Attachment 7:

Long Term Continuous Simulation Method

Long-Term Continuous Simulation for Pollutant Loading and Treatment for MassDOT Impaired Waters Program

Introduction

The Massachusetts Department of Transportation (MassDOT) operates stormwater systems along its roadways to control runoff. Stormwater systems in urbanized areas are regulated under a Municipal Separate Storm Sewer Systems (MS4) National Pollutant Discharge Elimination System (NPDES) general permit issued by the United States Environmental Protection Agency (EPA).

As part of its overall effort to comply with the requirements of the MS4 General Permit, MassDOT has created a program to assess its stormwater discharges located within both urbanized areas and watersheds of listed impaired waters and to implement stormwater best management practices (BMP) retrofit measures, where feasible, to reduce its contribution to known water quality impairments. This report describes the supplemental approach used by MassDOT to assess its relative pollutant contributions to impaired water bodies and to estimate the pollutant load reductions that can be achieved through various proposed measures. The approach includes the development and use of a long-term continuous simulation model to estimate pollutant loads and treatment through stormwater BMPs. This effort focuses on roadway areas and stormwater discharges located in both urbanized areas and watersheds of state listed impaired water bodies (known as the Massachusetts Department of Environmental Protection (MADEP) 303d list).

Based on the steps outlined in BMP 7U and 7R of MassDOT's Stormwater Management Plan (SWMP), MassDOT uses two different methods to assess pollutant loading depending on whether or not a Total Maximum Daily Load (TMDL) study has been completed for the subject water body. Where a TMDL has been established, the method (BMP 7R) involves identifying sufficient BMPs to achieve the targeted pollutant load reduction as specified by the TMDL study, to the maximum extent feasible.

For impaired water bodies where no TMDL has been established, the method (BMP 7U) involves the use of EPA's Stormwater TMDL Implementation Support Manual (EPA, 2006) as a basis for determining the amount of pollutant load reduction and associated stormwater treatment needed to reduce MassDOT's contribution of the impairment. Essentially, MassDOT's effective impervious cover (IC) is used as a surrogate measure to assessing its potential pollutant contribution. The goal is to reduce MassDOT's effective IC to or below a target effective IC relative to its total roadway area directly discharging to the subject water body. The target is based on the estimated percent reduction necessary to achieve an IC limit of less than 10 percent for the entire waterbody watershed, consistent with recent research that denotes that impacts to water quality and aquatic life are present in watersheds that exceed the 10 percent IC threshold (CWP, 2003). MassDOT, therefore, BMP 7U uses a watershed effective impervious cover target of 9 percent. "Description of MassDOT's Application of Impervious Cover Method in BMP 7U" (MassDOT Application of IC Method) (February 2011) documents MassDOT's application of the IC method.

The EPA's Stormwater BMP Performance Analysis (EPA 2010) can also be used, where appropriate, to assign pollutant removal efficiencies to existing and proposed BMPs. The report provides pollutant removal performance data for several types of stormwater BMPs of varying sizes relative to the contributing watershed. The use of EPA's BMP Performance Analysis or other static BMP pollutant reduction efficiencies can be limited, however, particularly in retrofit situations where topographic or other site constraints make it difficult to replicate or satisfy the design assumptions inherent to the BMP performance and removal efficiency data. These limitations are discussed in greater detail below. This document describes refinements to MassDOT's approach that are geared toward addressing these limitations through the use of site-specific long-term hydrologic and pollutant simulation analysis to estimate pollutant loads and evaluate BMP treatment performance.

This modeling analysis accounts for site specific conditions including the amount of pervious and impervious drainage area, the proposed type, configuration and sizing of BMPs, and soil conditions to estimate median annual pollutant load to impaired waters under existing and proposed conditions. MassDOT developed and calibrated the model using the highway runoff pollutant concentration data as reported in the U.S. Geological Survey (USGS) and Federal Highway Administration's (FHWA) Highway-Runoff Database (Granato and Cazenas, 2009) that includes stormwater sampling data from different MassDOT roadways. This data is summarized in Quality of Stormwater Runoff Discharged from Massachusetts Highways (Smith and Granato, 2010).

The following sections describe:

- Background
- Model Approach and Calibration
- Application to MassDOT's Impaired Waters Program

Background

MassDOT initiated an Impaired Water Bodies Program starting in 2010 as a means to reduce its potential pollutant contribution to impaired water bodies associated with highway runoff. As part of this program, MassDOT identified stormwater outfalls that discharge directly from its roadways throughout the state to impaired water bodies. As discussed above, MassDOT estimates the pollutant reduction needed at each outfall based on the recommended target load reduction as specified by a TMDL study, if available or the use of MassDOT Application of IC Method (MassDOT, 2011). The assessment methodology presented in this document is a supplemental approach to both methodologies.

To refine the assessments, MassDOT uses EPA's Storm Water Management Model (SWMM) to develop better estimates of the potential pollutant load from roadways using long-term, continuous simulations (10 years) of existing conditions. The same model is also used to develop representative BMP treatment performances under storm event conditions, which is necessary for the design of new and updated existing BMPs. Use of SWMM not only improves the ability to assess the effects of BMP design changes but also provides a more representative estimate of potential water quality improvements by accounting for site specific conditions as opposed to interpolating or extrapolating from the EPA BMP Performance Report.

This approach is similar to the approach used by EPA to develop the BMP Performance Analysis results. The following sections describe the approach and its use in more detail.

Need for Assessment Model

During the initial phases of the implementation of the Impaired Waters Program, MassDOT recognized limitations to using EPA's Stormwater BMP Performance Analysis for BMP performances given the inherent assumptions used in that analysis. Due to the linear nature of MassDOT roads and right-of ways, and the physical site constraints that often arise in a retrofit approach to installing BMPs, the design assumptions included in the EPA Report cannot often be exactly met or replicated. In addition, common MassDOT BMPs are not included in EPA's analysis (e.g. vegetative filter strips). The EPA analysis also assumes that BMPs collect runoff from only impervious areas and does not provide a straightforward means to assess BMPs connected in series. Therefore, to use the EPA's BMP performance results, MassDOT has had to rely on best professional judgment and/or made conservative assumptions to extrapolate EPA's published data for use in the impaired waters assessments.

As described in this report, MassDOT has enhanced the assessment methodology for specific cases through long-term continual simulation modeling using SWMM. Modeling BMP pollutant removal capability can directly demonstrate how different BMP design configurations and sizing and flow through vegetated areas affect BMP treatment efficiencies and pollutant loading from highway runoff. This approach is capable of analyzing scenarios that are not covered by the EPA's analysis. Simulating and assessing BMPs in this more detailed way facilitates more targeted designs and therefore, increased water quality improvement for the same BMP construction cost. This approach facilitates sizing and locating BMPs to more accurately reflect their performance in treating their contributing watersheds.

In addition, because SWMM can perform long term simulation for pollutant analysis *and* storm event simulation for design, the approach results in cost savings to MassDOT for both the assessment and design phases of the impaired waters program. Using one model for both phases makes analysis and design of BMPs more efficient.

Model Approach and Calibration

The purpose of MassDOT assessment model is to support assessing MassDOT stormwater discharges to impaired waters and selecting and designing stormwater improvements. The key elements of the model include:

- Long-term hydrologic, hydraulic, and water quality simulation
- Pollutant selection and configuration
- Watershed loading parameters
- BMP simulation parameters

The use of a long-term simulation for pollutant modeling is consistent with the compliance guidance for the General Permit for Designated Discharges in the Charles River Watershed within the Municipalities of Milford, Bellingham, and Franklin, Massachusetts (described in Appendix D, EPA 2010(a)). The guidance states that a long-term simulation of suggested 10 years can be used to demonstrate compliance with phosphorus removals, especially when using BMPs that are not included in EPA's Stormwater BMP Performance Analysis.

The model simulates watershed loads and BMP treatment of total phosphorus (TP) and total suspended solids (TSS). The model was initially set up using literature values for coefficients and calibrated parameters from similar models including the P8 Urban Catchment Model (based on National Urban Runoff Program (NURP) data) and EPA's BMP Performance Analysis. Model coefficients were then adjusted to calibrate performance to best match the following two data sets:

- Measured TSS and TP concentrations from the USGS/FHWA monitoring study by comparing the distribution of measured concentrations to the distribution of model-predicted concentrations for similar storm events for the "MA 2009 Highway Runoff Data" data subset.
- Annual total TSS and TP loads from the two Charles River TMDL studies (Total Maximum Daily Load for Nutrients In the Lower Charles River Basin, Massachusetts CN 301.0 and Total Maximum Daily Load for Nutrients in the Upper/Middle Charles River, Massachusetts CN 272.0) and other literature values.

This section describes the modeling approaches MassDOT chose for these purposes and the model calibration.

Long-Term Simulation

MassDOT selected EPA's SWMM to develop long-term continuous simulations to model pollutant loading and BMP performance. The model is capable of evaluation over an extended period of time (multiple years) under differing hydrologic conditions such as groundwater saturation, antecedent dry periods, rainfall distributions and depths and therefore produces a representative estimation of the potential BMP's performance over time under a variety of conditions.

SWMM primarily requires precipitation depth and distribution as inputs required for long term-continuous simulation. MassDOT's model uses hourly rainfall from the Logan Airport weather station in Boston, Massachusetts from 1984-1993, chosen to represent typical years to evaluate watershed loading and BMP's treatment capabilities on an annual average basis.

This 10-year period was selected from a larger historical record (1920-2011) to capture a representative range of yearly rainfall and storm events based on the following criteria:

- Annual mean rainfall for 10-year period within 0.75 inches for period of record annual mean
- At least one year with total annual rainfall within 0.5 inches of annual mean for period of record
- At least one year with total annual rainfall less than one standard deviation below annual mean for period of record
- At least one year with total annual rainfall greater than one standard deviation above annual mean for period of record
- At least one storm greater than 10-year one day storm

The analysis used to develop the treatment performance curves under EPA's Stormwater BMP Performance Analysis also included a long term simulation using Logan Airport's rainfall record (1992-2002). (EPA, 2010(a))

Watershed Parameters

SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. MassDOT uses design plans of stormwater infrastructure, visual inspection and survey to determine subcatchment boundaries. The following lists the primary watershed parameters required by SWMM to simulate runoff and MassDOT's methods for calculating these parameters:

- Percent Impervious: Calculated using the MassGIS impervious surface layer (2007) and/or site specific delineations of impervious surfaces
- Pervious Curve Number: Calculated using the hydrologic soil group (HSG) datalayer from the Natural Resources Conservation Service (NRCS) and pervious land cover assumed as grass in good condition.
- Watershed Slope: Calculated from topographic data from MassGIS (2005) and corrected based on visual observation and survey.
- Watershed Width: Defined by SWMM as the characteristic width of the overland flow path for sheet flow runoff. Calculated (as suggested by SWMM) by delineating the overland sheet flow path and dividing the length of that path by the watershed area.

Pollutants

SWMM is capable of simulating watershed loading and treatment of user-specified pollutants. Initially, the assessment model was set up to simulate TSS and TP to address urban runoff and the more common TMDL pollutants. Additional urban pollutants (e.g., nitrogen, zinc, lead, etc.) can be added in the future and to assess specific impairments. Similarly, both the NURP study (EPA, 1983) and USGS and Federal Highway Administration's (FHWA) Highway-Runoff Database (HRDB) (Granato and Cazenas, 2009) include stormwater runoff sampling results for TSS and phosphorus. EPA's Stormwater BMP Performance Analysis includes TSS, TP and zinc.

This section describes the methods and assumptions used to simulate TSS and TP in MassDOT's assessment model.

Total Suspended Solids

The MassDOT assessment model simulates multiple TSS particle sizes classes and urban pollutants that are typically associated with those classes. This produces a detailed simulation of the fate and transport of TSS and the associated pollutant removal in BMPs due to settling. MassDOT simulated the following classes, which are consistent with the particle classes used in the P8 Urban Catchment model, which are based on the NURP particle size distribution and settling velocity.

TSS Particle Classes

Particle Classes	Particle Diameters (mm)	Settling Velocity (ft/hr)
P10	0.0017 - 0.008	0.03
P30	0.0055 - 0.025	0.3
P50	0.013 - 0.057	1.5
P80	0.038 - > 0.1	15

Particulate removal via settling and filtration provides the primary removal mechanism for sediment and associated pollutants in several common BMPs. Settling rates depend on particle size and specific gravity. Larger particles settle out in less time than finer particles and the finer particles often bind and carry more urban pollutants including nutrients and metals. Therefore, simulating multiple particle size classes allows for a better representation of BMP pollutant removal through settling and filtration.

This is consistent with other long term simulation models including the P8 Urban Catchment model and in EPA's SUSTAIN BMP optimization model. In addition, the USGS/FHWA dataset includes a breakdown of measured pollutant concentrations by three particle classes and cite the correlation of various urban pollutants with different particle size groups. The USGS/FHWA reported that "the vast majority of sediment-associated concentrations of TP and metals are associated with sediment particles less than 0.063 mm in diameter." (Smith and Granato, 2010).

Total Phosphorus

MassDOT developed the assessment model to simulate pollutants that are generally correlated to TSS as fractional associations with TSS plus a dissolved fraction. The sum of the concentrations associated with each particle class and the dissolved portion makes up the total pollutant load or concentration. Pollutant association with TSS is a well documented occurrence for the pollutants chosen for this model. Table 18 of the USGS/FHWA data report lists the correlations of pollutants with varying TSS particle size and they report that "correlations are stronger between concentrations of suspended sediment less than 0.063 mm in diameter and concentrations of total P, total-recoverable metals, and PAH compounds (table 33) than for concentrations of total suspended sediment." (Smith and Granato, 2010)

Several urban pollutants, including phosphorus, can also travel in a dissolved form and cannot be simulated in association with TSS. MassDOT simulates the dissolved portion of pollutant as a constant concentration in the runoff based on the USGS/FHWA sampling data.

USGS/FHWA data suggests that the dissolved phosphorus concentration is relatively low and generally consistent under a variety of conditions. Table 36 of the USGS/FHWA data report provides summary statistics of the various selected constituents estimated on the basis of the suspended sediment concentrations for three particle-size ranges compared to the measured total concentrations. (Smith and Granato, 2010). In their analysis, the estimated pollutant concentration ignores the dissolved component of the pollutant and is based on the relationship between the pollutant and TSS alone. This table shows the percent difference between estimated particulate concentration and actual concentration, which decreases as TSS increases, indicating that dissolved fraction is proportionally less as TSS increases. This leads to the conclusion that the dissolved concentration is relatively consistent.

Table 18 of the USGS/FHWA data report provides the average measured fractional association of phosphorus with each of the three measured TSS particle sizes. Using the TSS measurements and TP/TSS associations, MassDOT calculated the phosphorus concentrations in each class. The remaining phosphorus not associated with each of the particle classes can be assumed to be the dissolved portion, given measuring error. From this analysis, the dissolved phosphorus concentration appears to be between 0.02-0.05 mg/L.

MassDOT simultaneously calibrated the association of TP to TSS and dissolved concentration of TP to best match TP concentrations from the USGS/FHWA monitoring study by comparing statistics of measured concentrations to the statistics of model results for similar storm events. The following TP to TSS ratios are used in the MassDOT assessment model.

MassDOT Model TP to TSS Ratios

Particle Classes	Particle Size Diameter (mm)	TP to TSS Ratio (mg TP / kg TSS)
P10	0.0017 - 0.008	2500
P30	0.0055 - 0.025	2500
P50	0.013 - 0.057	2500
P80	0.038 - > 0.1	500

The following section discusses the calibration process for TP parameters.

Watershed Loading

MassDOT simulated watershed pollutant loading using SWMM's pollutant build-up and wash-off relationships for user-defined land cover categories. These processes can be defined by the user in SWMM. The MassDOT model includes pervious and impervious land covers for the purpose of pollutant loading and simulates their loading as follows:

- Impervious surfaces: pollutants accumulate on the surface (build-up) and are washed off during runoff events. Runoff contains constant concentration of dissolved pollutants.
- Pervious surfaces: based on a user-specified event mean concentration (EMC).

Similar approaches to calculating watershed loads for pervious and impervious land covers have been used to support several watershed based TMDL analyses, including the Charles River Phosphorus TMDL studies and EPA's Stormwater BMP Performance Analysis.

MassDOT used SWMM's exponential function to represent the build-up (B) of particulate pollutants on impervious surfaces over time (t):

$$B = C_1(1 - e^{-C_2 t})$$

Where: C1 = maximum buildup possible (mass per unit of area), C2 = buildup rate constant and t = time-step. This relationship is similar to that used in the P8 Urban Catchment model.

MassDOT used SWMM's exponential function to represent the wash-off (W) of accumulated pollutants based on runoff (q):

$$W = C_1 q^{C_2} B$$

Where: C1 = wash-off coefficient, C2 = wash-off exponent, q = runoff rate per unit area.

For dissolved fractions of pollutants, MassDOT simulated the runoff as containing a constant concentration of pollutant by including a constant concentration in the precipitation.

Total Suspended Solids Calibration

MassDOT calibrated TSS loading parameters from impervious surfaces using the P8 Urban Catchment model buildup and wash-off parameters as the starting point for model calibration. The P8 Urban Catchment model's build-up and wash-off parameters were calibrated to the NURP dataset. MassDOT adjusted buildup and wash-off parameters and compared modeled annual load and storm-by-storm event EMC to USGS/FHWA measured data and published values. MassDOT compared predicted storm event concentrations with USGS/FHWA observed concentrations in highway runoff and adjusted input parameters to best match the observed concentration distribution. The USGS/FHWA observed concentrations were based on highway runoff samples collected from Massachusetts roadways during 41 storm events at 10 different locations for a total of 130 measurements. The USGS/FHWA samples were primarily taken during storm events of greater than 0.2 inches, which is greater than storm events that occur frequently in the northeast and the Boston record used in the model (likely due to difficulty in sampling small events).

The following table lists the TSS calibrated build-up and wash-off parameters. The appendix includes the calibration data and results including a plot of the USGS/FHWA data, MassDOT calibration runs, and results using the EPA BMP Performance Analysis build-up/wash-off relationships.

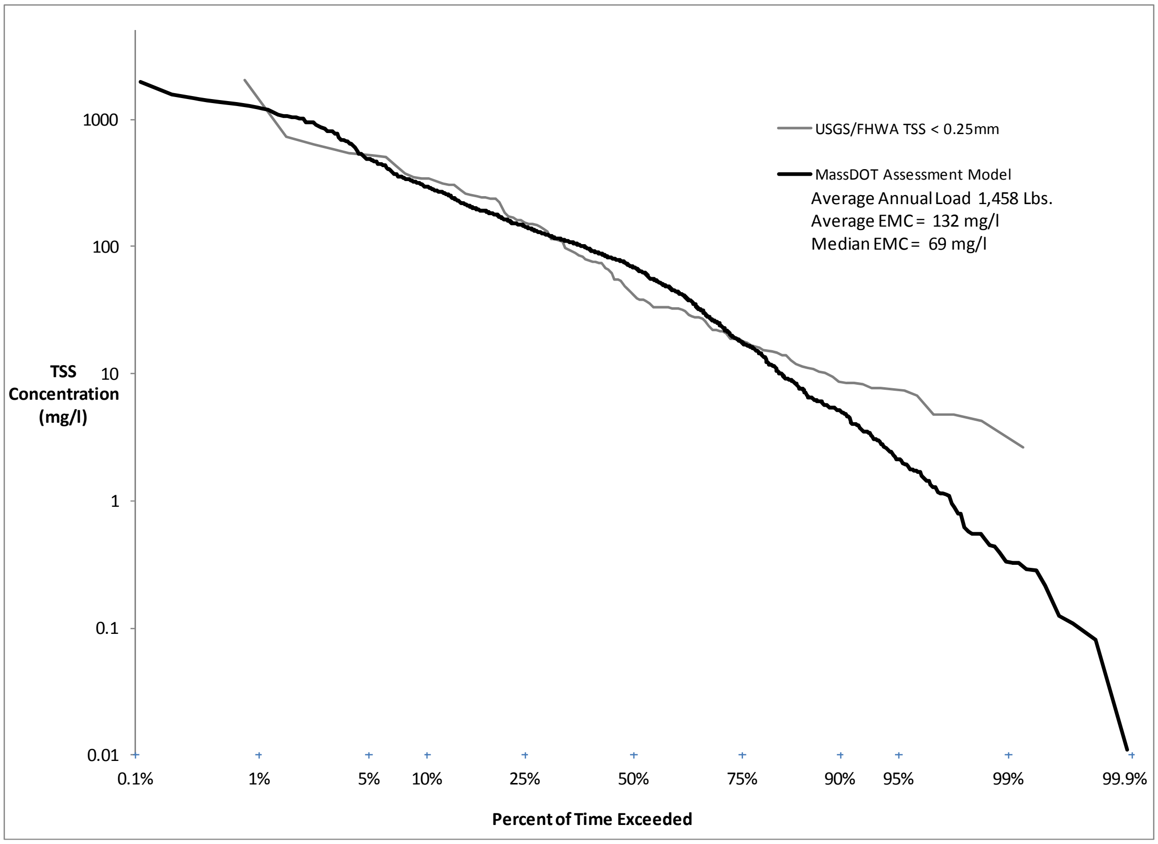
Model Build-Up and Wash-off Parameters

Pollutant Class	Impervious Build-Up $B = C_1 (1 - e^{-C2t})$ C1	C2	Impervious Wash-off $W = C_1 q^{C2} B$ C1	C2	Pervious Wash-off $W = C_1$ C1
TSS (total)	50	0.25	150	2.5	51.0
P10	10	0.25	150	2.5	10.2
P30	10	0.25	150	2.5	10.2
P50	10	0.25	150	2.5	10.2
P80	20	0.25	150	2.5	20.4

For pervious area loading, MassDOT used a TSS EMC of 51 mg/L based on the listed EMC for “urban open” land use in the New Hampshire Department of Environmental Services (NHDES) Stormwater Manual (NHDES, 2008).

The following figure compares the distribution of the predicted TSS concentrations (over a 10-year simulation period) using the calibrated model to USGS/FHWA observed data.

TSS Calibration



As shown, the model results compare well in magnitude and frequency to the sampling data collected from Massachusetts highways. The predicted range of concentration matched well with the observed range, but the model tended to slightly over-predict higher concentrations and under-predict lower concentrations. This bias results in model producing conservative estimates, and, therefore, is considered acceptable for the assessment model.

In addition to event concentrations, MassDOT compared the TSS annual average loadings predicted by the MassDOT assessment model compared to TSS loads from literature values, as shown in the following table.

TSS Annual Load Calibration (lbs/ac/yr)

Land Cover	MassDOT Assessment Model Impervious	MassDOT Assessment Model Pervious	Fundamentals of Urban Runoff Management[1]
Highway	1,480	3.5	
Commercial			1,000
Industrial			670
High-Density Residential			420
Medium-Density Residential			250
Low-Density Residential			65

1 Fundamentals of Urban Runoff Management: Technical and Institutional Issues (Shaver et al. 2007)

Total Phosphorus Calibration

To calibrate loading from impervious surfaces, MassDOT simultaneously adjusted the association of TP to TSS and dissolved concentration of TP to best match the observed values including USGS/FHWA measured concentrations and published annual loading estimates for similar land uses. Similar to the TSS calibration, MassDOT compared predicted storm event concentrations with USGS/FHWA measured concentrations for the same subset of locations and events.

MassDOT used the TP/TSS ratios from the P8 Urban Catchment model as initial values and modified them based on the USGS/FHWA dataset. For example, the P8 Urban Catchment model assumes that there is no phosphorus associated with the largest particle class (0.038-0.1 mm), however, the USGS data shows that phosphorus does travel with the larger simulated particle class (>0.25 mm). The calibration maintained that the majority of phosphorus associated with smaller particle classes but that some is associated with the largest class as well, as documented with USGS/FHWA dataset (Table 33, Smith and Granato, 2010).

The following table lists the calibrated TP to TSS ratios along with values from P8 and the USGS/FHWA data. The appendix includes the calibration data and results.

TSS to TP Ratios - Calibration

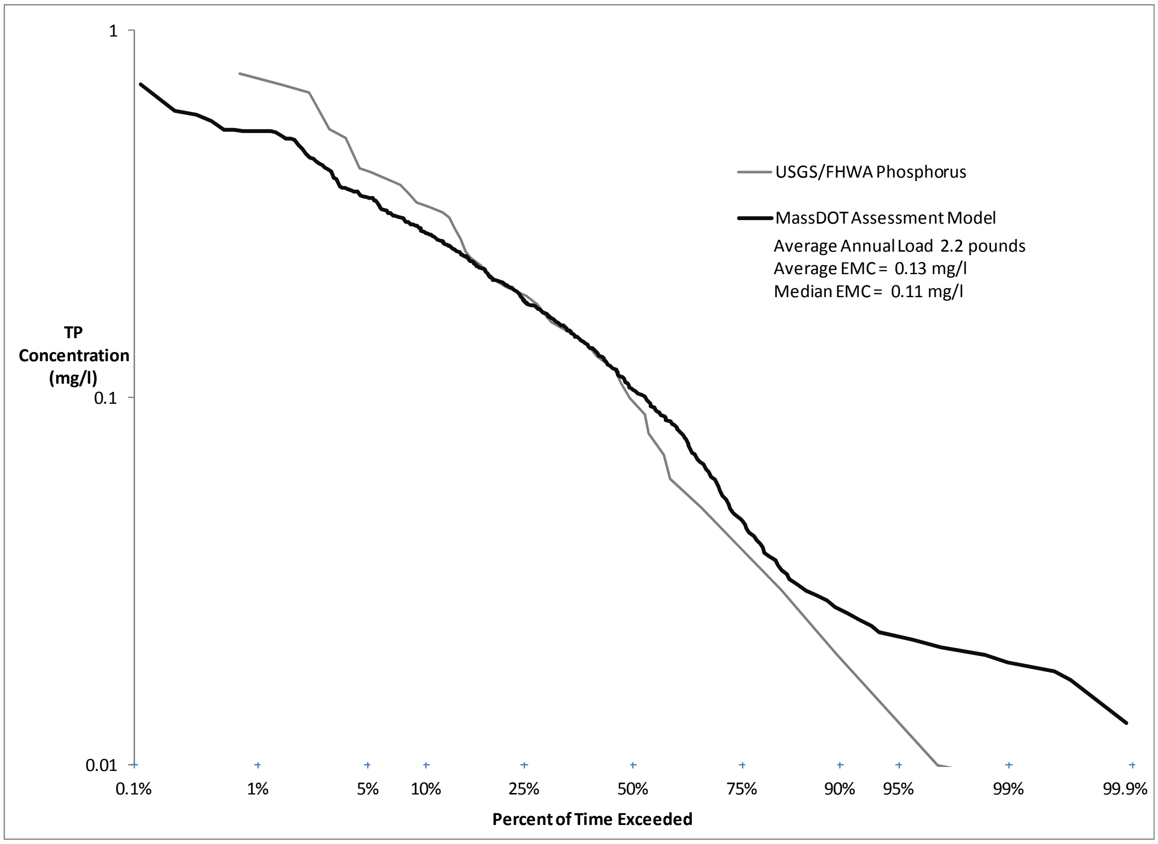
Particle Classes	Particle Size Diameter (mm)	TP to TSS Ratio (mg TP / kg TSS) P8 Model	TP to TSS Ratio (mg TP / kg TSS) USGS/FHWA[1]	TP to TSS Ratio (mg TP / kg TSS) MassDOT
P10	0.0017 - 0.008	3,850		2,500
P30	0.0055 - 0.025	3,850		2,500
P50	0.013 - 0.057	3,850	1,000	2,500
P80	0.038 - > 0.1	0	300-500	500

[1] 0.1 parts per 100 for sediment class <0.063 millimeters
0.03 to 0.05 parts per 100 for sediment classes >0.063 millimeters

During calibration, the TP/TSS relationships influenced the magnitude and distribution of predicted concentrations while the dissolved concentration affected the overall magnitude of the predicted concentrations. The calibrated dissolved phosphorus concentration was 0.02 mg/L, which is within the range indicated by the USGS/FHWA data (0.02-0.05 mg/L). Similar to the TSS results, the final calibration produced predicted values that match the range of USGS/FHWA measured concentration well and, therefore, is considered acceptable for the assessment model.

The following figure compares the distribution of calibrated model TP concentrations to USGS observed data. As shown, the model results compare well in magnitude and frequency to samples collected from Massachusetts highways.

TP Calibration



In addition, the TP annual average loadings predicted by the MassDOT assessment model compared well to TP loads reported in the two Charles River TMDL studies and other literature values, as shown in the following table. The MassDOT loading rates are conservatively higher than the reference values, but the calibration produced the best results when comparing both the distributions of concentrations and total annual load.

TP Annual Load Calibration (lbs/ac/yr)

Land Cover	MassDOT Assessment		Fundamentals of Urban Runoff Management [1]	Lower Charles TMDL [2]		Upper Chalres TMDL [3]			Charles River RDGP [4]	
	Impervious	Pervious		Literature Review	TMDL Values	Total	Impervious	Pervious	Impervious	Pervious
Highway	2.2	0.05							1.34	0.27
Commercial			1.50	1.50	1.51	1.81	2.24	1.18	2.23	0.27
Industrial			1.30	1.30	1.31	1.81	2.24	1.18	1.78	0.27
High-Density Residential			1.00	1.00	1.01				2.23	0.27
Medium-Density Residential			0.30	0.50	0.51				1.34	0.27
Low-Density Residential			0.04	0.04	0.04				0.89	0.13

1 Fundamentals of Urban Runoff Management: Technical and Institutional Issues (Shaver et al. 2007)

2 Lower Charles TMDL Table 6-2

3 Upper Charles TMDL Table 14 and Table 21/ES-3

4 Chalres River Residual Authority General Permit, Attachment 1 of Appendix D

Best Management Practices

The MassDOT assessment model simulates stormwater BMPs using a combination of nodes, links, and watersheds. The model routes runoff and associated pollutants from contributing watersheds to downstream nodes or downstream watersheds accounting for pollutant load reductions via treatment based on user-specified treatment equations. This section describes the MassDOT assessment model's treatment processes and BMPs simulated.

Pollutant Treatment

The MassDOT assessment model accounts for treatment of pollutants through four methods:

- Infiltration of runoff and associated pollutants
- Settling of particulate pollutants
- Filtration of particulate pollutants
- Biological treatment of dissolved pollutants

The following describes how the model simulates each of these processes.

Infiltration: SWMM simulates the washoff of pollutants with runoff. As runoff is infiltrated in a downstream node or pervious watershed, the pollutants are removed from the stormwater system in proportion with the infiltrated runoff volume. Therefore the treatment of pollutants due to infiltration is simulated directly through the removal of runoff. The model simulates infiltration for infiltration basins, vegetated swales, vegetated filter strips, and other infiltration BMPs (e.g. leaching catch basins).

Settling: As runoff accumulates in basins and swales with outlet control (represented as storage nodes), particulate pollutants will begin to settle out of the water column. The settling rate of particulates is dependent on their size (particle diameter) and specific gravity, as described by Stoke's Law. The MassDOT assessment model simulates four particulate size classes based on their settling velocity class. The model simulates settling of these classes using the following first-order decay function applied to TSS concentrations in runoff accumulated in storage nodes.

$$R = 1 - e^{\frac{-Vt}{D}}$$

Where: R = fractional removal, V = settling velocity, t = timestep, D = water column depth.

The following table lists the settling velocity for the four particle classes used in the MassDOT assessment model. These values correlate to those used in the P8 Urban Catchment model, based on the NURP measured settling velocities. The model simulates settling treatment in BMPs that create ponding, including basins and swales with outlet control.

TSS Particle Classes

Particle Classes	Particle Diameters (mm)	Settling Velocity (ft/hr)
P10	0.0017 - 0.008	0.03
P30	0.0055 - 0.025	0.3
P50	0.013 - 0.057	1.5
P80	0.038 - > 0.1	15

Filtration: MassDOT simulates the particulate pollutant removal by filtration as a constant fractional removal based on the particle class size. The model assumes no filtration removal for dissolved pollutants. The model simulates filtration in BMPs with filter media and under-drains that discharges to the receiving water such as porous pavement and bioretention areas.

Filtration Removal Efficiencies

Particle Classes	Removal by Filtration
Dissolved	0%
P10	50%
P30	100%
P50	100%
P80	100%

Biological Treatment: MassDOT simulates dissolved pollutant removal via biological and other processes from plantings or within soils media using a first-order decay relationship:

$$R = 1 - e^{-kt}$$

Where: R = fractional removal, k = decay coefficient (selected from literature based on BMP configuration and pollutant), t = timestep. The model simulates biological treatment for runoff that drains through plantings and soil media in BMPs prior to discharging to the receiving water such as bioretention areas, vegetated swales and gravel wetlands.

BMP Representation

The MassDOT assessment model represents BMPs using a variety of watersheds, nodes and links:

- Storage nodes represent BMPs where runoff accumulates and treatment processes occur.
- Links represent outlets and overflows from storage nodes.
- Watersheds represent vegetated filter strips and swales without outlet control, which receive and infiltrate runoff from upstream watersheds.

The following table lists the BMPs, their components and the treatment processes represented in each component.

BMP Model Representation

BMP SWMM Elements	Treatment Mechanisms: Infiltration	Settling	Filtration	Biological
Infiltration Basin and pervious pavement				
Watershed				
Node	X	X		
Link – overflow				
Extended Detention				
Watershed				
Node		X		
Link - low flow				
Link – overflow				
Swale with check dams and/or outlet control				
Watershed				
Node(s)	X	X		
Link - final outlet				
Swale without check dams or outlet control				
Watershed (LID option in SWMM)	X			
Bioretention basin, gravel wetland, pervious pavement or swale with underdrain				
Watershed				
Storage Node		X		
Link - overflow to outlet				
Link - infiltration to soil media				
Node - soil media			X	X
Link - underdrain to outlet				
Vegetated Filter Strip				
Watershed	X			

Model Application

MassDOT uses this assessment model to quantify pollutant loads with and without existing and proposed BMPs for use in addressing its impacts to impaired waters.

For discharges to waters with TMDLs, MassDOT uses the TMDLs to assess stormwater discharges from its stormwater systems and make necessary improvements to the systems to meet the target reduction in pollutant loading outlined in the TMDL, as outlined in BMP 7R of the SWMP. For waters without TMDLs, MassDOT uses impervious cover (IC) as a surrogate pollutant and strives to reduce the effective impervious cover of its property as discussed in BMP 7U of the SWMP. The model provides a refined approach to the calculation of pollutant loading and treatment reductions by the BMPs.

As this section describes, MassDOT uses the model results to quantify BMP performance and ability to meet the TMDL and IC targets:

- TMDL analysis: Summarize total pollutant loads post-BMPs and percent reductions through BMPs compared to TMDL waste load allocation
- Impervious cover analysis: Simulate watershed with the same contributing area with varying IC percentages and compare to MassDOT's. Use both hydrologic response and pollutant load to estimate the post-BMP effective IC.

TMDL Evaluation

The TMDL evaluation involves comparing the predicted MassDOT loads for the pollutant of concern to the specified waste load allocation (WLA) for the impaired waterbody as determined by the TMDL. As such, the TMDL evaluation includes the following steps:

1. Simulate the MassDOT pollutant contributions from the directly contributing roadways within the watershed under existing conditions (include existing BMPs) using the long-term simulation model. (Step 3B of BMP 7R)
2. Compare the predicted total annual load for the pollutant of concern compare existing conditions to the TMDL WLA for the various pollutant sources. (Step 3C of BMP 7R)
3. If the predicted loads exceed the WLA, identify appropriate BMPs that could achieve the level of treatment needed to meet the WLA, to the maximum extent practical. (Step 3C of BMP 7R)
4. Simulate those BMPs and summarize model results to determine if the pollutant load can be sufficiently reduced with additional BMPs. (Step 5 of BMP 7R)
5. Iteratively locate and size BMPs to achieve maximum treatment given site and cost constraints to meet WLA to maximum extent practical. (Step 5 of BMP 7R)

IC Method Evaluation

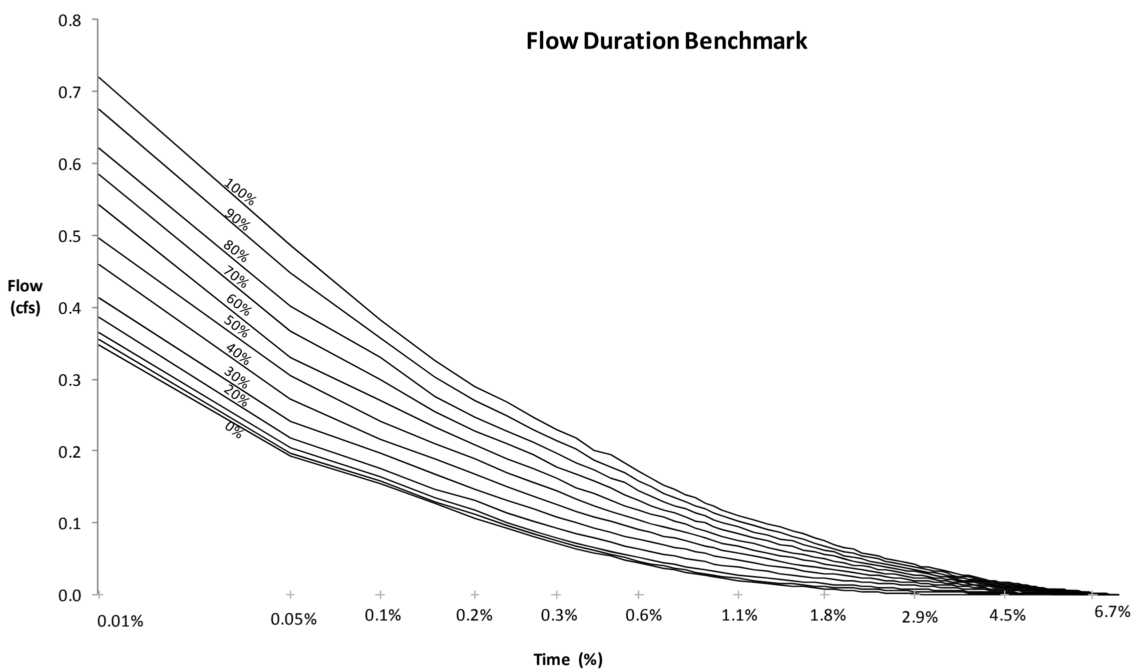
MassDOT's IC method of assessing impaired waters uses impervious cover as a surrogate to assess pollutant loading and the extent to which roadway runoff may contribute to an impaired water. As described in Description of MassDOT's Application of Impervious Cover Method in BMP 7U (MassDOT Application of IC Method) (2011). MassDOT uses the EPA recommended target of no more than 9% impervious cover in a subwatershed as a basis for determining if stormwater mitigation may be needed. The assessment model evaluates MassDOT's effective impervious cover by comparing long-term hydrologic response and pollutant loading under existing and/or proposed conditions to that of an equivalently sized watershed with varying impervious cover. This evaluation is based on the Center for Watershed Protection's Impacts of Impervious Cover on Aquatic Systems (2003) which links impervious cover to stormwater impairment specifically due to modification of the watershed's of hydrologic response and pollutant loading.

To evaluate a watershed's effective impervious cover, MassDOT used the SWMM to predict the following parameters for a given condition (e.g., existing or proposed):

- Median annual runoff volume
- Runoff flow/duration relationship
- Median annual total phosphorus load
- Median annual total suspended solids load

These values are then compared to those of simulated IC watersheds of equal size but with varying IC to establish the appropriate effective impervious cover of MassDOT's roadway and right-of-way area. The approach employs the following steps to determine effective impervious cover to evaluate the performance relative to the impervious cover reduction target (determined in accordance with in MassDOT Application of IC Method (2011)):

1. Evaluate a series of simulated IC watersheds to use as reference for estimating the subject watershed's effective impervious cover. Using the long-tem simulation model, calculate median annual runoff volume, phosphorus load, TSS load and flow duration statistics for one acre watersheds with impervious cover ranging from 0 to 100% and tabulate results. These results, shown below, then serve as the "benchmarks" for impervious cover conditions. For the assessment level analysis, the benchmark curves assume pervious area characterized as woods in good condition and 2% watershed slope based on the typical characteristics of MassDOT property. The benchmarks can be adjusted if site specific conditions vary considerably from these assumed properties. *Note that the horizontal (Time) axis terminates at approximately 7%, the percentage of total time that the model predicts runoff would occur.*



Median Annual Load Benchmark Table

Impervious Cover	Median Annual Load Runoff (ac-ft)	TP (lb.)	TSS (lb.)
0%	0.7	0.1	4
5%	0.9	0.1	17
10%	1.0	0.1	37
20%	1.2	0.3	102
30%	1.5	0.4	208
40%	1.7	0.7	351
50%	2.0	1.0	526
60%	2.2	1.3	717
70%	2.5	1.7	910
80%	2.7	2.0	1,102
90%	2.9	2.4	1,290
100%	3.2	2.7	1,481

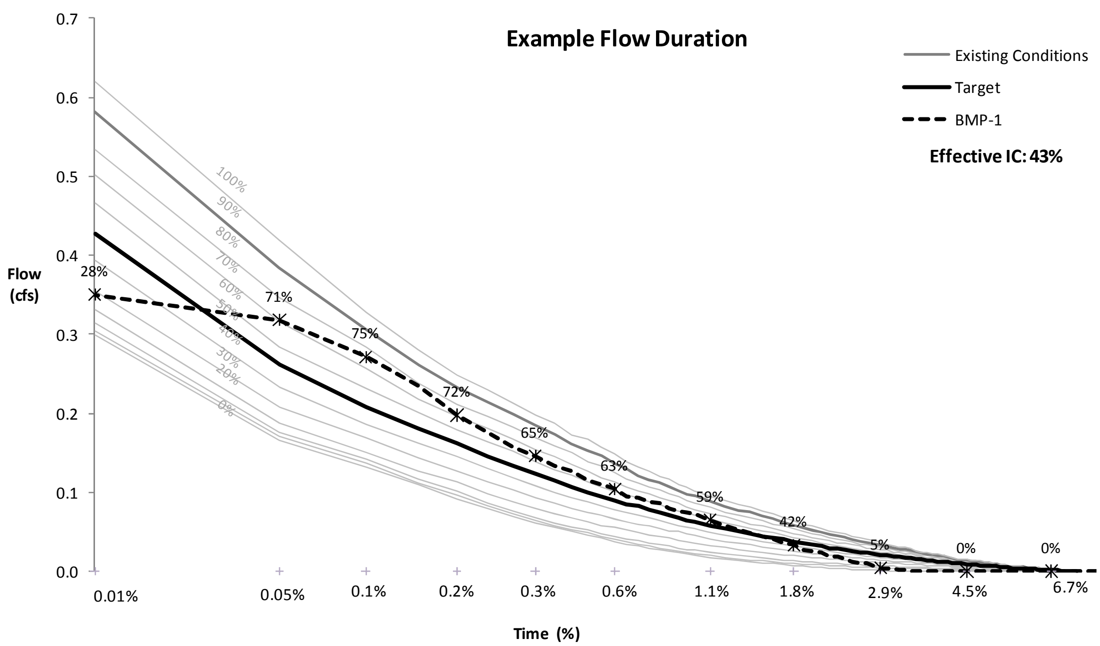
2. Interpolate between simulated IC watershed results to calculate runoff volume and pollutant loads predicted for target impervious cover condition. For example, for a target IC of 25%, interpolate between 20% and 30% IC "benchmark" values.
3. Scale "benchmark" and target values based on subject watershed's area relative to 1 acre (area of simulated IC watershed). For example, for a subject watershed area of 5.1 acres, multiply "benchmark" values by 5.1.
4. Simulate MassDOT contributing watershed under existing conditions (include existing BMPs) using the long-term simulation model.
5. Summarize model results for annual runoff volume, flow duration, and pollutant loading for existing conditions.
6. Determine approximate effective impervious cover under existing conditions based on comparison to simulated IC watershed "benchmark" values.
   a. Interpolate effective IC separately for each metric via interpolation of reference tables/curves
      i. For TSS, P and Flow volume, calculate effective percentage by using linear interpolation of percentage to closest benchmark load/volume values
      ii. For flow duration, calculate average of individually interpolated values taken at equal probability intervals (based on normal distribution) for the percentages of time that the model predicts runoff – see example
   b. Determine the IC indicator metrics for annual runoff volume and flow duration and the maximum IC indicator for the pollutant metrics (TSS load and TP load)
   c. Take the average of these three IC indicators (pollutant, annual runoff volume, flow duration) as the representative effective IC for the watershed
7. Compare effective impervious cover to target impervious cover (impervious reductions necessary for subwatershed to achieve 9 % - see MassDOT's Application of Impervious Cover Method in BMP 7U)
8. If the target is not met, identify BMPs to achieve additional treatment, if constraints allow.
9. Simulate those BMPs using the model and summarize model results to determine effective impervious cover with additional BMPs in same manner as existing conditions.
10. Iteratively locate and size BMPs to achieve maximum treatment given site and cost constraints to meet target.

IC Method Evaluation - Example

To demonstrate the IC method evaluation take the following hypothetical watershed:

Watershed Size: 0.86 acres
Watershed IC: 90%
Target IC: 50%

The following graph shows the predicted flow duration for the example watershed with added BMP, and the corresponding simulated IC watersheds. The points show the values at equal probability intervals where effective IC was evaluated. The average of these 11 values results in the effective IC based on the flow duration analysis alone. This visual representation shows how the hydrological response for a watershed with approximately 90% percent impervious cover can modified to respond in a similar manner as a watershed with 43% impervious cover with the addition of BMPs.



The following table shows the predicted runoff volume and TSS and TP load results for the same example watershed, including simulated IC and target “benchmarks”. The table also compares the model results of existing conditions (90% IC), proposed (with BMP) conditions and the target IC conditions. Comparing the runoff volumes, flow duration (from graph above) and pollutant loads, the watershed with the addition of BMPs produces similar runoff volume, flow duration and pollutant loads to those of a watershed of 35% to 43% IC.

Example Model Results

Condition	Runoff (ac-ft)	TP (lb.)	TSS (lb.)
0%IC	0.6	0.0	3
5%IC	0.7	0.1	15
10% IC	0.8	0.1	32
20% IC	1.1	0.2	88
30% IC	1.3	0.4	179
40% IC	1.5	0.6	302
50% IC	1.7	0.9	452
60% IC	1.9	1.2	617
70% IC	2.1	1.5	783
80% IC	2.3	1.7	948
90% IC	2.5	2.0	1,110
100% IC	2.7	2.3	1,274
Existing Conditions	2.4	2.1	1,133
With BMP	1.5	0.7	239
Target	1.7	0.9	452
Reduction % with BMP	**38%**	**68%**	**79%**
Effective IC	**40%**	**42%**	**35%**

The following demonstrates the calculation of the overall effective IC with BMPs for the example discussed above.

A	TSS Load Indicator	35%
B	Total P Indicator	42%
C	Overall Pollutant Indicator (max of A and B)	42%
D	Runoff Volume Indicator	40%
E	Runoff Flow Duration Indicator	43%
F	Overall Indicator (Average of C, D, and E)	42%

By averaging the effective IC percentages between the runoff volume, flow duration, and maximum of pollutant loading, the effective IC is approximately 42%. The effective IC can then be compared to the target IC. In addition, the model predicts actual runoff and pollutant loading reduction which can be used for addressing the numeric targets of TMDLs.

The analysis used to develop the treatment curves under EPA's Stormwater BMP Performance Analysis also included an impervious cover reduction analysis. Their study linked impervious cover reduction directly to runoff volume reduction alone. (EPA, 2010b). This method improves on that by including the additional metrics for flow duration and pollutant loads.

Summary

The MassDOT has demonstrated that the use of a long-term simulation model can be an effective tool to estimate pollutant loads, BMP performance, and the changes in hydrologic response under various impervious cover scenarios. Predicted pollutant concentrations for TSS and total phosphorus compared well with the observed data reported in a recent USGS study that was based on highway runoff sampling on MassDOT roads. The model output can be used to support the selection and design of various stormwater management BMPs to reduce the potential hydrologic and water quality impacts from roadway runoff. Modeling BMP pollutant removal capability can demonstrate how different BMP design configurations and sizing and flow through vegetated areas effect BMP treatment efficiencies and pollutant loading from highway runoff. Accounting for the fate and transport of various sediment particle sizes that are typically found in roadway runoff, as well as the effects of filtration and infiltration along the flow path, both under existing and proposed conditions, allows for a more detailed assessment of BMP needs and performance and a more representative depiction of the potential water quality improvements that may occur with the proposed BMPs.

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Appendix

USGS/FHWA Precipitation Data for Calibration Events

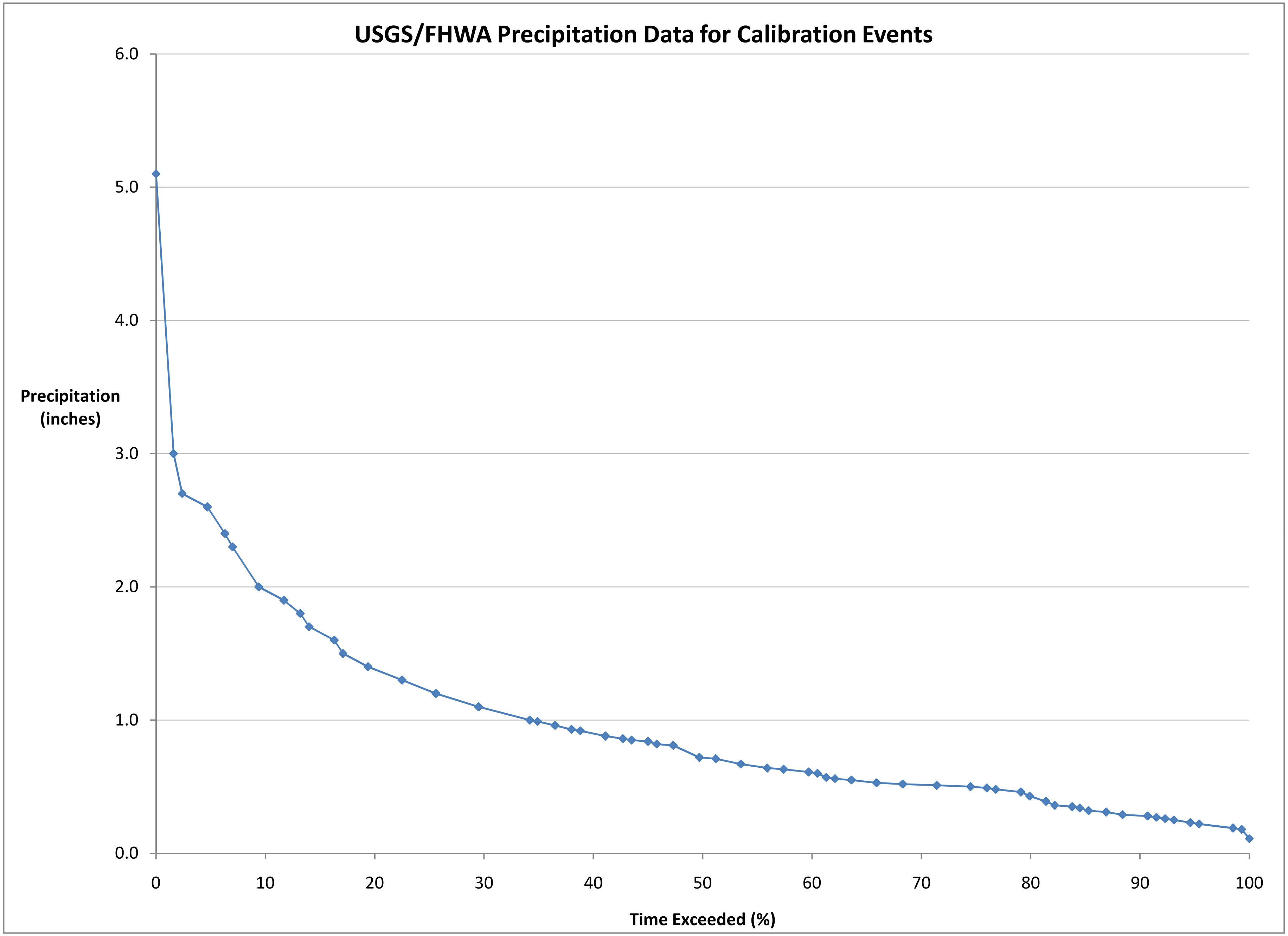
USGS and Federal Highway Administration's (FHWA) Highway-Runoff Database (HRDB) (Granato and Cazenas, 2009)

Number of Records	130
Mean	0.90
Median	0.71
Standard Deviation	0.63
Maximum	3.00
Minimum	0.11

Precipitation (inches)	Precipitation Percentile	Runoff Volume (cubic feet)	Event Type	Date	Site Name
5.10	0.00	3323	Rain	10/7/2005	MA I-190 423016071431501, Leominster
3.00	1.60	4825	Rain	10/24/2005	MA I-495 422716071343901, Bolton
3.00	1.60	6441	Rain	10/24/2005	MA I-495 422821071332001, Boxborough
2.70	2.40	1903	Rain	10/24/2005	MA I-190 423016071431501, Leominster
2.60	4.70	2130	Rain	6/24/2006	MA I-195 414339070462201, Marion
2.60	4.70	2442	Rain	6/2/2006	MA I-495 422716071343901, Bolton
2.60	4.70	8376	Rain	6/2/2006	MA I-495 422821071332001, Boxborough
2.40	6.30	342	Rain	11/8/2006	MA SR-119 424155071543201, Ashburham
2.40	6.30	11393	Rain	11/8/2006	MA SR-119 424209071545201, Ashburham
2.30	7.00	731	Snow/Mixed	3/17/2007	MA I-95 422420071153302, Waltham
2.00	9.40	8498	Snow/Mixed	3/2/2007	MA I-495 422821071332001, Boxborough
2.00	9.40	2064	Rain	10/24/2005	MA SR-119 424209071545201, Ashburham
2.00	9.40	3590	Rain	4/14/2007	MA SR-119 424209071545201, Ashburham
1.90	11.70	235	Snow/Mixed	3/17/2007	MA I-95 422620071153301, Lexington
1.90	11.70	209	Rain	10/24/2005	MA SR-119 424155071543201, Ashburham
1.90	11.70	3759	Rain	9/29/2005	MA SR-119 424209071545201, Ashburham
1.80	13.20	1338	Rain	11/12/2006	MA I-495 422821071332001, Boxborough
1.80	13.20	1836	Snow/Mixed	3/2/2007	MA I-95 422420071153302, Waltham
1.70	14.00	8685	Snow/Mixed	2/14/2007	MA I-93 421647071024703, Boston
1.60	16.30	6097	Rain	6/23/2006	MA I-93 421647071024703, Boston
1.60	16.30	4932	Rain	11/7/2006	MA SR-2 423027071291301, Littleton
1.60	16.30	1849	Rain	12/1/2006	MA SR-8 424019073062601, North Adams
1.50	17.10	2354	Rain	11/7/2006	MA I-95 422620071153301, Lexington
1.40	19.40	1391	Rain	8/20/2006	MA I-495 422716071343901, Bolton
1.40	19.40	3658	Rain	8/20/2006	MA I-495 422821071332001, Boxborough
1.40	19.40	811	Rain	5/16/2007	MA I-95 422420071153302, Waltham
1.30	22.50	784	Rain	10/22/2005	MA I-190 423016071431501, Leominster
1.30	22.50	2210	Rain	10/22/2005	MA I-495 422716071343901, Bolton
1.30	22.50	2987	Rain	10/22/2005	MA I-495 422821071332001, Boxborough
1.30	22.50	856	Rain	11/7/2006	MA I-95 422420071153302, Waltham
1.20	25.60	116	Rain	1/18/2006	MA SR-119 424155071543201, Ashburham
1.20	25.60	1892	Rain	1/18/2006	MA SR-119 424209071545201, Ashburham
1.20	25.60	1243	Rain	4/12/2007	MA SR-2 423027071291301, Littleton
1.20	25.60	1176	Rain	4/12/2007	MA SR-2 423027071291302, Littleton
1.10	29.50	1696	Rain	1/18/2006	MA I-495 422716071343901, Bolton
1.10	29.50	1057	Rain	4/12/2007	MA I-495 422821071332001, Boxborough
1.10	29.50	1542	Rain	5/9/2006	MA I-95 422620071153301, Lexington
1.10	29.50	1061	Rain	4/12/2007	MA I-95 422620071153301, Lexington
1.10	29.50	4172	Rain	10/24/2005	MA SR-2 423027071291301, Littleton
1.00	34.20	553	Rain	4/12/2007	MA I-95 422420071153302, Waltham
1.00	34.20	188	Rain	8/20/2006	MA SR-119 424155071543201, Ashburham
1.00	34.20	2657	Rain	1/8/2007	MA SR-119 424209071545201, Ashburham
1.00	34.20	656	Rain	6/23/2006	MA SR-2 423027071291301, Littleton
1.00	34.20	954	Rain	8/20/2006	MA SR-2 423027071291301, Littleton

Precipitation (inches)	Precipitation Percentile	Runoff Volume (cubic feet)	Event Type	Date	Site Name
1.00	34.20	177	Rain	8/20/2006	MA SR-2 423027071291302, Littleton
0.99	34.90	842	Rain	10/22/2005	MA I-95 422620071153301, Lexington
0.96	36.50	1756	Rain	9/15/2005	MA I-95 422620071153301, Lexington
0.96	36.50	6521	Rain	10/22/2005	MA SR-119 424209071545201, Ashburham
0.93	38.00	160	Rain	6/3/2007	MA SR-119 424155071543201, Ashburham
0.93	38.00	3558	Rain	6/3/2007	MA SR-119 424209071545201, Ashburham
0.92	38.80	960	Rain	8/14/2005	MA I-190 423016071431501, Leominster
0.88	41.10	1469	Rain	1/8/2007	MA I-495 422821071332001, Boxborough
0.88	41.10	1172	Rain	1/8/2007	MA SR-2 423027071291301, Littleton
0.88	41.10	23	Rain	1/8/2007	MA SR-2 423027071291302, Littleton
0.86	42.70	986	Rain	5/9/2006	MA I-495 422716071343901, Bolton
0.86	42.70	1980	Rain	5/9/2006	MA I-495 422821071332001, Boxborough
0.85	43.50	1726	Rain	8/27/2006	MA I-495 422821071332001, Boxborough
0.84	45.00	512	Rain	8/27/2006	MA SR-2 423027071291301, Littleton
0.84	45.00	283	Rain	8/27/2006	MA SR-2 423027071291302, Littleton
0.82	45.80	1041	Rain	4/23/2006	MA I-195 414339070462201, Marion
0.81	47.30	654	Rain	8/20/2006	MA I-95 422420071153302, Waltham
0.81	47.30	554	Rain	1/18/2006	MA SR-2 423027071291301, Littleton
0.72	49.70	443	Rain	8/27/2006	MA I-95 422420071153302, Waltham
0.72	49.70	1150	Rain	1/18/2006	MA I-95 422620071153301, Lexington
0.72	49.70	2226	Rain	8/27/2006	MA I-95 422620071153301, Lexington
0.71	51.20	542	Rain	9/19/2006	MA I-95 422420071153302, Waltham
0.71	51.20	3327	Rain	9/19/2006	MA I-95 422620071153301, Lexington
0.67	53.50	250	Rain	9/29/2006	MA I-195 414339070462201, Marion
0.67	53.50	778	Rain	9/19/2006	MA SR-2 423027071291301, Littleton
0.67	53.50	599	Rain	9/19/2006	MA SR-2 423027071291302, Littleton
0.64	55.90	1107	Rain	9/19/2006	MA I-495 422716071343901, Bolton
0.64	55.90	1081	Rain	9/19/2006	MA I-495 422821071332001, Boxborough
0.64	55.90	2315	Rain	4/23/2006	MA I-93 421647071024703, Boston
0.63	57.40	769	Rain	2/14/2007	MA I-195 414339070462201, Marion
0.63	57.40	1335	Rain	3/13/2006	MA SR-2 423027071291301, Littleton
0.61	59.70	2600	Rain	9/19/2006	MA I-93 421647071024703, Boston
0.61	59.70	254	Rain	7/11/2007	MA SR-119 424155071543201, Ashburham
0.61	59.70	4222	Rain	7/11/2007	MA SR-119 424209071545201, Ashburham
0.60	60.50	713	Rain	11/16/2005	MA I-95 422620071153301, Lexington
0.57	61.30	1528	Rain	10/22/2005	MA SR-2 423027071291301, Littleton
0.56	62.10	453	Rain	6/23/2006	MA SR-8 424019073062601, North Adams
0.55	63.60	132	Rain	1/11/2006	MA SR-119 424155071543201, Ashburham
0.55	63.60	3341	Rain	1/11/2006	MA SR-119 424209071545201, Ashburham
0.53	65.90	1389	Rain	3/13/2006	MA I-495 422716071343901, Bolton
0.53	65.90	2090	Rain	3/13/2006	MA I-495 422821071332001, Boxborough
0.53	65.90	75	Rain	3/13/2006	MA SR-119 424155071543201, Ashburham
0.52	68.30	625	Snow/Mixed	3/13/2006	MA I-95 422620071153301, Lexington
0.52	68.30	47	Rain	4/27/2007	MA SR-119 424155071543201, Ashburham
0.52	68.30	436	Rain	5/9/2006	MA SR-119 424209071545201, Ashburham
0.51	71.40	614	Rain	8/8/2007	MA I-495 422821071332001, Boxborough
0.51	71.40	289	Rain	9/29/2005	MA SR-119 424155071543201, Ashburham
0.51	71.40	498	Rain	8/8/2007	MA SR-2 423027071291301, Littleton
0.51	71.40	619	Rain	8/8/2007	MA SR-2 423027071291302, Littleton
0.50	74.50	920	Rain	1/11/2006	MA I-495 422716071343901, Bolton
0.50	74.50	2527	Rain	1/11/2006	MA I-495 422821071332001, Boxborough
0.50	74.50	456	Rain	12/1/2006	MA SR-2 423027071291302, Littleton
0.50	74.50	553	Snow/Mixed	3/2/2007	MA SR-8 424019073062601, North Adams
0.49	76.00	249	Snow/Mixed	3/13/2006	MA I-190 423016071431501, Leominster
0.49	76.00	2588	Rain	8/20/2006	MA I-95 422620071153301, Lexington

Precipitation (inches)	Precipitation Percentile	Runoff Volume (cubic feet)	Event Type	Date	Site Name
0.48	76.80	375	Rain	1/11/2006	MA SR-2 423027071291301, Littleton
0.46	79.10	460	Rain	9/29/2005	MA I-495 422716071343901, Bolton
0.46	79.10	1038	Rain	9/29/2005	MA I-495 422821071332001, Boxborough
0.46	79.10	1812	Rain	11/12/2006	MA SR-119 424209071545201, Ashburham
0.43	79.90	292	Rain	9/29/2005	MA SR-2 423027071291301, Littleton
0.39	81.40	106	Rain	12/1/2006	MA I-195 414339070462201, Marion
0.39	81.40	548	Rain	9/29/2005	MA I-95 422620071153301, Lexington
0.36	82.20	196	Rain	9/29/2005	MA I-190 423016071431501, Leominster
0.35	83.80	2096	Rain	6/1/2006	MA SR-119 424209071545201, Ashburham
0.35	83.80	1661	Rain	9/14/2006	MA SR-119 424209071545201, Ashburham
0.34	84.50	822	Rain	4/1/2007	MA SR-119 424209071545201, Ashburham
0.32	85.30	533	Rain	5/16/2007	MA SR-2 423027071291302, Littleton
0.31	86.90	847	Snow/Mixed	3/17/2007	MA SR-2 423027071291302, Littleton
0.31	86.90	196	Rain	8/6/2007	MA SR-2 423027071291302, Littleton
0.29	88.40	207	Rain	9/15/2005	MA I-495 422716071343901, Bolton
0.29	88.40	569	Rain	9/15/2005	MA I-495 422821071332001, Boxborough
0.28	90.70	91	Rain	8/6/2007	MA I-95 422420071153302, Waltham
0.28	90.70	230	Snow/Mixed	1/12/2006	MA I-95 422620071153301, Lexington
0.28	90.70	35	Rain	8/6/2007	MA I-95 422620071153301, Lexington
0.27	91.50	1040	Rain	9/19/2006	MA SR-119 424209071545201, Ashburham
0.26	92.30	829	Rain	12/1/2006	MA I-93 421647071024703, Boston
0.25	93.10	172	Rain	9/15/2005	MA SR-2 423027071291301, Littleton
0.23	94.60	200	Rain	8/6/2007	MA I-495 422821071332001, Boxborough
0.23	94.60	195	Snow/Mixed	3/11/2007	MA I-95 422620071153301, Lexington
0.22	95.40	398	Rain	9/23/2006	MA SR-8 424019073062601, North Adams
0.19	98.50	60	Rain	8/8/2007	MA I-95 422420071153302, Waltham
0.19	98.50	113	Rain	8/8/2007	MA I-95 422620071153301, Lexington
0.19	98.50	1386	Rain	3/13/2006	MA SR-119 424209071545201, Ashburham
0.19	98.50	96	Rain	8/6/2007	MA SR-2 423027071291301, Littleton
0.18	99.30	9876	Rain	6/2/2006	MA I-95 422620071153301, Lexington
0.11	100.00	286	Rain	9/15/2005	MA SR-119 424209071545201, Ashburham


USGS/FHWA Precipitation Data for Calibration Events
Precipitation (inches)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
10
20
30
40
50
60
70
80
90
100
Time Exceeded (%)

USGS/FHWA Total Suspended Solids Data for Calibration Events

USGS and Federal Highway Administration's (FHWA) Highway-Runoff Database (HRDB) (Granato and Cazenas, 2009)

Number of Records	127
Mean	202
Median	66
Standard Deviation	442
Maximum	4050
Minimum	3

TSS (mg/L) p80154 Suspended sediment concentration, milligrams per liter	TSS <0.063 mm (%) p69359 Suspended sediment, direct measurement, percent smaller than 0.063 millimeters	TSS <0.25 mm (%) p69351 Suspended sediment, direct measurement, percent smaller than 0.25 millimeters	TSS <0.063 (mg/L) Calculated Suspended sediment concentration, smaller than 0.063 millimeters, milligrams per liter	TSS <0.25 (mg/L) Calculated Suspended sediment concentration, smaller than 0.250 millimeters, milligrams per liter	Date	Site
4050	4	13	162	527	6/23/2006 2:27:00 PM	MA I-93 421647071024703, Boston
2060	95	98	1957	2019	3/2/2007 3:35:00 AM	MA I-495 422821071332001, Boxborough
1360	16	18	218	245	1/18/2006 1:11:00 PM	MA I-95 422620071153301, Lexington
958	58	66	556	632	1/11/2006 8:21:00 PM	MA I-495 422821071332001, Boxborough
879	68	83	598	730	3/13/2006 9:18:00 PM	MA SR-119 424209071545201, Ashburham
877	48	62	421	544	3/13/2006 1:09:00 PM	MA I-495 422821071332001, Boxborough
718	62	81	445	582	2/14/2007 11:08:00 AM	MA I-93 421647071024703, Boston
714	21	39	150	278	12/1/2006 4:34:00 PM	MA I-93 421647071024703, Boston
655	79	79	517	517	3/13/2006 11:11:00 PM	MA I-95 422620071153301, Lexington
572	13	25	74	143	9/29/2005 2:39:00 PM	MA I-495 422821071332001, Boxborough
528	86	96	454	507	3/13/2006 12:37:00 PM	MA I-190 423016071431501, Leominster
439	85	98	373	430	3/13/2006 9:50:00 PM	MA SR-119 424155071543201, Ashburham
406	77	84	313	341	3/2/2007 4:13:00 AM	MA SR-2 423027071291301, Littleton
406	74	84	300	341	3/17/2007 3:11:00 AM	MA I-95 422620071153301, Lexington
400	25	34	100	136	12/1/2006 1:29:00 PM	MA SR-8 424019073062601, North Adams
387	97	98	375	379	1/12/2006 12:26:00 AM	MA I-95 422620071153301, Lexington
351	98	99	344	347	1/11/2006 8:24:00 PM	MA I-495 422716071343901, Bolton
347	95	99	330	344	3/2/2007 2:57:00 AM	MA I-95 422420071153302, Waltham
347	72	89	250	309	4/12/2007 12:33:00 PM	MA I-495 422821071332001, Boxborough
336	84	94	282	316	4/12/2007 2:24:00 PM	MA SR-2 423027071291301, Littleton
327	87	94	284	307	3/13/2006 10:45:00 PM	MA SR-2 423027071291301, Littleton
284	18	39	51	111	6/2/2006 5:54:00 AM	MA I-495 422821071332001, Boxborough
278	63	80	175	222	1/18/2006 7:52:00 AM	MA SR-119 424209071545201, Ashburham
268	25	63	67	169	12/1/2006 4:18:00 PM	MA SR-2 423027071291302, Littleton
266	98	99	261	263	1/11/2006 8:45:00 PM	MA SR-2 423027071291301, Littleton
263	89	97	234	255	1/11/2006 8:40:00 PM	MA SR-119 424209071545201, Ashburham
263	64	95	168	250	1/11/2006 8:46:00 PM	MA SR-119 424155071543201, Ashburham
255	87	94	222	240	3/17/2007 2:26:00 AM	MA I-95 422420071153302, Waltham
254	9	15	23	38	9/29/2005 3:18:00 PM	MA I-95 422620071153301, Lexington
248	49	75	122	186	5/16/2007 3:32:00 PM	MA I-95 422420071153302, Waltham
242	99	100	240	242	3/2/2007 10:42:00 AM	MA SR-8 424019073062601, North Adams
242	98	99	237	240	3/13/2006 10:46:00 PM	MA I-495 422716071343901, Bolton
207	17	32	35	66	9/19/2006 10:35:00 PM	MA I-93 421647071024703, Boston
198	11	28	22	55	9/19/2006 8:59:00 PM	MA SR-2 423027071291302, Littleton
188	54	86	102	162	8/6/2007 3:41:00 PM	MA I-95 422420071153302, Waltham
187	63	71	118	133	4/12/2007 1:46:00 PM	MA SR-2 423027071291302, Littleton
174	88	93	153	162	4/12/2007 2:03:00 PM	MA I-95 422620071153301, Lexington
173	98	99	170	171	1/18/2006 2:59:00 AM	MA I-495 422716071343901, Bolton
169	77	88	130	149	4/12/2007 1:53:00 PM	MA I-95 422420071153302, Waltham
160	79	94	126	150	1/18/2006 10:58:00 AM	MA SR-119 424155071543201, Ashburham
157	90	99	141	155	6/1/2006 10:19:00 PM	MA SR-119 424209071545201, Ashburham
157	33	58	52	91	8/8/2007 6:29:00 AM	MA SR-2 423027071291302, Littleton
153	97	99	148	151	1/18/2006 9:10:00 AM	MA SR-2 423027071291301, Littleton
145	47	75	68	109	8/6/2007 3:14:00 PM	MA SR-2 423027071291302, Littleton
136	48	84	65	114	8/6/2007 3:02:00 PM	MA I-495 422821071332001, Boxborough
134	51	86	68	115	8/8/2007 6:12:00 AM	MA I-495 422821071332001, Boxborough
121	46	68	56	82	9/29/2005 2:49:00 PM	MA SR-2 423027071291301, Littleton
114	18	66	21	75	8/6/2007 3:15:00 PM	MA SR-2 423027071291301, Littleton
112	85	88	95	99	3/11/2007 3:20:00 AM	MA I-95 422620071153301, Lexington
112	56	88	63	99	9/29/2005 2:16:00 PM	MA I-190 423016071431501, Leominster
107	27	44	29	47	6/23/2006 9:00:00 PM	MA SR-8 424019073062601, North Adams
95	59	82	56	78	4/27/2007 6:36:00 AM	MA SR-119 424155071543201, Ashburham
94	57	90	54	85	8/8/2007 6:29:00 AM	MA SR-2 423027071291301, Littleton
91	18	36	16	33	9/19/2006 9:36:00 PM	MA I-95 422620071153301, Lexington
90	96	99	86	89	4/23/2006 2:44:00 PM	MA I-93 421647071024703, Boston
88	70	77	62	68	5/9/2006 2:56:00 PM	MA I-95 422620071153301, Lexington
87	66	91	57	79	5/16/2007 3:15:00 PM	MA SR-2 423027071291302, Littleton
87	36	63	31	55	9/15/2005 10:07:00 AM	MA I-95 422620071153301, Lexington
86	59	88	51	76	8/14/2005 5:36:00 PM	MA I-190 423016071431501, Leominster
80	85	92	68	74	3/17/2007 1:12:00 PM	MA SR-2 423027071291302, Littleton
78	39	46	30	36	6/2/2006 3:56:00 AM	MA I-95 422620071153301, Lexington
76	94	98	71	74	4/14/2007 1:31:00 PM	MA SR-119 424209071545201, Ashburham
74	70	83	52	61	8/8/2007 7:26:00 AM	MA I-95 422420071153302, Waltham
66	51	81	34	53	11/12/2006 12:06:00 PM	MA I-495 422821071332001, Boxborough
66	51	63	34	42	11/7/2006 11:06:00 PM	MA I-95 422620071153301, Lexington
59	28	65	17	38	8/20/2006 3:14:00 AM	MA I-495 422821071332001, Boxborough
58	51	85	30	49	8/6/2007 3:38:00 PM	MA I-95 422620071153301, Lexington
57	44	77	25	44	9/29/2005 1:59:00 PM	MA SR-119 424155071543201, Ashburham

TSS (mg/L) p80154 Suspended sediment concentration, milligrams per liter	TSS <0.063 mm (%) p69359 Suspended sediment, direct measurement, percent smaller than 0.063 millimeters	TSS <0.25 mm (%) p69351 Suspended sediment, direct measurement, percent smaller than 0.25 millimeters	TSS <0.063 (mg/L) Calculated Suspended sediment concentration, smaller than 0.063 millimeters, milligrams per liter	TSS <0.25 (mg/L) Calculated Suspended sediment concentration, smaller than 0.250 millimeters, milligrams per liter	Date	Site
57	50	56	29	32	9/15/2005 10:07:00 AM	MA SR-2 423027071291301, Littleton
56	34	59	19	33	9/19/2006 9:00:00 PM	MA SR-2 423027071291301, Littleton
52	46	76	24	40	9/19/2006 8:48:00 PM	MA I-495 422821071332001, Boxborough
51	31	66	16	34	10/22/2005 7:27:00 PM	MA SR-2 423027071291301, Littleton
49	29	57	14	28	8/20/2006 3:31:00 AM	MA SR-2 423027071291301, Littleton
48	63	70	30	34	2/14/2007 12:08:00 PM	MA I-195 414339070462201, Marion
41	89	92	36	38	9/15/2005 9:58:00 AM	MA I-495 422716071343901, Bolton
41	74	82	30	34	9/15/2005 9:51:00 AM	MA I-495 422821071332001, Boxborough
39	52	80	20	31	6/24/2006 2:15:00 AM	MA I-195 414339070462201, Marion
39	60	73	23	28	1/8/2007 4:55:00 AM	MA SR-2 423027071291301, Littleton
38	61	86	23	33	9/29/2005 1:57:00 PM	MA SR-119 424209071545201, Ashburham
38	29	40	11	15	10/24/2005 10:00:00 PM	MA I-495 422821071332001, Boxborough
37	86	91	32	34	4/23/2006 7:04:00 PM	MA I-195 414339070462201, Marion
35	88	95	31	33	8/8/2007 7:22:00 AM	MA I-95 422620071153301, Lexington
33	88	98	29	32	9/29/2005 2:41:00 PM	MA I-495 422716071343901, Bolton
33	80	88	26	29	4/1/2007 10:52:00 PM	MA SR-119 424209071545201, Ashburham
33	45	71	15	23	10/22/2005 7:40:00 PM	MA I-495 422821071332001, Boxborough
31	70	90	22	28	12/1/2006 9:07:00 AM	MA I-195 414339070462201, Marion
30	54	87	16	26	6/3/2007 3:50:00 PM	MA SR-119 424155071543201, Ashburham
28	91	97	25	27	5/9/2006 2:58:00 PM	MA I-495 422821071332001, Boxborough
28	59	77	17	22	9/29/2006 1:21:00 AM	MA I-195 414339070462201, Marion
26	74	83	19	22	1/8/2007 5:01:00 AM	MA SR-2 423027071291302, Littleton
26	32	46	8	12	8/20/2006 4:29:00 AM	MA I-95 422620071153301, Lexington
25	81	89	20	22	1/8/2007 4:56:00 AM	MA I-495 422821071332001, Boxborough
23	85	96	20	22	6/2/2006 8:58:00 PM	MA I-495 422716071343901, Bolton
22	79	94	17	21	5/9/2006 3:06:00 PM	MA I-495 422716071343901, Bolton
22	65	86	14	19	9/19/2006 8:28:00 PM	MA I-95 422420071153302, Waltham
22	56	82	12	18	7/11/2007 9:08:00 PM	MA SR-119 424209071545201, Ashburham
20	91	94	18	19	9/23/2006 8:10:00 AM	MA SR-8 424019073062601, North Adams
20	56	82	11	16	8/20/2006 3:34:00 AM	MA I-95 422420071153302, Waltham
19	82	99	16	19	8/20/2006 3:15:00 AM	MA I-495 422716071343901, Bolton
19	54	77	10	15	8/20/2006 3:28:00 AM	MA SR-2 423027071291302, Littleton
19	60	73	11	14	11/16/2005 8:56:00 PM	MA I-95 422620071153301, Lexington
19	28	44	5	8	11/8/2006 1:41:00 PM	MA SR-119 424155071543201, Ashburham
18	91	98	16	18	1/8/2007 12:59:00 AM	MA SR-119 424209071545201, Ashburham
18	64	93	12	17	7/11/2007 10:06:00 PM	MA SR-119 424155071543201, Ashburham
17	74	94	13	16	10/7/2005 11:45:00 PM	MA I-190 423016071431501, Leominster
17	84	89	14	15	9/15/2005 6:02:00 AM	MA SR-119 424209071545201, Ashburham
17	52	66	9	11	8/20/2006 3:13:00 AM	MA SR-119 424155071543201, Ashburham
16	84	95	13	15	11/7/2006 9:38:00 PM	MA I-95 422420071153302, Waltham
16	81	88	13	14	9/19/2006 8:48:00 PM	MA I-495 422716071343901, Bolton
14	42	61	6	9	8/27/2006 3:27:00 PM	MA SR-2 423027071291302, Littleton
13	96	98	12	13	4/22/2006 7:49:00 PM	MA SR-8 424019073062601, North Adams
13	37	60	5	8	10/24/2005 10:22:00 PM	MA SR-2 423027071291301, Littleton
12	82	95	10	11	8/27/2006 3:56:00 PM	MA I-95 422420071153302, Waltham
12	82	91	10	11	5/9/2006 5:05:00 PM	MA SR-119 424209071545201, Ashburham
12	65	86	8	10	8/27/2006 2:29:00 PM	MA I-495 422821071332001, Boxborough
12	56	71	7	9	8/27/2006 4:36:00 PM	MA I-95 422620071153301, Lexington
11	85	93	9	10	10/22/2005 6:56:00 PM	MA I-495 422716071343901, Bolton
11	53	86	6	9	10/22/2005 11:56:00 PM	MA I-95 422620071153301, Lexington
11	63	78	7	9	10/22/2005 6:31:00 PM	MA I-190 423016071431501, Leominster
8	94	97	8	8	9/14/2006 3:18:00 PM	MA SR-119 424209071545201, Ashburham
8	87	97	7	8	10/24/2005 9:48:00 PM	MA I-190 423016071431501, Leominster
8	79	93	6	7	10/24/2005 9:56:00 PM	MA I-495 422716071343901, Bolton
7	94	97	7	7	6/3/2007 3:46:00 PM	MA SR-119 424209071545201, Ashburham
6	59	79	4	5	8/27/2006 2:50:00 PM	MA SR-2 423027071291301, Littleton
6	47	71	3	4	11/7/2006 10:03:00 PM	MA SR-2 423027071291301, Littleton
5	90	95	5	5	9/19/2006 7:30:00 PM	MA SR-119 424209071545201, Ashburham
3	80	88	2	3	11/8/2006 4:50:00 AM	MA SR-119 424209071545201, Ashburham

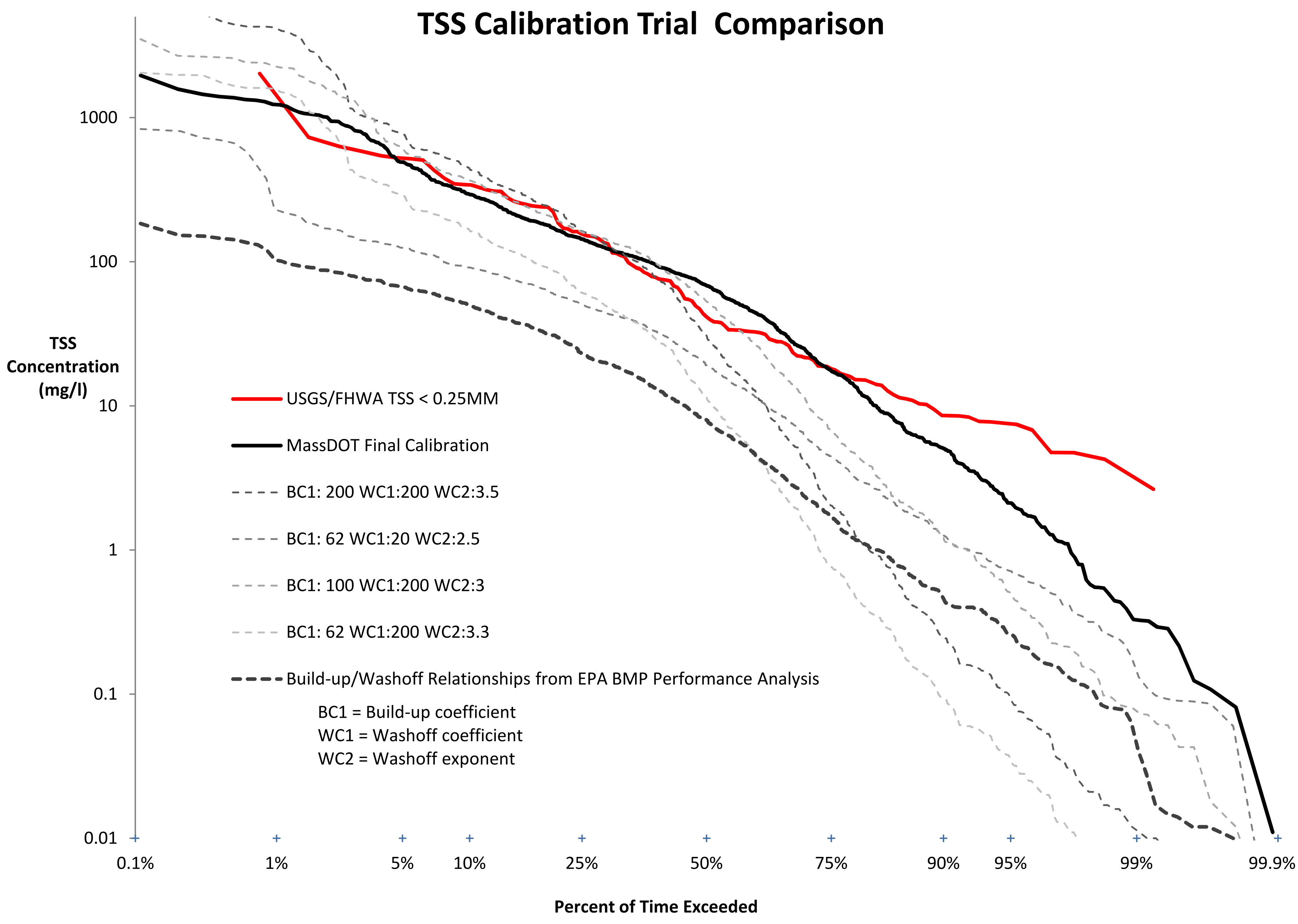
USGS/FHWA Total Phosphorus Data for Calibration Events

USGS and Federal Highway Administration's (FHWA) Highway-Runoff Database (HRDB) (Granato and Cazenas, 2009)

Number of Records	133
Mean	0.14
Median	0.10
Standard Deviation	0.14
Maximum	0.76
Minimum	0.01

TP Event Mean Concentration (mg/L) p00665 Phosphorus, water, unfiltered, milligrams per lite	Date	Site
0.76	2/14/2007	MA I-93 421647071024703, Boston
0.71	6/23/2006	MA I-93 421647071024703, Boston
0.68	3/13/2006	MA I-495 422821071332001, Boxborough
0.54	3/13/2006	MA I-95 422620071153301, Lexington
0.51	3/13/2006	MA SR-119 424209071545201, Ashburham
0.42	3/2/2007	MA I-495 422821071332001, Boxborough
0.41	8/6/2007	MA I-95 422420071153302, Waltham
0.40	3/13/2006	MA I-190 423016071431501, Leominster
0.39	1/11/2006	MA I-495 422821071332001, Boxborough
0.38	3/17/2007	MA I-95 422620071153301, Lexington
0.36	3/2/2007	MA I-95 422420071153302, Waltham
0.34	12/1/2006	MA I-93 421647071024703, Boston
0.34	3/2/2007	MA SR-2 423027071291301, Littleton
0.33	3/13/2006	MA SR-119 424155071543201, Ashburham
0.33	5/16/2007	MA I-95 422420071153302, Waltham
0.32	4/12/2007	MA SR-2 423027071291301, Littleton
0.31	1/12/2006	MA I-95 422620071153301, Lexington
0.29	3/13/2006	MA SR-2 423027071291301, Littleton
0.27	3/17/2007	MA I-95 422420071153302, Waltham
0.25	4/12/2007	MA I-495 422821071332001, Boxborough
0.24	1/11/2006	MA I-495 422716071343901, Bolton
0.24	6/1/2006	MA SR-119 424209071545201, Ashburham
0.23	1/18/2006	MA I-95 422620071153301, Lexington
0.23	3/13/2006	MA I-495 422716071343901, Bolton
0.23	8/6/2007	MA SR-2 423027071291302, Littleton
0.21	6/2/2006	MA I-495 422821071332001, Boxborough
0.21	3/2/2007	MA SR-8 424019073062601, North Adams
0.21	8/6/2007	MA I-95 422620071153301, Lexington
0.20	1/11/2006	MA SR-119 424209071545201, Ashburham
0.20	1/11/2006	MA SR-2 423027071291301, Littleton
0.20	4/12/2007	MA I-95 422420071153302, Waltham
0.20	4/12/2007	MA I-95 422620071153301, Lexington
0.20	8/6/2007	MA I-495 422821071332001, Boxborough
0.19	9/15/2005	MA I-495 422821071332001, Boxborough
0.19	1/11/2006	MA SR-119 424155071543201, Ashburham
0.19	1/18/2006	MA SR-119 424209071545201, Ashburham
0.18	9/15/2005	MA I-495 422716071343901, Bolton
0.18	12/1/2006	MA SR-8 424019073062601, North Adams
0.17	9/29/2005	MA I-495 422821071332001, Boxborough
0.17	4/12/2007	MA SR-2 423027071291302, Littleton
0.16	8/14/2005	MA I-190 423016071431501, Leominster
0.16	9/29/2005	MA SR-2 423027071291301, Littleton
0.16	1/18/2006	MA I-495 422716071343901, Bolton
0.16	1/18/2006	MA SR-2 423027071291301, Littleton
0.16	8/8/2007	MA SR-2 423027071291302, Littleton
0.16	8/8/2007	MA I-95 422620071153301, Lexington
0.15	9/15/2005	MA SR-2 423027071291301, Littleton
0.15	1/18/2006	MA SR-119 424155071543201, Ashburham
0.15	12/1/2006	MA SR-2 423027071291302, Littleton
0.15	3/11/2007	MA I-95 422620071153301, Lexington
0.15	8/8/2007	MA I-95 422420071153302, Waltham
0.14	9/29/2005	MA I-190 423016071431501, Leominster
0.14	9/19/2006	MA I-495 422821071332001, Boxborough
0.14	5/16/2007	MA SR-2 423027071291302, Littleton
0.13	9/15/2005	MA I-95 422620071153301, Lexington
0.13	4/23/2006	MA I-93 421647071024703, Boston
0.13	5/9/2006	MA I-95 422620071153301, Lexington
0.13	9/19/2006	MA SR-2 423027071291302, Littleton
0.13	8/8/2007	MA I-495 422821071332001, Boxborough
0.13	8/8/2007	MA SR-2 423027071291301, Littleton
0.12	9/29/2005	MA I-95 422620071153301, Lexington
0.12	6/2/2006	MA SR-2 423027071291301, Littleton
0.11	9/19/2006	MA I-93 421647071024703, Boston
0.11	3/17/2007	MA SR-2 423027071291302, Littleton

TP Event Mean Concentration (mg/L) p00665 Phosphorus, water, unfiltered, milligrams per lite	**Date**	**Site**
0.11	8/6/2007	MA SR-2 423027071291301, Littleton
0.10	9/15/2005	MA SR-119 424209071545201, Ashburham
0.10	5/9/2006	MA I-495 422821071332001, Boxborough
0.10	6/7/2006	MA I-95 422420071153301, Waltham
0.10	8/20/2006	MA I-495 422821071332001, Boxborough
0.10	11/7/2006	MA I-95 422620071153301, Lexington
0.09	6/2/2006	MA I-95 422620071153301, Lexington
0.08	9/29/2005	MA I-495 422716071343901, Bolton
0.08	8/20/2006	MA SR-2 423027071291302, Littleton
0.08	11/12/2006	MA I-495 422821071332001, Boxborough
0.08	4/14/2007	MA SR-119 424209071545201, Ashburham
0.08	4/27/2007	MA SR-119 424155071543201, Ashburham
0.07	6/23/2006	MA SR-8 424019073062601, North Adams
0.07	9/19/2006	MA I-95 422620071153301, Lexington
0.06	9/29/2005	MA SR-119 424155071543201, Ashburham
0.06	5/9/2006	MA I-495 422716071343901, Bolton
0.06	5/9/2006	MA SR-2 423027071291301, Littleton
0.06	9/19/2006	MA SR-119 424209071545201, Ashburham
0.06	9/19/2006	MA I-95 422420071153302, Waltham
0.06	9/19/2006	MA SR-2 423027071291301, Littleton
0.06	9/23/2006	MA SR-8 424019073062601, North Adams
0.06	11/7/2006	MA I-95 422420071153302, Waltham
0.06	12/1/2006	MA I-195 414339070462201, Marion
0.06	2/14/2007	MA I-195 414339070462201, Marion
0.05	10/7/2005	MA I-190 423016071431501, Leominster
0.05	10/22/2005	MA SR-2 423027071291301, Littleton
0.05	11/16/2005	MA I-95 422620071153301, Lexington
0.05	5/9/2006	MA SR-119 424209071545201, Ashburham
0.05	8/20/2006	MA SR-2 423027071291301, Littleton
0.05	8/20/2006	MA I-95 422420071153302, Waltham
0.05	9/19/2006	MA I-495 422716071343901, Bolton
0.05	1/8/2007	MA SR-2 423027071291301, Littleton
0.05	1/8/2007	MA SR-2 423027071291302, Littleton
0.05	4/1/2007	MA SR-119 424209071545201, Ashburham
0.04	9/29/2005	MA SR-119 424209071545201, Ashburham
0.04	10/22/2005	MA I-190 423016071431501, Leominster
0.04	4/23/2006	MA I-195 414339070462201, Marion
0.04	6/24/2006	MA I-195 414339070462201, Marion
0.04	8/20/2006	MA SR-119 424155071543201, Ashburham
0.04	8/20/2006	MA I-495 422716071343901, Bolton
0.04	8/20/2006	MA I-95 422620071153301, Lexington
0.04	9/29/2006	MA I-195 414339070462201, Marion
0.04	11/7/2006	MA SR-2 423027071291301, Littleton
0.04	1/8/2007	MA I-495 422821071332001, Boxborough
0.04	7/11/2007	MA SR-119 424209071545201, Ashburham
0.03	10/22/2005	MA I-495 422716071343901, Bolton
0.03	10/22/2005	MA I-95 422620071153301, Lexington
0.03	4/22/2006	MA SR-8 424019073062601, North Adams
0.03	6/2/2006	MA I-495 422716071343901, Bolton
0.03	8/27/2006	MA I-95 422620071153301, Lexington
0.03	9/14/2006	MA SR-119 424209071545201, Ashburham
0.03	11/8/2006	MA SR-119 424155071543201, Ashburham
0.03	1/8/2007	MA SR-119 424209071545201, Ashburham
0.03	6/3/2007	MA SR-119 424155071543201, Ashburham
0.03	7/11/2007	MA SR-119 424155071543201, Ashburham
0.02	10/22/2005	MA I-495 422821071332001, Boxborough
0.02	10/22/2005	MA SR-119 424209071545201, Ashburham
0.02	10/24/2005	MA SR-119 424209071545201, Ashburham
0.02	10/24/2005	MA I-495 422716071343901, Bolton
0.02	10/24/2005	MA I-495 422821071332001, Boxborough
0.02	10/24/2005	MA SR-119 424155071543201, Ashburham
0.02	10/24/2005	MA SR-2 423027071291301, Littleton
0.02	8/27/2006	MA SR-2 423027071291302, Littleton
0.02	11/8/2006	MA SR-119 424209071545201, Ashburham
0.02	6/3/2007	MA SR-119 424209071545201, Ashburham
0.01	10/24/2005	MA I-190 423016071431501, Leominster
0.01	8/27/2006	MA I-495 422821071332001, Boxborough
0.01	8/27/2006	MA I-95 422420071153302, Waltham
0.009	8/27/2006	MA SR-2 423027071291301, Littleton



TSS Calibration Trial Comparison
TSS Concentration (mg/l)
1000
100
10
1
0.1
0.01
USGS/FHWA TSS < 0.25MM
MassDOT Final Calibration
BC1: 200 WC1:200 WC2:3.5
BC1: 62 WC1:20 WC2:2.5
BC1: 100 WC1:200 WC2:3
BC1: 62 WC1:200 WC2:3.3
Build-up/Washoff Relationships from EPA BMP Performance Analysis
BC1 = Build-up coefficient
WC1 = Washoff coefficient
WC2 = Washoff exponent
0.1%
1%
5%
10%
25%
50%
75%
90%
95%
99%
99.9%
Percent of Time Exceeded