The Effects of Impervious Cover on Streamflow under Various Watershed Conditions in the Potomac Basin: Phase 1

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Prepared by
Heidi L.N. Moltz and James B. Palmer

Interstate Commission on the Potomac River Basin (ICPRB)
30 W. Gude, Suite 450
Rockville, MD 20850

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Cover Photo
Suburban development in Montgomery County, Maryland. Photo by ICPRB.

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Abbreviations

BMP	Best Management Practice
CART	Category and Regression Tree
CBP	Chesapeake Bay Program
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
DEM	Digital Elevation Model
DH17	High Flow Duration
DOS	Developed Open Space
EPA	United States Environmental Protection Agency
GIS	Geographic Information Systems
HID	High Intensity Developed
HIT	Hydrologic Index Tool
HSPF	Hydrologic Simulation Program-FORTRAN
HUC-12	12-Digit Hydrologic Unit Code
IHA	Indicators of Hydrologic Alteration
ICPRB	Interstate Commission on the Potomac River Basin
KFACT	Mean Soil Erodibility
KWFACT	Soil Erodibility Factor
MH21	High Flow Index
MID	Medium Intensity Developed
MS4	Municipal Separate Storm Sewer System
NLCD	National Land Cover Database
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
RESAC	University of Maryland's Regional Earth Science Applications Center
RPART	Recursive Partitioning and Regression Trees
RPS	Recovery Potential Screening tool
SSURGO	Soil Survey Geographic Database
TNC	The Nature Conservancy
U.S.	United States
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

Units of Measurement

cfs	Cubic feet per second
in.	Inches
m	Meter
sq. mi.	Square mile

Executive Summary

In natural landscapes such as forests, rainfall and snowmelt enter the soil and are either used by plants or percolate into the deeper groundwater. Impervious surfaces prevent rainfall and snowmelt from infiltrating the soil, causing the water to travel over the land's surface. Increased runoff associated with the impervious cover may change the magnitude, frequency, duration, and/or timing of streamflows (EPA 2009). A signature hydrologic impact of impervious cover is increased flashiness (higher high flows, lower low flows, and increased rate of change). It is plausible, however, that not all streams respond to impervious cover in the same way, but this raises the question: which watershed characteristics make streams most susceptible to the impacts of impervious cover?

To address this question, a two-phase project is being conducted by ICPRB that examines the ability of various watershed characteristics to influence the impact that impervious cover has on streamflow. The project builds on the results of the Middle Potomac River Watershed Assessment (USACE et al. 2013), hereafter called Middle Potomac Study, which found significant alteration in streamflow at impervious cover levels of 0.4% to 2.1%. Phase 1 is a proof of concept to finalize the methodology at a geographically course scale. Phase 2 includes full implementation of the methodology at a higher spatial resolution. This document presents the methods and findings of Phase 1 of the study and lays out the proposed approach for Phase 2.

The project rationale is presented in **Section 1** of this document. **Section 2** describes the study area, the Middle Potomac watershed plus the North Branch Potomac River watershed.

Section 3 details the Phase 1 methods. Specifically, Phase 5.2 of the Chesapeake Bay Program Watershed Model was utilized to simulate streamflows under two scenarios. A baseline scenario was developed to simulate reference conditions, or conditions that are minimally influenced by human activities. The second scenario simulated current land use conditions, including human impacts such as impervious cover. Prior to running the scenarios, efforts were undertaken to improve the baseline scenario definitions to address weaknesses identified in the Middle Potomac Study (**Section 3.1**). Six flow metrics (high flow index (MH21), high flow duration (DH17), high pulse count, flashiness, low pulse duration, and 3-day maximum flow) (**Section 3.2**) and six watershed characteristics (area, karst, precipitation, physiographic province, average watershed slope, and soil group) (**Section 3.3**) were statistically evaluated using regressions and an RPART analysis to understand the relationships between streamflow alteration caused by impervious cover and watershed characteristics.

Section 4 of this report highlights the findings of Phase 1. Namely, area, physiographic province, and average watershed slope are significantly correlated with alteration in numerous streamflow metrics. Percent karst is correlated with the alteration in high pulse count. Precipitation and soil group are not significantly correlated to alteration in the selected streamflow metrics. The results of the RPART analysis support the regression findings and strengthen confidence, especially that watershed area and slope significantly influence streamflow alteration from impervious cover in the Potomac basin.

Phase 2 will apply the methodology at a higher spatial resolution, the 12-digit hydrologic unit (HUC-12) scale to increase the sample size from 147 river segments to 361 HUC-12s. **Section 5** of this report describes the proposed approach for Phase 2 of the study including the method for calculating land uses (**Section 5.1**) and current and baseline simulated flows (**Section 5.2**); tasks and products (**Section 5.3**), and the Phase 2 timeline (**Section 5.4**).

The findings from both phases of this study may inform land management decision-making and proactive development strategies to meet the multiple, sometimes competing, water interests in the basin.

When completed, the impervious cover study will provide a scientific rationale for basin-wide, state, and local planning efforts.

1 Introduction

In natural landscapes such as forests, rainfall and snowmelt enter the soil and are either used by plants or percolate into the deeper groundwater. Impervious surfaces prevent rainfall and snowmelt from infiltrating the soil, causing the water to travel over the land's surface. Increased runoff associated with the impervious cover may change the magnitude, frequency, duration, and/or timing of streamflows (EPA 2009). A signature hydrologic impact of impervious cover is increased flashiness (higher high flows, lower low flows, and increased rate of change). It is plausible, however, that not all streams respond to impervious cover in the same way, but this raises the question: which watershed characteristics make streams most susceptible to the impacts of impervious cover?

To address this question, a two-phase project is being conducted by ICPRB that examines the ability of various watershed characteristics to influence the impact that impervious cover has on streamflow. The project builds on the results of the Middle Potomac Study conducted by the Army Corps of Engineers (USACE), ICPRB, and The Nature Conservancy (TNC) (USACE et al. 2013)[1] to assess flows in streams and small rivers utilizing an adapted Ecological Limits of Hydrologic Alteration framework (Poff et al. 2010).

The primary objectives of the Middle Potomac Study were to determine the ecological responses associated with hydrologic alteration in the Middle Potomac basin, existing and future impacts of human activities on flow, and the potential effects of climate change on the study area's hydrology. To accomplish the project objectives, two model scenarios were generated to quantify changes in streamflow under different amounts of impervious cover. A baseline scenario was developed to simulate reference conditions, or conditions that are minimally influenced by human activities. The second scenario simulated current land use conditions, including human impacts such as impervious cover. Baseline and current flow regimes were simulated at 747 macroinvertebrate sampling locations. This allowed for the subsequent assessment of flow alteration in relation to observed changes in ecological health. After extensive evaluation of over 200 flow metrics, a subset was selected to represent different aspects of the flow regime (including high-, mid-, and low-flows as well as flow duration, magnitude, and rate of change) and show relationships with watershed and water use factors (land uses, impoundments, withdrawals, and discharges). The watershed factor that had the strongest correlation with flow alteration in the Middle Potomac study area was urbanization, specifically impervious cover. The Middle Potomac Study found that alteration in many flow metrics begins to increase sharply when impervious surface exceeds 0.4% to 2.1%.

The results from the Middle Potomac Study provided general information on the significance of impervious cover as a driver of streamflow alteration; however, all streams may not respond to impervious cover in the same way due to watershed conditions. For example, impervious cover in areas with steep slopes or particular soil and geology types may be particularly prone to altering streamflows. To this end, the objective of this study is to determine whether streamflow in the Potomac basin is more susceptible to alteration from impervious cover in areas with certain watershed characteristics.

The project is designed 1) to assist land managers in identifying areas that are particularly sensitive to physical degradation associated with development and 2) to provide a scientific rationale to be utilized as part of the basin-wide, state, and local planning efforts. Numerous efforts are underway to

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[1] This report assumes that the reader has some understanding of the Middle Potomac Study. The report and supporting information is available at http://www.potomacriver.org/focus-areas/water-quality/middle-potomac-sustainable-flow-and-water-resources-analysis/, accessed 10/5/2015.

manage the effects of stormwater and impervious cover including the federal Energy Independence Act of 2007, the U.S. Clean Water Act's National Pollution Discharge Elimination System (NPDES) permitting program, and state regulations such as Maryland's Stormwater Management Act of 2007 and the Virginia Stormwater Management Act of 2004 as well as county and local stormwater controls.

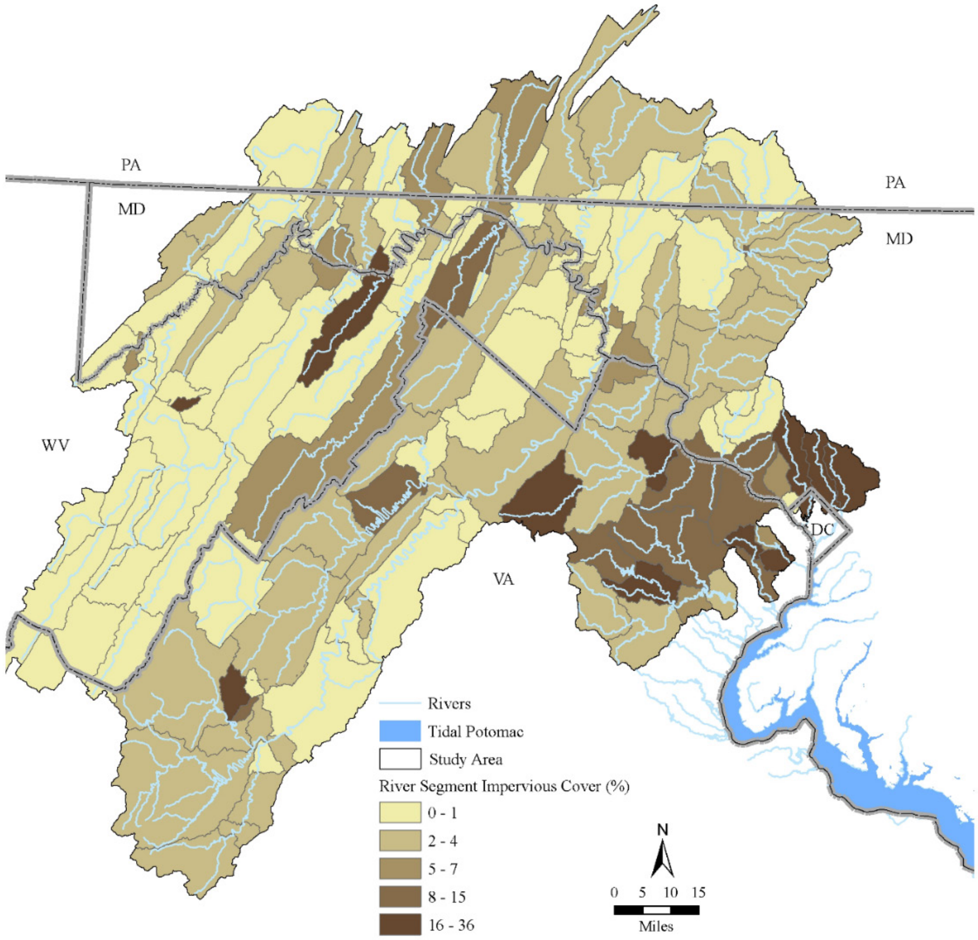
This project includes two phases. Phase 1 is a proof of concept study to finalize the methodology at a geographically courser scale. **Section 2** through **Section 4** of this report highlight the methods and findings of Phase 1. Phase 2 will apply the methodology at a higher spatial resolution. **Section 5** of this report describes the proposed approach for Phase 2 of the study.

2 Study Area

For comparability, the study area is similar to the one used for the Middle Potomac Study. It includes the Middle Potomac watershed plus the North Branch Potomac River watershed. The study area includes portions of Virginia, Maryland, West Virginia, Pennsylvania, and the District of Columbia. Due to its size, the study area is quite diverse in terms of geography, hydrology, and ecology.

The spatial resolution for Phase 1 of the study is the Chesapeake Bay Program Watershed Model, hereafter called Watershed Model, river segments. There are 147 river segments in the study area. Although river segments are not watersheds per se (i.e. they do not include the entire upstream drainage area), flows are routed downstream through the river segments; therefore, simulated flows at the river segment outlets do include flows from the entire upstream drainage area. Because of this, watershed characteristics were able to be calculated for the entire drainage area upstream of each river segment outlet. The total upstream area draining to a river segment outlet ranges from 3.1 square miles (sq. mi.) to 11,585 sq. mi. Impervious cover for those watersheds range from 0.03% to 35.7% (**Figure 1**).

Figure 1. River segments in the Phase 1 study area. Darker shades indicate higher percent impervious cover. Impervious cover data source: 2006 NLCD, including 2011 edits (Fry et al. 2011).



3 Methods

A combined geospatial, hydrologic simulation, and statistical approach was employed to determine which watershed characteristics influence the impact of impervious surface on streamflow. To implement this approach, the following steps were taken:

1. refined baseline and current land use scenarios,
2. used the Watershed Model to generate flow time series for both scenarios for each river segment watershed,
3. selected flow metrics likely to reflect the influence of impervious cover on streamflow,
4. calculated flow metrics from modeled baseline and current time series,
5. quantified level of alteration by calculating the change between the flow metrics in the two scenarios,
6. selected watershed characteristics to be evaluated for influence on hydrologic alteration associated with impervious cover,
7. calculated value for each selected watershed characteristic in each river segment,
8. determined relationships between watershed characteristics and flow metrics, and

9. calculated thresholds for the watershed characteristics found to influence hydrologic alteration associated with impervious cover.

The final products of these efforts, flow metrics, estimates of streamflow alteration, and watershed characteristics for each CBPWM river segment watershed, were compiled into a master spreadsheet that formed the basis of project analyses. Each of these steps is discussed in more detail in the sections below.

3.1 Baseline and Current Scenario Flows

Phase 5.2 of the Watershed Model was selected for use in this effort as it is a fully calibrated, community developed Hydrologic Simulation Program-FORTRAN (HSPF) model that includes the Potomac basin (Linker et al. 1999). Further, the Middle Potomac Study used the same model, resulting in fully complementary results. Two model scenarios were generated to quantify changes in streamflow under different amounts of impervious cover. Specifically, a baseline scenario was developed to simulate reference conditions, or conditions that are minimally influenced by human activities. The second scenario simulated current land use conditions[2], including human impacts such as impervious cover. In both the current and baseline scenarios, withdrawals, discharges, and Best Management Practices (BMPs) were not simulated; therefore, the alteration between scenarios is only based on the change in land use. The scenarios were configured to simulate daily flows for the 1984 to 2005 time period. Except for the described modifications, the model runs were initiated and executed as described in the Middle Potomac Study (USACE et al. 2013).

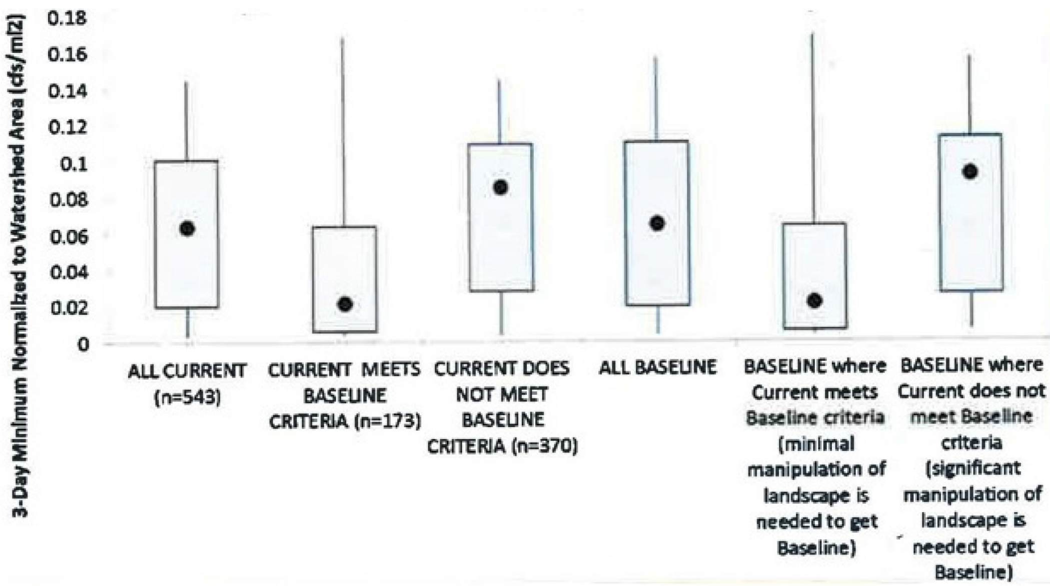
The first step in the modeling process was to address a known weakness in the Middle Potomac Study baseline model scenario (**Section 3.1.1**). The two scenarios were then executed and flow metrics and associated alteration values were calculated for each watershed (**Section 3.1.2**). Each of these steps is discussed in more detail below.

3.1.1 Improvement of the Middle Potomac Study Baseline Scenario

Baseline and current scenario flows were generated for 747 watersheds[3] in the Potomac basin as part of the Middle Potomac Study. During that study, a weakness in the baseline model scenario was identified. Specifically, the baseline scenario's modeled flow metrics should have had a similar distribution for reference watersheds[4] and for non-reference watersheds. That is, the baseline scenario conditions should cause the hydrology to become reference-like in watersheds that are not reference under current conditions. **Figure 2** demonstrates the identified weakness in the baseline scenario. The bar on the far right should be similar to the second and fifth bars.

[2] Current land use conditions were represented using the Watershed Model's land use inputs for the year 2002, the most current year of the simulation period (1984-2005) for which land uses were available.
[3] The Middle Potomac Study watersheds were delineated based on the location of the biological monitoring sites used in that study. The 747 Middle Potomac Study watersheds, therefore, are different than the 147 river segment watersheds for Phase 1 of this study.
[4] Reference watersheds exhibit no or minimal anthropogenic impact. For the purposes of the Middle Potomac Study and this study, reference watersheds exhibit no alteration in flow metrics between the current and baseline scenarios.

Figure 2. Middle Potomac Study analysis for 3-day minimum flow demonstrates that under low flow conditions, the baseline scenario does not create reference-like conditions for non-reference watersheds. If the baseline scenario was performing adequately, the far right bar would be similar to the second and fifth bars. Data source: Middle Potomac Study. Only watersheds with no karst and ≤9° channel slope were included.



An analysis was undertaken to evaluate why the baseline scenario was not creating a reference-like hydrology for non-reference watersheds. In the Middle Potomac Study, a CART analysis was conducted to determine the land and water use thresholds[5] at which watersheds become hydrologically reference-like (see Task A-8.3 project memo, dated 3/19/2010). These thresholds were utilized to generate the Middle Potomac Study baseline scenario[6]. Upon further investigation of the Middle Potomac Study results, it was noted that a wide range of land use conditions were classified as reference (and whose current scenario conditions were set as equal to baseline scenario conditions).

To address this issue, the baseline definition was tightened to reduce the amount of spread in reference watershed land use conditions. This was accomplished by setting the baseline scenario definition at the median land use value of reference watersheds, not at the boundary condition identified by the CART analysis. Further, constraints on pervious urban land uses were not imposed for the baseline scenario in the Middle Potomac Study. In this study, however, the combined urban land uses (including both impervious and pervious urban land uses) were set at the median reference watershed value. The baseline scenario in Phase 1 of this study, therefore, was defined as impervious cover ≤0.10%, urban area ≤1.76%, and forest ≥85.66%. The results of this change are described in **Section 4.1**.

3.1.2 Flow Time Series

After developing the baseline scenario land uses from the new criteria described in **Section 3.1.1**, the Watershed Model was run for both baseline and current scenarios for the 147 river segments over

[5] Thresholds were developed for percent forest, percent agriculture, percent impervious cover, discharges as a function of 10th and 50th percentile flows, withdrawals as a function of 10th and 50th percentile flows, and volume of impounded water as a function of 10th and 50th percentile flow volume.

[6] The thresholds used in the Middle Potomac Study baseline scenario were ≥78% forest, ≤0.35% impervious cover, no impoundments, no withdrawals, and no discharges.

historic observed meteorological conditions. This resulted in daily baseline and current scenario flow time series for each river segment watershed for the 1984 to 2005 simulation period.

3.2 Flow Metrics and Flow Alteration

Baseline and current scenario flow metrics were calculated for each river segment utilizing the modeled flow time series described in **Section 3.1.2**. A myriad of flow metrics are available for potential use in this type of analysis. For the purposes of this investigation, flow metrics were selected from the Middle Potomac Study (USACE et al. 2013, Section 5.3) that were found to be well-simulated and useful in describing the impacts of impervious cover on flow. These flow metrics are high flow index (MH21), high flow duration (DH17), high pulse count, flashiness, low pulse duration, and 3-day maximum flow. Definitions for these flow metrics are provided in **Appendix A**. A complete description of the evaluation and selection of these metrics can be found in USACE et al. (2013) and in Buchanan et al. (2013).

Calculation of flow metrics was performed on the baseline and current scenario time series for each river segment watershed using TNC's Indicators of Hydrologic Alteration (IHA) (TNC 2007), USGS's Hydrologic Index Tool (HIT) (Henriksen et al. 2006), EPA's DFLOW (Rossman 1990), and Excel-based macros. **Appendix B** contains the IHA software settings used for metric calculation. Default software settings were used when not explicitly noted otherwise. For each watershed, alteration in the metric values between the current and baseline scenario was calculated as (current-baseline)/baseline.

3.3 Watershed Characteristics

A number of watershed characteristics may influence the extent to which impervious cover alters streamflow. Six characteristics were selected for evaluation based on professional judgement including watershed area, karst geology, precipitation, soil characteristics, physiographic province, and slope. One watershed metric was selected for each characteristic except for soil and slope which initially had three and two metrics, respectively (**Table 1**). These characteristics were selected for the following reasons.

- Area: Smaller, headwater streams may be more susceptible to localized impacts of impervious cover and scattered rainfalls may not have a significant impact on streamflow characteristics at the outlet of very large watersheds.
- Karst geology: Karst geology is associated with an increased interaction of surface and groundwaters and, therefore, may have a fundamentally different response to increased surface runoff from impervious cover.
- Precipitation: Due to the natural properties of the fractured bedrock geology in the study area, streamflows are highly dependent on precipitation (Searcy and Hardison 1960; Tiruneh 2007). Precipitation characteristics may, therefore, be associated with streamflow alteration in areas with impervious cover.
- Soil characteristics: Soil properties can help to promote or inhibit surface runoff depending, for example, on the infiltration capacity.
- Physiographic province: Physiographic provinces are defined based on geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Wood et al. 1999) and may be a good indicator of the sensitivity of a stream to impervious cover. For example, the hydrogeologic conditions represented in these physiographic provinces can be quite different throughout the study area, ranging from confined aquifers consisting of alternating layers of

sand, gravel, silt, and clay in the Coastal Plan to typically unconfined fractured bedrock aquifers.

- Slope: Higher slopes can promote surface runoff during precipitation events because gravity may pull the water downhill before it has the opportunity to infiltrate the soil.

Table 1. Initial list of watershed metrics for evaluation.

Watershed Characteristic	Description (Data Source)
Watershed Area	Total watershed area (sq. mi.) (Watershed Model)
Karst Geology	Percent of the watershed with underlying karst geology (USGS state geologic maps)
Precipitation	Average annual precipitation (in.) (Watershed Model meteorological input files)
Mean Soil Erodibility	Average KFACT by watershed (USGS)
Soil Erodibility Factor	Average of KWFACT by watershed (NRCS SSURGO)
Soil Group	Dominant soil group in the watershed (NRCS SSURGO)
Physiographic Province	Numeric physiographic code (USGS)
Average Watershed Slope	Average watershed slope (°) (USGS DEM)
Variation in Watershed Slope	Standard deviation of watershed slope (USGS DEM)

Correlations between watershed metrics were evaluated to eliminate redundancies in selected factors (**Table 2**). The distribution of values for each watershed metric was also considered in the selection process. Characteristics with high variability among the river segment watersheds were considered to be more robust options for future statistical analysis.

Table 2. Correlation of watershed metrics. Red cells indicate a correlation of >0.5. Green cells indicate a correlation of <-0.5.

	Area	Karst	Precip	Mean Soil Erodibility	Soil Erodibility Factor	Physiographic Province	Average Watershed Slope	Variation in Watershed Slope	Soil Group
Area	1	0.03	-0.20	-0.15	-0.19	0.11	0.19	0.36	-0.20
Karst		1	-0.31	0.07	-0.05	0.06	-0.15	0.14	-0.19
Precip			1	0.14	0.22	0.19	-0.27	-0.32	0.19
Mean Soil Erodibility				1	0.65	-0.59	-0.62	-0.63	-0.03
Soil Erodibility Factor					1	-0.59	-0.75	-0.72	0.07
Physiographic Province						1	0.56	0.53	0.10
Average Watershed Slope							1	0.87	-0.16
Variation in Watershed Slope								1	-0.24
Soil Group									1

Based on the correlations and the distribution of the watershed metric values, redundant metrics were removed, and ultimately, one metric was selected to represent each watershed characteristic. The final six watershed metrics were 1) area, 2) karst, 3) precipitation, 4) physiographic province, 5) average watershed slope, and 6) soil group. Mean soil erodibility, the soil erodibility factor, and variation in watershed slope were removed from further consideration.

3.4 Statistical Analyses

Two methods were employed to evaluate the relationship between watershed characteristics and streamflow alteration associated with impervious cover; namely, a regression analysis and a Recursive Partitioning and Regression Trees (RPART) analysis. The regression analysis utilized Excel's regression tool. The variability in each streamflow alteration metric that could be explained by the variability in a particular watershed characteristic was calculated, represented by the R^2. The significance of the relationship, or p-value, was also evaluated.

The RPART package (Venables and Smith 2011) was utilized within R software to strengthen confidence in identified relationships and identify physical thresholds of importance. RPART divides and sub-divides the data until a user-defined minimum sample size is reached. For this study, the minimum sample size required for a split was 20. The minimum terminal group size was 7. The thresholds of independent variables (watershed characteristics) minimize the deviance of flow metric values within each group. The first threshold, or primary break, is identified for the watershed characteristic that optimizes homogeneity in the flow metric.

An RPART run consists of loading the dataset (flow alteration and watershed characteristic values for each watershed), and executing in the R console the following R scripts:

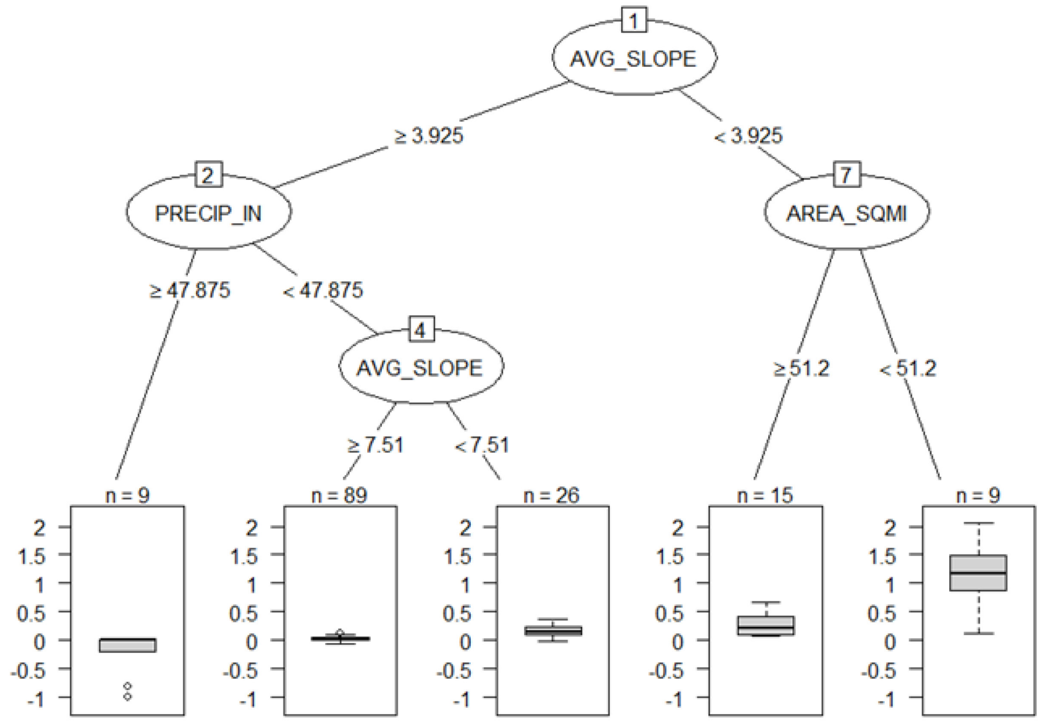
- *rpart* (the rpart function),
- *plot* (produces a plot of the results of the *rpart* function), and
- *summary* (produces a text summary of the results of the *rpart* function).

An example RPART command utilized in this study is:

```
rpart(formula = MH21 ~ AREA_SQMI + PCNT_KARST + PRECIP_IN + FCODE + AVG_SLOPE +
SOIL_GROUP, data = ImpCvr, control = rpart.control(minsplit = 20, maxcompete = 3)).
```

This example command looks for thresholds in watershed characteristics (area, karst, precipitation, physiographic province, slope, and soil group) to explain the variability in high flow index (MH21). An example RPART plot is provided in **Figure 3**.

Figure 3. Example RPART tree.



Only primary and secondary splits were used to evaluate the RPART results in an effort to maintain adequate sample sizes in each group and to avoid creating relationships that are specific to this data set rather than robust, generalizable results (Lawrence and Wright 2001).

Users build confidence in RPART results by identifying statistically and/or physically important sub-groups of data and re-running the analysis. It is important to utilize multiple runs to build confidence in the results and evaluate the credibility of a threshold, determining that it is not simply a product of the data set. Because of this, multiple RPART runs were developed by 1) examining the statistical distribution of the watershed characteristics and 2) conducting 20 initial RPART runs that divide and sub-divide data sets to distinguish significant factors and thresholds using the master spreadsheet (**Appendix C**). The results of these runs, in conjunction with maintaining as large of a sample size as possible and using professional judgment to capture physically important drivers, eight RPART runs were generated and implemented (**Table 3**).

Table 3. Conditions for each RPART run, associated number of river segments, and the rationale behind the definition of the run.

Run	Conditions	River Segments (#)	Rationale
1	Complete data set, no Coastal Plain physiographic province	146	Full data set without the hydrologically different Coastal Plain[7]
2	Run 1, average watershed slope >5°	109	Second highest number of splits for slope at 5° in exploratory RPART runs
3	Run 1, average watershed slope >7.3°	97	Third highest number of splits for slope at 7.3° in exploratory RPART runs
4	Run 1, karst <61%	139	Highest number of splits at 61% karst coverage in exploratory RPART runs
5	Run 1, Valley and Ridge and Appalachian Plateau physiographic provinces only	108	Highest number of splits in exploratory RPART runs
6	Run 1, drainage areas <1,348 sq. mi.	114	Highest number of splits to separate largest watersheds in exploratory RPART runs and statistical break in areas at 1,348 sq. mi.
7	Run 1, precipitation <45 in.	135	Highest number of splits to separate watersheds with highest precipitation in exploratory RPART runs and statistical break in areas at 45 in.
8	Run 1, average watershed slope >3.255°	138	Highest number of splits at 3.255° in exploratory RPART runs

4 Results

This section presents the results of Phase 1 of the impervious cover study including the model enhancements, the master spreadsheet, and the identified relationships.

4.1 Model Enhancements

At the geographic resolution of the Phase 1 analysis (Watershed Model river segments), there are only three watersheds that meet reference watershed criteria. Therefore, a similar analysis to the one in the Middle Potomac Study is not statistically meaningful with this data set. Utilizing the Middle Potomac Study data set for evaluation purposes, preliminary evidence suggests that the baseline scenario was improved by the described modifications (**Figure 4**, **Figure 5**, and **Figure 6**). In these graphs, the first bar displays the range of 3-day maximum flow values for all watersheds under the baseline scenario. The second bar shows the distribution of the flow metric values for only the reference watersheds. Finally, the third bar shows the distribution of the flow metric values for the non-reference watersheds. In an ideal simulation, the third bar would be close or identical to the second bar. In **Figure 4**, **Figure 5**, and **Figure 6**, the third bar looks more like the second bar than the first bar, which says the non-reference watersheds are similar to (but not identical to) the reference watersheds. This is an improvement to **Figure 2** where the fifth and sixth bars are quite different. Further testing of this conclusion can be conducted during Phase 2 of this study if, due to the larger sample size, a statistically significant number of reference watersheds are available for comparison purposes.

[7] The Coastal Plain is hydrologically different because the geology consists of alternating layers of sand, gravel, silt, and clay in a confined aquifer system. The geology in the rest of the basin consists of typically unconfined fractured bedrock aquifers.

Figure 4. Baseline 3-day minimum flow for watersheds with ≤1.76% urban area (pervious and impervious). Data source: Middle Potomac Study watersheds, flow metrics, and watershed characteristics to demonstrate whether there is improvement in the baseline simulation with modification to the scenario definition. Only watersheds with no karst and ≤9° channel slope were included to be directly comparable to the Middle Potomac Study analysis.

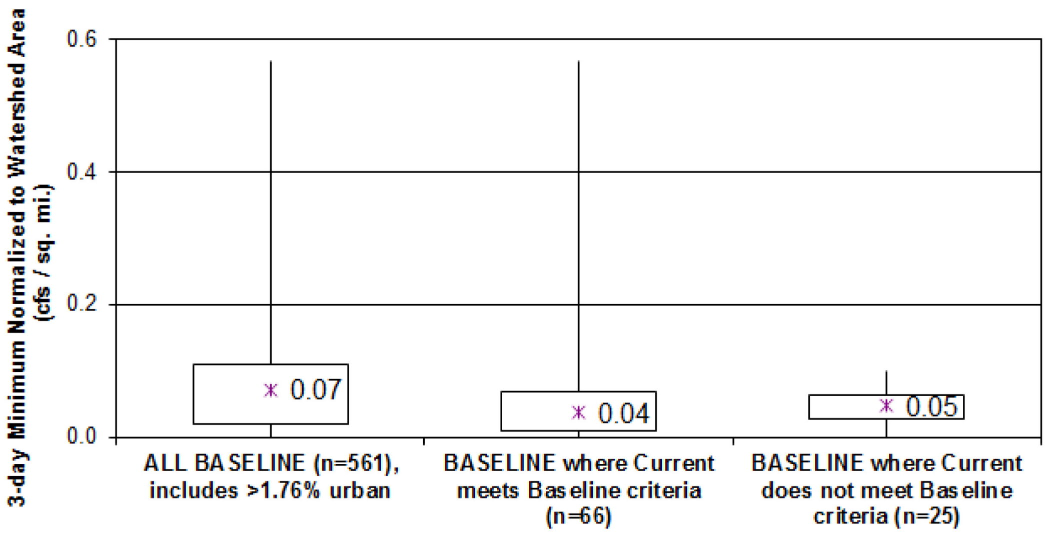


Figure 5. Baseline 3-day minimum flow for watersheds with ≤0.1% impervious cover. Data source: Middle Potomac Study watersheds, flow metrics, and watershed characteristics to demonstrate whether there is improvement in the baseline simulation with modification to the scenario definition. Only watersheds with no karst and ≤9° channel slope were included to be directly comparable to the Middle Potomac Study analysis.

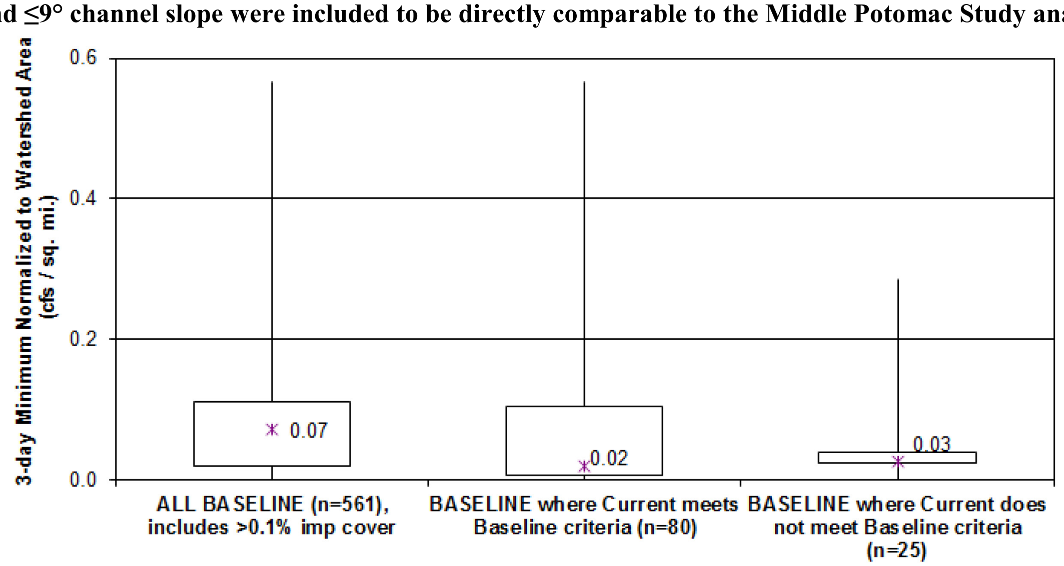
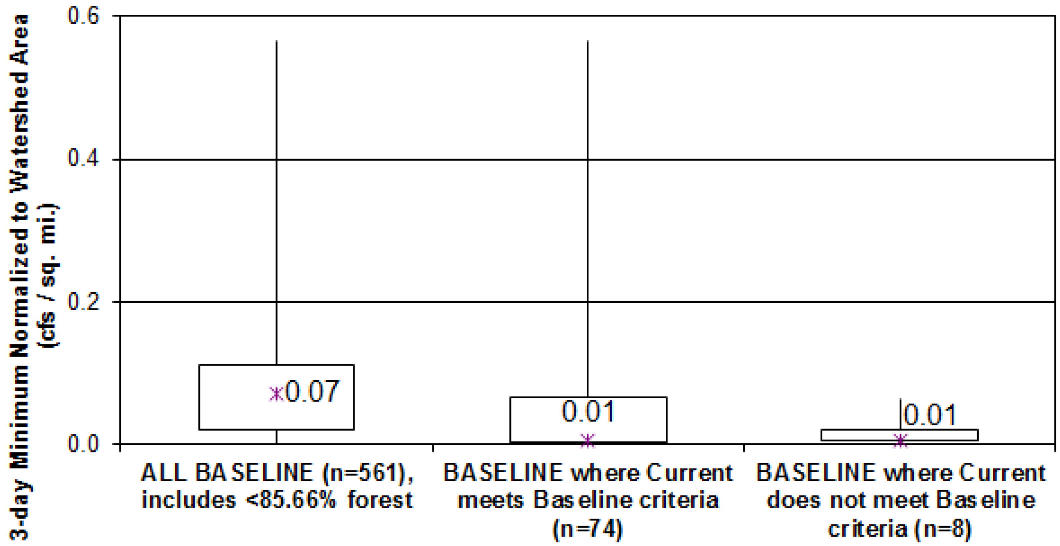


Figure 6. Baseline 3-day minimum flow for watersheds with ≥85.66% forest. Data source: Middle Potomac Study watersheds, flow metrics, and watershed characteristics to demonstrate whether there is improvement in the baseline simulation with modification to the scenario definition. Only watersheds with no karst and ≤9° channel slope were included to be directly comparable to the Middle Potomac Study analysis.



4.2 Master Spreadsheet

A master spreadsheet was prepared with all of the necessary data for statistical analysis (**Appendix C**). The master spreadsheet included watershed characteristic values, baseline and current scenario flow metrics, and the associated percent alteration for each flow metric between the baseline and current scenarios.

4.3 Relationships: Streamflow Alteration, Impervious Cover, and Watershed Characteristics

The Middle Potomac Study found that streamflow alteration for selected flow metrics was associated with urban areas, represented by impervious cover, among other factors (USACE et al. 2013). When compared to baseline conditions, the following relationships were identified with urban areas:

- decreases in high flow index (MH21) and high flow duration (DH17),
- increases in high pulse count,
- increases in 3-day maximum,
- sharp increases in flashiness, and
- decreases in duration of low pulses.

The relationships between flow metrics and impervious cover identified in this study support the findings of the Middle Potomac Study. The correlations for the Phase 1 river segment watersheds are provided in **Table 4**.

Table 4. Correlation (R) between alteration in flow metrics and percent impervious cover (n=147).

Alteration in Flow Metric (baseline-current)/current	R
High flow index, MH21 (days)	-0.70
High flow duration, DH17 (days)	-0.79
High pulse count (#)	0.70
Flashiness (ratio)	0.89
Low pulse duration (days)	-0.25
3-day maximum (cfs/sq. mi.)	0.86

Watershed characteristics that influence the relationship between streamflow alteration and impervious cover were also evaluated. Area, physiographic province, and average watershed slope are significantly correlated with alteration in streamflow metrics, meaning that the watershed characteristics explain a portion of the variability in the streamflow alteration in a statistically meaningful way (i.e. it is not due to chance). Slope and physiographic province are correlated with one another (**Table 2**), but were both considered in this analysis to determine which would be a better predictor of streamflow alteration from impervious cover. Both of these characteristics had significant relationships with all flow metrics and all relationships had the same sign (positive or negative); however, average watershed slope explained more of the variability for all flow metrics except low pulse duration. It can be interpreted, therefore, that average watershed slope is a better predictor of flow alteration from impervious cover overall while physiographic province may be a more useful indicator for management purposes under low flow conditions. It may be helpful to evaluate additional low flow metrics in Phase 2 of this study to determine whether this relationship holds for other low flow metrics. Percent karst is only correlated with alteration in high pulse count. Specifically, increasing karst is associated with an increase in the number of high pulses. Precipitation and soil group are not significantly correlated to alteration in the selected streamflow metrics.

Table 5. Correlation between watershed characteristics and alteration in flow metrics. The value provided in the table is the R^2 for all 147 river segment watersheds. An entry of "ns" indicates that the R^2 value is not significant. For significant relationships, the superscript after the value indicates the level of significance (p-value); <0.01=; 0.01 to 0.05=*. Direct and indirect correlations are indicated by (+) or (-), respectively.**

Alteration in Flow Metric (baseline-current)/current	Area	Karst	Precipitation	Physiographic Province	Average Watershed Slope	Soil Group
High flow index, MH21 (days)	0.073** (+)	ns	ns	0.19** (+)	0.41** (+)	ns
High flow duration, DH17 (days)	0.067* (+)	ns	ns	0.23** (+)	0.39** (+)	ns
High pulse count (#)	ns	0.06* (+)	ns	0.056** (-)	0.18** (-)	ns
Flashiness (ratio)	ns	ns	ns	0.12** (-)	0.26** (-)	ns
Low pulse duration (days)	0.11** (-)	ns	ns	0.095** (+)	0.058** (+)	ns
3-day maximum (cfs/sq. mi.)	ns	ns	ns	0.20** (-)	0.20** (-)	ns

The results of the RPART analysis identified repeated breaks in watershed area and average watershed slope, further strengthening confidence in their significance for altering streamflows in the

Potomac basin (**Table 6**). Other risk factor thresholds were weaker, particularly karst, precipitation, physiographic province, and soil group, and often varied between RPART analyses. This finding further supports the conclusion from **Table 5** that average watershed slope is a better overall indicator of streamflow alteration from impervious cover than physiographic province.

Table 6. Results of RPART analysis across eight runs to build confidence in identified key watershed characteristics and thresholds of importance.

	Area	Karst	Precipitation	Physiographic Province	Average Watershed Slope	Soil Group
High flow index, MH21 (days)	†				*	
High flow duration, DH17 (days)	†				‡	
High pulse count (#)	†				*	
Flashiness (ratio)	†				*	
Low pulse duration (days)	*				†	
3-day maximum (cfs/sq. mi.)	†		†		‡	

‡=identical RPART thresholds in primary split, >=5 runs
*=identical RPART thresholds in primary split, >=3 runs
†=identical RPART thresholds in primary or secondary split, >=3 runs
Gray=no primary or secondary splits

Thresholds of importance were identified for each watershed characteristic and are discussed below. These thresholds indicate the level at which, for each watershed characteristic, a change in the impact from impervious cover can be expected. In some cases, very similar although not identical thresholds were identified. In those instances, a range is provided instead of a discrete threshold.

Area:

The sizes of the watersheds used in Phase 1 vary widely (3.1 sq. mi. to 11,585 sq. mi.). The RPART analysis indicates that impervious cover has a greater influence on streamflow alteration in smaller watersheds. In fact, the largest watersheds were separated as a primary break in all runs except run 6 which excluded the largest watersheds. Area may not be as significant in Phase 2 because the range of HUC-12 areas is smaller (12.4 sq. mi. to 63.5 sq. mi - see **Section 5**).

Thresholds

51.2-59.9 sq. mi.

Threshold is explained by high pulse count (secondary break)[runs 1, 2, 6, 7]; 3-day maximum (secondary break)[runs 1, 6, 7]; and flashiness (secondary break)[runs 1, 6, 7].

72.7 sq. mi.

Threshold is explained by high flow index, MH21 (secondary break)[runs 1, 6, 7, 8] and high flow duration, DH17 (secondary break)[runs 1, 4, 6, 7, 8].

463.9 sq. mi.

Threshold is explained by high flow index, MH21 (secondary break)[run 3] and high pulse count (secondary break) [run 3].

3,047-3,100 sq. mi.

Threshold is explained by low pulse duration (primary break)[runs 1, 2, 3, 4, 5, 7, 8].

Karst:

The relationship between karst and streamflow alteration is relatively weak; however, one consistent threshold emerged, particularly in RPART runs that focus on watersheds with steeper slopes. Specifically, increased streamflow alteration occurs at greater than 44% karst.

Threshold

44%

Threshold is explained by flashiness (primary and secondary breaks)[run3, run2 respectively] and 3-day maximum (secondary break)[run3]. The 44% karst break was also identified in the Middle Potomac Study Category and Regression Tree (CART)[8] analysis (see Task A-8.3 project memo, dated 3/19/2010), explained by primary breaks in extreme low frequency in four runs.

Precipitation:

Like the karst threshold previously identified, precipitation is better at discerning the variability in streamflows in areas with higher slopes [(runs 2 and 3)]; however, precipitation does appear as a break in other runs as well. The most consistent break in precipitation occurs at high precipitation amounts (47.875 in.). Only nine watersheds in the datasets have precipitation amounts greater than this identified threshold. Increasing the sample size during Phase 2 of the analysis will provide an opportunity for further evaluation of the statistical significance of this threshold.

Thresholds

41.31 in.

Threshold is explained by high flow index, MH21 (primary break and secondary break) [run3, run2 respectively].

47.875 in.

Threshold is explained by low pulse duration (secondary break)[runs 3, 6] and 3-day maximum (primary and secondary breaks) [run 2, runs 1, 5, 6, 8, respectively].

Physiographic Province:

The consistent break found in physiographic province separates watersheds in the Piedmont Uplands and Coastal Plain from those in the Piedmont Lowlands, Blue Ridge, Valley and Ridge, and the Appalachian Plateaus.

Threshold

41.5

Threshold is explained by high pulse count (secondary break)[run 8] and 3-day maximum (primary and secondary breaks)[run 7, run 5, respectively].

[8] CART analysis is comparable to the RPART methodology but utilizes the SPLUS rather than R software.

Slope:

The most common watershed characteristic identified for RPART breaks was average watershed slope. A number of consistent breaks were identified in primary and secondary breaks, ranging from low to high slopes.

Thresholds

3.925°

Threshold is explained by high pulse count (primary break)[runs 1, 6, 7], flashiness (primary break)[runs 1, 6, 7, 8], and 3-day maximum (primary break)[runs 1, 6, 7, 8].

5.04°

Threshold is explained by high flow index, MH21 (primary break)[run5], high flow duration, DH17 (primary break) [run5], high pulse count (primary break) [run5], flashiness (primary break) [run5], and 3-day maximum (primary break) [run5].

5.065°

Threshold is explained by high flow index, MH21 (primary break)[runs 1, 6, 7, 8], high flow duration, DH17 (primary break)[runs 1, 4, 6, 7, 8], and flashiness (secondary break)[runs 6, 8].

5.8°

Threshold is explained by low pulse duration (primary break and secondary breaks)[run 6, run 1, 4, 7, respectively].

7.345°

Threshold is explained by high flow index, MH21 (primary break and secondary breaks)[run 2, run1, 4, 6, 8, respectively], flashiness (primary break and secondary break)[run 2, run 4, respectively].

8.32°

Threshold is explained by high flow duration, DH17 (primary breaks and secondary breaks) [run 2, 3, run 1, 4, 7, 8, respectively].

Soil Group:

Hydrologic soil groups range from high infiltration/low runoff (group A) to low infiltration/high runoff (group D). Soil group did not have any repeating primary or secondary breaks. The only soil group primary and secondary breaks are presented here for information purposes. In both cases, hydrologic soil group A is separated from the other type. The secondary split separates soil groups A and B from C and D.

Thresholds

2.5

Threshold is explained by high flow index, MH21 (primary break)[run 3].

1.5

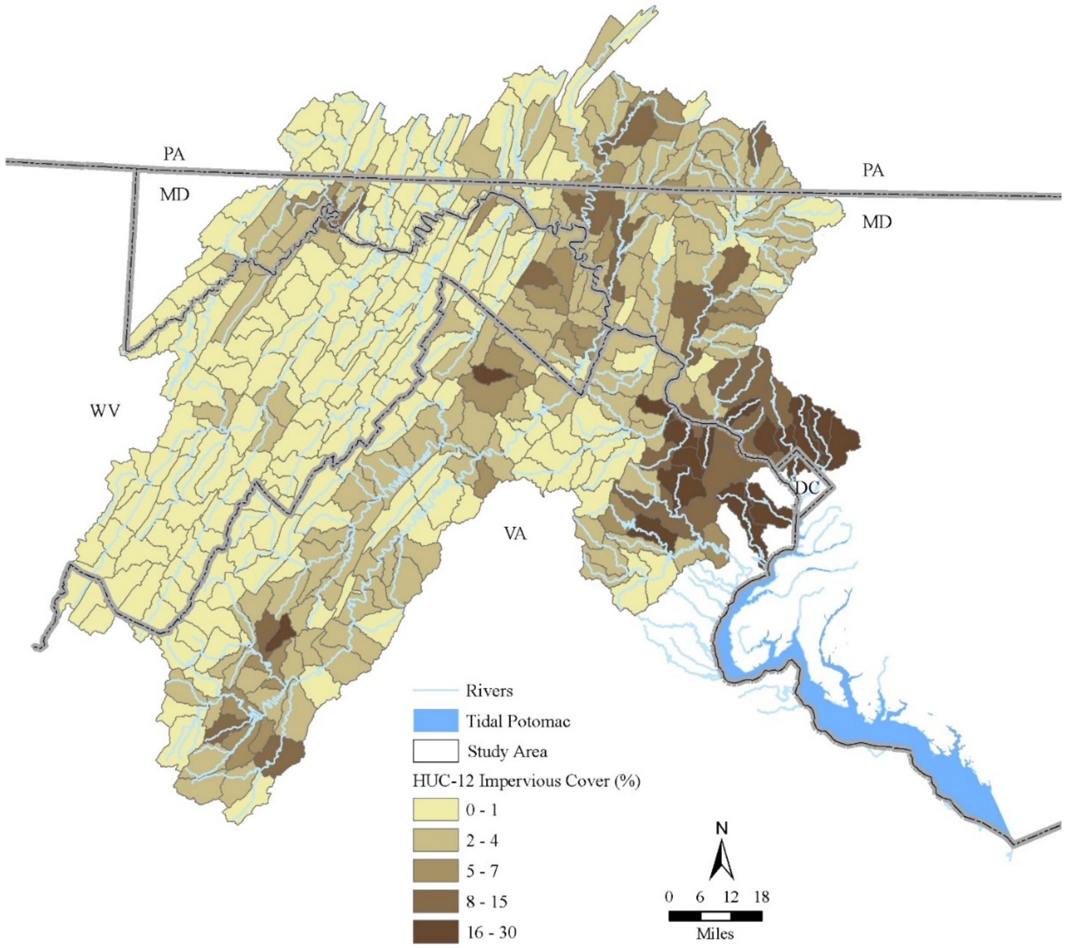
Threshold is explained by high pulse count (secondary break)[run 3].

5 Next Steps – Phase 2

The Phase 2 analysis is planned to run from October 2015 to September 2017 with continued funding from a U.S. EPA Section 106 grant. The second phase will provide the opportunity to implement the methodology utilizing the most recently available land use data and a higher spatial resolution to enhance confidence in the results.

The resolution of the Phase 2 analysis will be the 361 HUC-12s in the study area ranging from 12.4 sq. mi. to 63.5 sq. mi. Impervious cover at the HUC-12 scale ranges from 0.02% to 29% (**Figure 7**).

Figure 7. HUC-12s in the Phase 2 study area. Darker shades indicate higher percent impervious cover. Impervious cover data source: 2006 NLCD, including 2011 edits.



The Phase 1 approach to calculating flow metrics, development of the master spreadsheet, and statistical analysis will remain the same in Phase 2 unless the data demonstrate the need for an alternate approach. Where possible, the Watershed Model inputs and the EPA Recovery Potential Screening tool (RPS) (EPA 2014), available at the HUC-12 scale for the Potomac basin, will be used to obtain the selected watershed characteristic information. The primary benefits of the Phase 2 analysis include 1) increased sample size for improved statistical evaluation (**Figure 8** and **Figure 9**); 2) the use of updated land use information from Phase 5.3.2 of the Watershed Model; and 3) increase in the variability of watershed characteristics and flow metrics. The modified methods needed to use the new land use data are described in the next section.

Figure 8. Distribution of average watershed impervious cover in Phase 1 (left) and Phase 2 (right).

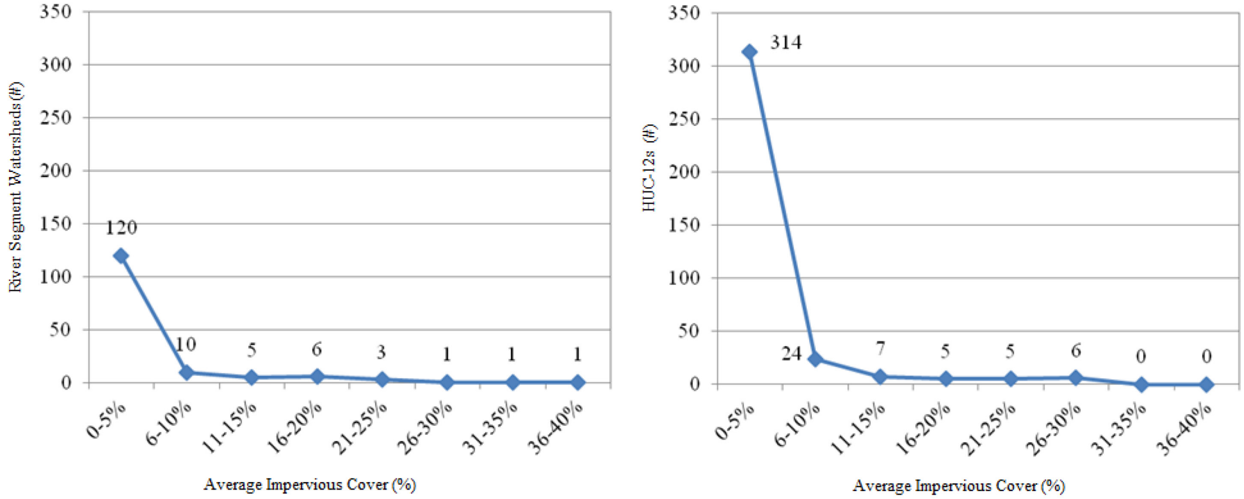
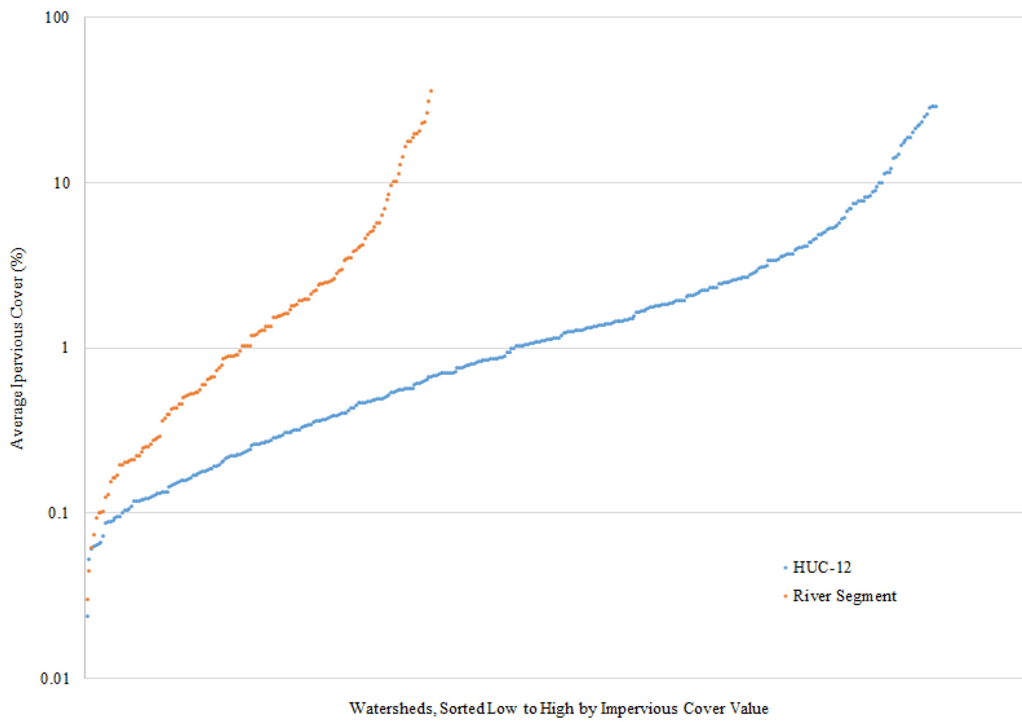


Figure 9. Impervious cover values for HUC-12s and river segments, sorted low to high based on impervious cover value.



5.1 HUC-12 Land Uses

As with Phase 1 of this study, land use changes will drive the flow alterations between the baseline and current scenarios. The most recent University of Maryland's Regional Earth Science Applications Center (RESAC) land use dataset, utilized in the development of the Phase 5.3.2 Watershed Model, will be used to estimate HUC-12 land uses. The spatially explicit data is available in raster grid format at 30 meter resolution from the CBP. Using spatial analysis techniques in GIS, a single number for each of the 26 land use categories will be calculated for each HUC-12 watershed.

The land use categories in the RESAC data set, however, do not match up with the land use categories required for input to the Watershed Model (**Figure 10**). To calculate how much of each Watershed Model land use category is contained in each HUC-12, an optimization routine will be developed to convert RESAC land uses to Watershed Model land use categories while maintaining 1) the total area of each HUC-12, 2) the total area of each major land use category (e.g. pasture, urban, forest), and 3) the proportion of each major land use category. This approach for land use estimation is documented in its entirety in ICPRB (2013).

Figure 10. Example land use designations in the spatially explicit RESAC data and the tabular Watershed Model inputs.

RESAC

AG	Cultivated Crops
AG	Scrub/shrub
DEV	Developed Open Space (DOS)
DEV	Low Intensity Developed (LID)
DEV	Medium Intensity Developed (MID)
DEV	High Intensity Developed (HID)
DEV	Barren
DEV	residential
DEV	Residential - DOS
DEV	Residential - LID
DEV	Residential - MID
DEV	Residential - HID
DEV	Rural Developed - DOS
DEV	Rural Developed - LID
DEV	Rural Developed - MID
DEV	Rural Developed - HID
EXT	Extractive
FOR	Deciduous Forest
FOR	Evergreen Forest
FOR	Mixed Forest
WAT	Water
WAT	Unconsolidated Shore
WAT	Woody Wetlands
WAT	Emergent Wetlands

Watershed Model

AG	Concentrated Animal Feeding Operations
AG	Hightill without Manure
AG	Hightill with Manure
AG	Hay without Nutrients
AG	Hay with Nutrients
AG	Lowtill with Manure
AG	Nutrient Management Alfalfa
AG	Nutrient Management Hightill with Manure
AG	Nutrient Management Hightill without Manure
AG	Nutrient Management Hay with Nutrients
AG	Nutrient Management Lowtill with Manure
AG	Nutrient Management Pasture
AG	Pasture
AG	Degraded Riparian Pasture
AG	Nursery
DEV	CSS Construction
DEV	CSS Impervious Developed
DEV	CSS Pervious Developed
DEV	CSO
DEV	Nonregulated Impervious Developed
DEV	Nonregulated Pervious Developed
DEV	Regulated Construction
DEV	Regulated Impervious Developed
DEV	Regulated Pervious Developed
EXT	CSS Extractive
EXT	Nonregulated Extractive
EXT	Regulated Extractive
FOR	Forest
FOR	Harvested Forest
WAT	Atmospheric Deposition
WAT	Industrial Discharge
WAT	Septic
WAT	Municipal WWTP

The results of this optimization routine will be the current scenario land uses. Baseline scenario land uses will be generated from current scenario values using the method discussed in **Section 3.1**.

5.2 Baseline and Current Scenario Flows

Baseline and current scenario flows will be generated using the land use inputs described in **Section 5.1** for each HUC-12. Specifically, flow contributions by land use category from within the HUC-12 will be estimated using 1) the area of each modeled land use category in each HUC-12 and 2) the flow/area contribution by land use estimated by the Watershed Model.

This approach to flow estimation does not include instream flow simulation. The influence of instream flow at this spatial resolution is expected to be minimal (personal comm., R. Mandel, 5/6/2015). Since percent alteration, used in the statistical analyses, is a comparison of the baseline and current scenarios, it is important that the relative difference between scenarios is well simulated, not the actual daily flow values. Since both scenarios do not include instream processes, it is expected that percent alteration will not be compromised.

5.3 Phase 2 Tasks and Products

Phase 2 consists of seven major components; namely, 1) calculating land uses; 2) calculating flows, flow metrics, and alteration; 3) calculating watershed characteristics; 4) developing the master spreadsheet; 5) evaluating the model; 6) conducting statistical analyses; and 7) documenting the methods and results. The sections below describe the tasks and anticipated products of each component.

5.3.1 Calculate Land Uses

Task 1: Calculate Phase 5.3.2 RESAC land uses for each HUC-12.

Product 1: Table containing RESAC land uses for each HUC-12.

Task 2. Convert Phase 5.3.2 RESAC land uses to Watershed Model land use categories for each HUC-12.

Product 2: Table containing land uses for each HUC-12 using the model land use categories.

5.3.2 Calculate Flows, Flow Metrics, and Alteration

Task 3: Multiply acres of each land use per area flow contribution for all land uses in each HUC-12 using Phase 1 baseline and current scenario land outputs.

Product 3: Two flow time series for each HUC-12, one baseline and one current scenario.

Task 4: Calculate select flow metrics (high flow index (MH21), high flow duration (DH17), high pulse count, flashiness, low pulse duration, and 3-day maximum flow) for each HUC-12 from baseline and current scenario flow time series. Consideration will be given to adding additional low flow metrics to further evaluate physiographic province and average watershed slope (see discussion in **Section 4.3**).

Product 4: Table containing flow metrics for each HUC-12.

Task 5: Calculate percent alteration in each flow metric (current-baseline)/baseline by HUC-12.

Product 5: Table containing calculated flow alteration values for each flow metric and HUC-12.

5.3.3 Calculate Watershed Characteristics

Task 6: Obtain watershed characteristic information utilizing the EPA RPS tool (EPA 2014) where possible. If watershed characteristic information is not available via the tool, either tabular model input data will be used or they will be calculated using GIS at the HUC-12 scale. Where possible, modeled characteristics will be used so that the characteristics accurately complement the modeled flow time series (e.g. impervious cover, area). Consideration will be given to adding additional watershed characteristics to the evaluation.

Product 6: Table containing watershed characteristic information for each HUC-12.

5.3.4 Develop the Master Spreadsheet

Task 7: Create the master spreadsheet that includes watershed characteristics, flow metrics, and streamflow alteration values.

Product 7: Master spreadsheet that combines products 4, 5, and 6 for each HUC-12.

5.3.5 Model Evaluation

Task 8: Confirm that the changes to the baseline scenario during Phase 1 adequately improved simulation of non-reference watershed conditions under the baseline scenario.

Product 8: Comparison boxplots similar to **Figure 2** through **Figure 6** for poorly performing Middle Potomac Study metrics (e.g. normalized 3-day minimum flow, baseflow index, 7Q10, and median flow). Performance of these metrics is important especially if additional low flow metrics are added to Task 4.

5.3.6 Statistical Analyses

Task 9: Conduct RPART exploratory runs, establish final run sequence, execute, and evaluate results.

Product 9: RPART model run outputs, summary tables, and written interpretation of results.

Task 10: Conduct additional statistical analyses (e.g. correlation tables, other).

Product 10: Summary tables and written interpretation of statistical results.

5.3.7 Documentation

Task 11: Prepare a journal article that documents project results.

Product 11: Submission of completed manuscript to a peer-reviewed journal.

5.4 Phase 2 Timeline

Phase 2 of this effort is scheduled to begin in October 2015 and proceed for two years, ending in September 2017 (**Table 7**). Preparation of the necessary data, project components 1 through 4, will be the primary focus of the first year. The statistical analysis and preparation of a manuscript for publication in a peer-reviewed journal will occur in the second year.

Table 7. Timeline for the Phase 2 study.

	Year 1				Year 2			
Project Components	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Calculate Land Uses								
2. Calculate Flows, Flow Metrics, and Alteration								
3. Calculate Watershed Characteristics								
4. Develop the Master Spreadsheet								
5. Model Evaluation								
6. Statistical Analyses								
7. Documentation								

6 Conclusions

Phase 1 of this study yielded preliminary evidence that the baseline scenario definition was successfully refined to overcome problems identified in the Middle Potomac Study. Specifically, the new baseline land use definitions resulted in non-reference watershed low flow metrics becoming more like reference watershed low flow metrics. Further, methods were successfully defined and implemented to develop the project's master spreadsheet and statistically evaluate the influence of the watershed characteristics on impervious cover's propensity to alter streamflow.

The results of Phase 1 of the study will primarily be utilized to inform the execution of Phase 2, following the task outline provided in **Section 5.3**. The results of Phase 1 also reveal management implications. At the river segment watershed resolution, watershed area and slope are most correlated with streamflow alteration from impervious cover; however, other watershed characteristics are correlated with alteration for specific aspects of the flow regime.

Given the significant development pressures in the basin, the results of this study are meant to inform land management decision-making and proactive development strategies to meet the multiple, sometimes competing, water interests in the basin. For example, the results of this preliminary phase of the study underscore the negative impacts of developing on steep slopes and in smaller, headwater streams. Development on steep slopes was identified in a 2015 survey of ICPRB stakeholders as a water resources challenge in the basin[9]. A repeating slope threshold found in this Phase 1 study was 7.345°. Utilizing this information, geographic analyses can be conducted to identify impervious cover in watersheds with slopes above this threshold. **Figure 11** displays impervious cover greater than 2% in red (the upper boundary at which alteration in many flow metrics began to increase sharply in the Middle Potomac Study) in HUC-12 watersheds with average slopes greater than 7.345°. Planners and managers in particularly susceptible areas such as these may wish to consider the added risk of streamflow alteration as a result of development. Development on the steep slopes in these watersheds (and in watersheds throughout the basin) may be avoided altogether or may benefit from implementing BMPs or low impact development techniques. A number of locales in the Potomac basin already discourage development on steep slopes (e.g. Franklin County, Pennsylvania; Fulton County, Pennsylvania; Loudoun County, Virginia; and Page County, Virginia). Utilizing the Phase 1 results, similar spatial analyses can be conducted for other watershed characteristics and thresholds of interest to inform planning and management efforts.

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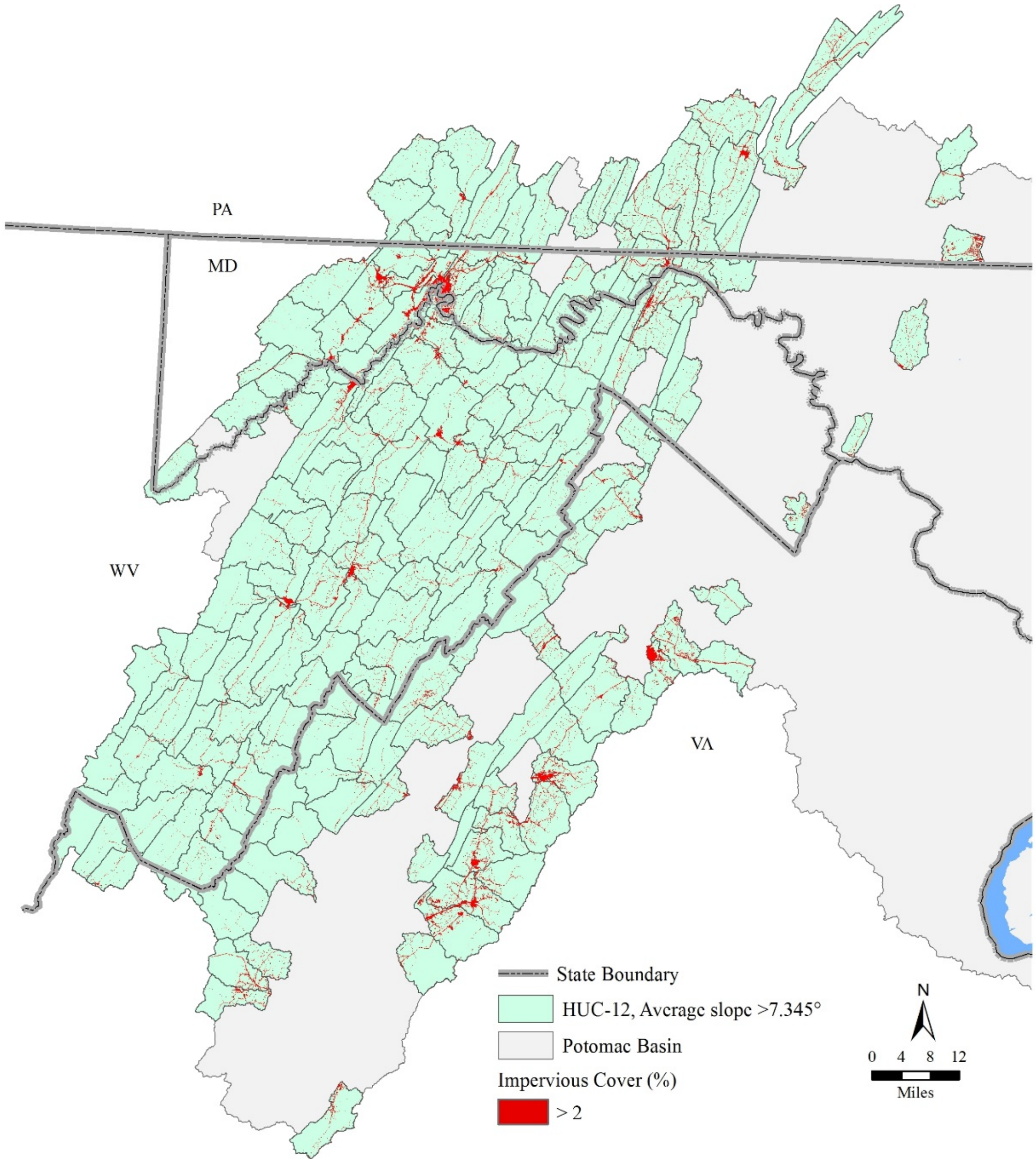
[9] http://www.potomacriver.org/focus-areas/water-resources-and-drinking-water/water-resources/planning/basin-wide-comprehensive-plan/, accessed 8/19/2015.

Figure 11. Impervious cover >2% in HUC-12 watersheds with average slope >7.345°.



7 References

C. Buchanan, H.L.N. Moltz, H.C. Haywood, J.B. Palmer, and A. Griggs. 2013. A Test of the Ecological Limits of Hydrologic Alteration (ELOHA) Method for Determining Environmental Flows. Journal of Freshwater Biology 58:2632-2647.

EPA. 2009. Technical guidance on implementing the stormwater runoff requirements for federal projects under Section 438 of the Energy Independence and Security Act. 61p. EPA, Washington, DC. http://www.epa.gov/oaintrnt/documents/epa_swm_guidance.pdf, accessed 8/19/2015.

EPA. 2014. Scoring spreadsheet for recovery potential screening. Version 12/20/2014. www.epa.gov/recoverypotential/, accessed 8/13/2015.

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and J. Wickham. 2011. Completion of the 2006 National Land Cover Database for the conterminous United States, PE&RS 77(9):858-864.

Henriksen, J.A., J. Heasley, J.G. Kennen, and S. Niewsand. 2006. Users' manual for the hydroecological integrity assessment process software (including the New Jersey Assessment Tools): USGS, Biological Resources Discipline, Open File Report 2006-1093, 71p. http://www.fort.usgs.gov/Products/Software/NATHAT/, accessed 7/22/2015.

Homer, C.G., J.A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N.D. Herold, J.D. Wickham, and K. Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States-representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing 81(5):345-354.

ICPRB. 2013. Technical memorandum: Methodology for assigning watershed model land use to small impoundment watersheds. Prepared for Maryland Department of the Environment. 18p.

Lawrence, R. and A. Wright. 2001. Rule-based classification system using Classification and Regression Tree (CART) Analysis. Photogrammetric Engineering and Remote Sensing 67:1137-1142.

Linker, L.C., G.W. Shenk, R.L. Dennis, and J.S. Sweeney. 1999. Cross-media models of the Chesapeake Bay watershed and airshed. Annapolis, MD: Chesapeake Bay Program Office. http://archive.chesapeakebay.net/pubs/948.pdf, accessed 8/13/2015.

Poff, N.L., B.D. Richter, A.H. Arthington, S.E. Bunn, R.J. Naiman, E. Kendy, M. Acreman, C. Apse, B.P. Bledsoe, M.C. Freeman, J. Henriksen, R.B. Jacobson, J.G. Kennen, D.M. Merritt, J.H. O'Keeffe, J.D. Olden, K. Rogers, R.E. Tharme, and A. Warner. 2010. The Ecological Limits of Hydrologic Alteration (ELOHA): A new framework for developing regional environmental flow standards. Freshwater Biology 55(1):147–170.

Rossman, L.A. 1990. DFLOW User's Manual. EPA, Washington, DC.

Searcy, J.K. and C.H. Hardison. 1960. Manual of hydrology: Part 1, general surface-water techniques. USGS Water Supply Paper 1541-B.

Tiruneh, N. 2007. Basin-wide annual baseflow analysis for the fractured bedrock unit in the Potomac River basin. ICPRB 07-6. 50p. http://www.potomacriver.org/wp-content/uploads/2014/12/ICPRB07-6.pdf, accessed 8/21/15.

TNC. 2007. Indicators of Hydrologic Alteration (IHA), Version 7 User's Manual. http://www.nature.org/initiatives/freshwater/conservationtools/, accessed 7/22/2015.

USACE, TNC, and ICPRB. 2013. Middle Potomac River watershed assessment: Potomac River sustainable flow and water resources analysis. Final Report. 144p. and 10 appendices.

USGS. 2014. NLCD 2001-2006 Percent developed imperviousness change pixels (2011 Edition). USGS, Sioux Falls, SD. http://www.mrlc.gov, accessed 5/6/2015.

Venables, W.N. and D.N. Smith. 2011. An introduction to R: Notes on R: A programming environment for data analysis and graphics. R Development Core Team.

Wood, A.J., J.M. Olmernik, and D.D. Brown. 1999. Level III and IV ecoregions of Delaware, Maryland, Pennsylvania, Virginia and West Virginia. http://www.epa.gov/wed/pages/ecoregions/reg3_eco.htm, accessed 8/19/2015.

Appendix A. Flow Metric Definitions

Flow metric definitions and additional information for the six selected metrics are provided in **Table 8**. This information was adapted from USACE et al. 2013.

Table 8. List of selected flow metrics, with value type, definitions, and calculation method.

3-Day Maximum Units: cfs/sq. mi. Value: long decimal Type: high flow – magnitude; IHA program Definition: study period's average of each year's maximum 3-day moving average of daily mean flows, normalized to watershed area.
High Flow Volume Index (MH21) Units: average high flow volume/median flow = days Value: long decimal Type: high flow – magnitude; HIT program Definition: the average volume for high flow events (above a threshold equal to the median flow of the entire record) divided by median annual daily flow for entire record.
High Pulse Count Units: count per year Value: rational number (ex. 2, 3, 4, 3.5, 2.5) Type: high flow – frequency; IHA program Definition: study period's average of each year's high pulse count. A high pulse occurs when the daily mean flow exceeds a threshold (90^{th} percentile of all flows) for one or more consecutive days. All initial high flows not classified as small floods or large floods will be classified as high flow pulses. A small flood event is defined as an initial high flow with a peak flow greater than the 2 year return interval event. A large flood event is defined as an initial high flow with a peak flow greater than the 10 year return interval event. All flows that exceed 90% of the daily flows for the period are classified as high flows. Between high and low flow levels, a high flow will begin when the flow increases by more than 25% per day and ends when the flow decreases by less than 10% per day.
High Flow Duration (DH17) Units: average duration (days) of high flow events Value: long decimal Type: high flow – duration; HIT program Definition: the average duration of flow events with flows above the median (for entire period of record) flow.
Flashiness Units: none (the index is a ratio) Value: long decimal Type: middle flow – other, Richards-Baker index Definition: sum of the absolute values of day-to-day changes in mean daily flow divided by the sum of the mean daily flows.
Low Pulse Duration Units: days per event Value: rational number (ex. 2, 3, 4, 3.25, 2.75) Type: low flow – duration; IHA program Definition: mean duration of low pulses (days) during the study period. A low pulse occurs when the daily mean flow falls below a threshold (10th percentile of all flows) for one or more consecutive days. Low pulse duration is the number of days that the pulse persists.

Appendix B. IHA Settings for Flow Metric Calculation

The following settings were used to run the IHA software programs as part of the flow metric calculation process.

High flow and Low flow pulse thresholds are the median plus or minus 40%.
RVA Category boundaries are the median plus or minus 17%.
High flow pulses are defined as:

All flows that exceed 90% of flows for the period are classified as high flow pulses,
No flows that are below 50% of flows for the period are classified as high flow pulses
Between these two levels, a high flow pulse will begin when flow increases by more than 25% per day, and will end when flow decreases by less than 10% per day.

A small flood event is defined as a high flow pulse with a recurrence time of at least 2 years. A large flood event is defined as a high flow pulse with a recurrence time of at least 10 years.
An extreme low flow is defined as a flow in the lowest 10% of all low flows in the period.

Appendix C. Master Data Spreadsheet

The master spreadsheet is divided into two tables for display purposes. The first table provides all of the watershed characteristics (a description of these watershed characteristics is provided in **Table 1**) and the second table includes the flow metrics for baseline and current modeled flow scenarios as well as the percent alteration calculated as a function of the two scenarios.

Table 9. Watershed characteristics calculated for each river segment, includes entire upstream drainage area.

River Segment	Area (sq. mi.)	Impervious Cover (%)	Karst (%)	Precipitation (in.)	KFACT	KWFACT	Soil Group	Physiographic Province	Average Watershed Slope (°)	Watershed Slope, Standard Deviation
PL0_4510_0001	52.14	21.15	0	43.15	0.38	0.32	B	Piedmont-Piedmont Upland	3.46	2.17
PL0_5010_5130	23.94	23.41	0	43.63	0.33	0.36	C	Piedmont-Piedmont Upland	3.02	1.76
PL0_5141_5140	74.46	1.01	0	42.90	0.23	0.32	B	Piedmont-Piedmont Upland	4.79	4.00
PL0_9918_9919	13.71	24.72	0	43.39	0.24	0.36	C	Piedmont-Piedmont Upland	3.03	1.98
PL0_9919_0001	34.80	27.40	0	43.31	0.23	0.32	C	Piedmont-Piedmont Upland	3.20	2.35
PL1_4460_4780	62.39	18.76	0	43.07	0.41	0.33	B	Piedmont-Piedmont Upland	3.38	2.21
PL1_4540_0001	75.05	18.83	0	43.38	0.30	0.28	D	Coastal Plain-Embayed	3.16	2.00
PL1_4780_0001	70.94	18.96	0	43.09	0.40	0.31	B	Piedmont-Piedmont Upland	3.65	2.60
PL1_5130_0001	50.42	22.73	0	43.47	0.30	0.33	C	Piedmont-Piedmont Upland	3.24	2.24
PL1_5370_5470	93.18	1.21	0	42.87	0.24	0.33	B	Piedmont-Piedmont Upland	3.27	2.71
PL2_4970_5250	194.56	8.76	0	43.00	0.28	0.31	C	Piedmont-Piedmont Lowlands	3.02	2.85
PL2_5140_5360	138.13	3.07	0	42.92	0.24	0.31	B	Piedmont-Piedmont Upland	3.66	3.38
PL2_5470_5360	195.93	0.71	0	42.90	0.24	0.33	B	Piedmont-Piedmont Lowlands	2.79	2.35
PL3_5250_0001	592.46	4.16	0	42.96	0.26	0.31	B	Piedmont-Piedmont Lowlands	3.29	2.92
PL3_5360_5250	362.80	1.68	0	42.91	0.24	0.32	B	Piedmont-Piedmont Upland	3.29	2.92
PM0_4640_4820	25.67	16.45	0	43.06	0.40	0.34	B	Piedmont-Piedmont Upland	3.75	2.44
PM1_3120_3400	107.77	1.07	0	44.18	0.26	0.26	C	Piedmont-Piedmont Upland	4.56	3.17
PM1_3450_3400	83.32	2.73	0	43.70	0.25	0.26	B	Piedmont-Piedmont Upland	4.28	2.48
PM1_3510_4000	67.14	0.72	0	44.47	0.24	0.25	B	Blue Ridge-Northern	7.31	4.35
PM1_3710_4040	89.04	2.10	0.002	42.85	0.23	0.24	C	Piedmont-Piedmont Upland	4.98	2.76
PM1_4000_4290	120.30	0.99	0	44.47	0.23	0.28	B	Blue Ridge-Northern	6.43	4.47
PM1_4430_4200	92.52	0.50	0	42.15	0.20	0.32	B	Blue Ridge-Northern	4.76	3.88
PM1_4500_4580	129.28	6.97	0	43.07	0.32	0.32	B	Piedmont-Piedmont Upland	3.85	2.49

River Segment	Area (sq. mi.)	Impervious Cover (%)	Karst (%)	Precipitation (in.)	KFACT	KWFACT	Soil Group	Physiographic Province	Average Watershed Slope (°)	Watershed Slope, Standard Deviation
PM1_9916_9917	6.65	4.69	0	43.10	0.29	0.32	C	Piedmont-Piedmont Lowlands	4.36	2.64
PM1_9917_4500	101.82	8.61	0	43.07	0.33	0.32	B	Piedmont-Piedmont Upland	4.12	2.52
PM2_2860_3040	172.62	2.33	0.01	44.04	0.24	0.27	B	Piedmont-Piedmont Lowlands	3.07	3.49
PM2_3400_3340	192.80	1.79	0	43.97	0.26	0.26	C	Piedmont-Piedmont Upland	4.43	2.89
PM2_4860_4670	121.08	0.23	0	42.88	0.22	0.33	B	Blue Ridge-Northern	6.79	4.98
PM3_3040_3340	318.92	1.99	0.01	44.13	0.24	0.27	B	Piedmont-Piedmont Lowlands	3.93	4.33
PM3_4660_4620	386.11	1.18	0	42.48	0.22	0.32	B	Piedmont-Piedmont Upland	5.15	4.01
PM3_4670_4660	331.74	0.30	0	42.53	0.22	0.32	B	Piedmont-Piedmont Upland	5.41	4.13
PM4_3340_3341	665.16	1.85	0.03	43.95	0.25	0.25	B	Piedmont-Piedmont Lowlands	4.43	4.13
PM4_3341_4040	726.64	2.50	0.06	43.86	0.25	0.25	B	Piedmont-Piedmont Lowlands	4.40	4.03
PM4_4040_4410	969.52	2.68	0.07	43.61	0.24	0.25	B	Piedmont-Piedmont Lowlands	4.54	3.81
PM7_4150_4290	9,460.99	0.86	0.24	40.79	0.22	0.20	B	Valley And Ridge-Middle	9.39	7.54
PM7_4200_4410	9,721.73	0.87	0.23	40.86	0.22	0.21	B	Valley And Ridge-Middle	9.29	7.50
PM7_4290_4200	9,588.15	0.87	0.24	40.84	0.22	0.20	B	Valley And Ridge-Middle	9.36	7.51
PM7_4410_4620	10,770.57	1.03	0.22	41.16	0.22	0.21	B	Valley And Ridge-Middle	8.82	7.36
PM7_4580_4820	11,709.69	1.46	0.20	41.22	0.23	0.22	B	Valley And Ridge-Middle	8.50	7.25
PM7_4620_4580	11,285.56	1.18	0.21	41.17	0.22	0.22	B	Valley And Ridge-Middle	8.62	7.29
PM7_4820_0001	11,746.34	1.51	0.20	41.23	0.23	0.22	B	Valley And Ridge-Middle	8.49	7.25
PS0_6150_6160	11.36	24.44	1.00	39.25	0.27	0.23	B	Valley And Ridge-Middle	3.80	2.79
PS0_6160_6161	44.19	10.57	1.00	39.76	0.26	0.23	B	Valley And Ridge-Middle	3.92	2.73
PS1_4790_4830	101.93	0.02	0.06	39.55	0.20	0.21	D	Valley And Ridge-Middle	10.44	6.82
PS1_4830_5080	157.21	0.29	0.33	39.50	0.22	0.25	B	Valley And Ridge-Middle	8.45	6.57
PS2_5100_9904	693.15	0.43	0.46	38.98	0.22	0.28	B	Valley And Ridge-Middle	9.49	7.61
PS2_5550_5560	209.43	0.10	0.00	37.17	0.20	0.31	D	Valley And Ridge-Middle	14.78	8.43
PS2_5560_5100	507.97	0.46	0.47	38.75	0.22	0.28	B	Valley And Ridge-Middle	9.84	7.84
PS2_6420_6360	234.63	1.22	0.58	43.07	0.24	0.17	B	Blue Ridge-Northern	7.85	8.28
PS2_6490_6420	211.98	1.26	0.55	43.24	0.24	0.17	B	Blue Ridge-Northern	8.13	8.26
PS2_6660_6490	148.31	1.61	0.53	43.30	0.24	0.18	B	Blue Ridge-Northern	8.28	8.15

River Segment	Area (sq. mi.)	Impervious Cover (%)	Karst (%)	Precipitation (in.)	KFACT	KWFACT	Soil Group	Physiographic Province	Average Watershed Slope (°)	Watershed Slope, Standard Deviation
PS2_6730_6660	127.03	0.59	0.53	43.05	0.24	0.18	B	Blue Ridge-Northern	8.45	8.32
PS2_9904_5080	772.26	0.54	0.48	39.01	0.23	0.28	B	Valley And Ridge-Middle	9.22	7.57
PS3_5990_6161	322.59	0.45	0.36	39.60	0.21	0.19	A	Valley And Ridge-Middle	11.71	8.68
PS3_6161_6280	375.79	1.65	0.45	39.63	0.22	0.20	B	Valley And Ridge-Middle	10.62	8.54
PS3_6280_6230	419.86	1.55	0.49	39.83	0.22	0.20	B	Valley And Ridge-Middle	10.04	8.32
PS3_6460_6230	373.82	1.10	0.72	41.88	0.24	0.21	B	Valley And Ridge-Middle	6.84	5.17
PS4_5080_4380	1,033.80	0.47	0.43	39.13	0.22	0.28	B	Valley And Ridge-Middle	9.23	7.43
PS4_5840_9901	1,334.50	1.12	0.57	41.27	0.23	0.21	B	Valley And Ridge-Middle	8.79	7.84
PS4_6230_6360	819.19	1.31	0.60	40.77	0.23	0.21	B	Valley And Ridge-Middle	8.40	7.14
PS4_6360_5840	1,075.71	1.27	0.59	41.30	0.23	0.20	B	Valley And Ridge-Middle	8.36	7.50
PS4_9901_9902	1,484.90	1.03	0.52	41.04	0.23	0.20	B	Valley And Ridge-Middle	9.29	8.05
PS4_9902_9903	1,380.77	1.10	0.57	41.24	0.23	0.21	B	Valley And Ridge-Middle	8.79	7.85
PS4_9903_5200	1,672.01	1.03	0.53	41.23	0.23	0.21	B	Valley And Ridge-Middle	9.08	7.94
PS5_4370_4150	3,057.72	0.86	0.50	40.38	0.23	0.24	B	Valley And Ridge-Middle	8.68	7.55
PS5_4380_4370	3,035.51	0.82	0.50	40.38	0.23	0.24	B	Valley And Ridge-Middle	8.71	7.56
PS5_5200_4380	1,672.01	1.03	0.52	41.22	0.23	0.21	B	Valley And Ridge-Middle	9.06	7.90
PU0_3000_3090	93.37	2.69	0.55	42.99	0.23	0.22	B	Blue Ridge-Northern	6.02	4.84
PU0_3611_3530	25.15	0.82	0.0001	41.61	0.21	0.19	D	Valley And Ridge-Middle	8.46	5.69
PU0_3751_3752	21.03	4.29	0.003	41.85	0.28	0.26	B	Valley And Ridge-Middle	2.83	2.02
PU0_3871_3690	61.98	0.21	0	39.57	0.19	0.15	D	Valley And Ridge-Middle	8.06	4.93
PU0_5620_5380	267.43	0.20	0.06	40.07	0.19	0.15	A	Valley And Ridge-Middle	13.96	7.74
PU0_6080_5620	179.49	0.14	0.09	40.86	0.19	0.15	A	Valley And Ridge-Middle	13.76	7.60
PU0_9913_9914	1.79	0.00	0	42.37	0.19	0.18	C	Valley And Ridge-Middle	11.21	7.28
PU0_9914_3602	18.11	0.49	0.002	41.94	0.23	0.20	B	Valley And Ridge-Middle	7.26	6.85
PU1_3030_3440	113.88	0.34	0.08	41.25	0.19	0.18	D	Valley And Ridge-Middle	8.79	5.89
PU1_3100_3690	104.34	0.15	0	40.64	0.19	0.18	D	Valley And Ridge-Middle	7.93	5.01
PU1_3850_4190	48.42	0.19	0	48.66	0.20	0.20	B	Appalachian Plateaus-Allegheny Mountain	11.54	7.06
PU1_3940_3970	74.52	0.95	0	43.54	0.20	0.18	C	Appalachian Plateaus-Allegheny Mountain	9.76	5.37

River Segment	Area (sq. mi.)	Impervious Cover (%)	Karst (%)	Precipitation (in.)	KFACT	KWFACT	Soil Group	Physiographic Province	Average Watershed Slope (°)	Watershed Slope, Standard Deviation
PU1_4190_4300	104.56	0.11	0	48.72	0.20	0.19	C	Appalachian Plateaus-Allegheny Mountain	12.70	7.41
PU1_4300_4440	115.65	0.12	0	48.72	0.20	0.19	C	Appalachian Plateaus-Allegheny Mountain	12.65	7.36
PU1_4760_4450	58.85	0.32	0	49.41	0.21	0.25	C	Appalachian Plateaus-Allegheny Mountain	5.41	3.94
PU1_4840_4760	49.02	0.33	0	49.43	0.21	0.24	C	Appalachian Plateaus-Allegheny Mountain	5.20	3.48
PU1_5380_5050	332.47	0.18	0.05	40.50	0.19	0.15	A	Valley And Ridge-Middle	14.51	7.90
PU1_5520_5210	67.81	0.06	0	41.13	0.23	0.16	B	Valley And Ridge-Middle	19.35	8.67
PU1_5820_5380	19.82	0.12	0	40.34	0.18	0.13	A	Valley And Ridge-Middle	14.63	7.08
PU1_9908_9910	54.68	0.07	0.26	40.75	0.20	0.16	C	Valley And Ridge-Middle	10.05	6.05
PU1_9909_9910	7.17	0.06	0.30	40.13	0.22	0.16	C	Valley And Ridge-Middle	9.96	6.65
PU1_9910_3780	94.47	0.52	0.19	40.36	0.20	0.17	C	Valley And Ridge-Middle	10.11	6.11
PU2_2790_3290	279.99	3.50	0.38	43.17	0.23	0.23	B	Valley And Ridge-Middle	4.47	4.89
PU2_2840_3080	158.69	0.35	0.10	41.28	0.20	0.19	D	Valley And Ridge-Middle	9.32	6.43
PU2_3080_3640	212.80	0.27	0.07	41.59	0.21	0.18	D	Valley And Ridge-Middle	9.60	6.46
PU2_3090_4050	280.13	4.01	0.73	42.30	0.25	0.23	B	Valley And Ridge-Middle	4.78	4.45
PU2_3140_3680	189.21	0.11	0	41.93	0.21	0.19	B	Appalachian Plateaus-Allegheny Mountain	11.20	6.16
PU2_3180_3370	66.42	0.02	0.10	40.68	0.20	0.18	B	Valley And Ridge-Middle	8.84	5.60
PU2_3370_4020	156.96	0.12	0.15	40.12	0.20	0.17	D	Valley And Ridge-Middle	9.56	5.95
PU2_3770_3600	274.02	0.14	0.07	39.51	0.23	0.18	D	Valley And Ridge-Middle	7.54	5.21
PU2_3900_3750	343.71	2.85	0.62	39.69	0.26	0.24	B	Valley And Ridge-Middle	3.67	3.29
PU2_4050_4180	290.94	3.87	0.72	42.29	0.25	0.23	B	Valley And Ridge-Middle	4.88	4.50
PU2_4160_3930	311.69	0.21	0	40.18	0.21	0.20	D	Valley And Ridge-Middle	10.72	6.58
PU2_4220_3900	277.35	2.54	0.63	39.65	0.26	0.24	B	Valley And Ridge-Middle	3.53	3.09
PU2_4340_3860	205.89	0.08	0	38.77	0.18	0.18	A	Valley And Ridge-Middle	9.81	6.20
PU2_4720_4750	72.97	0.23	0	48.55	0.21	0.21	C	Appalachian Plateaus-Allegheny Mountain	7.49	4.54
PU2_4730_4220	58.35	2.86	0.50	39.33	0.24	0.24	D	Valley And Ridge-Middle	3.72	3.03
PU2_4750_4450	84.94	0.23	0	48.66	0.21	0.21	C	Appalachian Plateaus-Allegheny Mountain	7.38	4.72
PU2_5190_4310	288.69	0.22	0	38.23	0.21	0.16	B	Valley And Ridge-Middle	15.84	8.97
PU2_5700_5210	171.23	0.24	0	41.63	0.21	0.15	A	Valley And Ridge-Middle	17.01	8.73

River Segment	Area (sq. mi.)	Impervious Cover (%)	Karst (%)	Precipitation (in.)	KFACT	KWFACT	Soil Group	Physiographic Province	Average Watershed Slope (°)	Watershed Slope, Standard Deviation
PU2_6050_5190	112.30	0.11	0	38.36	0.21	0.16	B	Valley And Ridge-Middle	14.79	8.20
PU2_9905_9907	0.91	0.23	0	43.58	0.20	0.19	D	Valley And Ridge-Middle	10.59	6.50
PU2_9906_9907	30.40	0.19	0	47.83	0.20	0.19	B	Appalachian Plateaus-Allegheny Mountain	13.21	7.19
PU2_9907_4160	248.05	0.17	0	40.73	0.21	0.19	B	Valley And Ridge-Middle	10.90	6.74
PU2_9911_9912	11.15	0.00	0	39.86	0.17	0.11	A	Valley And Ridge-Middle	8.74	5.22
PU2_9912_3590	144.82	0.08	0	40.04	0.20	0.16	D	Valley And Ridge-Middle	8.58	5.66
PU3_2510_3290	198.68	0.51	0.20	43.07	0.20	0.21	B	Valley And Ridge-Middle	7.48	7.75
PU3_3290_3390	502.14	2.31	0.32	43.11	0.22	0.22	B	Valley And Ridge-Middle	5.58	6.32
PU3_3390_3730	567.95	2.66	0.36	42.97	0.22	0.23	B	Valley And Ridge-Middle	5.29	6.11
PU3_3680_3890	253.33	0.52	0	41.93	0.20	0.19	B	Appalachian Plateaus-Allegheny Mountain	11.19	6.15
PU3_3860_3610	680.83	0.10	0	39.10	0.19	0.18	A	Valley And Ridge-Middle	10.92	6.77
PU3_4280_3860	414.42	0.12	0	39.22	0.20	0.18	B	Valley And Ridge-Middle	11.25	6.84
PU3_4450_4440	287.98	0.18	0	47.92	0.21	0.22	C	Appalachian Plateaus-Allegheny Mountain	7.89	5.63
PU3_5210_5050	317.20	0.18	0	42.59	0.21	0.15	B	Valley And Ridge-Middle	17.90	8.89
PU4_3780_3930	990.55	0.72	0.02	44.59	0.21	0.19	C	Appalachian Plateaus-Allegheny Mountain	10.43	6.78
PU4_3890_3990	875.16	0.63	0	45.18	0.21	0.20	C	Appalachian Plateaus-Allegheny Mountain	10.48	6.81
PU4_3970_3890	619.40	0.56	0	46.52	0.21	0.20	C	Appalachian Plateaus-Allegheny Mountain	10.20	7.04
PU4_3990_3780	877.74	0.71	0	45.16	0.21	0.20	C	Appalachian Plateaus-Allegheny Mountain	10.47	6.81
PU4_4210_4170	1,481.19	0.26	0.01	40.12	0.21	0.17	B	Valley And Ridge-Middle	14.45	8.58
PU4_4310_4210	1,461.82	0.27	0.01	40.14	0.21	0.17	B	Valley And Ridge-Middle	14.50	8.57
PU4_4440_3970	406.91	0.20	0	48.11	0.21	0.21	C	Appalachian Plateaus-Allegheny Mountain	9.31	6.59
PU4_5050_4310	900.19	0.27	0.02	41.32	0.21	0.16	A	Valley And Ridge-Middle	14.84	8.52
PU5_3930_4170	1,372.10	0.58	0.01	43.37	0.21	0.19	C	Valley And Ridge-Middle	10.48	6.72
PU5_4170_4020	2,856.92	0.42	0.01	41.64	0.21	0.18	B	Valley And Ridge-Middle	12.56	8.00
PU6_3440_3590	4,253.26	0.34	0	40.94	0.20	0.18	B	Valley And Ridge-Middle	11.71	7.60
PU6_3530_3440	4,121.28	0.34	0	40.97	0.20	0.18	B	Valley And Ridge-Middle	11.81	7.64
PU6_3590_3640	4,401.37	0.33	0	40.95	0.20	0.18	B	Valley And Ridge-Middle	11.61	7.57
PU6_3600_3602	4,945.03	0.32	0.02	40.89	0.21	0.18	B	Valley And Ridge-Middle	11.22	7.48

River Segment	Area (sq. mi.)	Impervious Cover (%)	Karst (%)	Precipitation (in.)	KFACT	KWFACT	Soil Group	Physiographic Province	Average Watershed Slope (°)	Watershed Slope, Standard Deviation
PU6_3602_3730	4,976.28	0.32	0.02	40.90	0.21	0.18	B	Valley And Ridge-Middle	11.18	7.48
PU6_3610_3530	4,079.22	0.33	0.01	40.97	0.20	0.18	B	Valley And Ridge-Middle	11.84	7.65
PU6_3640_3600	4,637.04	0.32	0.02	40.98	0.20	0.18	B	Valley And Ridge-Middle	11.49	7.53
PU6_3690_3610	3,377.15	0.37	0.02	41.35	0.21	0.18	B	Valley And Ridge-Middle	12.04	7.80
PU6_3730_3750	5,567.55	0.57	0.05	41.12	0.21	0.18	B	Valley And Ridge-Middle	10.55	7.56
PU6_3750_9915	5,931.47	0.70	0.09	41.03	0.21	0.19	B	Valley And Ridge-Middle	10.13	7.56
PU6_3752_4080	5,985.09	0.71	0.09	41.04	0.21	0.19	B	Valley And Ridge-Middle	10.06	7.55
PU6_3870_3690	3,189.09	0.38	0.02	41.41	0.21	0.18	B	Valley And Ridge-Middle	12.27	7.87
PU6_4020_3870	3,142.30	0.39	0.02	41.43	0.21	0.18	B	Valley And Ridge-Middle	12.27	7.87
PU6_4080_4180	5,994.86	0.71	0.09	41.04	0.21	0.19	B	Valley And Ridge-Middle	10.05	7.55
PU6_4180_4150	6,335.27	0.86	0.11	41.09	0.21	0.19	B	Valley And Ridge-Middle	9.77	7.51
PU6_9915_3752	5,948.96	0.70	0.09	41.03	0.21	0.19	B	Valley And Ridge-Middle	10.11	7.55

Table 10. Baseline and current scenario modeled flow metrics and percent alteration for each river segment.

	Baseline Flow Metrics (used in RPART)						Current Scenario Flow Metrics (used in RPART)						Alteration (calculated as (current-baseline)/baseline)					
River Segment	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)
PL0_4510_0001	36.46	23.30	9	0.29	7	7.6	18.13	7.00	20	0.72	4.5	12.7	-50%	-70%	122%	146%	-36%	67.2%
PL0_5010_5130	28.68	16.08	10	0.35	16	5.1	17.88	5.41	23	0.88	4	11.1	-38%	-66%	130%	148%	-75%	116.0%
PL0_5141_5140	28.77	15.14	11	0.51	4	8.8	26.98	12.25	10	0.56	0	8.6	-6%	-19%	-9%	10%	-100%	-2.2%
PL0_9918_9919	35.53	19.00	7	0.29	28	3.3	27.04	6.29	24	0.95	4	10.2	-24%	-67%	243%	231%	-86%	205.7%
PL0_9919_0001	36.18	20.00	7	0.28	11.5	3.6	23.27	6.03	24	0.95	4.5	10.0	-36%	-70%	243%	236%	-61%	174.7%
PL1_4460_4780	39.10	26.20	9	0.27	8	7.9	17.56	7.17	20	0.66	5	12.3	-55%	-73%	122%	149%	-38%	55.2%
PL1_4540_0001	40.96	18.91	11	0.37	9	8.2	21.10	7.29	22	0.80	4.5	12.4	-48%	-61%	100%	114%	-50%	51.0%
PL1_4780_0001	33.09	21.42	9	0.28	8	8.0	16.89	6.93	19	0.65	5	12.4	-49%	-68%	111%	129%	-38%	54.6%
PL1_5130_0001	36.30	20.33	8	0.29	15.5	4.3	22.48	7.50	22	0.80	4	9.9	-38%	-63%	175%	172%	-74%	133.7%
PL1_5370_5470	54.81	25.00	9	0.46	6.5	8.9	47.02	21.25	10	0.52	7.25	9.5	-14%	-15%	11%	14%	12%	7.2%

	Baseline Flow Metrics (used in RPART)						Current Scenario Flow Metrics (used in RPART)						Alteration (calculated as (current-baseline)/baseline)					
River Segment	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)
PL2_4970_5250	30.58	19.00	10	0.35	12.5	7.0	20.89	10.89	14	0.49	6	8.9	-32%	-43%	40%	41%	-52%	27.1%
PL2_5140_5360	27.98	14.18	11	0.44	9	9.0	24.71	12.44	12	0.51	6	9.7	-12%	-12%	9%	15%	-33%	7.7%
PL2_5470_5360	40.45	22.43	9	0.39	9	8.6	38.50	19.38	10	0.43	10.5	9.4	-5%	-14%	11%	8%	17%	9.2%
PL3_5250_0001	38.35	21.09	9	0.30	56	7.2	34.08	17.63	9	0.35	0	8.1	-11%	-16%	0%	16%	-100%	13.2%
PL3_5360_5250	32.40	16.17	9	0.36	14	8.3	30.15	15.89	11	0.40	10.5	9.0	-7%	-2%	22%	10%	-25%	9.2%
PM0_4640_4820	35.50	21.00	9	0.30	9	8.1	16.12	6.41	20	0.72	5.5	12.4	-55%	-69%	122%	140%	-39%	52.8%
PM1_3120_3400	48.13	26.38	7	0.29	10.5	9.9	37.60	20.13	10	0.34	7	10.8	-22%	-24%	43%	18%	-33%	9.9%
PM1_3450_3400	39.78	22.38	8	0.30	10.25	8.6	25.64	14.38	10	0.40	6.5	10.3	-36%	-36%	25%	31%	-37%	19.3%
PM1_3510_4000	43.55	24.73	7	0.32	8.75	9.8	39.82	24.17	9	0.36	7	10.8	-9%	-2%	29%	12%	-20%	10.0%
PM1_3710_4040	36.02	24.33	10	0.32	10	8.1	23.49	12.91	12	0.42	5.5	9.5	-35%	-47%	20%	32%	-45%	16.6%
PM1_4000_4290	47.38	28.60	7	0.30	10	9.7	41.87	25.50	9	0.34	9	11.0	-12%	-11%	29%	16%	-10%	13.9%
PM1_4430_4200	43.36	19.70	8	0.36	11	9.0	41.89	19.11	11	0.40	12.5	10.1	-3%	-3%	38%	9%	14%	12.3%
PM1_4500_4580	40.97	27.00	9	0.26	10	7.5	20.39	12.30	13	0.43	7	10.0	-50%	-54%	44%	66%	-30%	33.8%
PM1_9916_9917	144.13	38.00	10	0.26	0	5.9	126.05	32.06	13	0.32	0	6.5	-13%	-16%	30%	24%	0%*	10.8%
PM1_9917_4500	41.91	27.10	9	0.26	8	7.4	19.31	11.16	14	0.47	7	10.1	-54%	-59%	56%	79%	-13%	36.3%
PM2_2860_3040	65.18	23.00	9	0.56	12	12.9	52.36	15.88	12	0.63	6	14.0	-20%	-31%	33%	14%	-50%	8.7%
PM2_3400_3340	44.25	25.00	8	0.29	11	9.5	31.38	15.93	10	0.36	7.5	11.0	-29%	-36%	25%	23%	-32%	15.1%
PM2_4860_4670	42.31	29.14	7	0.37	11	7.9	40.60	25.50	8	0.39	9.5	8.6	-4%	-13%	14%	7%	-14%	9.2%
PM3_3040_3340	52.35	23.33	10	0.40	7.25	11.4	43.24	17.63	10	0.45	4	12.4	-17%	-24%	0%	12%	-45%	7.9%
PM3_4660_4620	43.99	23.00	8	0.36	17.5	8.0	42.92	24.00	10	0.39	15.75	8.7	-2%	4%	25%	10%	-10%	8.4%
PM3_4670_4660	44.16	22.67	9	0.38	17	7.9	44.73	26.29	9	0.41	14	8.5	1%	16%	0%	8%	-18%	7.9%
PM4_3340_3341	42.42	22.67	9	0.32	12	10.0	37.92	20.00	9	0.36	5.5	11.0	-11%	-12%	0%	14%	-54%	11.0%
PM4_3341_4040	42.55	22.29	9	0.31	12	9.6	36.65	17.86	9	0.35	6	10.7	-14%	-20%	0%	14%	-50%	12.2%
PM4_4040_4410	42.03	24.57	8	0.28	12	8.4	33.08	19.50	8	0.32	8	9.6	-21%	-21%	0%	16%	-33%	15.0%
PM7_4150_4290	50.91	33.88	4	0.18	21	5.9	51.18	34.00	5	0.18	10.5	6.3	1%	0%	25%	3%	-50%	6.7%
PM7_4200_4410	50.62	34.13	4	0.17	23.5	6.0	52.24	37.80	4	0.18	9.5	6.2	3%	11%	0%	3%	-60%	3.6%
PM7_4290_4200	50.35	34.13	4	0.17	23	5.9	51.94	38.00	5	0.18	9	6.3	3%	11%	25%	3%	-61%	6.0%

	Baseline Flow Metrics (used in RPART)						Current Scenario Flow Metrics (used in RPART)						Alteration (calculated as (current-baseline)/baseline)					
River Segment	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)
PM7_4410_4620	49.83	37.60	4	0.17	22	6.0	48.83	35.67	4	0.17	11	6.2	-2%	-5%	0%	4%	-50%	3.5%
PM7_4580_4820	51.26	43.25	4	0.15	21	5.7	49.15	36.80	4	0.15	4	5.7	-4%	-15%	0%	4%	-81%	0.8%
PM7_4620_4580	52.04	43.17	4	0.15	21	5.9	49.30	35.67	4	0.16	14	6.0	-5%	-17%	0%	4%	-33%	1.4%
PM7_4820_0001	51.59	43.25	4	0.15	21	5.7	48.67	36.80	4	0.15	5	5.7	-6%	-15%	0%	4%	-76%	0.9%
PS0_6150_6160	24.08	18.00	4	0.13	4	4.1	9.58	4.08	23	0.62	4	10.2	-60%	-77%	475%	373%	0%	149.5%
PS0_6160_6161	37.76	21.14	3	0.15	9	3.1	14.36	7.67	14	0.42	5	6.0	-62%	-64%	367%	185%	-44%	91.5%
PS1_4790_4830	42.65	18.78	9	0.47	6	9.9	42.65	18.78	9	0.47	6	9.9	0%	0%	0%	0%	0%	0.0%
PS1_4830_5080	46.86	21.88	8	0.46	8	9.4	48.44	20.10	9	0.47	7	9.5	3%	-8%	13%	2%	-13%	1.8%
PS2_5100_9904	45.11	21.38	7	0.40	9	7.6	49.85	23.63	7	0.40	10.5	8.3	11%	11%	0%	2%	17%	10.0%
PS2_5550_5560	69.09	20.82	9	0.56	6.25	10.2	69.12	20.82	9	0.56	6.5	10.2	0%	0%	0%	0%	4%	0.1%
PS2_5560_5100	57.11	22.86	5	0.37	12	6.6	62.49	24.20	7	0.38	12	7.5	9%	6%	40%	2%	0%	12.5%
PS2_6420_6360	32.91	26.25	6	0.27	11	9.7	32.15	23.22	7	0.29	5.5	10.3	-2%	-12%	17%	8%	-50%	6.2%
PS2_6490_6420	32.26	26.11	7	0.28	11	10.2	30.98	21.70	7	0.31	7.25	10.9	-4%	-17%	0%	8%	-34%	6.8%
PS2_6660_6490	31.66	25.89	7	0.30	12	10.2	28.18	20.00	8	0.33	6	11.2	-11%	-23%	14%	11%	-50%	9.6%
PS2_6730_6660	32.85	26.00	7	0.30	10	10.0	33.28	24.00	7	0.31	8.5	10.3	1%	-8%	0%	5%	-15%	2.8%
PS2_9904_5080	63.25	29.88	6	0.32	21.5	7.5	60.08	27.29	6	0.33	15.75	8.2	-5%	-9%	0%	3%	-27%	9.8%
PS3_5990_6161	48.90	21.29	9	0.41	10	6.6	50.22	24.17	9	0.41	9	6.8	3%	14%	0%	1%	-10%	2.1%
PS3_6161_6280	47.11	22.00	7	0.37	10	6.0	36.54	16.70	8	0.40	7	6.4	-22%	-24%	14%	8%	-30%	6.0%
PS3_6280_6230	45.02	25.00	7	0.34	10	6.0	39.21	16.67	7	0.37	7	6.3	-13%	-33%	0%	8%	-30%	4.9%
PS3_6460_6230	65.87	31.60	5	0.21	6	7.1	64.25	24.13	6	0.21	5	7.8	-2%	-24%	20%	3%	-17%	11.1%
PS4_5080_4380	59.49	26.29	6	0.33	23	8.1	58.10	27.57	7	0.34	11.75	8.3	-2%	5%	17%	3%	-49%	1.9%
PS4_5840_9901	34.20	23.86	5	0.25	11	6.2	36.81	23.89	6	0.26	7	6.9	8%	0%	20%	6%	-36%	10.0%
PS4_6230_6360	49.05	30.60	5	0.26	9	6.1	50.91	35.20	6	0.27	7	6.5	4%	15%	20%	5%	-22%	7.6%
PS4_6360_5840	39.00	25.43	5	0.25	11	6.7	42.87	30.57	6	0.26	5	7.1	10%	20%	20%	6%	-55%	5.4%
PS4_9901_9902	35.56	24.14	5	0.24	13	5.8	36.25	27.13	6	0.26	7.5	6.3	2%	12%	20%	5%	-42%	8.3%
PS4_9902_9903	35.41	24.14	5	0.24	13	6.3	35.69	27.13	6	0.26	8	6.8	1%	12%	20%	5%	-38%	7.9%
PS4_9903_5200	32.77	23.86	5	0.22	12	6.7	33.58	28.13	6	0.22	11	7.1	2%	18%	20%	4%	-8%	6.6%

	Baseline Flow Metrics (used in RPART)						Current Scenario Flow Metrics (used in RPART)						Alteration (calculated as (current-baseline)/baseline)					
River Segment	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)
PS5_4370_4150	44.39	28.25	4	0.21	21	6.9	44.25	26.75	4	0.22	13.75	7.1	0%	-5%	0%	3%	-35%	3.2%
PS5_4380_4370	44.34	28.50	4	0.21	15	6.9	44.18	27.14	4	0.22	14.5	7.1	0%	-5%	0%	3%	-3%	3.1%
PS5_5200_4380	31.79	25.40	6	0.22	12.75	6.9	32.59	26.67	7	0.23	11.75	7.3	3%	5%	17%	4%	-8%	6.4%
PU0_3000_3090	30.78	20.88	7	0.25	5	6.6	20.45	13.92	8	0.33	5.5	8.1	-34%	-33%	14%	34%	10%	23.3%
PU0_3611_3530	29.87	14.18	8	0.30	7.75	5.2	24.60	14.59	8	0.31	6	5.6	-18%	3%	0%	6%	-23%	8.8%
PU0_3751_3752	38.95	28.00	1	0.06	8.5	2.0	14.17	11.83	6	0.19	6.5	3.8	-64%	-58%	500%	229%	-24%	87.5%
PU0_3871_3690	77.88	21.56	8	0.53	5	7.8	77.09	21.56	8	0.53	5	7.8	-1%	0%	0%	0%	0%	0.3%
PU0_5620_5380	53.53	24.57	9	0.40	8	9.2	53.15	24.71	10	0.41	6.5	9.4	-1%	1%	11%	2%	-19%	1.8%
PU0_6080_5620	47.34	24.43	9	0.40	6	10.1	45.92	21.44	9	0.41	6	10.3	-3%	-12%	0%	2%	0%	1.3%
PU0_9913_9914	90.58	94.67	3	0.13	31	5.5	90.58	94.67	3	0.13	31	5.5	0%	0%	0%	0%	0%	0.0%
PU0_9914_3602	45.66	33.75	1	0.06	5	2.5	30.65	31.22	1	0.08	6	3.1	-33%	-8%	0%	29%	20%	26.0%
PU1_3030_3440	63.24	18.00	9	0.52	5	9.8	63.63	17.80	10	0.54	4.5	10.3	1%	-1%	11%	3%	-10%	5.2%
PU1_3100_3690	69.73	20.27	8	0.45	6	8.9	68.36	20.36	8	0.46	6	9.0	-2%	0%	0%	1%	0%	1.1%
PU1_3850_4190	31.22	15.88	10	0.38	12	11.9	31.02	15.09	10	0.38	12	11.9	-1%	-5%	0%	0%	0%	0.2%
PU1_3940_3970	34.97	17.91	10	0.44	9	11.0	30.72	16.09	11	0.46	7	11.3	-12%	-10%	10%	6%	-22%	2.5%
PU1_4190_4300	109.76	80.00	6	0.18	45	10.4	109.82	80.00	5	0.18	50	10.4	0%	0%	-17%	0%	11%	-0.1%
PU1_4300_4440	78.55	57.25	6	0.19	7.5	10.4	77.59	57.25	6	0.19	7	10.4	-1%	0%	0%	0%	-7%	-0.1%
PU1_4760_4450	19.17	15.00	8	0.24	4	10.6	18.89	15.00	12	0.24	4	1.9	-1%	0%	50%	1%	0%	-81.9%
PU1_4840_4760	18.81	15.00	8	0.23	4	10.6	18.50	15.00	0	0.23	0	0.0	-2%	0%	-100%	1%	-100%	-100.0%
PU1_5380_5050	50.57	24.86	8	0.35	9	9.0	47.12	25.17	9	0.36	8	9.2	-7%	1%	13%	2%	-11%	1.6%
PU1_5520_5210	58.01	35.75	8	0.31	11	9.5	58.01	35.75	8	0.31	11	9.5	0%	0%	0%	0%	0%	0.0%
PU1_5820_5380	58.75	32.33	8	0.36	10	9.7	59.45	32.33	8	0.36	8	9.7	1%	0%	0%	0%	-20%	0.2%
PU1_9908_9910	46.06	22.13	8	0.39	9	10.9	45.00	22.13	8	0.40	8.75	10.9	-2%	0%	0%	1%	-3%	0.1%
PU1_9909_9910	192.98	175.50	3	0.23	88	8.3	174.43	145.75	3	0.23	88.5	8.1	-10%	-17%	0%	-2%	1%	-2.7%
PU1_9910_3780	48.38	26.29	8	0.39	8	9.0	42.65	23.13	8	0.41	7	9.1	-12%	-12%	0%	4%	-13%	0.5%
PU2_2790_3290	39.63	28.75	6	0.21	8	6.8	27.35	16.70	7	0.28	6	8.9	-31%	-42%	17%	34%	-25%	30.2%
PU2_2840_3080	70.37	21.14	9	0.44	4	9.5	68.28	19.90	9	0.45	4.75	10.0	-3%	-6%	0%	3%	19%	5.3%

	Baseline Flow Metrics (used in RPART)						Current Scenario Flow Metrics (used in RPART)						Alteration (calculated as (current-baseline)/baseline)					
River Segment	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)
PU2_3080_3640	61.50	25.50	9	0.36	10	8.3	60.31	24.86	9	0.37	9.5	8.8	-2%	-3%	0%	3%	-5%	5.8%
PU2_3090_4050	37.65	28.30	3	0.11	9	4.4	18.45	12.76	6	0.19	5	5.9	-51%	-55%	100%	76%	-44%	33.5%
PU2_3140_3680	43.61	20.89	9	0.39	8.5	11.7	43.41	20.89	9	0.39	8.5	11.8	0%	0%	0%	0%	0%	0.2%
PU2_3180_3370	63.62	22.25	8	0.45	6	11.1	63.62	22.25	8	0.45	6	11.1	0%	0%	0%	0%	0%	0.0%
PU2_3370_4020	69.72	26.57	8	0.39	5	9.0	69.38	26.71	8	0.39	5.5	9.0	0%	1%	0%	0%	10%	0.4%
PU2_3770_3600	60.53	41.75	5	0.28	16.5	7.3	57.13	24.00	5	0.29	11.5	7.4	-6%	-43%	0%	2%	-30%	1.3%
PU2_3900_3750	47.31	20.00	6	0.24	10	6.4	30.10	14.00	7	0.30	5.5	8.1	-36%	-30%	17%	23%	-45%	26.1%
PU2_4050_4180	38.25	28.40	3	0.11	9	4.3	18.87	13.33	6	0.19	5.5	5.8	-51%	-53%	100%	73%	-39%	34.3%
PU2_4160_3930	55.73	26.50	6	0.24	12	5.8	54.21	25.27	6	0.24	12	5.8	-3%	-5%	0%	2%	0%	0.0%
PU2_4220_3900	52.15	18.89	6	0.27	14	6.7	34.53	12.83	7	0.33	6	7.9	-34%	-32%	17%	21%	-57%	16.8%
PU2_4340_3860	78.12	27.17	6	0.41	8	7.6	76.20	25.00	7	0.41	7	7.7	-2%	-8%	17%	1%	-13%	2.3%
PU2_4720_4750	22.36	13.29	12	0.36	6	10.8	22.08	13.13	12	0.37	6	10.8	-1%	-1%	0%	2%	0%	0.0%
PU2_4730_4220	81.82	25.25	8	0.48	10.25	8.6	51.51	14.21	9	0.56	5.5	10.4	-37%	-44%	13%	18%	-46%	21.3%
PU2_4750_4450	22.16	12.61	12	0.36	5	10.7	22.16	12.61	11	0.36	5.5	10.7	0%	0%	-8%	1%	10%	0.0%
PU2_5190_4310	69.18	26.00	9	0.44	12	8.1	68.70	26.17	9	0.44	11	8.2	-1%	1%	0%	1%	-8%	0.6%
PU2_5700_5210	49.02	25.86	8	0.30	8.5	9.7	48.32	25.75	8	0.30	8.5	9.8	-1%	0%	0%	0%	0%	1.0%
PU2_6050_5190	56.31	17.44	11	0.57	5.5	10.0	56.12	17.56	11	0.57	6	10.0	0%	1%	0%	0%	9%	0.1%
PU2_9905_9907	39.98	26.57	4	0.13	7.25	5.2	41.92	25.75	4	0.13	7.5	5.4	5%	-3%	0%	2%	3%	3.6%
PU2_9906_9907	26.97	22.10	5	0.13	17.5	8.9	26.84	22.10	5	0.13	18	8.9	0%	0%	0%	0%	3%	-0.1%
PU2_9907_4160	47.36	24.64	7	0.23	12	6.0	47.72	24.73	7	0.24	12	5.9	1%	0%	0%	2%	0%	-0.1%
PU2_9911_9912	86.32	100.17	1	0.02	68	2.2	86.32	100.17	1	0.02	68	2.2	0%	0%	0%	0%	0%	0.0%
PU2_9912_3590	64.12	29.30	7	0.42	11.25	10.0	63.77	29.40	7	0.42	11.25	10.1	-1%	0%	0%	0%	0%	0.5%
PU3_2510_3290	50.26	34.60	8	0.28	10	8.3	47.52	28.71	8	0.30	8	10.0	-5%	-17%	0%	7%	-20%	20.1%
PU3_3290_3390	42.05	31.20	7	0.23	19.75	7.0	35.18	24.00	7	0.27	6	8.7	-16%	-23%	0%	20%	-70%	23.9%
PU3_3390_3730	45.99	35.50	5	0.20	18	6.3	34.68	25.86	7	0.24	5	8.1	-25%	-27%	40%	21%	-72%	28.2%
PU3_3680_3890	41.71	22.13	9	0.40	8	11.1	40.24	21.75	9	0.41	7.5	11.2	-4%	-2%	0%	2%	-6%	0.9%
PU3_3860_3610	78.27	28.43	7	0.32	26	8.2	78.77	28.86	7	0.32	13	8.2	1%	2%	0%	0%	-50%	-0.1%

	Baseline Flow Metrics (used in RPART)						Current Scenario Flow Metrics (used in RPART)						Alteration (calculated as (current-baseline)/baseline)					
River Segment	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)
PU3_4280_3860	61.77	24.14	8	0.38	9.25	8.7	61.89	24.00	8	0.38	8	8.7	0%	-1%	0%	0%	-14%	0.1%
PU3_4450_4440	32.19	27.63	5	0.13	15	8.0	31.98	27.63	5	0.13	51	7.0	-1%	0%	0%	1%	240%	-12.2%
PU3_5210_5050	33.57	19.00	8	0.28	8.5	9.1	33.00	19.50	8	0.28	9	9.2	-2%	3%	0%	0%	6%	0.6%
PU4_3780_3930	36.90	29.50	8	0.23	9	7.0	33.64	26.86	8	0.23	8	6.6	-9%	-9%	0%	3%	-11%	-5.7%
PU4_3890_3990	35.00	29.00	8	0.23	9.5	7.3	33.61	27.56	8	0.24	7.5	6.9	-4%	-5%	0%	3%	-21%	-5.3%
PU4_3970_3890	35.37	27.33	7	0.19	8.5	7.5	33.11	27.14	8	0.19	6.5	7.2	-6%	-1%	14%	3%	-24%	-3.6%
PU4_3990_3780	35.63	29.00	8	0.23	9.5	7.3	33.25	27.56	8	0.24	8	6.9	-7%	-5%	0%	4%	-16%	-5.1%
PU4_4210_4170	54.10	23.86	7	0.26	12	7.1	51.95	22.14	7	0.26	12	7.0	-4%	-7%	0%	1%	0%	-0.8%
PU4_4310_4210	53.23	23.71	7	0.26	11	7.1	51.52	22.43	7	0.27	11.75	7.0	-3%	-5%	0%	1%	7%	-0.8%
PU4_4440_3970	34.83	31.75	6	0.14	8	7.7	34.86	31.75	6	0.14	6	6.2	0%	0%	0%	1%	-25%	-20.5%
PU4_5050_4310	38.57	17.25	7	0.32	10	8.5	37.38	17.00	8	0.32	10	8.5	-3%	-1%	14%	2%	0%	0.8%
PU5_3930_4170	41.52	29.89	7	0.22	11.25	6.6	38.72	26.83	8	0.23	9	6.4	-7%	-10%	14%	3%	-20%	-2.1%
PU5_4170_4020	43.30	23.00	7	0.23	15	6.3	42.48	23.00	7	0.23	11.75	6.3	-2%	0%	0%	2%	-22%	-0.8%
PU6_3440_3590	60.22	35.86	6	0.22	18	5.9	59.89	34.40	6	0.22	8	5.9	-1%	-4%	0%	1%	-56%	-0.3%
PU6_3530_3440	59.07	35.86	7	0.22	20	6.0	57.32	32.56	6	0.22	8	6.0	-3%	-9%	-14%	1%	-60%	-0.6%
PU6_3590_3640	60.57	35.86	6	0.22	17	5.9	61.25	34.83	6	0.22	7	5.8	1%	-3%	0%	1%	-59%	-1.0%
PU6_3600_3602	63.19	39.33	6	0.21	17	5.7	61.14	35.33	6	0.21	14	5.6	-3%	-10%	0%	2%	-18%	-0.7%
PU6_3602_3730	63.67	39.50	6	0.21	16.5	5.6	62.16	35.00	6	0.21	14	5.6	-2%	-11%	0%	2%	-15%	-0.7%
PU6_3610_3530	58.84	35.86	7	0.22	20	6.0	57.11	32.56	6	0.22	8	6.0	-3%	-9%	-14%	1%	-60%	-0.6%
PU6_3640_3600	62.58	35.86	6	0.21	18	5.7	63.87	36.00	6	0.22	6	5.7	2%	0%	0%	2%	-67%	-0.5%
PU6_3690_3610	53.83	35.43	7	0.21	18.25	5.9	52.01	33.29	6	0.21	6.25	5.8	-3%	-6%	-14%	2%	-66%	-1.7%
PU6_3730_3750	58.54	36.86	6	0.20	21.5	5.2	59.33	41.20	6	0.20	11.5	5.2	1%	12%	0%	2%	-47%	0.7%
PU6_3750_9915	59.17	37.14	6	0.19	20.5	5.1	59.21	42.50	6	0.20	8.5	5.4	0%	14%	0%	2%	-59%	4.1%
PU6_3752_4080	59.08	37.29	5	0.19	21.25	5.0	62.57	44.00	5	0.19	12	5.2	6%	18%	0%	2%	-44%	4.6%
PU6_3870_3690	53.54	32.60	6	0.21	22	6.1	50.61	29.33	6	0.22	7.5	6.0	-5%	-10%	0%	2%	-66%	-2.1%
PU6_4020_3870	46.65	26.86	8	0.23	14.75	6.0	44.22	23.57	7	0.24	0	6.0	-5%	-12%	-13%	2%	-100%	-0.7%
PU6_4080_4180	59.62	37.29	5	0.19	21	5.0	63.17	46.50	5	0.19	11	5.2	6%	25%	0%	2%	-48%	4.8%

	Baseline Flow Metrics (used in RPART)						Current Scenario Flow Metrics (used in RPART)						Alteration (calculated as (current-baseline)/baseline)					
River Segment	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)	MH21	DH17	High Pulse Count	Flashiness	Low Pulse Duration	Normalized 3-day Maximum (cfs/sq. mi.)
PU6_4180_4150	60.02	40.00	5	0.18	19.75	4.9	62.14	41.00	5	0.18	11.5	5.2	4%	3%	0%	2%	-42%	6.3%
PU6_9915_3752	58.52	35.20	6	0.19	20.5	5.1	59.64	42.50	6	0.20	8.5	5.4	2%	21%	0%	2%	-59%	4.2%

*: the baseline value is zero so the calculation results in a Divide-by-Zero error.

An actual value of zero is displayed as "0.0".