = Fecal coliform buildup at time t (#)
a = Buildup rate (#/day/mi^2)
A = Drainage area (mi^2)
k = Die-off rate (day^{-1})

This equation can be integrated to give: $P(t) = \frac{aA}{k}\left(1 - e^{-kt}\right)$

Thus, for increasing dry weather time, the buildup tends towards a maximum value of *aA/k*. The time needed to reach 95% of this ultimate value is: t_{95} = 3.00 / k. Die-off rates for fecal coliform buildup during dry weather is not well documented. Using a value of k = 0.5 day^{-1} (somewhat smaller than die off rate in water) gives t_{95} = 4.5 days, which is reasonable.

During wet weather, washoff is dependant on the previous buildup and the runoff rate:

$$L(t) = -\frac{dP(t)}{dt} = \alpha\, Q_R^{\beta}\, P(t)$$

where: L(t) = bacterial loading to stream through washoff (#/day)
Q_R = runoff flowrate, cfs
α, β = coefficients determined by calibration

The resulting concentration in the stream is:

$$C = \frac{Q_B C_B + L(t)}{Q_B + Q_R}$$

where: Q_B = base flow, cfs
C_B = base flow concentration,

Calibration plots for this model for the storms of July 16, 2002, July 27, 2002 and November 4, 1992 are attached. The values of the coefficients that were used are a = 2.0×10^{11} #/mi^2/day, $\alpha = 1.25 \times 10^{-3}$, β = 1.3 and k = 0.5 day^{-1}. The peak bacteria count for the November 1992 storm is underpredicted by the model. This may be because improvements have taken place since 1992 that reduce non-point sources.

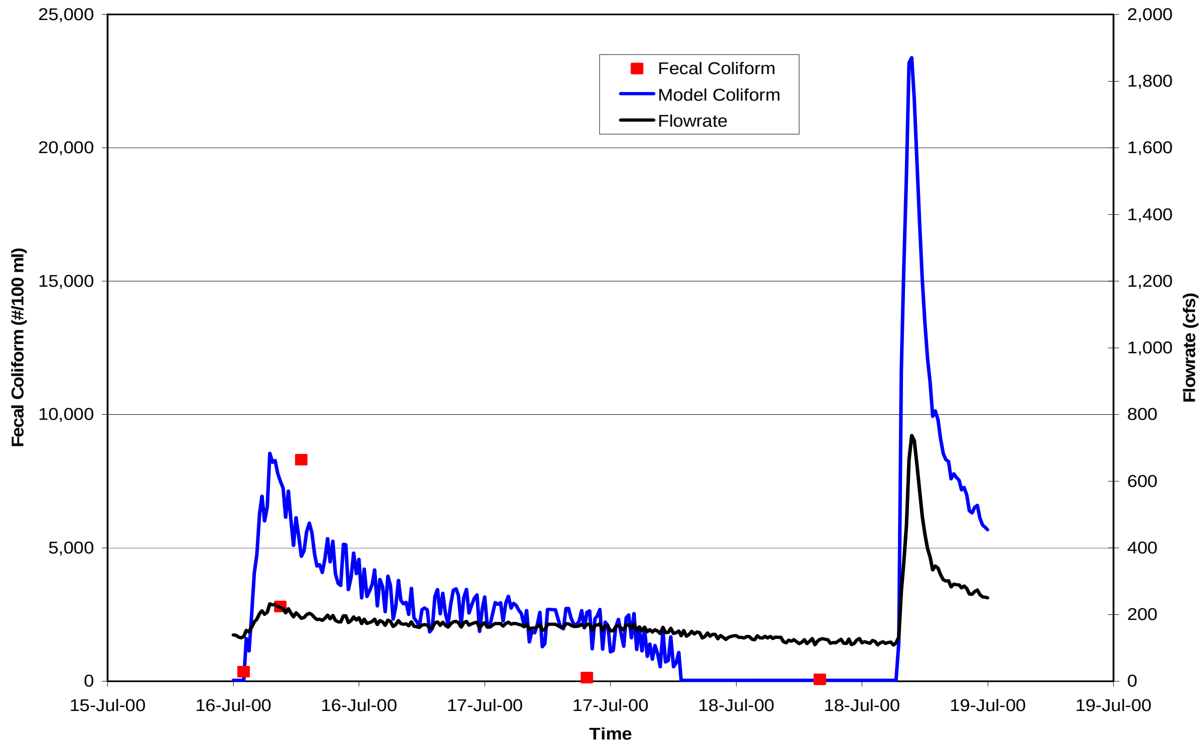

Figure 1. Model and Measurements for July 16, 2000 Storm

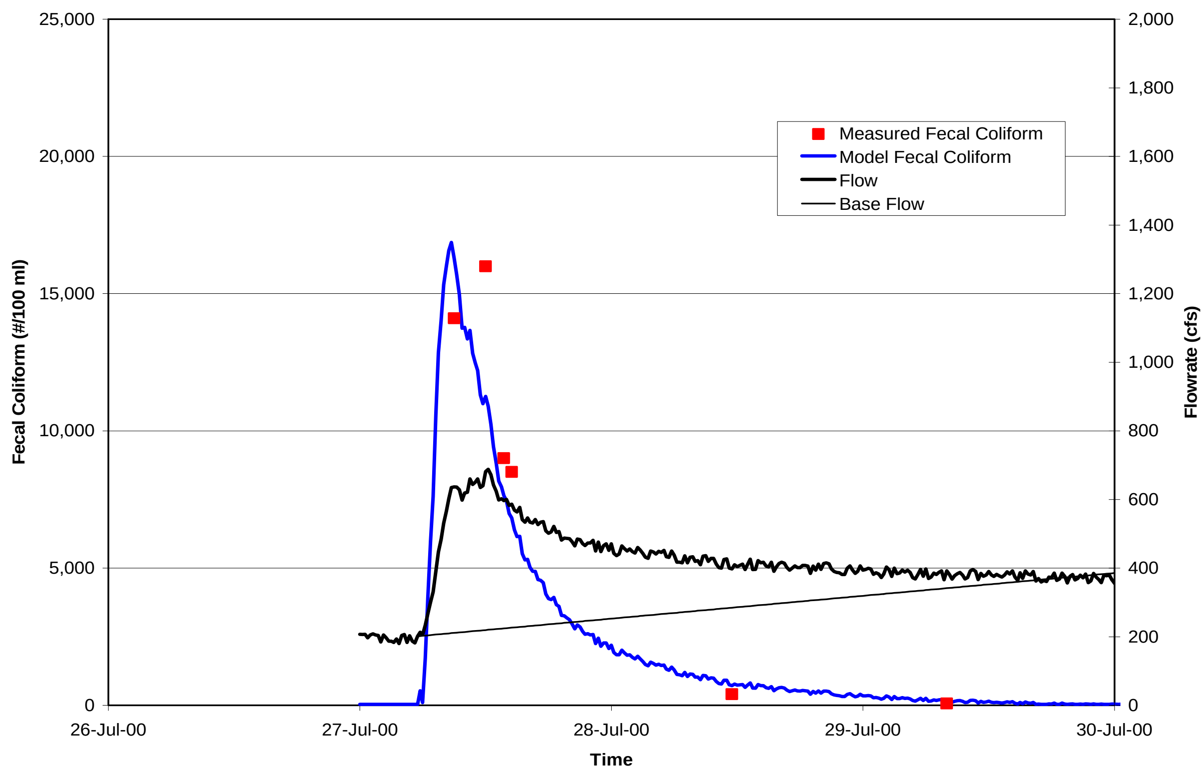

Figure 2. Model and measurements for July 27, 2000 Storm

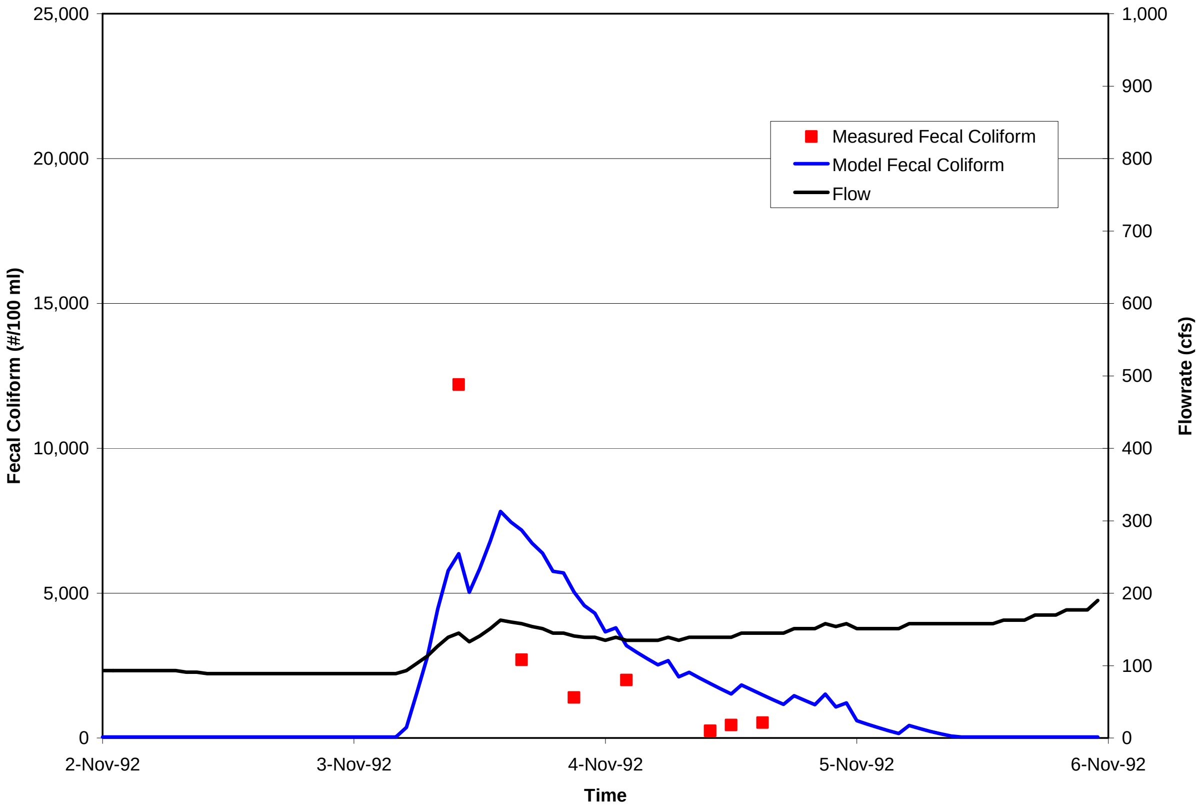

Figure 3. Model and Measurements for November 3, 1992 Storm

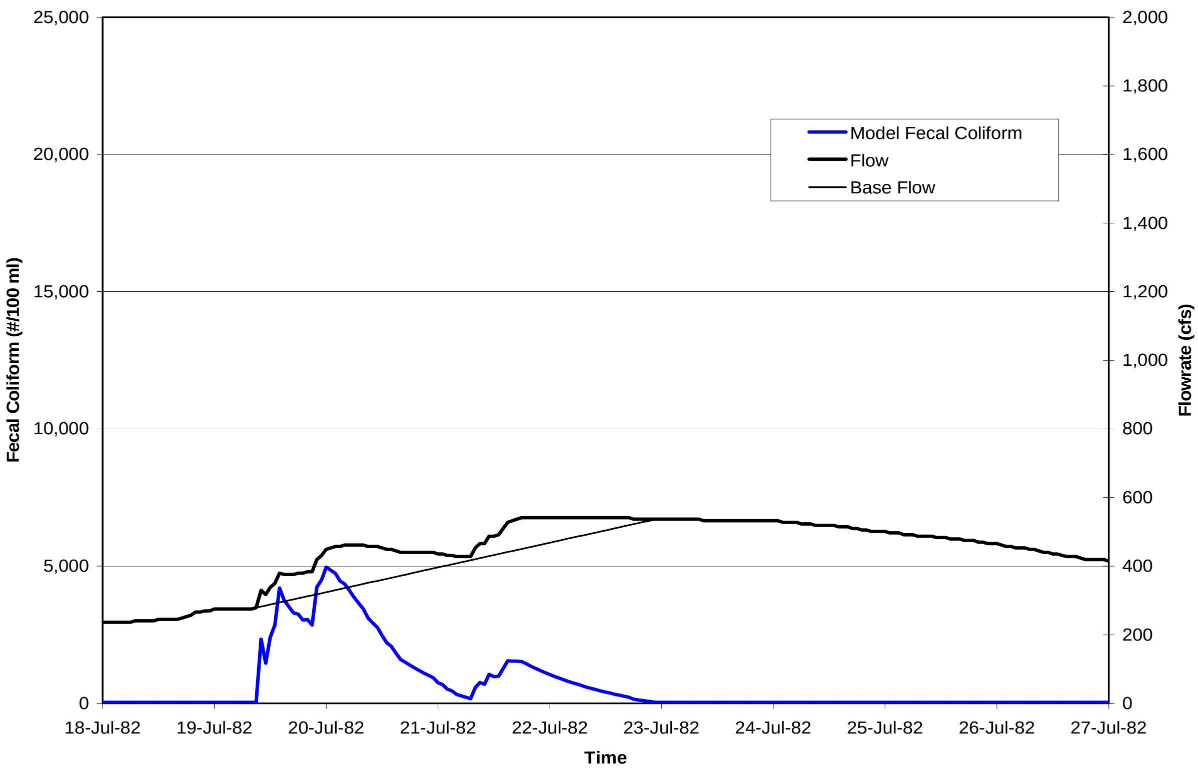

Figure 4. Upstream boundary Condition for 3-Month Design Storm

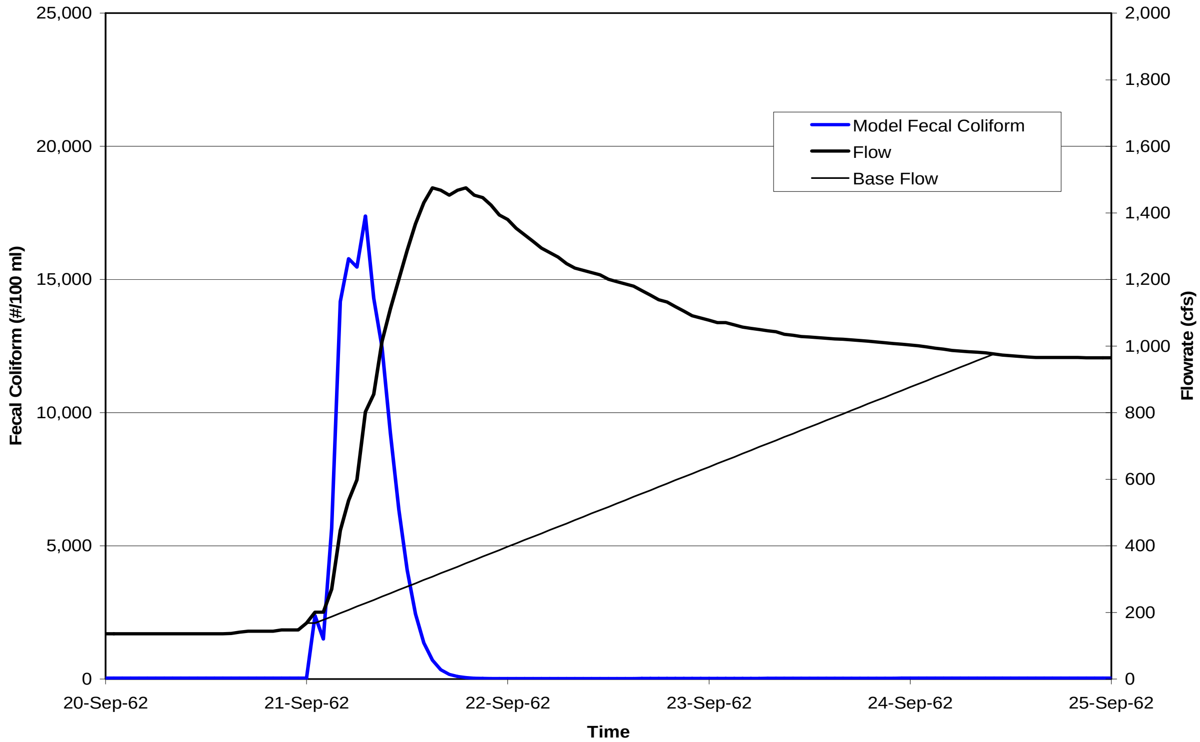

Figure 5. Upstream Boundary Condition for 1-year Design Storm

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