MEMORANDUM

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To: Permit File for Draft Small Massachusetts MS4 General Permit

From: Mark Voorhees, Stormwater Permitting Program, EPA Region 1

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Subject: Annual Average Phosphorus Load Export Rates (PLERs) for Use in Fulfilling Phosphorus Load Reduction Requirements in EPA Region 1 Stormwater Permits

Introduction:
This document describes the development of average annual Phosphorus Load Export Rates (PLERs) for use by permittees subject to stormwater-related phosphorus load reduction requirements in upcoming General Stormwater Permits issued by EPA Region 1 for discharges in MA and NH. Phosphorus load reduction requirements are being included in EPA Region 1 Stormwater permits for those waterbodies where EPA approved phosphorus Total Maximum Daily Loads (TMDLs) have been established and that include reductions for stormwater discharges potentially covered by stormwater permits. This document describes the development of two sets of land use specific PLERs for the permitting process. A third set of PLERs have been developed specifically for calculating baseline phosphorus loads and associated required load reductions for the Charles River watershed communities. The Charles River specific PLERs are described in a separate Memorandum (dated 4/22/14) with the subject heading: *Overview of Methodology to Calculate Baseline Stormwater Phosphorus Loads and Phosphorus Load Reduction Requirements for Charles River Watershed – Draft MA MS4 Permit.*

The first set of PLERs described in this document are intended to be used by **all** permittees (Charles River communities included) for accounting and tracking stormwater phosphorus load reduction credits as part of demonstrating compliance with phosphorus load reduction permit requirements. These PLERs are developed for several land use categories and provide distinct estimates of average annual phosphorus loads based on land surface type: (1) directly connected impervious area (DCIA) and (2) pervious area (PA). For example, PLERs for the commercial land use category consist of a PLER specific to DCIA and five other PA PLERs based on hydrologic soil conditions.

The second set of PLERs are intended to be used by only those permittees that are subject to phosphorus reduction requirements consistent with approved phosphorus TMDLs, **excluding the Charles River Phosphorus TMDLs.** For these TMDLs, EPA has determined that additional information is needed to estimate the TMDL baseline phosphorus loads and the associated phosphorus load reductions assigned to applicable MS4 drainage areas. For these cases, land use specific PLERs, referred to as "composite PLERs", are to be used by permittees to calculate baseline phosphorus loading and required load reductions that are consistent with the wasteload allocation (WLA) associated reductions identified in the TMDL documents. The composite PLERs are for estimating the combined average annual phosphorus load from both impervious area (IA) and PA for a specified land use category. For example, there is one composite PLER for the commercial land use category that is to be applied to commercial areas comprised of both IA and PA as determined through Mass GIS.

Background on Permit Requirements for Phosphorus Control:
Phosphorus load reduction requirements for stormwater sources are being proposed for numerous municipalities in Massachusetts and New Hampshire in the upcoming Massachusetts (MA) and New Hampshire (NH) MS4

General Permits if their jurisdictional drainage areas discharge to waterbodies for which phosphorus TMDLs have been established and approved by EPA. The Draft MS4 Permits propose to require applicable permittees to develop and implement a Phosphorus Control Plan (PCP) which includes conducting a phosphorus loading analysis and developing an implementation plan to achieve the required phosphorus load reduction.

Depending on the receiving water and the applicable TMDL, the phosphorus loading analysis will serve one or two purposes: (1) to estimate the permittee's baseline phosphorus load for its TMDL watershed areas, which will in turn be used to calculate the overall phosphorus load reduction requirement based on information from the applicable TMDL; and/or (2) to calculate the average annual stormwater phosphorus load for drainage areas that will be implemented with stormwater controls in order to calculate phosphorus load reduction credits. The required overall reduction for each applicable MS4 permittee will be set to be consistent with WLA associated reductions established in the applicable TMDL analysis. The permittee shall develop an implementation plan that identifies the mix of non-structural and structural stormwater controls that will be implemented in the TMDL watershed to achieve the phosphorus load reductions being required.

The Draft MA MS4 Permit will provide methodologies for permittees to calculate baseline average annual phosphorus loads and required load reductions for watershed areas subject to phosphorus TMDLs. In the case of the Charles River watershed, the draft permit will provide the baseline phosphorus load and required phosphorus load reduction for each community based on two scenarios: (1) the entire Charles River Watershed area within the community; and (2) the designated urban area from which the MS4 jurisdictional area is defined. For discharges to phosphorus TMDL waterbodies other than the Charles River, the permit will provide the methodology, which includes using a set of composite PLERs, to calculate the baseline phosphorus load and the corresponding required phosphorus load reduction.

Development and implementation of the PCP will require accounting and tracking of phosphorus load reductions by permittees. The draft permit will provide a set of methodologies to be used by all permittees subject to phosphorus reduction requirements for calculating annual phosphorus load reduction credits for a variety of BMPs. The permittee shall use the methodologies to develop an acceptable PCP and to demonstrate compliance with the phosphorus load reduction requirements of the permit. The estimates will also allow the municipality, EPA and State Authorities to evaluate the adequacy of PCPs and to track progress towards achieving the overall phosphorus load reduction requirement.

Distinct PLERs representing the annual phosphorus load from DCIA and PA separately have been developed for the purpose of accounting and tracking of phosphorus load reduction credits. EPA has developed distinct PLERs for DCIA and PA in order to more accurately characterize stormwater phosphorus source areas that receive or will receive application of control practices. The methodology to develop these distinct PLERs has been s described first below, followed by the description of the development of the "composite PLERs", which have been, to some degree, based on development of the distinct PLERs.

I. Methodology for Developing Distinct Phosphorus Load Export Rates for Accounting and Tracking of Reduction Credits

A. Summary

Table 1 presents the proposed Distinct Phosphorus Load Export Rates for use in the Massachusetts MS 4 permit. These PLERs represent estimates of the average annual phosphorus load that would be delivered from directly connected impervious and pervious surfaces for nine (9) land use categories, and are to be used for calculating phosphorus load reduction credits. Individual PLERs for DCIA and PA surfaces are provided to improve the accounting of phosphorus reduction credits for individual BMPs. In many cases BMPs are targeted to address runoff from primarily impervious surfaces. As indicated in Table 1, the DCIA PLERs for each of land use groupings are much higher than their corresponding PA PLERs because impervious surfaces generate much greater volumes of runoff than pervious surfaces and because phosphorus is more readily washed off from impervious surfaces than from pervious surfaces.

Table 1: Proposed Average Annual Phosphorus Load Export Rates for use in the MA MS4 Permit			
Phosphorus Source Category by Land Use	**Land Surface Cover**	**Phosphorus Load Export Rate, Kg/ha/yr**	**Comments**
Commercial (Com) and Industrial (Ind)	Directly connected impervious	2.0	Derived using a combination of the Lower Charles USGS Loads study and NSWQ dataset. This PLER is approximately 75% of the HDR PLER and reflects the difference in the distributions of SW TP EMCs between Commercial/Industrial and Residential.
	Pervious	See* DevPERV	
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.6	Largely based on loading information from Charles USGS loads, SWMM HRU modeling, and NSWQ data set
	Pervious	See* DevPERV	
Medium -Density Residential (MDR)	Directly connected impervious	2.2	Largely based on loading information from Charles USGS loads, SWMM HRU modeling, and NSWQ data set
	Pervious	See* DevPERV	
Low Density Residential (LDR) - "Rural"	Directly connected impervious	1.7	Derived in part from Mattson Issac, HRU modeling, lawn runoff TP quality information from Chesapeake Bay and subsequent modeling to estimate PLER for DCIA (Table 14) to approximate literature reported composite rate 0.3 kg/ha/yr.
	Pervious	See* DevPERV	
Highway (HWY)	Directly connected impervious	1.5	Largely based on USGS highway runoff data, HRU modeling, information from Shaver et al and subsequent modeling to estimate PLER for DCIA for literature reported composite rate 0.9 kg/ha/yr.
	Pervious	See* DevPERV	
Forest (For)	Directly connected impervious	1.7	Derived from Mattson & Issac and subsequent modeling to estimate PLER for DCIA that corresponds with the literature reported composite rate of 0.13 kg/ha/yr (Table 14)
	Pervious	0.13	
Open Land (Open)	Directly connected impervious	1.7	Derived in part from Mattson Issac, HRU modeling, lawn runoff TP quality information from Chesapeake Bay and subsequent modeling to estimate PLER for DCIA (Table 14) to approximate literature reported composite rate 0.3 kg/ha/yr.
	Pervious	See* DevPERV	
Agriculture (Ag)	Directly connected impervious	1.7	Derived from Budd, L.F. and D.W. Meals and subsequent modeling to estimate PLER for DCIA to approximate reported composite PLER of 0.5 kg/ha/yr.
	Pervious	0.5	
*Developed Land Pervious (DevPERV)- Hydrologic Soil Group A	Pervious	0.03	Derived from SWMM and P8 - Curve Number continuous simulation HRU modeling with assumed TP concentration of 0.2 mg/L for pervious runoff from developed lands. TP of 0.2 mg/L is based on TB-9 (CSN, 2011), and other PLER literature and assumes unfertilized condition due to the upcoming MA phosphorus fertilizer control legislation.
*Developed Land Pervious (DevPERV)- Hydrologic Soil Group B	Pervious	0.13	
*Developed Land Pervious (DevPERV) - Hydrologic Soil Group C	Pervious	0.24	
*Developed Land Pervious (DevPERV) - Hydrologic Soil Group C/D	Pervious	0.33	
*Developed Land Pervious (DevPERV) - Hydrologic Soil Group D	Pervious	0.41	

Table 1 provides a brief description of the basis used to develop the land use based PLERs. The nine land use categories identified in Table 1 represent aggregated land use categories made up of land use categories identified by MassGIS and grouped according to similarities in terms of generating phosphorus loads. Appendix A below provides the cross walk between the Mass GIS land use categories and the land use groups used for calculating phosphorus loading in Table 1.

The export rates presented in Table 1 have been developed based on detailed analyses of the following types of information:

- Stormwater quality data from the National Stormwater Quality Database (NSQD, 2008) for rainfall Regions 1 and 2;

- Various stormwater quality datasets collected in New England (many sources);
- Hydrologic Response Unit (HRU) Modeling: Results of long-term (5 year) continuous hydrologic model simulations using the Stormwater Management Model (SWMM) and P8 Model (Curve Number Method) that are representative of local climatic conditions (hourly precipitation and daily temperature). These models were applied to watershed areas with homogeneous land characteristics relating to surface type (impervious or pervious), hydrologic soil condition (e.g., hydrological soil groups A, B, C and D) and vegetative cover (e.g., grass or forested).
- Various stormwater/watershed modeling efforts, including the following pollutant loading analyses:
  - *Streamflow, Water Quality, and Contaminant Loads in the Lower Charles River Watershed, Massachusetts, 1999-2000,* Breault, et al., 2002;
  - *Measured and Simulated Runoff to the Lower Charles River, Massachusetts, October 1999–September 2000,* Zariello and Barlow, 2002;
  - *Calibration of Phosphorus Export Coefficients for Total Maximum Daily Loads of Massachusetts Lakes*, Mattson and Isaac, 1999;
  - *Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities, Tetra Tech, Inc., December 2009;*
  - *Updating the Lake Champlain Basin Land Use Data to Improve Prediction of Phosphorus Loading,* Troy, et al., 2007;
  - *Literature Review of Phosphorus Export Rates and Best Management Practices, LaPlatte River Watershed Project*, Artuso, et. al., 1996;
  - *Lake Champlain Nonpoint Source Pollution Assessment,* Budd and Meals, 1994; and
- Literature values from various sources including the *Fundamentals of Urban Runoff Management*, (Shaver, et al., 2007); *Review of Published Export Coefficient and Event Mean Concentration Data* (Lin, 1994); and the *Draft Chesapeake Stormwater Network (CSN) Technical Bulletin No. 9, Nutrient Accounting Methods to Document Local Stormwater Load Reductions in the Chesapeake Bay Watershed, Version 1.0*, (Schueler, 2011);
- Data collected by the USGS in the study of *Potential Reductions of Phosphorus in Urban Watershed using a High-Efficiency Street-Cleaning Program, Cambridge, Massachusetts*, Sorenson, 2011; and
- Sutherland models to estimate directly connected impervious area from total impervious area.

The PLERs presented in Table 1 were developed based on a weight-of-evidence approach summarized below.

- Representative stormwater quality event mean concentration (EMC) data were compiled and reviewed to determine phosphorus characteristics and relative differences among land use source types. This process was used to aid identification of appropriate groupings of land use categories for characterizing phosphorus loadings, to determine the relative strength of phosphorus loading among the various land use groups and to determine the typical magnitude of phosphorus concentrations in stormwater runoff from developed lands;
- Hydrologic Response Unit modeling was conducted to estimate average annual runoff yields and corresponding average annual PLERs for a varying stormwater phosphorus quality based on land surface type, hydrologic soil condition, vegetative cover and regional climatic conditions. The HRU modeling result assisted in developing the linkage between stormwater monitoring results that measured EMCs (mg/L) for many individual storm events and average annual PLERs (kg/ha/yr);
- For certain categories such as forested, agricultural sources and rural/open space type sources, estimates of PLERs are based both directly and indirectly on reported values from published papers and reports. For example, the PLERs for low density residential, highway and forested are based in part on reported "composite" PLERs values (i.e., represent combined influence of areas with both impervious and pervious surfaces) and subsequent HRU modeling to estimate the individual PLERs for impervious and pervious surface within that source category. For example, the composite PLER

for forested (For) of 0.13 kg/ha/yr (Mattson and Isaac, 1999) is used as a starting point, and then refined further into distinct PLERs for DCIA and PA by using continuous simulation hydrologic modeling with regional climatic data, estimated % DCIA, average % impervious associated with forested, and a typical pervious runoff total phosphorus (TP) concentration (0.1 mg/L) to estimate PLERs of 1.7 kg/ha/yr for impervious surfaces and 0.13 kg/ha/yr for pervious areas.

- Various pollutant loading studies were evaluated in combination with the HRU modeling results to assist in developing the relationship between source category phosphorus EMC data and annual loading rates. The USGS pollutant load study for the Lower Charles River, MA (Breault, et. al, 2002) provided relevant information in that it included extensive flow and quality monitoring data for each of three land use categories, medium density residential, multi-family residential and commercial. Additionally, the USGS developed and calibrated hydrologic (SWMM) models of these drainages and estimated annual phosphorus loads for the year-long flow-gauging and monitoring period (water year 2000). EPA used HRU modeling results in combination with the USGS data and the robust NSQD dataset to estimate impervious and pervious PLERs for these land use groupings.
- For all source categories included in Table 1, EPA cross-checked various sources of information to ensure that the proposed PLERs are in reasonable agreement with other reported information related to phosphorus loading.

Again, the distinct PLERs in Table 1 are for all permittees to estimate load reduction credits for BMPs treating runoff from varying land uses, and to provide a consistent accounting methodology that is applicable for all municipalities within a given watershed. Ultimately, the calculated reductions based on the provided PLERs are for a permittee to demonstrate compliance with the phosphorus load reduction requirement for their regulated area.

B. Stormwater Runoff Quality Data – Total Phosphorus Event Mean Concentrations (EMC)
EPA compiled and evaluated readily available stormwater total phosphorus (TP) event mean concentration (EMC) quality data that were and are considered to be representative of precipitation patterns in MA and the New England region in general. Results of a previous analysis of precipitation data from various precipitation gauging stations located in each of the six New England states showed that precipitation patterns among the New England States were generally consistent (Tetra Tech, 2008). Furthermore, EPA accessed and reviewed the extensive stormwater quality data available from the National Stormwater Qualty Database (NSQD) compiled by Pitt for EPA (Pitt, 2008). The NSQD included storm water quality data collected from Phase 1 MS4 permittees from around the nation. However, for use in informing the development of PLERs in MA and New England, only EMC data from Rainfall Zones 1 and 2 were considered in the Region's data analysis.

Rainfall Zones 1 and 2 included New England and the northern mid-west area of the country (Zone 1), and the mid-Atlantic region (Zone 2). The vast majority of the data for Rainfall Zones 1 and 2 in the NSQD were collected in the mid-Atlantic region (Zone 2). A review of precipitation data from gauging stations located in the mid-Atlantic region (Reagan National Airport) and New England (Boston, MA) found there to be similar precipitation patterns in terms of event precipitation depth distributions and intermittent dry periods between events (See Appendix B). Therefore, EPA chose to include the EMC data from Zone 2 in order to substantially increase the size of the overall data set being evaluated, and to improve the robustness of the analyses. Inclusion of the stormwater TP EMC data collected from Zone 2 into the data analysis described below increased the number of TP EMC events analyzed from about 50 to over 1400.

In addition to the NSQD, the Region compiled readily available TP EMC data that have been collected under various projects throughout the New England Region and that were not included in the NSQD. The

Regional TP EMC data were assessed separately from the NSQD in order to assess the overall representativeness of the NSQD for use in informing the development of PLERs for New England.

The primary objectives for analyzing representative stormwater TP EMC data were to:
1. Determine the typical magnitude of TP stormwater EMCs for runoff from major land use categories such as residential, commercial and industrial;
2. Evaluate the **relative** strengths of the TP EMCs among the various land use groups; and
3. Identify appropriate groupings of land use categories for characterizing phosphorus loadings.

B.1 National Stormwater Quality Data Base (NSQD)

Stormwater EMC data from the NSQD were filtered as follows:
1. EMC data for rainfall zones 1 and 2 were included;
2. Only EMC data for whole events (not first flush) were included; and
3. Only composite sampling results were included.

TP EMC data reported in the NSQD as < (less than) or < minimum reporting levels (MRL) were treated as follows:
1. < set to equal 0.01 mg/L; and
2. < MRL set to equal ½(MRL)

The TP EMC data were organized and summarized for 10 sets of conditions based on varying precipitation depths and duration of dry periods preceding the monitored rain events. Also, data were summarized for various predominant land use conditions identified in the NSQD. For each condition and associated land use groupings the data were summarized by:
1. Count (i.e., number of samples in the grouping);
2. Arithmetic Mean;
3. Median;
4. Geometric Mean;
5. Coefficient of Variation
6. 1st Quartile (25th Percentile);
7. 3rd Quartile (75% Percentile); and
8. Range (i.e., minimum – maximum).

These summary statistics are intended to indicate the general distribution of the data with emphasis on characterizing the values that are representative of the central portion of the distributions. As indicated above, a primary objective of estimating PLERs is to select values that are representative of **average annual** conditions for climatic conditions in the New England region. Therefore, the summary statistics for central tendency, arithmetic mean, median, and geometric mean, and the lower and upper quartiles that bracket the central portion of the distribution are of particular interest for this analysis.

A stepwise approach was performed in analyzing the NSQD TP EMC data and developing the summary information presented in Table 2 below:

Condition No. 1: Filtered TP EMC data for all storms are grouped together and separately by land use category. A comparison of median and geometric mean values for each of these land use groupings indicates that all land use groups (1 a, b, c, e, and f) with the exception of the industrial data (1 d) have median and the geometric mean values that are very similar in magnitude (differences range from 0.00 to 0.02 mg/L). In contrast, median values for all of these groups are notably less than the corresponding arithmetic mean values (differences range from 0.10 to 0.13 mg/L). This pattern indicates these data distributions may be log-normal and that median and geometric means are likely to be better indicators of central tendency than arithmetic means. For the industrial category, the median is slightly higher than the geometric mean (difference of 0.04 mg/l) and less than the arithmetic mean (difference of 0.04).

Comparison of the TP EMCs summary statistics among the land use groupings indicate that stormwater TP EMCs for commercial and industrial groups are similar but lower in magnitude than TP EMCs for both the residential and open land groupings. As the data source for the NSQD is Phase 1 MS4s, the open land category likely represents stormwater quality of managed lands in suburban/urban environs.

Table 2: Summary of NSQD (2008) Stormwater TP EMCs data for Various Land Use Groups and Conditions

National Stormwater Quality Database, V. 3 Feb 2008, Analysis of Precipitation Events in EPA Rainfall Regions 1 and 2 - Data filtered to include only composite samples from automatic samplers. Values below detection were assumed to be 1/2 of MRL	**Summary of Stormwater Event Mean Concentrations Total Phosphorus, mg/L**							
Data set description	**count**	**arithmetic mean**	**median**	**geometric mean**	**Coefficient of Variation**	**25th %**	**75th%**	**range**
1) Rain Region 1&2, all precip. events								
1 a) all land uses - all storm events	1435	0.36	0.25	0.24	1.45	0.15	0.41	0.01 - 10.20
1 b) all commercial & industrial	557	0.30	0.20	0.19	1.42	0.11	0.34	0.01 - 6.72
1 c) commercial & mixed commercial	329	0.33	0.20	0.20	1.57	0.12	0.36	0.01 - 6.72
1 d) industrial & mixed industrial	234	0.25	0.21	0.17	0.88	0.10	0.34	0.02 - 1.29
1 e) all residential	733	0.41	0.29	0.29	1.47	0.18	0.47	0.02 - 10.20
1 f) open	63	0.39	0.27	0.27	1.09	0.16	0.46	0.04 - 2.50
2) Rain Region 1&2								
2 a) all data - precipitation ≤ 0.5 in	659	0.39	0.26	0.25	1.50	0.16	0.44	0.01 -9.67
2 a) all data - precipitation ≤ 0.4 in	532	0.40	0.25	0.26	1.58	0.14	0.44	0.01 -9.67
2 b) all data - precipitation ≤ 0.3 in	380	0.39	0.27	0.26	1.13	0.16	0.47	0.01 - 3.67
2 c) all data - precipitation ≤ 0.2 in	224	0.40	0.26	0.27	1.05	0.16	0.47	0.01 -3.06
3) Rain Region 1&2 , precip. ≤ 0.3 in								
3 a) all data	380	0.39	0.27	0.26	1.13	0.16	0.47	0.01 -3.67
3 b) all commercial & industrial	170	0.33	0.23	0.21	1.30	0.12	0.38	0.01 -3.67
3 c) all commercial & mixed commercial	111	0.37	0.22	0.22	1.39	0.13	0.38	0.01 -3.67
3 b) all industrial & mixed industrial	62	0.28	0.23	0.20	0.85	0.12	0.38	0.03 -1.21
3 c) all residential	176	0.40	0.30	0.29	0.89	0.17	0.49	0.05 -1.98
3 d) open	10	0.60	0.31	0.36	1.21	0.22	0.67	0.04 -2.50
4) Rain Region 1&2, precip. ≤ 0.3 in, IDP ≥ 7days								
4 a) all data	68	0.49	0.36	0.33	1.09	0.20	0.58	0.03 -3.67
4 b) all commercial & industrial	29	0.50	0.30	0.29	1.42	0.14	0.50	0.03 -3.67
4 c) all residential	35	0.47	0.38	0.36	0.75	0.21	0.59	0.08 -1.45
5) Rain Region 1&2, precip. ≤ 0.3 in, IDP < 7days								
4 a) all data	119	0.38	0.26	0.26	1.28	0.17	0.38	0.03 -3.56
4 b) all commercial & industrial	48	0.32	0.25	0.22	1.37	0.12	0.36	0.03 -3.06
4 c) all residential	63	0.36	0.26	0.27	0.98	0.18	0.37	0.05 -1.98
6) Rain Region 1&2, precip. ≥ 1.0 in								
5 a) all data	229	0.37	0.29	0.29	0.84	0.20	0.43	0.02 -2.27
5 b) all commercial & industrial	99	0.22	0.15	0.16	0.91	0.10	0.27	0.02 - 1.00
5 c) all residential	165	0.39	0.30	0.30	0.87	0.20	0.44	0.02 -2.27
7) Rain Region 1&2, precip. ≥ 1.0 in, IDP ≥ 7days								
5 a) all data	41	0.36	0.26	0.26	0.90	0.16	0.42	0.03 -1.76
5 b) all commercial & industrial	14	0.23	0.18	0.17	0.89	0.10	0.27	0.03 -0.83
5 c) all residential	26	0.43	0.38	0.33	0.83	0.20	0.55	0.08 -1.76
8) Rain Region 1&2, precip. ≥ 1.0 in, IDP < 7days								
5 a) all data	107	0.29	0.24	0.24	0.65	0.16	0.36	0.02 -0.92
5 b) all commercial & industrial	31	0.25	0.16	0.18	0.89	0.11	0.32	0.06 -0.82
5 c) all residential	65	0.30	0.25	0.25	0.58	0.20	0.36	0.02 -0.92
9) Rain Region 1&2, precip. ≥ 1.5 in								
5 a) all data	129	0.32	0.26	0.23	0.98	0.14	0.39	0.02 -2.27
5 b) all commercial & industrial	43	0.19	0.13	0.13	0.99	0.08	0.23	0.02 -0.82
5 c) all residential	77	0.40	0.31	0.31	0.90	0.21	0.43	0.02 -2.27
10) Rain Region 1&2, precip. ≥ 2.0 in								
5 a) all data	75	0.29	0.23	0.21	0.89	0.12	0.38	0.02 -1.57
5 b) all commercial & industrial	29	0.19	0.11	0.12	1.01	0.07	0.24	0.02 -0.82
5 c) all residential	39	0.37	0.29	0.30	0.79	0.21	0.41	0.11 -1.57
Precip = precipitation, IDP = inter-event dry period								

Condition No. 2: TP EMC data collected from precipitation events less than 0.5 inches are analyzed to assess TP runoff quality primarily associated with impervious surfaces. Based on modeling results and reported empirical literature, small precipitation events on pervious areas are expected to generate little to no runoff. TP EMC data are evaluated using different precipitation depth thresholds of less than or equal to 0.2, 0.3, 0.4 and 0.5 inches (see Condition No. 2 in Table 2). As indicated, the results for each of these datasets (2 a) – 2 d)) are very similar for the various depths analyzed indicating that runoff quality from impervious surfaces is generally similar for smaller sized precipitation events among the land use groups. In light of these results, and after considering typical initial abstraction values and runoff coefficients for pervious areas with varying hydrologic soil conditions (see Table 3), a depth threshold of $\leq$ 0.3 inches isselected for further analyses of impervious area runoff quality among the land use groupings (Condition Nos. 3, 4 and 5).

Table 3: Developed Land Pervious Area Runoff Depths based on Precipitation Depth and Hydrological Soil Groups (HSGs)

	Runoff Depth, inches		
Rainfall Depth, Inches	**Pervious HSG A/B**	**Pervious HSG C**	**Pervious HSG D**
0.10	**0.00**	**0.00**	**0.00**
0.20	**0.00**	**0.01**	**0.02**
0.40	**0.00**	**0.03**	**0.06**
0.50	**0.00**	**0.05**	**0.09**
0.60	**0.01**	**0.06**	**0.11**
0.80	**0.02**	**0.09**	**0.16**
1.00	**0.03**	**0.12**	**0.21**
1.20	**0.04**	**0.14**	**0.39**
1.50	**0.11**	**0.39**	**0.72**
2.00	**0.24**	**0.69**	**1.08**

Notes: Runoff depths derived from combination of volumetric runoff coefficients from Table 5 of *Small Storm Hydrology and Why it is Important for the Design of Stormwater Control Practices*, Pitt, 1999 and using the Stormwater Management Model (SWMM) in continuous model mode for hourly precipitation data for Boston, MA, 1998-2002.

Condition No. 3: Summary statistics for TP EMC data for a precipitation depth threshold of $\leq$ 0.3 inches are provided for each of the land use groups. A comparison of these results with results for Condition No. 1 shows that the mean, median and geometric mean values are slightly higher than the corresponding summary statistic values for all storm events (Condition No. 1). Similar to Condition No. 1, the commercial data set and the industrial data set have similar median, geometric mean, 25th percentile and 75th percentile values. Due to the similarity of these statistics for the commercial and industrial categories in Conditions No. 1 and 3, these data sets are combined into one grouping (commercial & industrial) for all further TP EMC data analyses (Condition Nos. 4 through 10). Also, consistent with Condition No. 1, the summary statistics for residential and open land use categories are again higher than the values for commercial and industrial. However, the number of EMC samples analyzed for the open land category drop to 10 for Condition No. 3, which is significantly less that the number of samples for the other categories. Open land is excluded in further data analyses (Condition Nos. 4 through 10) because the number of TP EMC samples available further declines.

Condition Nos. 4 and 5: Further analyses of TP EMC statistics for precipitation events of $\leq$ 0.3 inches are accomplished by segregating the data based on the length of time between rain-events, noted as the inter-event dry period (IDP) in Table 2. The IDP is expected to be an important factor affecting impervious area runoff quality because it is the time during which pollutant build-up occurs on impervious surfaces. Based on the build-up wash-off theory related to runoff quality from impervious surfaces, pollutants continue to accumulate on impervious surfaces over time (until a maximum holding capacity is reached) of which a portion are available for potential wash-off during the next rain event (Pitt et. al, 2004). Theoretically, the longer the IDP, the higher the potential is for having increased pollutant concentrations for small precipitation events, providing there is sufficient energy (i.e., rainfall intensity) to wash-off pollutants. Based on the results for Condition Nos. 4 and 5, TP EMCs are higher for the IDP $\geq$ 7 for both land use groupings (commercial & industrial and residential) when compared to values for IDP $\leq$ 7 days. Also, again similar to Conditions Nos. 1and 3, residential TP EMCs statistics for IDP $\geq$ 7 (Condition No. 4) are notably higher than the corresponding values for the commercial & industrial grouping.

Condition Nos. 6 through 10: Additional analyses are performed on data sets with varying precipitation depth thresholds (1.0, 1.5 and 2.0 inches) and IDP. These analyses are performed to assess the similarities and differences in stormwater TP quality among the land use groups for larger storm events where pervious runoff is likely to be contributing to TP EMCs. Following are observations from these results:

1. Statistical measures are generally consistent for the residential TP EMC data sets for all precipitation depth thresholds evaluated when not considering IDP. For example, median EMC values for depth thresholds of 0.3, 1.0, 1.5 and 2.0 inches are 0.30, 0.30, 0.31 and 0.29 mg/L, respectively. Consistency among the summary statistics for the higher precipitation depth thresholds of ≥ 1.0, 1.5 and 2.0 inches indicates that pervious area runoff is a contributor of TP for larger storm events, since TP EMC statistic values do not change much as storm events increase in size. As discussed below, this is clearly a different pattern than is revealed by the results for the commercial & industrial group, where the summary statistics decline as precipitation depths increase.

   Residential land areas are typically made-up of predominantly pervious areas, including turf with impervious areas comprised of roads, driveways and roof tops. Typically, the percent imperviousness for residential areas is in the range of 20-50% impervious. If pervious area runoff were not a notable contributor of TP, then it would be expected that TP EMCs would decline for the larger storm depths due to dilution from the larger precipitation volumes with lower TP content, and the exhaustion of the phosphorus mass available for wash-off from contributing impervious surfaces. On street surfaces, a significant portion of phosphorus is typically associated with very fine particles (< 100 microns)(Walker and Wong, 1999) which can be readily washed off during small precipitation events or the early portions of larger storms.
2. Summary statistics for the commercial & industrial group decline as precipitation depth thresholds increase. For example, median values for depth thresholds of 0.3, 1.0, 1.5 and 2.0 inches are 0.23 mg/L, 0.15 mg/l, 0.13 mg/l and 0.11 mg/L, respectively. However, the values among the higher depth thresholds of 1.0, 1.5 and 2.0 inches are generally consistent. Unlike residential areas, commercial and industrial areas are typically made up of predominantly impervious surfaces such as roads, parking lots and roof tops, (typically 60-90% impervious) with relatively little pervious area. A possible explanation for the lower TP EMCs for the higher precipitation depth thresholds is that after initial wash-off, TP EMCs decline due to dilution from rainfall with lower TP content, and because there is less phosphorus on the surfaces available for wash-off. These results also indicate that pervious runoff is less of a factor in contributing to the overall TP EMCs when compared to the results for residential areas.

B.1 Summary and Conclusions for the NSQD Analysis:

1. Summary statistics of TP EMCs for commercial and industrial areas are similar, and consequently, have been grouped together for the purposes of informing the development of PLERs;
2. Summary statistics of TP EMCs for residential land uses are notably higher than the commercial and industrial grouping for all precipitation depth thresholds evaluated;
3. For increasing precipitation depth thresholds, pervious areas in residential areas contribute TP and appear to maintain consistent TP EMC statistics even with increasing precipitation depths, indicating that TP quality of pervious area runoff is overall fairly consistent for the precipitation depths evaluated; and
4. Ratios of the statistical measures describing the central portion of the distributions (median, geometric mean, 25^{th}% and 75%) between the commercial & industrial grouping and the residential group are fairly consistent (see Table 4), indicating that the two distributions are proportional to one another and may be used to inform the relative magnitude of the PLERs for the two land use groups.

Table 4: Ratios of Summary Statistics for TP EMC Data of the Commercial & Industrial Group to the Residential Group					
All Precipitation Events, NSQD, 2008 (Rain Zones 1&2)	**Median, mg/L**	**Geometric mean, mg/L**	**25th %, mg/L**	**75th %, mg/l**	**Average of ratio C&I:R**
Commercial & Industrial (C&I)	0.21	0.21	0.12	0.37	
Residential (R)	0.28	0.29	0.18	0.44	
Ratio of C&I:R	0.75	0.72	0.67	0.84	0.75

B.2 New England Region Stormwater TP EMC Data

Table 5 summarizes statistical measures of TP EMC collected from several investigations conducted in the New England region. These data are compiled to assess TP EMC characteristics of stormwater runoff collected in the New England region, and to assess the representativeness of the NSQD data for informing development of PLERs in MA, NH and New England. Data from the New England studies that are representative of residential and commercial land uses are compiled and analyzed to assess the representativeness of the NSQD for New England (see Table 6), and to inform the selection of PLERs. While the size of the aggregated residential and commercial data sets for New England are relatively small compared to the NSQD data sets, the statistical results of the corresponding data sets are similar, indicating that use of the NSQD to inform setting PLERs is reasonable for New England.

Table 5: Summary of Stormwater TP EMC Data for Individual Investigation in New England Region

Summary of Stormwater Event Mean Concentration (EMC) Data for Total Phosphours Collected in New England			Total Phosphorus EMC, mg/L							
Location (source)	Predominant Land Use	Station	Count (n)	arithmetic mean	median	geomean	standard deviation	25th%,	75th%	range
Lower Charles River Watershed, MA (USGS, Breault et. al., 2002)	Single-family residential	USGS -01104630	8	0.39	0.35	0.39	0.26	0.20	0.50	0.10 - 0.93
Lower Charles River Watershed, MA (USGS, Breault et. al., 2002)	Multifamily residential	USGS-01104673	8	0.24	0.25	0.24	0.13	0.10	0.33	0.10 - 0.40
Lower Charles River Watershed, MA (USGS, Breault et. al., 2002)	Commercial (01104677)	USGS-01104677	9	0.22	0.30	0.22	0.10	0.10	0.30	0.10 - 0.30
MA Highways - Low traffic volume (USGS, Smith & Granato, 2009)	Highway	Rte 119-P 424209071545201	17	0.10	0.05	0.05	0.13	0.03	0.10	0.01 - 0.51
MA Highways - Medium traffic volume (USGS, Smith & Granato, 2009)	Highway	Route 2 -P 423027071291301	18	0.13	0.12	0.09	0.10	0.05	0.16	0.01 - 0.34
MA Highways - Medium/High traffic volume (USGS, Smith & Granato, 2009)	Highway	Interstate 495 -P 422821071332001	17	0.19	0.14	0.11	0.17	0.08	0.21	0.01 - 0.68
MA Highways High traffic volume (USGS, Smith & Granato, 2009)	Highway	Interstate 95 -P 422620071153301	18	0.17	0.13	0.12	0.13	0.08	0.21	0.03 - 0.54
Englsby Watershed, Burlington, VT, (UVM, J. Nipper, 2012)	Medium - High Residential	Inlet to Wet Pond	46	0.72	0.49	0.48	0.75	0.24	1.03	0.052 - 3.690
Butler Farms Subdivision - South Burlington, VT (UVM, J. Nipper, 2012)	Agricultrue	Upstream in stream	36	0.175	0.164	0.150	0.094	0.115	0.195	0.024 - 0.390
Butler Farms Subdivision - South Burlington, VT (UVM, J. Nipper, 2012)	Low Residential	SW-West Pipe	17	0.103	0.084	0.086	0.068	0.055	0.091	0.034 - 0.240
Butler Farms Subdivision - South Burlington, VT (UVM, J. Nipper, 2012)	Low Residential	SW-East Pipe	11	0.071	0.054	0.062	0.040	0.041	0.093	0.030 - 0.160
Butler Farms Subdivision - South Burlington, VT (UVM, J. Nipper, 2012)	Agriculture	Downstream in stream	51	0.190	0.122	0.142	0.172	0.091	0.255	0.036 - 0.855
University of New Hampshire Parking lot near Stormwater Center	Institutional	parking lot	16	0.12	0.10	0.10	0.07	0.07	0.15	0.02 - 0.29
Tedeschi Parking Lot, Durham, NH (UNH 2011-12)	Commercial	parking lot	9	0.23	0.20	0.19	0.13	0.15	0.28	0.06 - 0.49

Table 6: Summary of Residential and Commercial Stormwater TP EMC Data – New England and NSQD, 2008

Data Set - Source	Total Phosphorus Stormwater EMC, mg/L					
	Count	Arithmetic Mean	Median	Geometric Mean	25th%	75th%
NE Region - Residential	90	0.45	0.30	0.24	0.10	0.50
NSQD, 2008 Residential	733	0.41	0.29	0.29	0.18	0.47
NE Region - Commercial	18	0.22	0.23	0.11	0.12	0.30
NSQD, 2008 – Commercial & Industrial	557	0.30	0.20	0.19	0.11	0.34

C. Hydrologic Response Unit Modeling

EPA conducted Hydrologic Response Unit (HRU) modeling for the purpose of providing a linkage between representative stormwater quality data for various land uses (measured in terms of EMCs) and average annual PLERs for impervious and pervious surfaces based on MA climatic conditions. EPA used continuous simulation hydrologic models to estimate average annual runoff yields for impervious surfaces and pervious surfaces with varying hydrologic soil (Hydrological Soil Groups (HSGs) A, B, C and D) and vegetative cover conditions. The runoff yields were then used to calculate PLERs using a range of potential representative annual flow-weighted mean stormwater total phosphorus (TP) concentrations, henceforth referred to as "annual mean TP concentrations". For this analysis, the HRU modeling was done using the Stormwater Management Model (SWMM) and the P8 model. Hourly and daily temperature records for Boston were used as inputs to the models to reflect Massachusetts climatic conditions for the Charles River TMDL simulation period (1998-2002). This timeframe corresponds to the timeframe during which most of the other phosphorus TMDLs were prepared.

The SWMM and P8 models are both continuous simulation models capable of generating long-term estimates of runoff from impervious and pervious areas using long-term climatic records (e.g., hourly precipitation and daily temperature data). SWMM is a process driven mechanistic model that explicitly represents key hydrologic processes such as precipitation, infiltration, and evapo-transpiration. In contrast, the P8 model simulates runoff from pervious areas using the widely used empirical Curve Number Method (CN Method) developed by the Soil Conservation Service (now the Natural Resource Conservation Service, NRCS). Both models are used by EPA for developing average annual runoff yields for land areas because each offers strengths in representing varying land conditions. For example, SWMM includes infiltration sub-models that simulate the dynamics of infiltration based on soil conditions, including constantly changing percent saturation related to climatic conditions. The CN method is an empirical model that was developed based on extensive observations of runoff from varying surface types such as wooded and grassed areas with varying underlying soil characteristics.

SWMM-derived runoff yields and calculated PLERs are provided in Table 7. A range of PLERs are calculated for each surface type and associated runoff yield using stormwater annual mean TP concentrations ranging from 0.1 mg/L to 1.0 mg/L. As indicated, there are significant differences among runoff yields and associated PLERs based on surface type and hydrologic soil condition. For example, using an annual mean TP concentration of 0.3 mg/L, PLERs for pervious surfaces range from a low of 0.08 kg/ha/yr (for well drained HSG A soils) to 0.78 kg/ha/yr (for poorly drained HSG D soils), while the corresponding PLER for impervious surface is significantly higher at 2.94 kg/ha/yr. Also, the results in Table 7 illustrate the change in PLERs based on varying annual mean TP concentrations.

Table 7: SWMM Continuous Simulation Modeling Results & Estimates of PLERs for Varying Stormwater TP Concentrations

Runoff yield by SWMM hourly rainfall Boston MA (1998-2002)				Annual Phosphorus Load Export Rate (PLER), kg/ha/yr					
	MG/acre/yr	MG/ha/yr	Avg Annual Flow weighted SW TP conc., mg/l --->	0.10	0.20	0.30	0.40	0.50	1.00
Impervious surface	1.05	2.59		0.98	1.96	2.94	3.92	4.90	9.79
Pervious area HSG A	0.03	0.07		0.03	0.05	0.08	0.10	0.13	0.25
Pervious area HSG B	0.08	0.21		0.08	0.16	0.24	0.32	0.40	0.79
Pervious area HSG C	0.16	0.41		0.15	0.31	0.46	0.62	0.77	1.54
Pervious area HSG D	0.28	0.69		0.26	0.52	0.78	1.04	1.30	2.60

The P8 model is being specifically used in this analysis to supplement runoff yield estimates for forested and grassed areas with varying HSGs. Figure 1 shows average annual runoff yields derived from the P8 model for a range of runoff curve numbers. The runoff curve number is the parameter used in the CN Method to characterize watershed hydrologic features. Table 8 provides information on selecting curve numbers for different vegetative covers and HSGs, and Table 9 presents tabulated runoff yields and calculated PLERs based on the P8 modeling. As the CN method is an empirical model developed from extensive observed runoff data, the estimated runoff yields reflect volume losses due to evapo-transpiration, which can be significant for areas with complete vegetative cover. Table 10 presents the P8-generated runoff yield estimates, and a range of calculated PLERs for grassed and wooded areas for each HSG and for varying vegetative cover conditions (good, fair and the average of good and fair). As indicated by the footnote in Table 10, the concentrations used to calculate PLERs are values considered to be representative of runoff from fertilized and non-fertilized lawns, based on work done in the Chesapeake Bay region.

Figure 1: Curve Number Method - Average Annual Runoff Yield for Varying Curve Numbers - P8 Model Continuous Simulations, Boston, MA 1998-2002

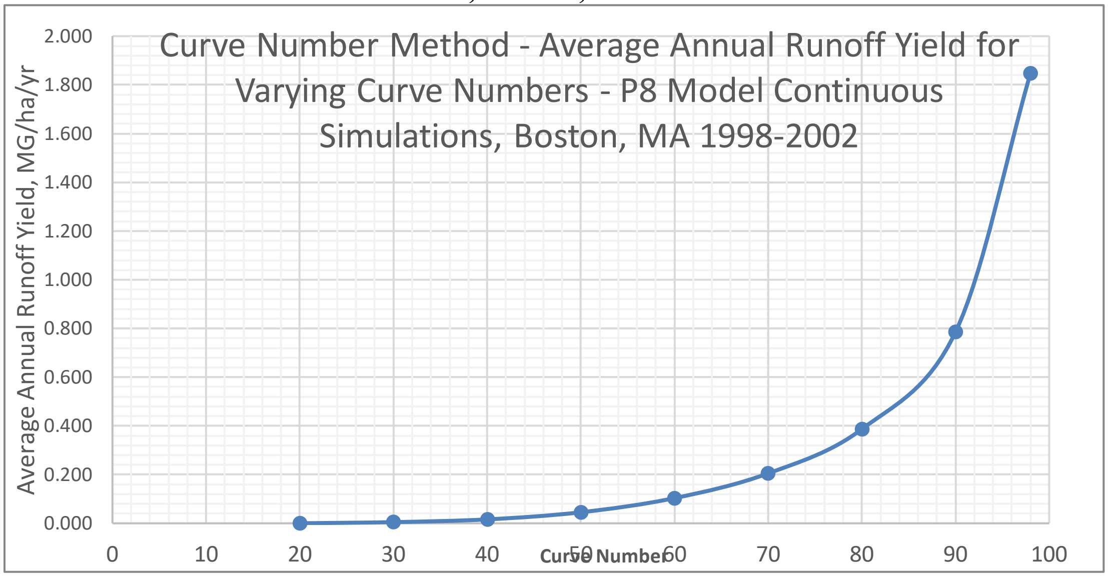

Table 8: Curve Numbers for Curve Number Method

Runoff Curve Numbers for Curve Number Method						
The specified SCS Curve Number (CN) reflects an area-weighted-average of the pervious areas, which generally reflect land cover and soil hydrologic group.						
This is a change from previous P8 versions (<=3.2), which assumed that the specified CN value also reflected indirectly connected impervious areas (see below). When input files from previous versions are read, the indirectly connected fraction is set to 0, so simulation results should not change relative to previous versions. If a distinction between pervious and indirect impervious areas is desired, the specified CN values should be revised to reflect only the pervious portions.						
The following table lists typical CN values as a function of land use, hydrologic condition, and soil group:						
			Curve Number			
Land Use	**Hydrologic Condition**	**Hydrologic Soil Group -->**	**A**	**B**	**C**	**D**
Grassed Areas	Good (>75% Cover)		39	61	74	80
	Fair		49	69	79	84
	Poor (<50% Cover)		68	79	86	89
Meadow / Idle	Good		30	58	71	78
Woods	Good (thick forest)		25	55	70	77
	Fair		36	60	73	79
	Poor (thin, no mulch)		45	66	77	83
Construction Site	Newly Graded		81	89	93	95
Impervious	Not Connected (Draining to Pervious Areas)		98	98	98	98

The runoff yield results for impervious surfaces by SWMM and P8 modeling are nearly identical at 2.59 and 2.60 MG/ha/yr, respectively. This is expected, since the methodology to calculate impervious runoff used by both models is essentially the same. However, runoff yields calculated for pervious areas by the two models do differ notably, as indicated in Table 11. Differences in the estimates are expected because of the differences in vegetative cover and soil conditions simulated by the models. For example, estimated runoff yields from forested areas are lowest because of the greater volume losses due to interception/evapo-transpiration.

Table 9: P8 Continuous Simulation Modeling Results & Estimates of PLERs for Varying Stormwater TP Concentrations

P8 model simulations - Boston, MA hourly precipitation, 1998-2002			Avgerage Annual Flow Weighted Total Phosphorus Concentration, mg/l							
			0.025	0.050	0.100	0.200	0.300	0.500	0.700	1.000
	Curve Number, CN	Runoff yield, MG/ha-yr	Annual phosphorus load yield - kg/ha-yr							
curve number	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02
	40	0.02	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.06
	50	0.05	0.00	0.01	0.02	0.03	0.05	0.09	0.12	0.17
	60	0.10	0.01	0.02	0.04	0.08	0.12	0.20	0.27	0.39
	70	0.21	0.02	0.04	0.08	0.16	0.23	0.39	0.54	0.78
	80	0.39	0.04	0.07	0.15	0.29	0.44	0.73	1.02	1.46
	90	0.79	0.07	0.15	0.30	0.59	0.89	1.49	2.08	2.97
	98	1.85	0.17	0.35	0.70	1.40	2.10	3.50	4.90	6.99
100%IA		2.60	0.25	0.49	0.98	1.97	2.95	4.92	6.89	9.84

Table 10: Average Annual Runoff Yields and Calculated PLERs for Wooded and Grassed Pervious Areas from P8 Continuous Simulation Modeling Results (i.e., Curve Number Method) – Boston, MA (1998 – 2002)

Curve number Method- P8 Continuous Simulation Boston, MA (1998-2002)				Annual Mean TP concentration, mg/L				
Vegetative cover	HSG	CN	Runoff yield, MG/ha/yr	**0.10** Forested	**0.15**	**0.20*** grass - unfertilized	**0.30** Grass -50% fertilized	**0.40*** grass - fertilized
				Average Annual PLER, kg/ha/yr				
Grass good	A	39	0.015	0.01	0.01	0.01	0.02	0.02
	B	61	0.113	0.04	0.06	0.09	0.13	0.17
	C	74	0.278	0.11	0.16	0.21	0.32	0.42
	D	80	0.387	0.15	0.22	0.29	0.44	0.59
Grass fair	A	49	0.042	0.02	0.02	0.03	0.05	0.06
	B	69	0.195	0.07	0.11	0.15	0.22	0.29
	C	79	0.378	0.10	0.15	0.20	0.30	0.40
	D	84	0.546	0.21	0.31	0.41	0.62	0.83
Grass avg of good & fair	A		0.029	0.01	0.02	0.02	0.03	0.04
	B		0.154	0.06	0.09	0.12	0.17	0.23
	C		0.328	0.10	0.15	0.21	0.31	0.41
	C/D		0.398	0.14	0.21	0.28	0.42	0.56
	D		0.467	0.18	0.26	0.35	0.53	0.71
Woods good	A	25	0.001	0.00	0.00	0.00	0.00	0.00
	B	55	0.080	0.03	0.05	0.06	0.09	0.12
	C	70	0.205	0.08	0.12	0.16	0.23	0.31
	D	77	0.320	0.12	0.18	0.24	0.36	0.48
Woods fair	A	36	0.002	0.00	0.00	0.00	0.00	0.00
	B	60	0.103	0.04	0.06	0.08	0.12	0.16
	C	73	0.250	0.09	0.14	0.19	0.28	0.38
	D	79	0.380	0.14	0.22	0.29	0.43	0.58
Woods avg of good & fair	A		0.002	0.00	0.00	0.00	0.00	0.00
	B		0.092	0.03	0.05	0.07	0.10	0.14
	C		0.228	0.09	0.13	0.17	0.26	0.34
	C/D		0.289	0.11	0.16	0.22	0.33	0.44
	D		0.350	0.13	0.20	0.26	0.40	0.53

*Taken from Table 8 of the *Chesapeake Stormwater Newtwork (CSN) TECHNICAL BULLETIN No. 9-Nutrient Accounting Methods to Document Local Stormwater Load Reductions in the Chesapeake Bay Watershed, Version 1.0- REVIEW DRAFT* (Schuler, 2011),

Table 11: Average Annual Runoff yields for Pervious Areas by SWMM and Curve Number Method

Hydrologic Soil Condition (HSG)	Average Annual Runoff Yield, MG/ha/yr		
	SWMM Pervious	CN Method - P8, Grass -Average of Good & Fair	CN Method - P8, Woods - Average of Good & Fair
A	0.067	0.029	0.002
B	0.210	0.154	0.092
C	0.407	0.328	0.228
C/D	0.547	0.397	0.289
D	0.686	0.467	0.350
Avg. A/B/C/D	0.343	0.244	0.192
MG= Million Gallons, ha = hectare			

The results of the HRU modeling are initially used with results of stormwater TP EMC data analyses and other stormwater quality information to narrow the range of PLERs for specific surfaces associated with land use categories in the New England region. For example, if the annual mean TP concentration for an industrial & commercial impervious surface is bracketed by the median and mean TP EMC values of 0.20 and 0.30 mg/L, respectively (see Table 2), then the associated PLER for this group should fall within the range of 1.96 to 2.94 kg/ha/yr (see Table 7).

D. Annual Average Phosphorus Loading Information

D.1 Phosphorus Load Export Rates

Following the Region's review of pertinent PLER information and pollutant loading studies to inform the derivation of PLERs for MA and the New England region, Table 12 presents some of the relevant PLER information considered in this analysis. As indicated, Table 12 identifies land use categories typically studied in storm water research with reported PLERs (kg/ha/yr) from land use-based research collating numerous storm water studies (2^{nd} column) and calculated PLERs based on the results of using the Simple Method (Schueler, 1987)(6^{th} column). The Simple Method includes an empirical runoff model, and has been widely used in the field of stormwater management as it takes into account annual rainfall, impervious cover, and stormwater TP strength to calculate annual loadings (see Appendix C). Also included in Table 12 are ranges of typical percent imperviousness of various land uses, based on general storm water research (3^{rd} column) and average percent impervious of land uses in the Charles River watershed, MA (discussed further below). The PLERs in Table 12 represent "composite" PLERs, which represent the combined loading from both impervious and pervious surfaces within the designated land use category.

Table 12: Annual Average Phosphorus Load Export Rates (PLERs) reported in literature and by land use using Simple Method					
Land Cover	**Literature reported phosphorus load export rate kg/ha/yr (source)**	**Ranges in percent impervious values typical for various land uses (Schueler 1987 & Charles River)**	**Range of annual phosphorus load export rates developed using the Simple Method, Schueler,1987 (5) kg/ha/yr**	**Charles River watershed percent impervious by land use (MassGIS, 2005)**	**Annual phosphorus load export rates for Charles River using the Simple Method, Schueler,1987 (5) kg/ha/yr**
Commercial	1.679 (1)	60-90%	1.17 - 2.57	61.4%	1.20
Industrial	1.455 (1)	60-90%	1.17 - 2.57	69.1%	1.35
High Density Residential	1.12 (1)	35-60%	0.80 - 1.76	43.3%	1.13
Medium Density Residential	0.56 (1)	20-35%	0.59 - 1.09	27.4%	0.76
Low Density Residential	0.30 (3)	5-25.2%	0.25 – 0.71	25.2%	0.71
Agriculture	0.50 (2)	0-7.2%	0.22 – 0.60	7.2%	0.60
Forest	0.13 (3&4)	0-6.2%	0.07 - 0.15	6.2%	0.15
Open Space	0.30 (3)	0-20.4%	0.11 - 0.59	20.4%	0.59

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5. Schueler, Thomas R. July 1987. Controlling urban runoff; a practical manual for planning and designing urban BMPs. For this Table stormwater TP concentrations of 0.26 mg/L was used residential and open space uses, 0.20 mg/l for commercial & industrial uses, 0.5 mg/L for agriculture and 0.15 mg/L for forested.
6. Values in red are specific to the Charles River watershed, MA.

EPA determined that the composite PLERs in column 2 were reasonably representative of the New England region, based on a loading analysis that was conducted as part of developing the implementation plan for the Lower Charles River Phosphorus TMDL in MA (MassDep, 2007). The Charles River watershed analysis was conducted to gain insight into the magnitude of phosphorus source categories within watershed. The Charles analysis was conducted using GIS spatial data layers and literature reported PLERs to estimate average annual phosphorus loading for the five year TMDL analysis period (1998-2002). The calculated net watershed load results were compared to "measured" loads to the lower Charles that were derived based on extensive information including: 1) the results of a USGS year-long investigation of watershed pollutant loads to the Lower Charles River (Breault, et. al, 2002)(Zariello and Barlow, 2002); 2) continuous flow gauging; 3) extensive water quality monitoring (dry and wet weather); 4) the application of calibrated hydrologic models developed by the USGS (Zariello, 2002) and the MWRA; and 5) a calibrated water quality model of the Charles River. Net watershed loads calculated by using the composite PLERs were found to be in very close agreement with the annual average of the P loads that were estimated, based on the more detailed and rigorous methods used for the TMDL analysis (Mass DEP and EPA, 2007).

Using the literature reported PLERs in Table 12, additional modeling analyses were conducted as part of a follow-up stormwater management optimization analyses conducted by Tetra Tech, Inc. for EPA and Mass DEP (Tetra Tech, Inc. 2009). For this study, *Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities*, it was necessary to estimate phosphorus loads for impervious and pervious surfaces separately for each of the land use categories.

For this analysis, the model was used to estimate PLERs for impervious areas and pervious areas by taking into account the average percent imperviousness of the land use categories in the Charles River watershed, local climatic data, and representative total phosphorus (TP) concentrations for pervious runoff (0.3 mg/L for developed land uses, 0.1 mg/L for forested). This modeling analysis resulted in estimates of impervious and pervious PLERs that, when combined, would equal the literature reported composite PLER for the given land use.
Table 13 presents the results of the continuous simulation hydrologic modeling analysis using SWMM.

Table 13: Composite Phosphorus Load Export Rates (PLERs) and estimated PLERS for impervious and pervious surfaces by land-use for the Charles River Watershed (Table 3-2 from the *Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities* (Tetra tech, Inc. 2009)

Land use	TP load export rate (kg/ha/yr)	Land surface cover	Average Annual P Load Export rate (kg/ha/yr)	Source of export rate
Agriculture *	0.5	Pervious	0.5	1
Commercial **	1.679	Impervious	2.5	2
		Pervious	0.3	
Forest	0.13	Impervious	1	3
		Pervious	0.1	
Freeway	0.9	Impervious	1.5	2
		Pervious	0.3	
High-density residential	1.119	Impervious	2.5	2
		Pervious	0.3	
Industrial	1.455	Impervious	2	2
		Pervious	0.3	
Low-density residential (rural)	0.30	Impervious	1	3
		Pervious	0.15	
Medium-density residential	0.560	Impervious	1.5	2
		Pervious	0.3	
Open space	0.30	Impervious	1	3
		Pervious	0.25	

Sources: (1) Budd and Meals 1994; (2) Shaver et al. 2007; (3) Mattson and Isaac 1999
Notes:
* Agriculture includes row crops, actively managed hay fields and pasture land.
** Institutional type land uses such as government properties, hospitals, and schools are included in the commercial land use category for the purpose of calculating phosphorus loadings.

The PLER information presented in Table 13 provided insights into the relative magnitudes of PLERs among impervious and pervious surfaces for various land uses. However, EPA has continued to further evaluate and refine the results of this analysis by incorporating other information from regional loading studies, results of continuous hydrologic modeling, and the results of the stormwater TP data analyses discussed above. An additional analysis was performed considering the amount of "effective" impervious area, rather than total impervious area, in order to better estimate the contribution of DCIA and PA to the composite PLERs. Sutherland equations, for calculating the amount of DCIA based on drainage system characteristics and total impervious area, were employed to refine the estimates provided in the Tetra Tech study. For this analysis, PA PLERSs were calculated based on land use, HSG distribution, HRU modeling and annual mean TP concentrations of 0.3 mg/L for developed land PA, and 0.1 mg/L for forested PA.

Table 14 provides the results of applying the Sutherland equations to estimate DCIA using the total impervious area (TIA) percentages for the Upper Charles River watershed above Watertown Dam (268 sq. mi). The results of estimating distinct PLERs for DCIA using the Sutherland equations are generally similar to the Tetra Tech estimates especially for the land uses that have higher percentages of TIA (Com, Ind, and HDR) and for which drainage systems are typically highly connected. The differences become greater for the land uses with more disconnected TIA. The purpose of this analysis is obtain deeper insight into the relative magnitudes of DCIA and PA PLERs that when combined would be of similar magnitude to the reported composite PLERs. As indicated in column 4 of Table 12, PLERs vary depending on the amount of impervious cover.

Table 14: Estimates of Distinct PLERS for DCIA in the Charles River Watershed based on Reported Composite PLERs

Land Cover	Composite Literature reported Phosphorus Load Export Rates (PLERs) kg/ha/yr.	Weighted Average Upper Charles River watershed percent TIA by land-use (Mass GIS 2007)	Sutherland Eqt. Used To Estimate Directly Connected Impervious Area (DCIA)	DCIA Eqt. description	Estimated DCIA - weighted average Upper CRW, %	DCIA PLER, kg/ha/yr.	Weighted Average Pervious Area PLER*, kg/ha/yr.	Calculated composite PLER - weighted average CRW, kg/ha/yr.
Commercial	1.679 (1)	62.2	$DCIA=0.4(TIA)^{1.2}$	Highly connected	56.8	2.60	0.38	**1.64**
Industrial	1.455 (1)	71.1	$DCIA=0.4(TIA)^{1.2}$	Highly connected	66.7	2.00	0.35	**1.45**
High Density Residential	1.12 (1)	41.5	$DCIA=0.4(TIA)^{1.2}$	Highly connected	35.0	2.40	0.42	**1.11**
Medium Density Residential	0.56 (1)	28.6	$DCIA=0.1(TIA)^{1.5}$	average	15.3	2.20	0.33	**0.57**
Low Density Residential	0.30 (2)	22.9	$DCIA=0.1(TIA)^{1.5}$	average	11.0	1.70	0.25	**0.41**
Freeway	0.90 (1)	57.9	$DCIA=0.1(TIA)^{1.5}$	average	44.1	1.50	0.39	**0.92**
Open Space	0.30 (2)	19.1	$DCIA=0.1(TIA)^{1.5}$	average	8.3	1.70	0.25	**0.32**
Agriculture	0.50 (3)	6.2	$DCIA=0.01(TIA)^{2.0}$	Mostly disconnected	0.38	1.70	0.43	**0.43**
Forest	0.13 (2)	2.5	$DCIA=0.01(TIA)^{2.0}$	Mostly disconnected	0.06	1.70	0.14	**0.14**

1. Shaver, E., Horner R., Skupien J., May C., and Ridley G. 2007 Fundamentals of urban runoff management: technical and institutional issues. Prepared by the North American Lake Management Society, Madison, WI, in cooperation with the U.S. Environmental Protection Agency.

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

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

Notes:* Weighted average pervious area PLER is based on hydrologic soil distribution by land use in the upper Charles River Watershed (CRW), HRU modeling runoff yield results for HSG groups and annual mean TP concentrations of 0.3 mg/L for all LU categories except Ag and For where TP concentrations of 0.5 mg/L and 0.1 mg/l were used, respectively.

D.2 USGS Lower Charles River Pollutant Loads Analysis

EPA evaluated the USGS's Lower Charles River pollutant loads and modeling studies, *Streamflow, Water Quality, and Contaminant Loads in the Lower Charles River Watershed, Massachusetts, 1999-2000* (Breault, et al., 2002), and *Measured and Simulated Runoff to the Lower Charles River, Massachusetts, October 1999–September 2000,* (Zariello and Barlow, 2002). The results of these USGS studies were particularly relevant for this analysis because they included investigations of stormwater discharges from specific land uses that involved continuous flow gauging, collection of stormwater pollutant EMC data, development and calibration of detailed hydrologic models, and estimations of annual loadings using local climatic data.

Table 15 presents annual flow yields, composite PLERs and calculated TP annual mean concentrations for dry weather flows (i.e., base flow), stormwater flows and total flow for the 9 gauging locations included in the studies. One important point to note is that the commercial site in this study was found to be highly contaminated with raw sewage from illicit discharges. This is evidenced by the extremely high PLERs for total flow and dry weather flow and the elevated PLER for stormwater flow.

Table 15: Lower Charles River Watershed Phosphorus Loading as determined by the USGS (Breault, et. al, 2002) (Zariello & Barlow, 2002)

USGS -Lower Charles Monitoring Water Year 2000 (Breault, 2002)			Water Year 2000 Flow Yields MG/ha-yr			Water Year 2000 Phosphorus Loads kg/ha/yr			Calculated WY 2000 Annual Mean (Annual Flow-Weighted) Total Phosphorus concentration, mg/l		
Sub-basin	Estimated DCIA, %	Drainage Area (ha)	Dry Weather	Stormwater	Total	Dry Weather	Stormwater	Total	Dry Weather	Stormwater	Total
Single Family Residential	17	92.2	0.26	0.51	0.77	0.18	0.43	0.62	0.19	0.22	0.21
Commercial	86	6.0	7.51	2.67	10.18	6.38	3.53	9.90	0.22	0.35	0.26
Multifamily	73	9.8	0.15	2.16	2.31	0.25	2.03	2.29	0.44	0.25	0.26
Laundry Brook	11	1217.3	0.16	0.35	0.51	0.05	0.23	0.28	0.08	0.18	0.15
Faneuil Brook	14	461.0	0.27	0.53	0.80	0.11	0.37	0.48	0.10	0.18	0.16
Muddy River	42	1636.9	0.42	1.13	1.55	0.18	0.78	0.41	0.11	0.18	0.07
Stoney Brook	19	3315.3	0.58	0.53	1.10	0.20	0.69	0.90	0.09	0.35	0.21
Charles River at Watertown Dam	N.E.*	69413.2	1.14	0.50	1.65	0.33	0.19	0.52	0.08	0.10	0.08
* Not Estimated											

Using the information available from these USGS studies, together with results of the EPA HRU modeling, and the storm water quality data analyses discussed above, EPA estimated stormwater PLERs for DCIA and PA for each of the USGS land use stations and two of the smaller watershed monitoring locations, as presented in Table 16 below. EPA used the following steps to derive the impervious and pervious yields for these locations listed in Table 15 above:

1. Compile composite stormwater runoff yields (CSRY) in million gallons per hectare per year (MG/ha/yr) and phosphorus yields (CSPY) in kg/ha/yr for selected gauging/monitoring locations as reported by USGS;
2. Conduct independent continuous simulation modeling using SWMM (same model as used by USGS) to estimate the annual average impervious area runoff yield (IARY) using Boston, MA hourly precipitation data (IARY = 2.76 MG/ha/yr) (see Table 17 below);
3. Calculate pervious area runoff yield (PARY) using the following equation: PARY= (CSRY-(DCIA*IARY))/ (1-DCIA). Where DCIA = fraction of directly connected impervious area in drainage area as determined through USGS model calibration;
4. Calculate pervious area phosphorus yield (PAPY) by setting the annual flow-weighted pervious runoff TP concentration to 0.3 mg/L and multiplying by the pervious area runoff yield (see following equation): PAPY = PARY x 0.3 mg/L X (1kg/1,000,000 mg) x (1,000,000 gal/1 MG) x (3.7854 L/1 gal). The selection of 0.3 mg/L TP is based on results of the NSQD analyses described above and representative TP EMC for turf grass areas as discussed more fully in a separate Memorandum dated January, 2016 with the subject heading*: Calculation of Phosphorus Load Reductions for Cessation of Excessive Phosphorus Fertilization of Turf Grass in the Charles River Watershed*. Regarding the NSQD, the median and geometric means of residential TP EMC data sets for the larger precipitation

depth-thresholds (≥ 1.0, 1.5 and 2.0 inches) are consistent at around 0.3 mg/L. As discussed earlier, pervious runoff for larger precipitation depths in residential areas is believed to be a significant contributor to measured TP EMCs; and

5. Calculate impervious area phosphorus yield (IAPY) using following equation: IAPY = (CSPY-((1-DCIA)*PAPY))/DCIA.

Table 16 below present estimates of annual impervious and pervious flow and phosphorus yields for water year 2000 for each of the locations.

Table 16: Estimated Impervious and Pervious PLERs for Monitored Sub-Watersheds to the Lower Charles River

USGS -Lower Charles Monitoring Water Year 2000 (Breault, 2002)			Water Year 2000 Flow Yields MG/ha/yr				Water Year 2000 Phosphorus Load Yields kg/ha/yr		
Sub-basin	Estimated DCIA	Drainage Area (ha)	Composite Stormwater Runoff Yield (CSRY) (1)	Impervious Area Runoff Yield (IARY)(2)	Calculated Pervious Area Runoff Yield(PARY)(3)	Likely Hydrological Soil Group (HSG) based on PARY	Composite Stormwater Phosphorus Yield (CSPY) (1)	Calculated Impervious Area Phosphorus Yield (IAPY)(5)	Pervious Area Phosphorus Yield(PAPY)(6)
Single Family	17%	92.2	0.51	2.76	0.05	A	0.43	2.27	0.06
Commercial	86%	6.0	2.67	2.76	2.15	N/A(4)	3.53	3.70	2.44
Multifamily	73%	9.8	2.16	2.76	0.53	C/D	2.03	2.56	0.61
Laundry Brook	11%	1217.3	0.35	2.76	0.05	A	0.23	1.65	0.05
Faneuil Brook	14%	461.0	0.53	2.76	0.16	A/B	0.37	1.49	0.19

(1) As reported by USGS in the Lower Charles Rive Load Study (Breault,2002)
(2) Derived from SWMM modeling for WY 2000 using hourly precipitation data for Boston, MA
(3) Calculated assuming runoff yield for IA is 2.76 MG/ha/yr and using: PARY=(CSRY- (DCIA*IARY))/(1-DCIA)
(4) Not Applicable -This monitoring location indicated the presence of significant non-SW sources (e.g., illicit discharge presence)
(5) Calculated assuming pervious area phosphorus yield (PAPY) = PARY x TP concentration of 0.3 mg/L (CSN, 2011 &NSQD, 2008) and using : IAPY = (CSPY-((1-DCIA)*PAPY))/DCIA
(6) PAPY = PARY x 0.3 mg/L X (1kg/1,000,000 mg) x (1,000,000 gal/1 MG) x (3.7854 L/1 gal)

Table 17: Calculated Runoff Yields using SWMM and P8 Hydrologic Models for WY 2000 and the 1998-2002 Period

Period of analysis - hourly precipitation, Boston, MA	Impervious cover -Average annual runoff yield, MG/ha/yr	
	P8 Model	SWMM Model
1998-2002	2.61	2.59
WY 2000	2.78	2.76

The calculated DCIA PLERs for the single family residential and multi-family residential stations of 2.27 and 2.56 kg/ha/yr, respectively (shown in Table 16 above), are of similar magnitude with the calculated PLERs for medium density and high-density residential (2.2 and 2.4 kg/ha/yr, respectively) that were derived from literature reported PLERs using estimates of DCIA from the Sutherland equations, as shown in Table 14 above. The relatively similar magnitude between the USGS calculated values and the literature-derived values provides added support that the literature values are reasonably representative for the New England region. Unfortunately, the presence of significant contamination at the USGS commercial monitoring station lends the results for this station not useful for informing PLERs for commercial impervious surfaces.

E. **Selection of PLERs for Final MA MS4 Permit**

The Region considered all of the above referenced information in deriving the proposed PLERs for use in MA and the New England region. The purpose of this analysis wasto derive PLERs that: (1) reasonably represent the magnitude of average annual phosphorus loading for land use based source categories that are present in MA watersheds; and (2) adequately characterize the **relative** magnitude among the various sources.

Table 18 below (same as Table 1 above) provides the recommended PLERs for each of the phosphorus source categories by land use and is followed by a description of the basis for selecting the proposed PLERs.

Table 18: Proposed Average Annual Phosphorus Load Export Rates for use in the MA MS4 Permit

Phosphorus Source Category by Land Use	Land Surface Cover	Phosphorus Load Export Rate, Kg/ha/yr	Comments
Commercial (Com) and Industrial (Ind)	Directly connected impervious	2.0	Derived using a combination of the Lower Charles USGS Loads study and NSWQ dataset. This PLER is approximately 75% of the HDR PLER and reflects the difference in the distributions of SW TP EMCs between Commercial/Industrial and Residential.
	Pervious	See* DevPERV	
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.6	Largely based on loading information from Charles USGS loads, SWMM HRU modeling, and NSWQ data set
	Pervious	See* DevPERV	
Medium -Density Residential (MDR)	Directly connected impervious	2.2	Largely based on loading information from Charles USGS loads, SWMM HRU modeling, and NSWQ data set
	Pervious	See* DevPERV	
Low Density Residential (LDR) - "Rural"	Directly connected impervious	1.7	Derived in part from Mattson Issac, HRU modeling, lawn runoff TP quality information from Chesapeake Bay and subsequent modeling to estimate PLER for DCIA (Table 14) to approximate literature reported composite rate 0.3 kg/ha/yr.
	Pervious	See* DevPERV	
Highway (HWY)	Directly connected impervious	1.5	Largely based on USGS highway runoff data, HRU modeling, information from Shaver et al and subsequent modeling to estimate PLER for DCIA for literature reported composite rate 0.9 kg/ha/yr.
	Pervious	See* DevPERV	
Forest (For)	Directly connected impervious	1.7	Derived from Mattson & Issac and subsequent modeling to estimate PLER for DCIA that corresponds with the literature reported composite rate of 0.13 kg/ha/yr (Table 14)
	Pervious	0.13	
Open Land (Open)	Directly connected impervious	1.7	Derived in part from Mattson Issac, HRU modeling, lawn runoff TP quality information from Chesapeake Bay and subsequent modeling to estimate PLER for DCIA (Table 14) to approximate literature reported composite rate 0.3 kg/ha/yr.
	Pervious	See* DevPERV	
Agriculture (Ag)	Directly connected impervious	1.7	Derived from Budd, L.F. and D.W. Meals and subsequent modeling to estimate PLER for DCIA to approximate reported composite PLER of 0.5 kg/ha/yr.
	Pervious	0.5	
*Developed Land Pervious (DevPERV)- Hydrologic Soil Group A	Pervious	0.03	Derived from SWMM and P8 - Curve Number continuous simulation HRU modeling with assumed TP concentration of 0.2 mg/L for pervious runoff from developed lands. TP of 0.2 mg/L is based on TB-9 (CSN, 2011), and other PLER literature and assumes unfertilized condition due to the upcoming MA phosphorus fertilizer control legislation.
*Developed Land Pervious (DevPERV)- Hydrologic Soil Group B	Pervious	0.13	
*Developed Land Pervious (DevPERV) - Hydrologic Soil Group C	Pervious	0.24	
*Developed Land Pervious (DevPERV) - Hydrologic Soil Group C/D	Pervious	0.33	
*Developed Land Pervious (DevPERV) - Hydrologic Soil Group D	Pervious	0.41	

Multi-family and High-density Residential Directly Connected Impervious Area: EPA chose a PLER of 2.6 kg/ha/yr for DCIA located within multi-family and high-density residential areas. This

PLER was derived based on a weight of evidence approach, considering the following information listed in order of importance:

1. EPA calculated a PLER of 2.56 kg/ha/yr (Table 16) for WY 2000 using the results of the USGS studies (Table 15), combined with EPA continuous simulation SWMM modeling (Table 7), TP EMC data analyses of the NSQD, and reported TP concentrations for lawns (Table 10).
2. A comparison of stormwater quality TP EMC data collected by the USGS at multi-family station (median 0.25 mg/L and annual average flow-weighted concentration of 0.25 mg/L) with the results of the NSQD analyses for residential areas (median = 0.28 mg/L) indicated that the data wereof similar magnitudes (12% difference). Given the small sample size number (8) collected at this station, EPA has put more weight on the calculated annual average flow-weighted concentration, which wasbased on a multivariate regression analysis performed by the USGS to estimate TP EMCs for un-monitored events during WY 2000; and
3. The literature reported "composite" PLER of 1.119 kg/ha/yr (Table12) and the subsequent modeling analyses estimated an impervious PLER of 2.4 kg/ha/yr (Table 14) by considering average percent imperviousness, estimated DCIA and local climatic data. This estimate wassimilar to the calculated value of 2.6 kg/ha/yr using the USGS data (8% difference). EPA chose to select the slightly higher PLER of 2.6 kg/ha/yr after considering the slightly higher median TP EMC for the residential category in the NSQD.

Commercial and Industrial Directly Connected Impervious Area: EPA chose a PLER of 2.0 kg/ha/yr for DCIA located within commercial and industrial areas. This PLER was derived based on a weight of evidence approach, considering the following information listed in order of importance:

1. The NSQD provided a robust TP EMC data set that indicates a relationship exists in the TP EMC distributions between the commercial and industrial group data set and the residential data set. As indicated by the ratios of statistical measures in Table 4 (e.g., Com. & Ind. Median: Residential Median = 0.75),the average of the ratios 0.75 was applied to the PLER of 2.6 kg/ha/yr for impervious residential to calculate the PLER for commercial and industrial impervious surfaces: 0.75 x 2.6 kg/ha/yr = 2.0 kg/ha/yr;
2. A PLER of 2.06 kg/ha/yr was calculated using the results of EPA's continuous simulation HRU modeling (Table 7) and a TP concentration of 0.21 mg/L, which was equal to the median and geometric mean values from the NSQD analysis for the commercial and industrial data set (Table 2, Condition No. 1). This value was very similar to the proposed PLER of 2.0 kg/ha/yr for this source category;
3. The literature reported "composite" PLER of 1.455 kg/ha/yr for industrial land use (Table 12) and the subsequent modeling analyses estimated an impervious PLER of 2.0 kg/ha/yr (Table 14). This estimate was equal to the proposed value of 2.0 kg/ha/yr. However, the literature reported "composite" PLER of 1.679 kg/ha/yr for the commercial land use and the subsequent modeling analyses estimated a higher impervious PLER of 2.6 kg/ha/yr (Table 14), which was more similar to the residential impervious PLER. To further evaluate a commercial PLER, EPA used the SWMM continuous simulation modeling results (Table 7) and applied the median TP concentration of 0.20 mg/L from the Region's one useable commercial site, Tedeschi parking lot – Durham, NH (Table 5), and estimated a PLER of 1.96 kg/ha/yr. This estimate agreed well with the proposed PLER. Overall, EPA considered these results to support the proposed DCIA PLER for this category; and
4. As part of a recently completed USGS investigation into the performance of high–efficiency street sweeping in Cambridge MA, the street dust and dirt samples were collected from a high-density residential street and commercial street. Median concentrations of phosphorus in dust and dirt on the multi-family streets were found to be 29% greater than those found on commercial streets (Sorenson, 2011). If all factors were considered equal, then this would have suggested that the residential impervious phosphorus load would have been approximately 29%

higher than the commercial street load for these locations (2.0 kg/ha/yr x 1.29 = 2.58 or ~2.6 kg/ha/yr).

Medium-Density Residential Directly Connected Impervious Area: EPA chosen a PLER of 2.2 kg/ha/yr for DCIA located within medium-density residential areas. This PLER was derived based on a weight of evidence approach, considering the following information listed in order of importance:

1. EPA calculated a PLER of 2.27 kg/ha/yr (Table 16) for WY 2000 using the results of the USGS studies (Table 15), combined with EPA continuous simulation modeling (Table 7), and reported TP concentrations for lawns (Table 10);
2. A slightly lower PLER of 2.2 was proposed after considering the composite literature value of 0.56 kg/ha/yr and the associated estimated PLER for DCIA 2.2 kg/ha/yr. Also, the USGS monitoring work was conducted in WY 2000 which had slightly higher precipitation and runoff than the average for the five year period used in the TMDL analysis, 1998 through 2002 (Table 17).

Highway Directly Connected Impervious Area: EPA chose a PLER of 1.5 kg/ha/yr for highway DCIA. This PLER was derived based on a weight of evidence approach, considering the following information listed in order of importance:

1. The literature reported "composite" PLER for highways (identified as "freeways" in Tables 12 and 14) of 0.9 kg/ha/yr, and the subsequent EPA modeling analyses that estimated a PLER for DCIA of 1.5 kg/ha/yr (Table 14);
2. The Regional TP EMC data from MA highway stormwater monitoring (Table 5) was further summarized below in Table 19. As indicated, median TP EMCs were lower for locations with lower average daily traffic counts (ADT). Excluding sites with ADTs less than 39,000, the overall median of EMC data from all sites combined was0.14 mg/L. EPA chose to represent highways as more highly travelled (i.e., higher ADTs) in order to avoid underestimating the magnitude of phosphorus loading from this source category and, in part, because MS4s are located in more populated areas. Using the median EMC concentration of 0.14 mg/L to approximate the annual mean TP concentration together with the SWMM modeling results in Table 7 resulted in a calculated PLER for DCIA of 1.33 kg/ha/yr. EPA considered this result to be reasonably close to the proposed PLER of 1.5 kg/ha/yr (difference of 11%) estimated by EPA in the DCIA analysis (Table 14). Given the uncertainty of how well the median TP EMC approximates the annual mean TP concentration, EPA chose the slightly higher PLER of 1.5 kg/ha/yr, which was based on continuous simulation modeling that reflects build-up and wash-off of phosphorus with local precipitation conditions.

Table 19: Summary of Median Total Phosphorus Stormwater EMCs for Massachusetts Highways

Highway and designation	USGS Station number	Monitoring period	Annual ADT	Median TP EMC, mg/L	n
Route 119 -P	424209071545201	9/15/2005 - 7/11/2007	3,000	0.05	17
Route 119 -S	424155071543201	9/29/2005 - 7/11/2007	3,000	0.05	10
Route 2 -S	423027071291302	8/20/2006 - 8/6/2007	39,693	0.14	10
Route 2 -P	423027071291301	9/15/2005 - 8/8/2007	39,700	0.12	18
Interstate 495 -P	422821071332001	9/15/2005 - 8/8/2007	81,900	0.14	17
Interstate 495 -S	422716071343901	9/15/2005 - 9/19/2006	81,900	0.06	11
Interstate 95 -P	422620071153301	9/15/2005 - 8/8/2007	154,500	0.13	18
Interstate 95 -S	422420071153302	9/15/2005 - 8/8/2007	180,600	0.18	10

ADT= average daily traffic count
From *Quality of Stormwater Runoff Discharged from Massachusetts Highways, 2005–07*",Scientific Investigations Report 2009–5269 (Kirk P. Smith and Gregory E. Granato, 2010)

Low-Density Residential and Open Land Directly Connected Impervious Area: EPA chose a PLER of 1.7 kg/ha/yr for DCIA located within the low-density residential and open land categories. This PLER was derived based on a weight of evidence approach considering the following information listed in order of importance:

1. The literature reported "composite" PLER for rural (Mattson & Isaac) 0.3 kg/ha/yr was used to represent LDR and Open Land in this analysis. In this case, EPA used the composite rate as a starting point and has placed considerable weight on the HRU modeling and PA PLER calculations to calculate a PLER for DCIA of 1.7 kg/ha/yr (Table 14). Also, EPA theorized that the DCIA PLER for LDR and Open would likely have been higher than the DCIA PLER for highway (1.5 kg/ha/yr) because of the greater amount of vegetative matter that can accumulate on impervious surfaces from trees and lawns in these land uses; and
2. The Regional TP EMC data for the two residential sites (Table 5) indicated that the magnitude of TP EMCs of these two sites were notably lower than TP EMCs, collected at the medium and high-density residential sites by the USGS, as well as lower than the residential TP EMCs in the NSQD data set.

Forested Directly Connected Impervious Area: EPA chose a PLER of 1.7 kg/ha/yr for DCIA located within areas designated as forested and adjacent to forested areas. This PLER was derived based primarily on the literature reported "composite" PLERs of 0.13 kg/ha/yr for forests (Tables 12 and 14) and the subsequent EPA DCIA modeling analyses, which estimated a PLER of 1.7 kg/ha/yr (Table 14). In this case, EPA has placed considerable weight on the composite PLER of 0.13 kg/ha/yr for deriving this PLER because it was derived based on an extensive model calibration effort for many Massachusetts lake watersheds (Mattson and Isaac, 1999) and was equal to the average PLER calculated from runoff data collected from 13 New Hampshire forested drainages (USEPA, 1974). Also, this value fell within the probable range of 0.12 to 0.18 kg/ha/yr for forested areas as determined in a literature review of phosphorus export rates (Artuso et. al., 1996).

Forested Pervious Surfaces: EPA chose a PLER of 0.13 kg/ha/yr for forested pervious surfaces. This PLER was derived based on a weight of evidence approach considering the following information listed in order of importance:

1. The literature reported "composite" PLER for forested areas of 0.13 kg/ha/yr and the subsequent EPA HRU modeling analyses, which estimated a PLER of 0.14 kg/ha/yr (Table 14) for PA in the Charles River watershed. In this case, EPA has place considerable weight on the composite PLER of 0.13 kg/ha/yr for deriving this PLER because it was derived based on an extensive model calibration effort for many lakes in Massachusetts (Mattson and Isaac, 1999); and
2. EPA has decided to treat the pervious area differently from the more developed land uses (e.g., HDR, Com, Ind, MDR, LDR and HWY) by proposing only one pervious PLER. This decision was based on the likelihood that pervious areas in forested areas are less managed and have greater contiguous areas with significantly greater flow-path travel lengths than more developed pervious landscapes for runoff to reach down-gradient discharge points (greater opportunity for capture and attenuation). Developed landscapes have greater amounts of impervious surface in close proximity to the pervious areas.

Developed Land Pervious Areas: EPA chose pervious area PLERs for five HSG categories as shown in Table 20. These PLERs were derived based on a weight of evidence approach considering the following information listed in order of importance:

1. Continuous simulation HRU modeling results (Table 7 and 10) were used in combination with a TP concentration of 0.2 mg/l to estimate PLERs for HSG A, B, C, C/D and D. As indicated in Table 10, this concentration was representative of turf grass areas without phosphorus fertilizer applications based on nutrient source characterization work done for the Chesapeake Bay region. The non-fertilized TP concentration was used for these PLERs because it was expected that over time, as a result of MA's adoption of turf grass fertilizer control regulations in Massachusetts, runoff from turf grass areas would reflect phosphorus free fertilized conditions. The Massachusetts fertilizer regulations are, in part, aimed at eliminating the use of phosphorus containing fertilizer on turf grasses when it is not needed for healthy growth. The runoff yields provided in Table 20 and used to calculate the PLERs were averages of three model estimates: 1) SWMM; 2) P8 - CN Method for grass in good condition; and 3) P8 – CN method for grass in fair condition; and
2. EPA determined that specific PLERs for pervious areas based on hydrologic soil conditions within developed landscapes was needed, considering the difference in PLERs among the soil groups and the importance for characterizing the relative magnitude of loadings from various sources in a watershed that would receive treatment and reduction credits. Furthermore, pervious areas in developed areas tended to be smaller with shorter runoff path lengths to down-gradient discharge points, and thus offered less opportunity to capture or attenuate runoff flows.

Table 20: Proposed Pervious Area PLERs for Developed Lands

Cover and Hydrologic Soil Group	Average Annual Runoff Yield, MG/ha/yr	Annual Average TP Concentration for Lawn Runoff, mg/L "non-fertilized" 0.2 Annual Phosphorus Load Export Rate(PLER), kg/ha/yr
Grass HSG A	0.041	0.03
Grass HSG B	0.172	0.13
Grass HSG C	0.354	0.27
Grass HSG C/D	0.477	0.36
Grass HSG D	0.540	0.41

Agriculture Directly Connected Impervious Area: EPA chose a PLER of 1.7 kg/ha/yr for DCIA located within areas designated as agriculture and adjacent to agricultural areas. This PLER was derived based primarily on the literature reported "composite" PLER of 0.5 kg/ha/yr for agriculture (Tables 12 and 14) and the subsequent EPA DCIA modeling analyses which estimated a PLER of 1.7 kg/ha/yr (Table 14). Also, EPA theorized that the DCIA PLER for Ag would likely be higher than the DCIA PLER for highway (1.5 kg/ha/yr) because of the greater amount of vegetative matter and soil that could accumulate on impervious surfaces adjacent to agricultural lands.

Agriculture Pervious Surfaces: EPA chose a PLER of 0.5 kg/ha/yr for agricultural pervious surfaces. This PLER was based on the literature-reported value of 0.5 kg/ha/yr.

II. Methodology for Developing Composite Phosphorus Load Export Rates For Calculating Baseline Phosphorus Load

A. Summary

Table 21 presents the Composite Phosphorus Load Export Rates proposed for use by those permittees subject to phosphorus reduction requirements based on EPA approved phosphorus TMDLs other than the Charles Rivers phosphorus TMDLs. The composite PLERs represent estimates of the average annual phosphorus load that would be delivered from the combination of impervious and pervious surfaces for nine (9) land use categories. The permittees are to use the composite PLERs to: 1) calculate baseline annual phosphorus loading from their MS4 drainage areas tributary to the applicable TMDL waterbodies; and 2) calculate the required reduction in annual phosphorus load to be achieved by the MS4.

The nine land use categories identified in Table 21 represent aggregated land use categories or groupings made up of land use categories identified by MassGIS, and are grouped according to similarities in terms of generating phosphorus loads. Appendix A provides the cross walk between the Mass GIS land use categories and the land use groupings used for calculating phosphorus loading shown in Table 21.

Table 21: Composite Average Annual Composite Phosphorus Load Export Rates for Calculating Base Line Phosphorus Load (excluding the Charles River watershed)

Land Cover	Composite PLERs for Calculating Base Line Phosphorus Load for MA MS4, kg/ha/yr	Basis of PLER
Commercial	1.27	Derived from representative % TIA for Land use, estimated DCIA, and use of distinct PLERs of 2.0 and 0.32 kg/ha/yr for DCIA and PA, respectively
Industrial	1.42	Derived from representative % TIA for Land use, estimated DCIA, and use of distinct PLERs of 2.0 and 0.27 kg/ha/yr for DCIA and PA, respectively
High Density Residential	1.16	Derived from representative % TIA for Land use, estimated DCIA, and use of distinct PLERs of 2.6 and 0.37 kg/ha/yr for DCIA and PA, respectively
Medium Density Residential	0.55	Derived from representative % TIA for Land use, estimated DCIA, and use of distinct PLERs of 2.2 and 0.24 kg/ha/yr for DCIA and PA, respectively
Low Density Residential	0.34	Derived from representative % TIA for Land use, estimated DCIA, and use of distinct PLERs of 1.7 and 0.17 kg/ha/yr for DCIA and PA, respectively
Freeway	0.82	Derived from representative % TIA for Land use, estimated DCIA, and use of distinct PLERs of 1.5 and 0.28 kg/ha/yr for DCIA and PA, respectively
Open Space	0.29	Derived from representative % TIA for Land use, estimated DCIA, and use of distinct PLERs of 1.7 and 0.16 kg/ha/yr for DCIA and PA, respectively
Agriculture	0.50	Budd, Lenore F. and Donald W. Meals. February 17, 1994. Draft Final Report. Lake Champlain Nonpoint Pollution Assessment.
Forest	0.13	Mattson, Mark D. and Russell A. Isaac. 1999. Calibration of phosphorus export coefficients for Total Maximum Daily Loads of Massachusetts's lakes. Lake Reservoir. Management, 15:209-219.

B. Methodology

The export rates presented in Table 21 have been developed using:

1) Distinct PLERs described in Section I of this document;
2) Estimates of average total impervious area (TIA) for each land use category; and
3) Estimates of directly connected impervious area (DCIA) based on the Sutherland equations.

Table 22 presents the values of TIA (column 2), DCIA (column 5), DCIA-PLER (column 6) and PA-PLER (column 7) used to estimate the composite PLER (column 8) for each land use category. Also shown are literature reported composite PLERs (column 9) and recommended PLERS (column 10) for use in the Massachusetts MS4 permitting process (excluding the Charles River watershed). Composite PLERs are calculated using the following equation:

Composite PLER = ((% DCIA/100) x DCIA PLER) + ((100 -%DCIA)/100) x PA-PLER)

Table 22: Calculated and Recommended Composite PLERs based on TIA, DCIA, and Distinct PLERs

Land Cover	Representative Total Impervious Area Percentage, %	Sutherland Eqt. Used To Estimate Directly Connected Impervious Area (DCIA)	Sutherland DCIA eqt. description	Estimated DCIA, %	DCIA PLER, kg/ha/yr	Weighted Average Pervious Area PLER*, kg/ha/yr	Calculated composite PLER, kg/ha/yr PLER=((%DCIA/100)xDCIA-PLER)+(((100-%DCIA)/100)xPA-PLER)	Composite Literature reported Phosphorus Export Loading Rates (kg/ha/yr)	Composite PLERs for Calculating Base Line Phosphorus Load for MA MS4, kg/ha/yr
Commercial	62	$DCIA=0.4(TIA)^{1.2}$	Highly Connected	56.6	2.00	0.32	1.27	1.679 (1)	**1.27**
Industrial	71	$DCIA=0.4(TIA)^{1.2}$	Highly Connected	66.6	2.00	0.27	1.42	1.455 (1)	**1.42**
High Density Residential	42	$DCIA=0.4(TIA)^{1.2}$	Highly Connected	35.5	2.60	0.37	1.16	1.12 (1)	**1.16**
Medium Density Residential	29	$DCIA=0.1(TIA)^{1.5}$	Average	15.6	2.20	0.24	0.55	0.56 (1)	**0.55**
Low Density Residential	23	$DCIA=0.1(TIA)^{1.5}$	Average	11.0	1.70	0.17	0.34	0.30 (2)	**0.34**
Freeway	58	$DCIA=0.1(TIA)^{1.5}$	Average	44.2	1.50	0.28	0.82	0.90 (1)	**0.82**
Open Space	19	$DCIA=0.1(TIA)^{1.5}$	Average	8.3	1.70	0.16	0.29	0.30 (2)	**0.29**
Agriculture	6	$DCIA=0.01(TIA)^{2.0}$	Mostly Disconnected	0.4	1.70	0.43	0.43	0.5 (3)	**0.50**
Forest	3	$DCIA=0.01(TIA)^{2.0}$	Mostly Disconnected	0.1	1.70	0.12	0.12	0.13 (2)	**0.13**

1. Shaver, E., Horner R., Skupien J., May C., and Ridley G. 2007 Fundamentals of urban runoff management: technical and institutional issues. Prepared by the North American Lake Management Society, Madison, WI, in cooperation with the U.S. Environmental Protection Agency.

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

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

Notes:* Weighted average pervious area PLER is based on hydrologic soil distribution by land use in the upper Charles River Watershed (CRW) upstream of Watertown Dam, HRU modeling runoff yield results for HSG groups and annual mean TP concentrations of 0.3 mg/L for all LU categories except Ag and For where TP concentrations of 0.5 mg/L and 0.1 mg/l were used, respectively.

The distinct PLERS for DCIA and PA that were developed in the previous section were used to calculate composite PLERs. Pervious area PLERs varied by land use category, based on the distribution of HSGs within the land use category. These values were calculated using the HRU modeling runoff yield results, the HSG distribution by land use category observed in the Upper Charles River watershed (upstream of Watertown Dam), and annual mean phosphorus concentration of 0.3 mg/L for PA runoff for all land use categories except forested and agriculture, for which 0.1 mg/L and 0.5 mg/l were used, respectively.

The average % TIA and distribution of HSGs by land use category from the Upper Charles River watershed are being used to represent conditions in other watersheds with urban areas tributary to phosphorus TMDL waterbodies. Currently, the MS4 drainage areas are not available to estimate actual % TIA and HSG distribution by land use for each MS4. Since much of the Upper Charles River watershed is designated as an urban area it is assumed that average % TIA and HSG distribution for the land use categories are reasonable approximations for calculating composite PLERs to be used by the MS4 for their urban areas.

A comparison of the calculated composite PLERs (Table 22. above, column 8) and the literature-reported composite PLERs (Table 22, column 9) indicates that the corresponding values are of similar magnitude. As indicated in Table 22, the calculated composite PLERs for all land use categories, except for the forest and agriculture categories, are proposed for use in the Massachusetts MS4 permitting process. The recommended composite PLERs for the Forest and Agriculture categories are based on the reported literature rates.

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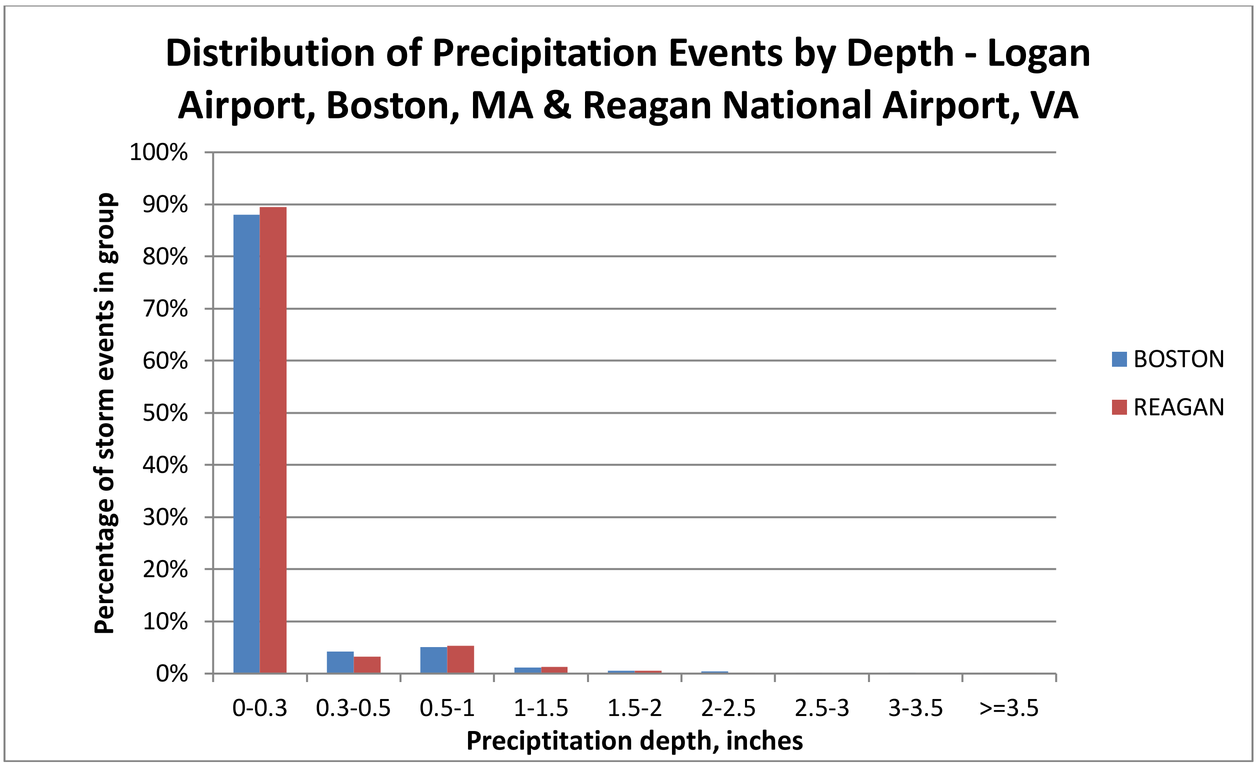
APPENDIX A
Cross-Walk between Mass GIS Land Use Categories and Land Use Groupings for Calculating Annual Phosphorus Loads for the MA MS4 Permit

Table A1. Cross-Walk between Mass GIS Land Use Categories and Land Use Categories for Calculating Annual Phosphorus Loads for MA MS4 Permit		
Mass GIS Land Use LU_CODE	Description	Land Use Category for Calculating Annual Phosphorus Load 2013/14 MA MS4
1	Crop Land	Agriculture
2	Pasture (active)	Agriculture
3	Forest	Forest
4	Wetland	Forest
5	Mining	Industrial
6	Open Land includes inactive pasture	open land
7	Participation Recreation	open land
8	spectator recreation	open land
9	Water Based Recreation	open land
10	Multi-Family Residential	High Density Residential
11	High Density Residential	High Density Residential
12	Medium Density Residential	Medium Density Residential
13	Low Density Residential	Low Density Residential
14	Saltwater Wetland	Water
15	Commercial	Commercial
16	Industrial	Industrial
17	Urban Open	open land
18	Transportation	Highway
19	Waste Disposal	Industrial
20	Water	Water
23	cranberry bog	Agriculture
24	Powerline	open land
25	Saltwater Sandy Beach	open land

26	Golf Course	Agriculture
29	Marina	Commercial
31	Urban Public	Commercial
34	Cemetery	open land
35	Orchard	Forest
36	Nursery	Agriculture
37	Forested Wetland	Forest
38	Very Low Density residential	Low Density Residential
39	Junkyards	Industrial
40	Brushland/Successional	Forest

APPENDIX B

Comparison of Precipitation Patterns between Boston, MA and Reagan National Airport, VA



REAGAN NATIONAL AIRPORT (1998-2002)			
Precipitation depth, inches	count	Cumulative count	Percentage
0-0.3	1634	1634	89.44%
0.3-0.5	59	1693	3.23%
0.5-1	97	1790	5.31%
1-1.5	24	1814	1.31%
1.5-2	10	1824	0.55%
2-2.5	2	1826	0.11%
2.5-3	0	1826	0.00%
3-3.5	0	1826	0.00%
>=3.5	1	1827	0.05%

LOGAN AIRPORT - BOSTON, MA (1998-2002)			
Precipitation depth, inches	count	Cumulative count	Percentage
0-0.3	1609	1609	88.07%
0.3-0.5	78	1687	4.27%
0.5-1	93	1780	5.09%
1-1.5	22	1802	1.20%
1.5-2	11	1813	0.60%
2-2.5	8	1821	0.44%
2.5-3	1	1822	0.05%
3-3.5	3	1825	0.16%
>=3.5	2	1827	0.11%

Average annual rainfall, inches				Average intermittent dry period, days		
	BOSTON	Reagan			BOSTON	Reagan
1998	52.9	33.3		1998	4.0	5.1
1999	39.6	40.0		1999	4.0	4.2
2000	50.1	39.3		2000	3.3	4.0
2001	34.7	29.9		2001	3.9	4.5
2002	45.4	33.4		2002	3.3	4.6
Average	44.5	35.2		Average	3.7	4.5

APPENDIX C
Simple Method Results for Boston, MA Rainfall and Varying Annual Mean TP Concentrations

Typical land use associated with percent impervious values (1)	Percent Impervious (%)	Annual Phosphorus export rate developed from the Simple Method (Schueler 1987) (kg/ha/yr)					
		Annual Mean TP Concentration, mg/L					
		0.15	0.2	0.22	0.26	0.3	0.5
Rural residential	0	0.07	0.10	0.11	0.13	0.15	0.25
	5	0.14	0.19	0.21	0.25	0.28	0.47
	10	0.21	0.28	0.31	0.36	0.42	0.70
Large lot single family	15	0.28	0.37	0.40	0.48	0.55	0.92
	20	0.34	0.46	0.50	0.59	0.69	1.14
Medium to high density residential	25	0.41	0.55	0.60	0.71	0.82	1.37
	30	0.48	0.64	0.70	0.83	0.96	1.59
	35	0.54	0.73	0.80	0.94	1.09	1.82
Multi-family residential	40	0.61	0.82	0.90	1.06	1.22	2.04
	45	0.68	0.91	1.00	1.18	1.36	2.26
	50	0.75	0.99	1.09	1.29	1.49	2.49
	55	0.81	1.08	1.19	1.41	1.63	2.71
	60	0.88	1.17	1.29	1.53	1.76	2.93
Light commercial/industrial	65	0.95	1.26	1.39	1.64	1.90	3.16
	70	1.01	1.35	1.49	1.76	2.03	3.38
	75	1.08	1.44	1.59	1.88	2.16	3.61
	80	1.15	1.53	1.69	1.99	2.30	3.83
Heavy commercial	85	1.22	1.62	1.78	2.11	2.43	4.05
	90	1.28	1.71	1.88	2.22	2.57	4.28
	95	1.35	1.80	1.98	2.34	2.70	4.50
	100	1.42	1.89	2.08	2.46	2.84	4.73
Annual rainfall for Boston 43.5 inches used to calculate export rates							