



FINAL REPORT

Mitigating Pollutants from Highway Infrastructure for Total Maximum Daily Load (TMDL) Compliance: Phase I

December 2016

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16. Abstract The protection of United States waters, such as the Chesapeake Bay, is of critical importance and has strategic significance to associated state transportation agencies. These organizations must assist in the effort to meet multi-jurisdictional stormwater regulations within the watershed. Stormwater runoff from roads and highways may carry nutrients, debris, oil, heavy metals, solids and other compounds, often directly into waterways. The resulting runoff may have detrimental pollutants that often go untreated into waters and can damage ecologically sensitive habitat. As stormwater regulations are implemented, effective guidance for understanding pollutant loadings from highway infrastructure has become essential. State transportation agencies will need additional tools to consider appropriate watershed scale impacts and evaluate actions for stormwater compliance. In this study, an amended framework for the Long-Term Hydrologic Impact Assessment Model (L-THIA) is used to determine stormwater pollutant loading from highways. The L-THIA method estimates the long-term impacts of land use on stormwater quantity and quality. The methodology is applied to estimate the average annual pollutant loading from the associated amount of impervious surface of highways. A case study demonstrates using this method to assess the average annual pollutant loading from Maryland's state roads and highways within 11 regulated counties. The results indicate that L-THIA can provide direct estimation of targeted stormwater pollutants from highways and estimate pollution reduction of best management practices.			
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1. INTRODUCTION

The Clean Water Act (CWA), enacted in 1972 and enforced by the U.S. Environmental Protection Agency (USEPA), requires states to evaluate if current water quality is supported for human activities and habitable for aquatic life. If the water quality is not supported, a limit, designated as a Total Maximum Daily Load (TMDL), is developed to determine the maximum amount of a target pollutant that a waterbody can safely receive. The CWA regulations have evolved to require that discharges from various sources (such as Municipal Separate Storm Sewer Systems (MS4s), industrial, and construction sites) are brought under the *National Pollutant Discharge Elimination System (NPDES)* permit program, with major provisions for stormwater regulations. Many state Departments of Transportation (DOTs) are considered Phase I and/or Phase II MS4s. As MS4s operators, state DOTs must obtain an NPDES permit and develop an appropriate stormwater management program.

Highway systems are potential sources for a wide variety of pollutants which can impact nearby water resources following storm events. Highway stormwater runoff may carry with it a variety of non-point source pollutants, including heavy metals, salts, oil, grease, nutrients (nitrogen and phosphorus), suspended solids, bacterial contamination, debris, and other pollutants. The responsibility of the drainage from impervious surfaces and related infrastructure for highway systems has an increasingly significant role with the planning, design, construction, and operation of transportation systems.

The TMDL represents the maximum loading that a waterbody can have in order to meet a designated Waters Quality Standard (WQS). It is calculated based on non-point source and point source contributions. TMDLs are developed for nutrients (nitrogen and phosphorus), sediment, pathogens, suspended solids, heavy metals, dissolved oxygen, temperature, pH, salts, and trash. In order to properly assess the TMDL and its sources, DOT stakeholders must understand the various conditions that arise within a tributary. To ensure compliance within a watershed, controlling the non-point sources using best management practices (BMPs) may be most important. A primary step in assessing the pollutant loading is the ability to estimate the contributions from a particular land use. The focus for DOTs is the amount of impervious surface that they operate.

Protecting the Mid-Atlantic's Chesapeake Bay

The protection of waters within the Chesapeake Bay Watershed is of critical regional importance and strategic significance to state highway programs. State agencies must assist in the effort to meet multi-jurisdictional stormwater regulations within the watershed. Stormwater runoff from roads, highways and other infrastructure such as bridges, carries debris, oil, heavy metals, suspended solids and other compounds, often directly into waterways. The resulting runoff may have detrimental pollutants that often go untreated into waters and can damage ecologically sensitive habitat.

Maryland's State Highway Administration (SHA) facilities are ultimately part of the Chesapeake Bay watershed, as the highway system connects multiple land uses and crosses jurisdictional boundaries; therefore the SHA is viewed as major stakeholder in the watershed management process along with Maryland's other state and local agencies. In the normal course of

maintaining and operating these roadways and adjacent lands, the SHA undertakes additional actions to protect the environment and reduce impacts from pollution along existing corridors and nearby waters.

SHA's need to comply with federal and state water regulations requires a greater understanding and characterizing of stormwater attributes, as well as identifying the enhancements needed for existing systems and new highway infrastructure. Adjacent vegetation, buffer areas, and best management practices have become very important in controlling pollution. As stormwater regulations and TMDLs are implemented, guidance for effective stormwater controls with highway infrastructure has become essential.

SHA and other state DOTs will have to contend with meeting TMDLs and will rely on monitoring, modeling, and data analysis activities. Methods and tools are required to assist various watershed stakeholders in selecting strategies that lead to cost-effective, environmentally friendly solutions. To make informed decisions, transportation agencies will need tools to:

- Calculate baseline pollutant loads
- Identify areas most vulnerable to contaminant transport and erosion.
- Provide assessments of best management practices (BMPs) implementation as a function of varying field, source, and climatologic conditions.

Land use-based models can be used to estimate targeted stormwater pollutant loads and assist in determining the impact of best management practices. Land use and location information is required to determine:

- Imperviousness
- Runoff coefficients
- Historic climate/precipitation
- Event mean concentrations (EMCs)

This research will investigate SHA's highway pollution loads with respect to highway property and impervious surface within the state's 11 MS4 counties. This study will also evaluate SHA's Bay Restoration activities and best management practices. With key land use and climatic data, an approach to estimate the pollutant load on an average annual basis can be used.

2. METHODOLOGY

Long-Term Hydrologic Impact Assessment (L-THIA) Method

The Long-Term Hydrologic Impact Assessment (L-THIA) (Lim and Engel, 1999) method that assesses stormwater quality and quantity using 30-50 years of historic rainfall data is used to calculate the average annual pollutant loading from highway infrastructure for TMDL compliance. L-THIA will evaluate monitoring efficacy of stormwater BMP and provide advanced decision support. L-THIA employs the Soil Conservation Service (SCS) curve number

method (NRCS, 1986). The event mean concentration (EMC) coefficient is then used to determine the pollution loading using land use, hydrologic soil group, and long-term daily precipitation data. L-THIA has had extensive applications; many studies have been performed to evaluate the impact of land use change on long-term surface runoff change and applicability of this model has been approved through these studies (Harbor, 1994; Bhaduri, 1997, 2001; Grove *et al.*, 2001; Kim *et al.*, 2002; Tang *et al.*, 2005). The online version of L-THIA generates easy to discern tables, graphs, and charts which can be used to inform stakeholders of a watershed and create awareness of the potential long-term problems related to stormwater. It provides support for decision makers who need information regarding the hydrologic impacts of water quantity and quality resulting from land use change. This information can support planning aimed at minimizing disturbance of critical areas. L-THIA is also provided as web applications within a decision support system based on the integration of web-based programming, geographic information system (GIS) capabilities, and relational databases.

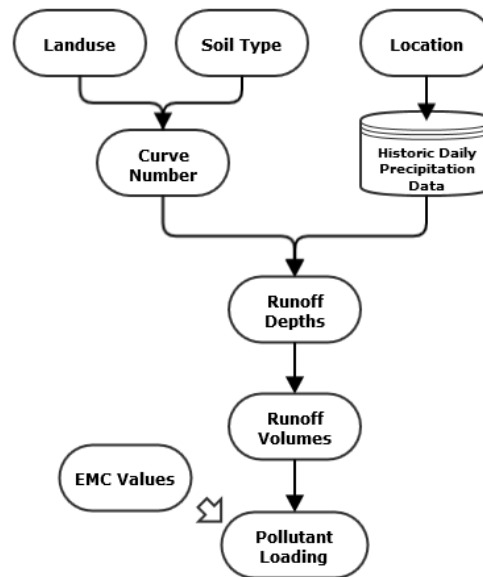


Figure 1. L-THIA Methodology with data and analysis components.

Curve Number Method

The SCS-Curve Number Method (NRCS, 1986) is utilized to calculate the runoff from the highway land-use. Curve numbers (CN) values range from 30 to 98, and are influenced by land uses, amount of impervious surface, hydrologic soil group, and antecedent moisture condition (AMC). Since the focus is only for highway impervious surface, the highest curve number, 98, is used for all the runoff calculations. The initial abstraction term, I_a , defines all losses (due to evaporation, infiltration, interception, or surface depressions) of precipitation before runoff commences. I_a is a function of the CN and is calculated as:

$$I_a = 0.2S \quad (1)$$

$$S = \frac{1000}{CN} - 10 \quad (2)$$

The stormwater runoff depth (Q) is then calculated when $P > I_a$:

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \quad (3)$$

Rearranged,

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad (4)$$

Where:

P = precipitation (in)

Q= runoff depth (in)

S = potential maximum retention after runoff begins (in)

However,

$$Q = 0 \text{ when } P < 0.2S \quad (5)$$

The L-THIA method runs equation (4) against every day of a historic precipitation data set. All rainfall events that yield runoff in a year are added up to determines the total runoff depth accumulated in a year. This is done repeatedly over the duration of the precipitation data.

Precipitation Data

The L-THIA model uses historic daily precipitation, typically over 30 years, to calculate runoff and pollutant loads on an average annual basis. For the case study, the precipitation data for a centrally located rain gauge in Baltimore County is used, with 60 years of daily precipitation dating from 1950-2010 (Fig. 2). This data is obtained from the USDA created by the Grassland, Soil and Water Research Laboratory (<http://www.ars.usda.gov/>). The weather data are derived from National Oceanic and Atmospheric Administration (NOAA) data. This dataset includes COOP Cooperative Observer network and WBAN Weather-Bureau-Army-Navy stations dating back to 1950. This data was used based on the quality control of the data and ease to format for analysis. Daily precipitation, minimum temperature, and maximum temperatures are included in the standard data set. Where data may be missing from a weather station location, the climatic data are interpolated by an ‘inverse distance weighted interpolation algorithm’ based on data acquired by five nearby weather stations. This yields a high degree of accuracy which is estimated based on the percent completeness and correlation coefficient.

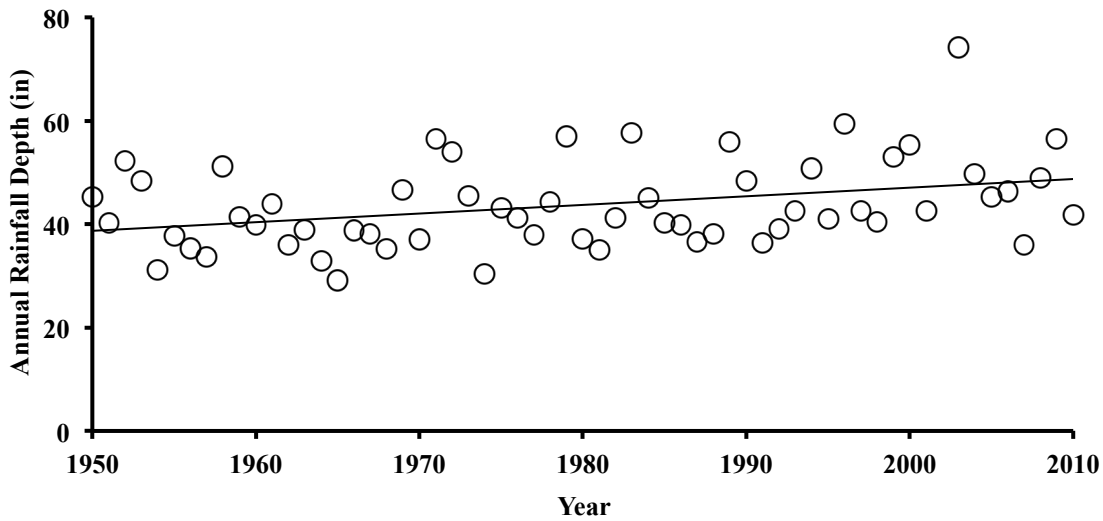


Figure 2. Annual rainfall data used in analysis, Years 1950-2010.

Case Study Location

Maryland's State Highway Administration (SHA) is charged with the responsibility of protecting the environment from pollution caused by its highways. The SHA is responsible for more than 28,000 acres of impervious roadway surfaces, which is 41.35% of SHA property (Table 1). There is an indicated need for monitoring and decision support that will allow SHA decision makers and related stakeholders to evaluate pollution loading from highway infrastructure. Maryland's SHA is the designated MS4 required to bring the state's highways into compliance with the Chesapeake Bay TMDL, NPDES Phase I and II permits, and local TMDLs, by implementing stormwater and environmental best management practices. Requirements for regulated stormwater represent the largest TMDL compliance challenges for Maryland's SHA. Maryland SHA's Phase I MS4 permit area covers a significant portion of the state, and the Phase II permit area increases the area to 11 urban counties (Fig. 3). SHA maintains MS4 permit coverage for the SHA roadway storm drain systems in all nine Maryland MS4 Phase I counties (Anne Arundel, Baltimore, Carroll, Charles, Frederick, Harford, Howard, Montgomery and Prince George's) and in the two (2) MS4 Phase II counties (Cecil and Washington). Figure 3 depicts SHA MS4 coverage. Maryland SHA anticipates it will require a 20 percent retrofit of its existing impervious cover, and has assessed its treated and untreated impervious cover and developed its own TMDL compliance implementation plan (Straughn, 2012; SHA, 2014).

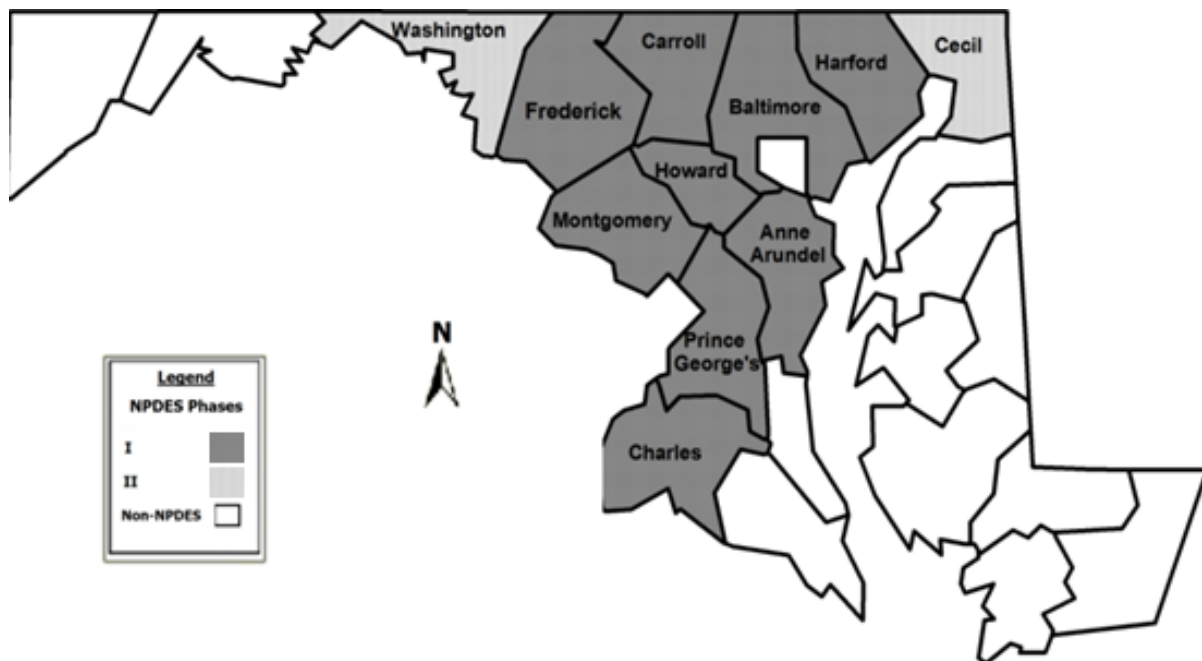


Figure 3. Maryland State Highway Administration MS4 Counties

Table 1. SHA's Impervious Surface Totals for The 11 Phase 1 NPDES Counties

Maryland MS4 County	SHA Property	SHA Impervious	Percent Impervious
	(acres)	(acres)	
Anne Arundel	9,711.57	3,889.18	40.05%
Baltimore	8,651.95	3,889.85	44.96%
Carroll	3,726.60	1,312.75	35.23%
Cecil	2,334.33	1,176.82	50.41%
Charles	3,298.91	1,324.32	40.14%
Frederick	6,667.21	2,444.95	36.67%
Harford	3,677.17	1,661.80	45.19%
Howard	6,008.17	2,134.68	35.53%
Montgomery	7,002.29	3,677.21	52.51%
Prince George's	9,706.02	4,398.56	45.32%
Washington	6,985.56	2,115.77	30.29%
Total	67,769.77	28,025.90	41.35%

Table 2. Literature Reviews of Event Mean Concentration (EMC) Values for Highway Runoff

	TN (mg/l)	TKN* (mg/l)	NO ⁻³ (mg/l)	TP (mg/l)	SS** (mg/l)	AADT***	Location
EPA(1983)	4.5	3.1	0.86	0.45	551	5,000~120,000	California
Barrett et al., (1995)	N/A	N/A	1.07	0.33	129	9,000~58,000	Texas
Irish et al., (1995)	2.59	1.83	0.76	0.4	142	N/A	Texas
Sansalone & Buchberger (1995)	N/A	N/A	N/A	N/A	105.6	135,000	Ohio
Thomson et al., (1996)	2.39	1.77	0.725	0.562	118.26	114, 000	Minnesota
Kebblin et al., (1997)	N/A	1.59	1.24	N/A	204	N/A	Texas
Walsh et al., (1997)	N/A	2.61	1.27	0.24	190	47,000	Texas
Walsh et al., (1997)	N/A	2.17	0.91	0.55	157	111,000	Texas
Wu et al., (1998)	N/A	1.48	0.66	N/A	93	6,000~25,000	North Carolina
Dammel et al., (2001)	1.01	1.61	N/A	0.23	81	N/A	California
Regenmorter et al., (2002)	N/A	2.2	0.37	0.57	824	N/A	California & Nevada
Griffin et al., (2003)	N/A	N/A	0.77	0.32	84.35	42,650	Louisiana
Han et al., (2003)	N/A	9.6	2.7	0.9	68	260,000~328,000	California
Lee-Hyung (2003)	N/A	6.3	N/A	0.41	159.57	N/A	California
Flint (2004)	N/A	3.9	0.93	0.59	405	20,375	Maryland
Lee-Hyung et al., (2005)	N/A	6.3	N/A	0.41	160	N/A	California
Kayhanian et al., (2006)	N/A	2.06 (1.4)§	1.07 (0.6)§	0.29 (0.18)§	112.7 (59.1)§	2,000~328,000	California
Stagge (2006)	N/A	50	5	2	500	N/A	Maryland
Stagge (2006)	N/A	1	0.01	0.5	10	N/A	Maryland
Kayhanian et al., (2008)	2.9	2.1	0.3	1.49	778	N/A	Michigan
Stagge et al., (2012)	5.33	3.38	2.25	0.55	98	N/A	Maryland
Opher et al., (2009)	N/A	N/A	N/A	N/A	108	N/A	California
Opher & Friedler (2009)	N/A	N/A	N/A	N/A	105	104,700	California
Sansalone (1999)	N/A	N/A	N/A	N/A	131	N/A	Louisiana
* Total Kjeldahl Nitrogen						Highway Urban	
** Suspended Solids					§	Highway Rural	
*** Annual Average Daily Traffic							

Highway Pollutant Loading

The data supplied for the model runs are based on the literature review and certain assumptions are made for the land use dataset. The pollutant loads are predicted within the model by multiplying estimated runoff volume by the event mean concentration (EMC) value. Pollutant masses are computed by multiplying runoff depth for the highway impervious surface, by the area of that land use, and the appropriate EMC value, converting units to lbs/year. Only nitrogen, phosphorus, and suspended solids (lbs) are considered in this analysis. Highway runoff pollutant characterization's literature review of EMC values for Total Nitrogen, Total Phosphorus, Suspended Solids, NO⁻³ (Nitrate), PO⁻⁴ (Phosphate), TKN (Total Kjeldahl nitrogen) are shown in Table 2. A Federal Highway Administration (FHWA) release report called "Pollutant Loadings and Impacts from Highway Stormwater Runoff" (released 1990) contains useful information related to highway runoff. The main study contained data points from several states across the United States of America. The National Stormwater Quality Database (NSDQ) was another source of information used in this study. This study database was started in 2001 and continues to receive data updates today. The NSQD consists of an abundance of information related to

stormwater runoff of various land use and road types. NSQD contains the most data points, with over 190 study areas.

SHA Impervious Restoration Strategies

The SHA owns and manages impervious surfaces in the form of interstate highways, arterial and collector roads, park and rides, rest areas, maintenance shops, material storage facilities, and offices. For alternate BMPs, the basis for calculation of equivalent impervious acres restored is based upon the pollutant loads from forested cover. By complying with the 20 percent impervious restoration requirement, the SHA will be accomplishing its part in restoring the Chesapeake Bay. The MDE and SHA agreed on October 21, 2010, to define baseline treatment requirements. In other words, impervious surfaces, stormwater control structures and alternative restoration practices built prior to this date are used in this baseline inventory and assessment for calculating the amount of impervious surfaces that the SHA is responsible for treating. The baseline development process and data are being compiled into a separate protocol and will be included in SHA's 2016 annual report. The results are:

- The SHA owns 26,301 acres of impervious surfaces within the MS4 areas.
- Treated impervious surfaces total 2,705 acres.
- Untreated impervious surfaces total 23,596 acres.

The SHA determined 4,719 acres of existing impervious surfaces must be retrofitted for runoff treatment or offset by alternative practices. This is the 20 percent restoration requirement that must be met by October 9, 2020. The SHA plans to meet the 20 percent treatment requirement through a combination of built practices, maintenance activities, redevelopment credit and credit trading (future practice). SHA restoration treatment will be accomplished by practices including tree planting, pavement removal, new stormwater control structures, retrofitting of stormwater control structures, stream restoration and outfall stabilization. The completed and proposed projects being implemented by the SHA to improve water quality in the Chesapeake Bay are shown in Figure 4. Inlet cleaning (26.57%), retrofit (13.08%), stream restoration (25.70%), and tree planting (18.03%) are a major restoration treatment accomplished by practice type. The maintenance activities such as inlet cleaning and street sweeping will be increased during the permit term to meet its ultimate impervious credit acreage goal. The examples of practice types are shown in Figures 6 to 9.

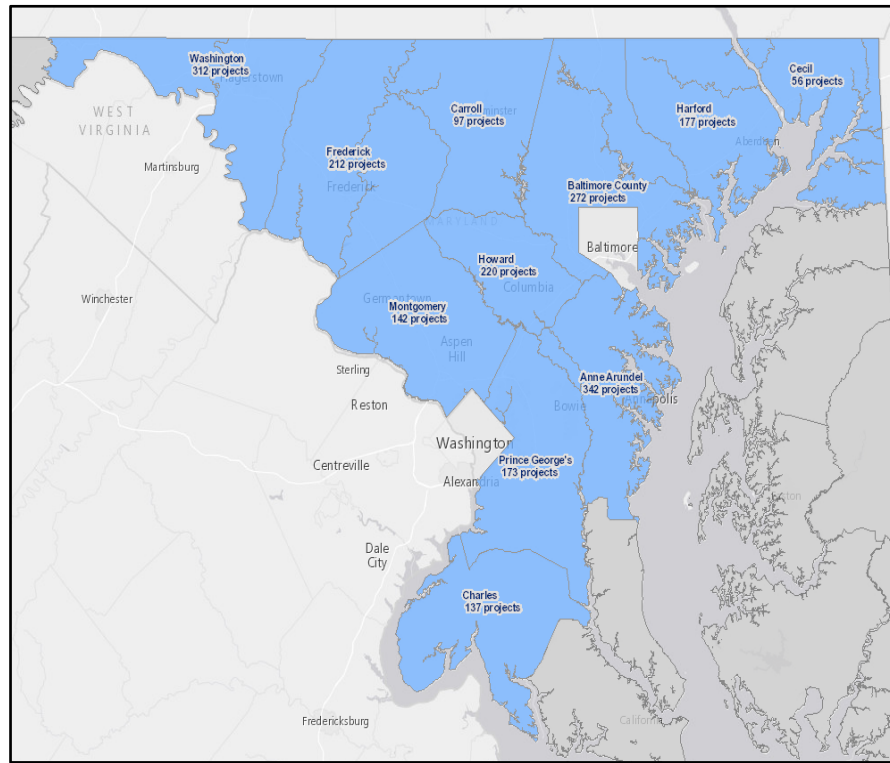


Figure 4. The completed and proposed projects being implemented by the SHA to improve water quality in the Chesapeake Bay. (SHA, 2016)



Figure 5. Example of Tree Planting of 15.2 acres by the SHA at the I-70 and I-695 interchange in Baltimore County near Security Mall. (SHA, 2016)



Figure 6. Example of bioswale installations within SR-214 in Bowie, Maryland, in Prince George's County. (SHA, 2016)



Figure 7. Example of pavement removal on SR 99. (SHA, 2016)



Figure 8. Example of pavement removal 0.26 acres on MD 216 in Howard County. (SHA, 2016)

3. RESULTS

The data sets from the literature review, 1990 FHWA study, and NSQD are aggregated and statistically summarized in charts to show the various EMC values from the different studies. The summarized highway urban EMC values are used for input with the L-THIA model. After gathering information, the data that are highway runoff pollutant characterization's literature review of EMC values, FHWA and NSQD were compiled and statistically analyzed. (Figs. 3,4,5 and Table 3). The range of total nitrogen EMC values for highway runoff is 2.33 mg/L to 3.15 mg/L. Average total nitrogen EMC value for highway runoff is 2.67mg/L (Fig. 3)

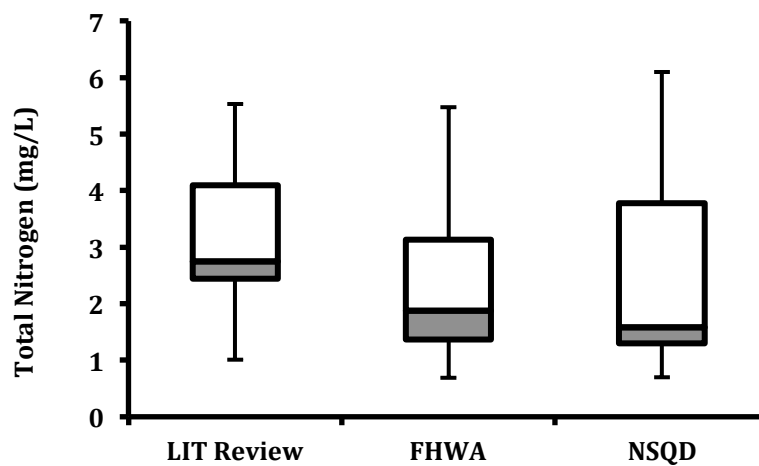


Figure 9. Summary statistics of Total Nitrogen EMC values for the literature review, FHWA study, and the NSQD.

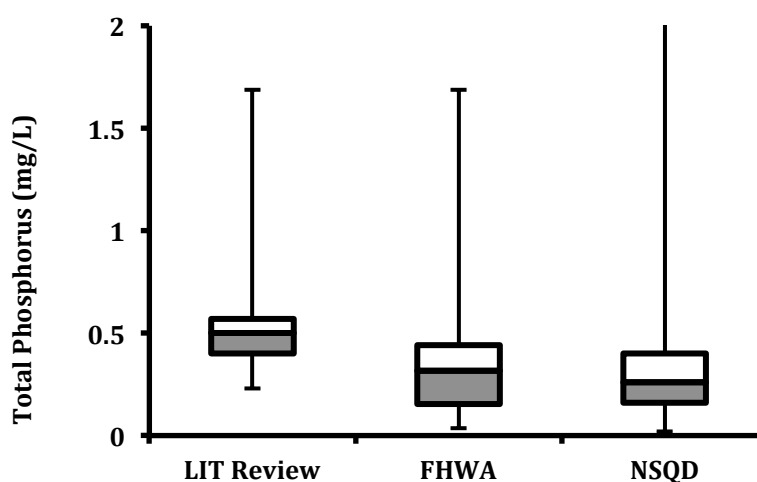


Figure 10. Summary statistics of Total Phosphorus EMC values for the literature review, FHWA study, and the NSQD.

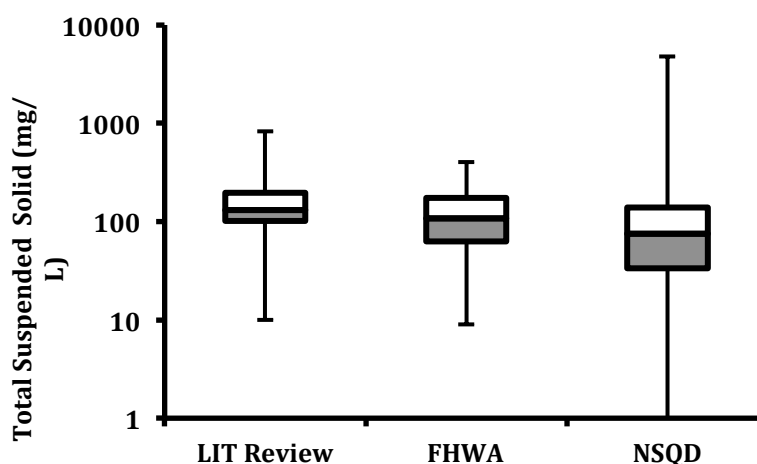


Figure 11. Summary statistics of Suspended Solid EMC values for the literature review, FHWA study, and the NSQD.

The range of total phosphorus EMC values for highway runoff is 0.40 mg/L to 0.62 mg/L. The average phosphorus EMC value of highway runoff is 0.48mg/L. And the range of suspended solid EMC values for highway runoff is 129.58 mg/L to 226.15 mg/L. Average suspended solid EMC value for highway runoff is 165.50 mg/L. Average annual runoff from SHA Permit Counties is 28.97 inches. Precipitation information was collected from NOAA - National Climatic Data Center (NCDC) weather station/rain gauge which is Baltimore Washington International Airport, MD US (network HCND : USW 00093721). Based on literature review, average highway EMC values are used as input data. Non-point source (NPS) pollutant masses are computed by multiplying runoff depth for the highway impervious surface by the area of that land use, and the appropriate EMC value, converting units to lbs/year. Estimated Average Annual Pollutant Load for SHA Permit Counties is shown in Table 4. Some 491,214 pounds of total

nitrogen, 88,308 pounds of total phosphorous and more than 30 million pounds of total suspended solid are loading from the impervious surfaces of SHA permit counties.

Table 3. Estimated Average Annual Pollutant Load for SHA Permit Counties

County	TN (lbs)	TP (lbs)	TSS (lbs)
Anne Arundel	68,166	12,255	4,225,290
Baltimore	68,178	12,257	4,226,018
Carroll	23,009	4,136	1,426,200
Cecil	20,626	3,708	1,278,523
Charles	23,212	4,173	1,438,770
Frederick	42,853	7,704	2,656,247
Harford	29,127	5,236	1,805,416
Howard	37,415	6,726	2,319,163
Montgomery	64,451	11,587	3,995,001
Prince George's	77,094	13,860	4,778,691
Washington	37,083	6,667	2,298,619
Total	491,214	88,308	30,447,937

The completed and proposed tree planting projects being implemented by the SHA to improve water quality in the Chesapeake Bay are shown in Figure 12. Tree planting (18.03%) is one of the major restoration treatments, and the completed and proposed tree planting project areas total 1,512 acres.

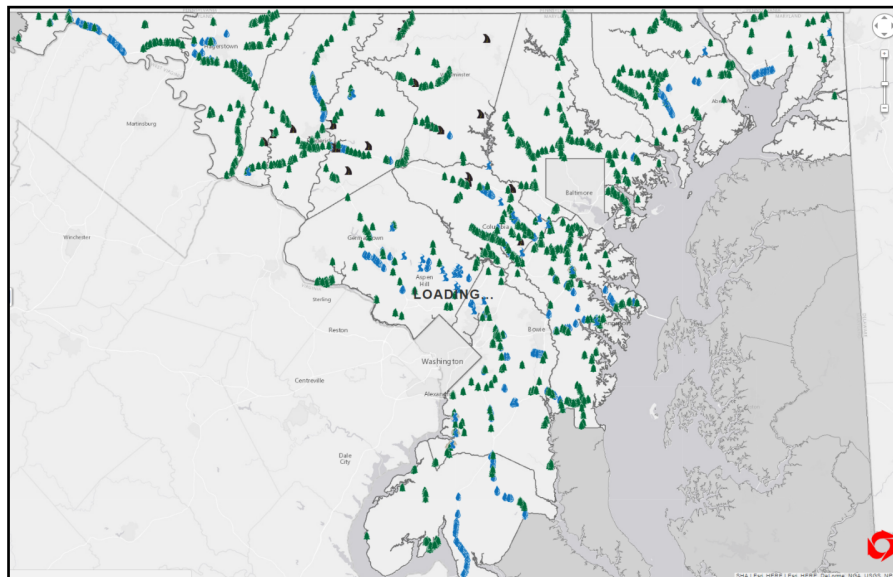


Figure 12. The completed and proposed tree planting project area being implemented by the SHA to improve water quality in the Chesapeake Bay. (SHA, 2016)

The highway before and after tree planting EMC values and average annual runoff values are used for input with the L-THIA model to evaluate tree planting achievement. Average annual runoff from highway pervious property area – which is the completed and proposed tree planting project area (total 1,512 acres) being implemented by the SHA to improve water quality in the Chesapeake Bay – is 3.82 inches before planting and 1.62 inches after tree planting. The total nitrogen EMC values for highway pervious property load is 1.86 mg/l before tree planting and 1.37 mg/l after tree planting.

The total phosphorous EMC values for highway pervious property load are 0.35 mg/l before tree planting and 0.22 mg/l after tree planting. The suspended solid EMC values for highway pervious property load are 73.5 mg/l before tree planting and 57.9 mg/l after tree planting. Stormwater quantity depended on tree planting for SHA Permit Counties is shown in Table 4. The total tree planting area is 1,513.84 acres. Stormwater quantity from impervious highway area which is designated as tree planting projects is 481.86 acre-ft before tree planting and 203.79 acre-ft after planting. 58% of stormwater quantity will be reduced by tree planting (Table 4).

Table 4. Stormwater Quantity Before and After Tree Planting

Maryland MS4 County	Tree Planting	Stormwater Quantity Before Tree Planting	Stormwater Quantity After Tree Planting
	(acres)	(acre-ft)	(acre-ft)
Anne Arundel	174.69	55.60	23.52
Baltimore	240.67	76.60	32.40
Carroll	60.68	19.32	8.17
Cecil	29.42	9.36	3.96
Charles	106.76	33.98	14.37
Frederick	124.11	39.50	16.71
Harford	198.25	63.10	26.69
Howard	156.37	49.77	21.05
Montgomery	90.19	28.71	12.14
Prince George's	99.70	31.74	13.42
Washington	233.01	74.17	31.37
Total	1513.84	481.86	203.79

Stormwater quality for EMC values for before and after tree planting are shown in Figure 13 for total nitrogen, Figure 14 for total phosphorous and Figure 15 for total suspended solid. Stormwater quality for total nitrogen EMC values in accordance with before tree planting is 2,437.24 lbs and 759.22 lbs after planting. 69% of total nitrogen EMC loading will be reduced by tree planting (Fig. 13). Stormwater quality for total phosphorous EMC values in accordance with before tree planting is 458.62 lbs and 759.22 lbs after planting. The difference for total phosphorous EMC values in accordance with before and after tree planting is 336.7 lbs, which is a 73% reduction of total phosphorous EMC loading (Fig. 14). Stormwater quality for suspended solid EMC values depended on before tree planting is 155,055.96 lbs and 16,092.13 lbs after

planting. The reduction for total suspended solid EMC values according to before and after to tree planting is 138,963.83 lbs, which is a 90% reduction of total suspended solid EMC loading (Fig. 15).

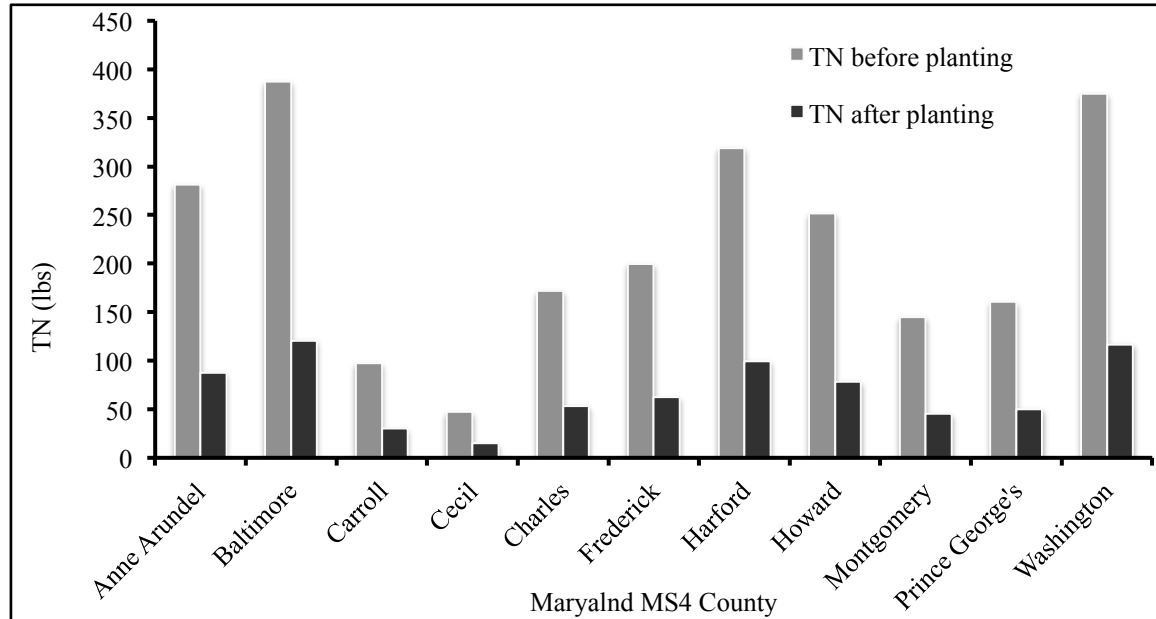


Figure 13. Stormwater Quality for Total Nitrogen EMC Before and After Tree Planting

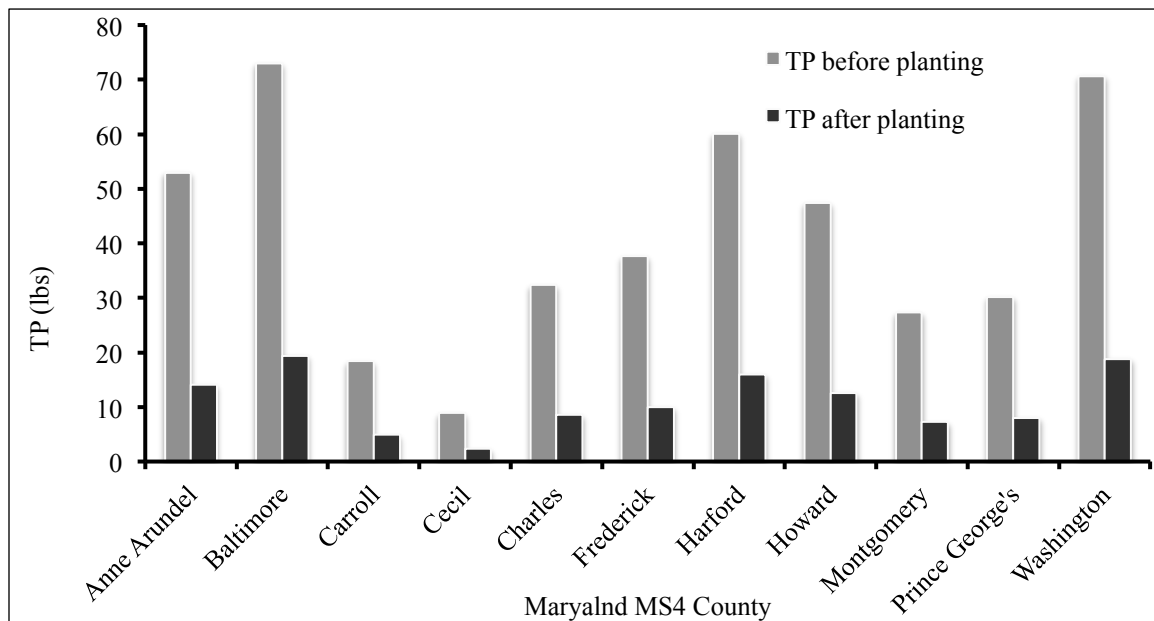


Figure 14. Stormwater Quality for Total Phosphorous EMC Before and After Tree Planting

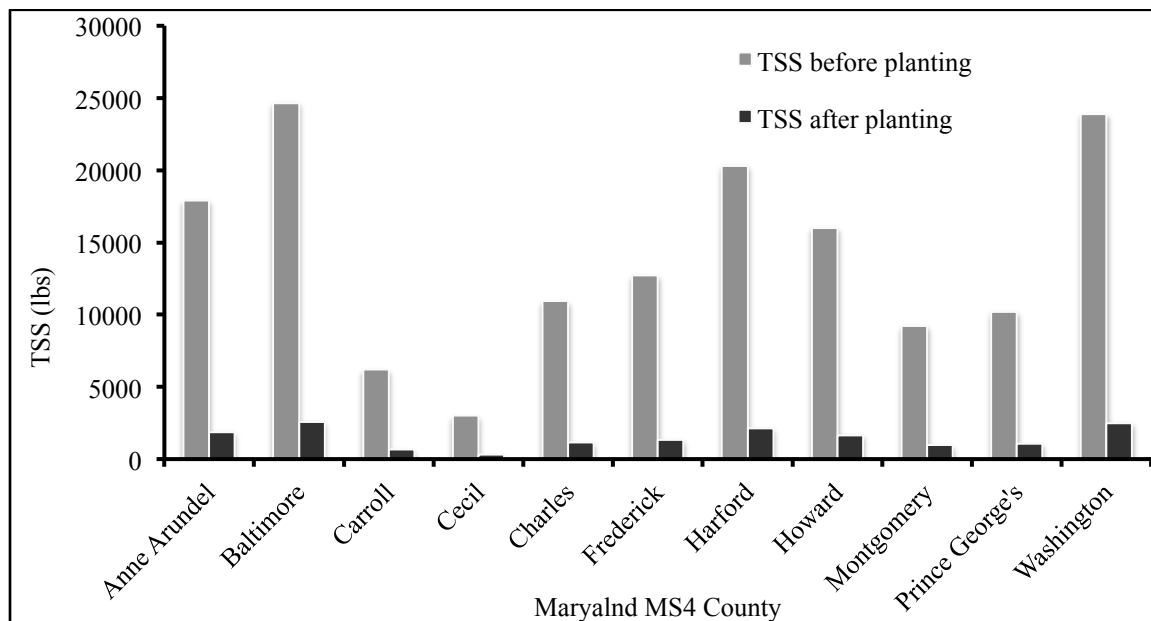


Figure 15. Stormwater Quality for Total Suspended Solid EMC Before and After Tree Planting

The highway before and after pavement removal EMC values and average annual runoff values are used for input with the L-THIA model to evaluate pavement removal achievement. Average annual runoff from highway pervious property area – which is the completed and proposed tree planting and pavement removal area being implemented by the SHA to improve water quality in the Chesapeake Bay – is 28.97 inches before planting and 4.2 inches after pavement removal. The total nitrogen EMC values for highway impervious property load are 2.67 mg/l before pavement removal and 1.86 mg/l after pavement removal. The total phosphorous EMC values for highway pervious property load are 0.48 mg/l before pavement removal and 0.35 mg/l after pavement removal. The suspended solid EMC values for highway pervious property load are 165.5 mg/l before pavement removal and 73.5 mg/l after pavement removal. Total pavement removal area is 6.51 acres. Stormwater quantity from impervious highway area which is designated as pavement removal projects is 15.72 acre-ft before pavement removal and 2.28 acre-ft after pavement removal. 86% of stormwater quantity will be reduced by tree planting (Table 5). Stormwater quality for total nitrogen EMC values in accordance with before pavement removal is 114.1 lbs and 11.52 lbs after pavement removal. 90% of total nitrogen EMC loading will be reduced by pavement removal. Stormwater quality for total phosphorous EMC values in accordance with before pavement removal is 20.51 lbs and 2.17 lbs after pavement removal. Total phosphorous EMC reduction in accordance with before and after pavement removal is 18.34 lbs, which means pavement removal reduced total phosphorous EMC loading by 89 percent. Stormwater quality for suspended solid EMC values before pavement removal is 123,962.74 lbs and 805.53 lbs after pavement removal. The reduction for total suspended solid EMC values according to before and after pavement removal is 123,157.20 lbs, which is a 99% reduction of total suspended solid EMC loading (Table 5).

Table 5. Stormwater Quantity and Quality Before and After Pavement Removal

Maryland MS4 County	Pavement removal area	Stormwater Quantity	Average Annual Stormwater Quality		
	(acres)	(acre-ft)	TN (lbs)	TP (lbs)	TSS (lbs)
Before Pavement Removal	6.51	15.72	114.10	20.51	123962.74
After Pavement Removal		2.28	11.52	2.17	805.53
Reduction (%)		86%	90%	89%	99%

4. CONCLUSIONS

A highway-specific and watershed-scale approach targets strategies for pollution control measures and identifies critical source areas. Critical sources are the pollutants that intensively contribute to non-point source pollution loading. The information afforded by the effort should encourage a greater appreciation and knowledge of the benefits of green highway infrastructure. The research will provide opportunities to view case studies, understand models to measure the benefits, and understand tradeoffs yielded by integrating green infrastructure components and management practices.

This effort will make information and guidance regarding highway-appropriate BMPs available to those directly managing highways. By getting this information to these professionals and officials, best practices will become more widely understood, accepted, and implemented, helping our partner DOTs and related stakeholders meet their water quality goals. Dissemination of results would impact those individuals who are likely to influence policy and management decisions.

With available EMC values, pollutant loading can be determined if impervious area or percentage is known for transportation infrastructure. As transportation agencies are required to identify the types and quantities of pollutants in the stormwater discharge, this framework may provide another option for pollutant loading assessment for TMDL compliance. This information is also important to help prioritize monitoring and placement/implementation of BMPs.

In many instances, transportation agencies may be minor contributors and land uses surrounding the highway facility have a far greater impact on the characteristics of the stormwater runoff than do highway surfaces. Agencies must make sure that they play an active role in the TMDL process to ensure that they are treating an equitable amount of impervious surface.

For pollutant loading from Maryland highways, the SHA utilizes loading rates from the MDE, which can be extracted from the Maryland Assessment and Scenario Tool (MAST). MAST allows users to rapidly develop scenarios with varying best management practices. The pollutant values from MAST and the presented model can be compared for further study.

5. PHASE II STUDY: Assessing source control strategies for regulatory credit

Source control strategies, such as catch basin/inlet cleaning, prevent pollution at the source by removing trash, sediment, and other contaminants from roadway surfaces. Source control may be a key measure for TMDL compliance. The ongoing field and laboratory study will provide SHA data on pollutant characterization and prioritization of highway maintenance operations. The research for inlet cleaning could determine appropriate crediting of these practices for TMDL compliance and collect information that could support enhancements to the existing credit allowed by MDE. A prime challenge of meeting TMDL requirements is the mandate to quantify the pollutants captured and removed from inlets and road surface. Defining the composition of those captured solids is of major interest to the SHA for compliance reporting.

Therefore, characterization of stormwater-borne gross, coarse, and fine solids is needed. At its end, the work will provide the SHA a final report based on an extensive programmatic and field study to characterize stormwater-borne gross, coarse, and fine solids removed by its ongoing maintenance practices.

The primary goals and objectives include:

- Determine the mass of pollutants removed by inlet cleaning by removal of stormwater borne solids
- Quantify the mass and accumulation rate of target pollutant loads related to gross, coarse, and fine solids entering highway catch basins
- Provide the SHA highly valued data required to justify regulatory credit regarding inlet cleaning practices
- Provide guidance to optimize maintenance operations

Evaluation of the SHA's inlet cleaning efforts to meet TMDL compliance will rely on evaluating current operations, monitoring, modeling, and data analysis activities. This research will investigate the highway pollution loads with respect to accumulation from traffic loadings and cleaning frequencies. This study will evaluate the maintenance/mitigation activities with interest relevant to nearby impaired waterways. Data obtained from this study will inform recommendations to optimize pollutant load reduction credits for SHA inlet cleaning via programmatic decision support and provide information that can potentially improve the credit allowed by MDE.

This would involve project coordination and programmatic decision support to SHA (CWP lead) and sampling and analysis of materials collected from inlet cleaning (MSU lead). This project would develop and implement a study designed to validate the pollutant removal efficiencies representative of current and proposed inlet cleaning efforts from targeted SHA Regional District geographic areas. Assessment of SHA's inlet cleaning activities will be done to determine the

potential to optimize program outputs and seek appropriate credit for compliance as well as provide information that can enhance the crediting protocols allowed by MDE.

The results of this analysis will assess and recommend how the SHA can optimize its inlet cleaning operations to maximize nutrient and sediment load reduction credits under MDE's current MS4 Guidelines. A synthesis of information derived from programmatic review of current operations and credits, and implementation of a study design to monitor practices with varying ADTs and land use will inform these recommendations that may warrant additional nutrient load reduction benefits. This study also aims to provide metrics and track the effectiveness of these practices reported to the State for NPDES MS4 compliance and Chesapeake Bay TMDL reporting.

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