



## E X T E R N A L    M E M O R A N D U M

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BMP Evaluation Software creates an interface for stakeholders to explore and engage with relationships between sampling frequency and precision and accuracy of sediment, total phosphorus, and nitrate load estimates for different watershed characteristics. The goal of the Software is to allow users to assess the effect of sampling frequency and watershed characteristics on the uncertainty of pollutant load estimates.

This Software was developed as part of Exponent’s FY2019 Restoration Research Program awarded contract. A presentation delivered June 9, 2020 at the Forum (available here: <https://cbtrust.org/wp-content/uploads/Lana.pdf>) summarizes the project’s goals, results achieved, Software outputs, and what end-users could do with the outputs.

The relationships between watershed characteristics and annual pollutant load estimation error were developed from a data simulation exercise subsampling from high-frequency water quality datasets to calculate error associated with lower frequency sampling methods. Error magnitude was then predicted from watershed characteristics using stepwise generalized linear models.

An explanation of model assumptions and interpretation is provided at the end of the User Guide. Additional details about the process used to create the statistical models underlying this Software, including raw data, descriptions of methods, results interpretation, and code for model development are available here: <https://cbtrust.org/grants/restoration-research/deliverables>.

Prior to release of this version of the BMP Evaluation Software, these Tools were vetted by key MS4 managers and those that support MS4 managers to improve the usefulness of these Tools for your management and decision needs. This User Guide and the Software itself reflects changes made as a result of their valuable feedback.

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# **1 User Guide for BMP Evaluation Software**

## **1.1 General Purpose of Software**

The BMP Evaluation Software is designed to guide users to optimal and economical sampling strategies for detection of anticipated water quality improvements that result from best management practices (BMPs). The BMP Evaluation Software consists of two tools:

- (1) Educational Tool
- (2) Management Tool

Both tools will dynamically update results based on changes to the user inputs.

### **1.1.1 Education Tool**

Continuous measurement of pollutant concentrations in stormwater is both physically and financially impractical. Thus, it is important to understand how well a fixed number of water samples can estimate annual average concentrations in a watershed and whether the error in these estimates exceeds the expected pollutant load reduction that result from BMPs.

The Educational Tool allows users to select a watershed and adjust the number of samples collected within a year. This user-selected number of samples is then randomly drawn from 2017 and 2018 near-continuous data for the selected watershed monitoring site and used to estimate annual average pollutant loads. The error introduced from the reduced sampling is calculated by subtracting the sampled estimate from the “true” (full dataset) estimate. The user can adjust the sample size and observe the impact on the error in estimating annual average pollutant load.

### **1.1.2 Management Tool**

The Management Tool compares six sampling methods with respect to median error in predicting annual pollutant load from watershed characteristics. The predicted annual load estimates, and thus the error estimates, incorporate uncertainty from measured data as well as sampling frequencies and the predictive relationships with key hydrologic and land-use properties of watersheds.

The user can input values for various watershed characteristics (Table 1, below) to understand how they may affect annual pollutant load estimates. The Management Tool shows the predicted estimate of median error in annual pollutant load (difference between predicted load and “true” load based on the complete measured data) for each sampling method (Table 2, below). The uncertainty in the estimates are characterized by 95% prediction limits. The error estimates and uncertainty ranges for each sampling method are compared to user-input percent expected annual reduction in pollutant load. Sampling methods with error ranges less than the expected load reduction will be sufficient to detect the anticipated reduction. However, sampling methods with error

ranges greater than the expected load reduction will not provide sufficient data to detect the anticipated load reduction because of variability in conditions, sampling frequency, and prediction error.

The Management Tool will highlight which sampling methods are able to detect the expected load reductions, the annual cost of those sampling methods, as well as the watershed characteristics predictive of sampling error for each sampling method. The Tool will update automatically as the user changes the input values for any of the watershed characteristics, expected load reductions, or cost per sample.

## 1.2 How to Access or Install the BMP Evaluation Software

The BMP Evaluation Software is available by clicking the link:

[https://bmpevaluation.shinyapps.io/bmp\\_app\\_r/](https://bmpevaluation.shinyapps.io/bmp_app_r/). Internet access is required to access this version of software. The software is set to disconnect after 15 minutes of inactivity (due to time restrictions on the hosting platform). If this occurs, please select the “Reload” prompt to reload the Tools.

Alternately, if you prefer to run the software from your own computer, there are two ways to install the BMP Evaluation Software:

- (1) Run from within RStudio
  - using provided file: “BMP\_APP\_R.zip”, or
- (2) Install standalone desktop (Windows) application
  - using provided file: “BMP\_APP\_installer.zip”.

### 1.2.1 Run from within RStudio

Step 1. Install RStudio<sup>1</sup> and R<sup>2</sup>.

Step 2. Download “BMP\_APP\_R.zip”, unzip file and extract all contents.

Step 3. Open the “BMP\_APP\_R” folder and double-click the file “BMP\_Evaluation\_shiny.RProject”.

Step 4. In RStudio, open the file “Run\_BMP\_App.R” from the “BMP\_APP\_R” folder.

Step 5. Install the “shiny” package by running lines 1–10 of the file “Run\_BMP\_App.R”. (This only needs to be done the first time you run the app.)

Step 6. Run line 10 or click the “Run App” button to launch the BMP Shiny App. To see the user guide use the “Show in new window” icon found in the “Viewer” pane.

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<sup>1</sup> RStudio Team (2019). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL <https://rstudio.com/>

<sup>2</sup> This tool set was developed under R version 3.6.1 and may not function correctly under different versions of R.

*To view in new window, click the “Open in Browser” button.*

Step 7. You can stop running the application by clicking the “Stop” button.

### **1.2.2 Install standalone desktop (Windows) application**

*This version does not require R, RStudio, or other programs to run.*

Step 1. Download “BMP\_APP\_installer.zip”, unzip file and extract all contents.

Step 2. Open the “BMP\_APP\_installer” folder and double-click the file “setup\_BMP\_APP.exe”.

Step 3. Read the license agreement, select the “I accept the agreement” radio button, and click Next if you accept.

Step 4. Read the disclaimer information, and click Next if you accept.

Step 5. Select the folder where you would like the BMP\_APP to be installed, ensure you have the required disk space (~286 MB), and click Next.

Step 6. Select the folder where you would like the BMP\_APP Start Menu shortcut to be installed, and click Next.

Step 7. Select whether you would like a BMP\_APP desktop shortcut, and click Next.

Step 8. Click Install.

Step 9. Read the Information screen, and click Next.

Step 10. If you would like to run the BMP\_APP immediately after installation, keep the “Launch BMP\_APP” box checked. If not, uncheck this box. Click Finish.

There are three ways to launch the BMP\_APP after installation:

- (1) Double-click the BMP\_APP desktop shortcut, if you chose to install it.
- (2) Double-click BMP\_APP from the Start Menu location you selected during installation.
- (3) Double-click BMP\_APP.bat (Windows Batch File) in BMP\_APP folder.

To uninstall the BMP\_APP, double-click the file “unins000.exe” in the BMP\_APP folder.

The software is subject to the following disclaimers:

## BMP Evaluation Software

**Version:** 1.0.1

**Date:** August 31, 2020

**Authors:** Josh Thompson (Watershed Restoration and Protection Program in Annapolis), Roxolana Kashuba (Exponent, Inc.), Melanie Edwards (Exponent, Inc.), and Sean F. Ryan (Exponent, Inc.)

**Disclaimer:** The user acknowledges that R and RStudio are open source platforms and that the user covenants that it will comply with any and all license requirements included with the R and RStudio packages, including but not limited to, those found at <https://www.r-project.org/Licenses/> and <https://rstudio.com/about/opensourcelicenses/>. Subject to the foregoing, permission is hereby granted, free of charge, to any user obtaining a copy of this software tool and associated documentation files (the "Software Tool"), to deal in the Software Tool without restriction, including without limitation the rights to use, copy, modify, merge, distribute, and/or sublicense copies of the Software Tool, and to permit persons to whom the Software Tool is furnished to do so, subject to the following conditions: THIS SOFTWARE TOOL IS PROVIDED "AS IS", WITHOUT REPRESENTATIONS AND WARRANTY OF ANY KIND, EXPRESSED OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE AUTHORS BE REQUIRED TO PROVIDE ONGOING CODEBASE SUPPORT, UPKEEP, BUG FIXES OR HOSTING AFTER DELIVERY. IN NO EVENT SHALL THE AUTHORS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE TOOL OR THE USE OR OTHER DEALINGS IN THE SOFTWARE TOOL. THE RESPONSIBILITY FOR APPLICATION OF THE OUTPUT FROM THE SOFTWARE TOOL RESIDES WITH THE USER.

**Built using:** R 3.6.1 and R packages shiny, tidyr, dplyr, RColorBrewer, DT, shinydashboard, ggplot2, zoo, hydroTSM, stats, utils, ggpubr, shinycssloaders, and openxlsx.

**Description:** This program is designed to evaluate how sampling method (interval) affects the ability to detect the efficacy of Best Management Practices (BMPs) in reducing annual pollutant loads and identify the most economical method. Users can input watershed characteristics, expected annual load reductions resulting from BMPs, and estimated cost-per-sample. These inputs are used to calculate, from previously fitted models, the 95th percentile prediction intervals for the median estimated percent error in annual load estimates for each sampling method and total cost. The tool will then highlight which methods are able to detect expected pollutant reductions and rank them by cost.

**Funding:** This project was funded by the Pooled Monitoring Initiative led by the Chesapeake Bay Trust with the support from Maryland Department of Transportation State Highway Administration, the Maryland Department of Natural Resources, and the National Fish and Wildlife Foundation through the U.S. Environmental Protection Agency's Chesapeake Bay Program Office.

### 1.3 How to use the BMP Evaluation Software

There are two tools contained in the BMP Evaluation Software:

- (1) Educational Tool
- (2) Management Tool

Select which Tool you would like to use by clicking on either the Educational Tool tab or the Management Tool tab at the top of the screen. The user can select inputs for each tool separately using the drop-down menus in the left sidebar. A link to this user guide is located on the User Guide tab. Version details and disclaimers are on the Software Information tab.

#### 1.3.1 How to use the Educational Tool

Select the Educational Tool tab at the top of the screen. Open the Educational Tool menu on the left side of the screen. (The menu will not open automatically after you select the tab and needs to be opened independently.)

##### 1.3.1.1 Educational Tool Inputs

The Educational Tool lets the user select the values of two inputs:

- (1) *USGS High-Frequency Monitoring Site*: Select USGS high-frequency monitoring site from the drop-down menu.
- (2) *Sample size (per year)*: Enter number of water quality samples per year in the provided text field.

##### 1.3.1.2 Educational Tool Outputs

The Educational Tool randomly sub-samples the user-selected number of samples per year from the high-frequency monitoring data for two years (2017 and 2018) for the user-selected monitoring site, calculates the error in simulated pollutant load estimates (relative to the complete data), and provides two types of outputs:

- (1) *Simulated sampling based on sample size (top set of plots)*: Plots for each pollutant (nitrate, total phosphorus, and suspended sediment concentration) showing the sub-samples of the user-selected sample size over time, compared to the discharge of the high-frequency dataset from which the sub-samples were randomly drawn.
- (2) *Effect of sample size on the error of load estimates (bottom set of plots)*: Boxplots showing the distribution of error in annual load estimates for the user-selected sample size for each pollutant and year simulated. Results are based on 100 simulations of the user-selected sample size.

Users can change the sample size and observe how the pollutant time series, and the error rate in estimating load for each pollutant, changes as a function of sample size. The intent is to allow the user to better visualize how changing annual sample size influences the representativeness of sampling events over time and the magnitude of error in annual load estimation.

### 1.3.2 How to use the Management Tool

Select the Management Tool tab at the top of the screen. Open the Management Tool menu on the left side of the screen. (The menu will not open automatically after you select the tab, and needs to be opened independently.)

#### 1.3.2.1 Management Tool Inputs

The Management Tool lets the user enter the values of three categories of input variables in the provided text fields (scroll to the bottom of the page to access all values):

- (1) *Watershed Characteristics*: Enter ten different qualities of a watershed that may be related to annual load estimation error due to sampling method. Table 1 lists these ten watershed characteristics and the range of values for each characteristic in the dataset used to develop the regression models implemented in this Tool. If the user enters a value outside this range for any input variable, that cell will turn red and a message will pop up instructing the user to select a value within the fitted dataset range (for example, if the user enters “90” for “Percent impervious surface”, the message displayed over the red cell will read: “Value must be less than or equal to 50.”). The Tool will still calculate results; however, these results are highly uncertain as the inputs are beyond the calibration range of the model.
- (2) *Expected Annual Load Reduction*: Enter the percent annual load reduction expected from implemented BMPs or other watershed management activities, for suspended sediment, total phosphorus, and nitrate loads, to determine whether this load reduction is detectable via different sampling methods given error rates in load estimation simulated for each method.
- (3) *Monitoring Costs*: Enter analytical cost per sample to calculate and compare annual cost of each monitoring program.

Values for watershed characteristics default to median values from the complete dataset.

Values for expected annual load reduction default to 5%.

Value for analytical cost per sample defaults to \$35.<sup>3</sup>

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<sup>3</sup> <https://www.abe.iastate.edu/soupir/files/2016/11/Water-Quality-Research-Laboratory-Method-Price-List.pdf>



**Table 1. Descriptions and ranges of watershed characteristics**

Watershed Characteristic	Description	Minimum Value	Maximum Value
Watershed Size (square miles)	Area of the watershed.	0.14	6252
Discharge (cubic meters per year)	Cumulative annual volume of water moving through watershed.	2.45E+05	1.02E+10
Flashiness Index (unitless ratio)	Standard hydrological metric for gauging the flashiness of a watershed: flow rate (m <sup>3</sup> /s) that is exceeded 5% of the time divided by the flow rate that is exceeded 95% of the time.	2.2	53.9
Baseflow Index (%)	Modeled baseflow totals (contribution from groundwater and interflow, etc.) in a given year divided by the total flow. <sup>4</sup>	0.093	0.67
% Woody Wetlands	Percent of watershed area where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	0	5.3
% Impervious Surface	Percent of watershed area composed of materials that water does not permeate through (e.g., concrete, asphalt, etc.).	0.33	50
% Developed Open Space	Percent of watershed area with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	2.1	35
% Developed Low Intensity	Percent of watershed area with a mixture of constructed materials and vegetation. Impervious surfaces account for 20–49% of the total cover. These areas most commonly include single-family housing units.	0.4	37
% Developed Medium Intensity	Percent of watershed area with a mixture of constructed materials and vegetation. Impervious surfaces account for 50–79% of the total cover. These areas most commonly include single-family housing units.	0.022	62
% Developed High Intensity	Percent of watershed area with highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80–100% of the total cover.	0	8

<sup>4</sup> Calculated using a digital recursive filter following standard hydrological methods; <https://www.bgs.ac.uk/research/groundwater/waterResources/thames/BFI.html>

### 1.3.2.2 Management Tool Outputs

For each pollutant and sampling method, the Management Tool calculates 95<sup>th</sup> percentile prediction intervals on median percent error in annual load estimates predicted from regression models with watershed characteristics, and the annual cost of each method. The Tool compares the percent error in estimates of pollutant load to the expected percent reduction in pollutant load as a result of BMPs and ranks sampling methods based on their ability to detect expected reductions and cost to do so. Table 2 describes the six sampling methods evaluated.

Every time the user sets values (or uses default values) for Watershed Characteristics, Expected Annual Load Reductions, or Monitoring Costs, the Tool automatically updates outputs. There are three types of outputs shown on three tabs for each pollutant:

- (1) *Plot tab*: Plots showing, for each sampling method (x-axis), the 95<sup>th</sup> percentile prediction intervals on median percent error in annual load estimates (y-axis), calculated from best-fit regression with watershed characteristics. These percent error intervals attributable to sampling method and regression prediction are compared to expected percent reduction in annual load attributable to BMP implementation (horizontal red dashed line) to determine whether that percent reduction in annual load is detectable by each sampling method.
- (2) *Parameters tab*: Chart showing which watershed characteristics (rows) were predictive of median percent error in annual load estimates for each sampling method (columns) in best-fit linear regression models. This is not a correlation table, but rather a simple identification of variables included in each model.
- (3) *Summary tab*: Table showing results of sampling method optimization evaluation sorted and ranked by sampling methods (rows) able to detect expected reduction in annual pollutant load for the lowest cost. In the middle column, sampling methods are designated as green, yellow, or red based on whether expected load reduction is always, sometimes, or never detectable (i.e., load estimation error is less than, overlapping with, or greater than expected load reduction). Annual cost of each sampling method is calculated based on the number of samples required for each method per year (shown in Table 2) multiplied by the analytical cost per sample entered by the user.

The user can change any of the inputs to evaluate the impact of different values on recommended sampling programs.

Number of annual samples for each sampling method is currently set to the values reported in Table 2 for the purposes of monitoring program cost calculation.

**Table 2. Descriptions of sampling methods assessed**

Sampling Method	Number of Annual Samples Analyzed	Simulation Description
Monthly	12	Sample taken every month (7 am–6.30 pm, M–F).
Weekly	52	Sample taken every week (7 am–6.30 pm, M–F).
Weekly + Storm	72 <sup>a</sup>	Sample taken every week (7 am–6.30 pm, M–F) with a daily sample taken when flow >90 <sup>th</sup> percentile.
Seven-Hour	1,248	Sample taken every 7 hours.
Flow-Paced	52	Sample taken when flow exceeds cumulative threshold (threshold set to yield an average 80 sampling pumps per week and aggregated into weekly composite <sup>5</sup> ).
MDE MS4 Permittee Requirements	12	Samples taken every month with preference given to flow >90 <sup>th</sup> percentile storm events.

MDE – Maryland Department of the Environment; MS4 - NPDES Municipal Separate Storm Sewer System

<sup>a</sup>Based on the average number of annual samples collected in the 1,000 simulations of Weekly + Storm sampling conducted for this analysis.

## 2 Modeling assumptions and interpretation

### 2.1 Data

The Educational Tool subsamples water quality data collected continuously from two different Chesapeake-area watersheds whose characteristics are shown in Table 3.

The regression models use high-frequency water quality data collected from 2015-2018 at 22 different sites in the greater Chesapeake Bay watershed (MD, VA, DC, and PA) shown in Figure 1.

### 2.2 Models

These high-frequency data were subsampled according to the six different sampling methods described in Table 2, and annual load estimates were calculated and compared to the “true” load estimate calculated from the high-frequency datasets, resulting % load errors attributable to each sampling method.

<sup>5</sup> <https://www.sciencedirect.com/science/article/abs/pii/S0925857418303537>

For each sampling method/pollutant combination ( $6 \times 3 = 18$  total), watershed characteristics of the 22 different watersheds in the high-frequency dataset were used to predict % error in annual load estimation.

Regressions reported in Tables 3–5 are used to calculate the error range estimates shown in the Management Tool. The software is built such that the underlying coefficients can be updated should additional data or revised regression models be appropriate in the future. The software also can be amended to incorporate more complex changes involving different types of prediction models or variables (watershed characteristics or others).

## 2.3 Interpretation

Error predictions from these regression models are made at the annual scale for an average year and are not time-dependent (i.e. the load error for a given year is not modeled as dependent on the previous year's load error, as there is no element of time in the regression models).

Model predictions are also not spatially explicit, as the associations between watershed characteristics and load estimation errors are estimated across the full dataset and represent average overall relationships across all watersheds in the Chesapeake Bay area represented in the dataset, and not specific watersheds.

This set of Tools is not intended to calculate % reduction in annual load as a result of BMP implementation. Expected annual load reduction is a model input, estimated by the user outside this software. The Management Tool uses this expected load reduction to compare to annual load estimation error to determine whether a particular sampling method will be able to detect that load reduction in the context of known error magnitude attributable to a particular sampling method given a set of watershed characteristics.

Comparisons are done on a percent basis so that expected load reduction and load estimation error are calculated in the same unit so that they can be directly compared.

Additional information and details about these analyses are available at <https://cbtrust.org/grants/restoration-research/deliverables/>, including:

- project background and impetus,
- data collection, selection, and quality control processes,
- raw data and R code used in data cleaning, load calculation and regression model fitting,
- summary plots of patterns in load error,
- discussion of scientific interpretation of model results,
- suggestions for future inquiry and potential model modifications.

**Table 3. Characteristics of the two watersheds used in the Educational Tool**

<b>Watershed Characteristics (for year 2016 unless otherwise indicated)</b>	<b>01648010 Rock Creek at Joyce Rd Washington, DC</b>	<b>01673000 Pamunkey River Near Hanover, VA</b>
Watershed Size (square miles)	65.32	1078.61
Discharge (cubic meters per year)		
2015	61,828,969	613,068,754
2016	59,736,638	858,670,121
2017	53,802,365	403,111,323
2018	117,480,680	1,545,306,663
Flashiness Index (unitless ratio)		
2015	30.14	24.48
2016	20.20	20.26
2017	15.65	16.26
2018	20.83	23.40
Baseflow Index (%)		
2015	35.28	31.52
2016	30.73	34.60
2017	27.84	47.99
2018	22.45	22.62
Impervious Surface (%)	18.78	0.75
Woody Wetlands (%)	1.60	4.92
Developed Open Space (%)	33.85	4.91
Developed Low Intensity (%)	22.69	0.78
Developed Medium Intensity (%)	8.91	0.26
Developed High Intensity (%)	3.69	0.11

The entirety of a watershed area is comprised of open water, developed open space, developed low intensity, developed medium intensity, developed high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, woody wetlands, and emergent herbaceous wetlands.

% Impervious Surface reflects the percentage of the entire watershed, not additional to the other coverage type percentages.



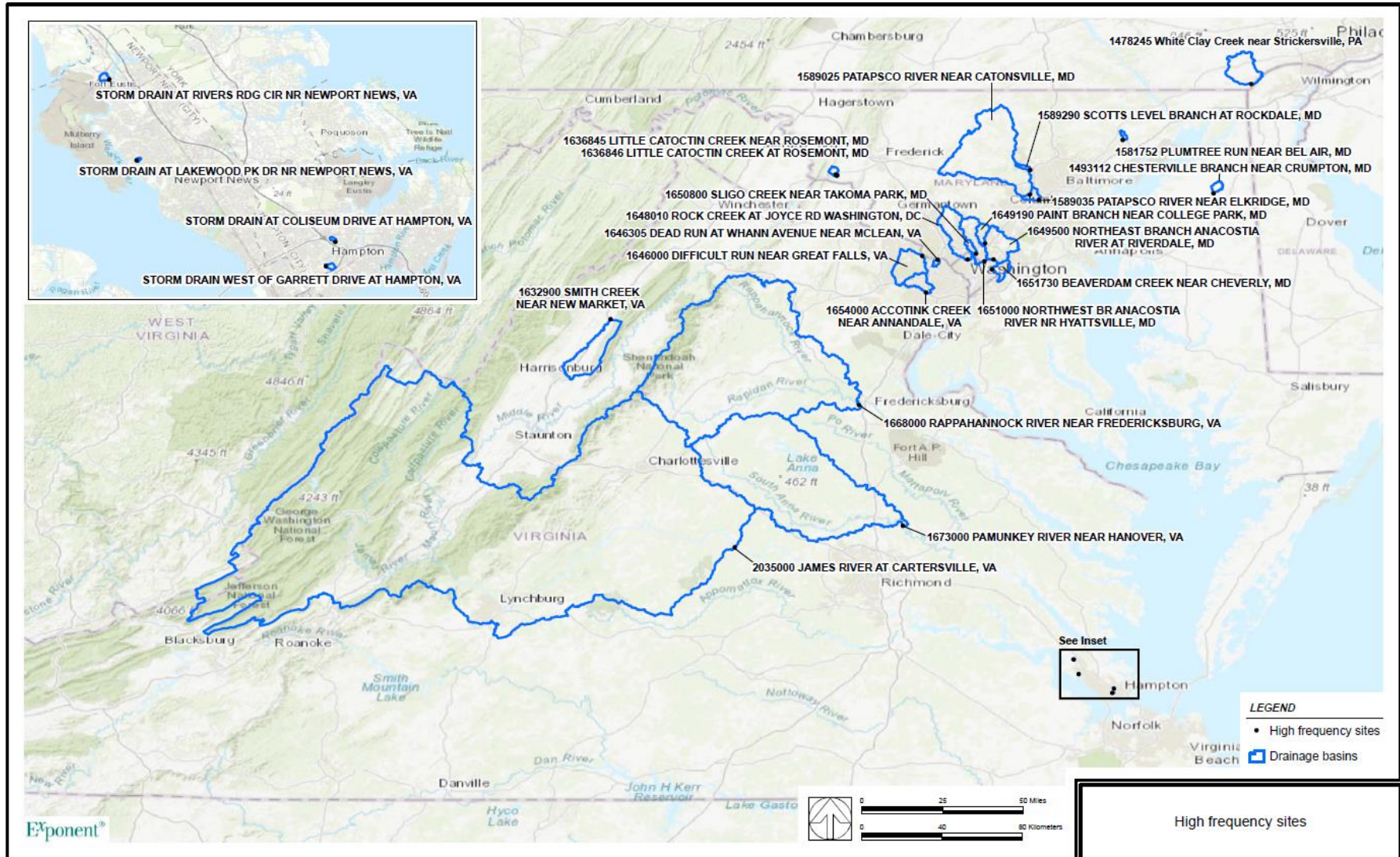


Figure 1. Locations of the watersheds used in the regression analysis

**Table 4. Results of stepwise linear regression models for suspended sediment**

Model Fit	Monthly		Weekly		Weekly+Storm		Seven-Hour		Flow-Paced		MDE MS4	
AIC	-12.19		28.76		125.78		111.72		98.28		77.91	
Adjusted R-squared	62.7%		69.3%		13.0%		35.7%		23.6%		3.5%	
Overall p-value	<0.0001		<0.0001		0.0094		<0.0001		0.0005		0.1168	
Residual standard error (df)	0.1972 (40)		0.3110 (39)		0.9661 (42)		0.8146 (41)		0.7067 (42)		0.5607 (42)	
Model Terms	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value
Intercept	0.08140	0.4594	-0.9875	0.0038	-2.265	0.0003	-0.7647	0.0054	1.148	0.1670	-1.115	0.0018
Log Watershed Size	-0.06871	0.0002	-0.1657	<0.0001	--	--	-0.2140	0.0002	--	--	--	--
Log Discharge	--	--	--	--	--	--	--	--	-0.1693	0.0005	--	--
Baseflow Index	--	--	2.253	0.0028	4.499	0.0094	--	--	--	--	1.537	0.1168
Flashiness Index	--	--	0.0203	0.0362	--	--	--	--	--	--	--	--
% Developed Low Intensity	-0.5668	0.0858	--	--	--	--	--	--	--	--	--	--
% Woody Wetlands	-14.30	<0.0001	-18.00	<0.0001	--	--	-16.98	0.0773	--	--	--	--

**Table 5. Results of stepwise linear regression models for total phosphorus**

Model Fit	Monthly		Weekly		Weekly+Storm		Seven-Hour		Flow-Paced		MDE MS4	
AIC	32.72		66.74		77.62		77.53		89.65		65.74	
Adjusted R-squared	27.0%		20.1%		30.6%		26.0%		5.6%		21.5%	
Overall p-value	0.0064		0.0208		0.0068		0.0028		0.1147		0.0284	
Residual standard error (df)	0.3914 (26)		0.7035 (26)		0.8363 (25)		0.8608 (27)		1.061 (27)		0.6813 (25)	
Model Terms	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value
Intercept	-2.190	<0.0001	-2.270	<0.0001	-4.208	<0.0001	-3.366	<0.0001	-3.450	<0.0001	-2.084	0.0002
Log Discharge	0.0431	0.1054	--	--	--	--	--	--	--	--	--	--
Baseflow Index	--	--	--	--	7.1545	0.0012	--	--	--	--	2.676	0.0780
Flashiness Index	--	--	--	--	0.0322	0.1610	--	--	--	--	--	--
% Developed High Intensity	--	--	--	--	--	--	--	--	--	--	-10.52	0.1413
% Developed Open Space	--	--	1.434	0.1742	--	--	4.099	0.0028	2.501	0.1150	--	--
% Woody Wetlands	-15.31	0.0020	-18.95	0.0212	-26.00	0.0142	--	--	--	--	-21.32	0.0130



**Table 6. Results of stepwise linear regression models for nitrate**

Model Fit	Monthly		Weekly		Weekly+Storm		Seven-Hour		Flow-Paced		MDE MS4	
AIC	47.38		64.80		71.91		84.52		65.47		42.75	
Adjusted R-squared	35.5%		32.2%		6.6%		0%		27.4%		30.8%	
Overall p-value	0.0048		0.0153		0.1257		<0.0001		0.02814		0.0097	
Residual standard error (df)	0.6108 (20)		0.8762 (19)		1.061 (21)		1.424 (22)		0.8890 (19)		0.5524 (20)	
Model Terms	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value
Intercept	-1.786	0.0003	0.4709	0.5445	-1.782	<0.0001	-2.463	<0.0001	-1.004	0.2228	-1.485	0.0004
Log Watershed Size	-0.1070	0.1039	-0.3309	0.0026	--	--	--	--	-0.1912	0.0908	-0.1285	0.0355
Baseflow Index	--	--	-1.517	0.2460	--	--	--	--	--	--	--	--
% Developed Medium Intensity	--	--	--	--	--	--	--	--	5.310	0.2024	--	--
% Developed High Intensity	--	--	--	--	--	--	--	--	--	--	11.42	0.1349
% Developed Open Space	2.516	0.0216	--	--	--	--	--	--	--	--	--	--
% Woody Wetlands	--	--	-14.80	0.1923	-18.24	0.1260	--	--	-26.83	0.0255	--	--