Total Maximum Daily Load of Sediment in the Upper Monocacy River Watershed, Frederick and Carroll Counties, Maryland

FINAL

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List of Abbreviations

BIBI	Benthic Index of Biotic Integrity
BIP	Buffer Incentive Program
BMP	Best Management Practices
CBP P5	Chesapeake Bay Program Phase 5
CV	Coefficient of Variation
CWA	Clean Water Act
DNR	Maryland Department of Natural Resources
EOF	Edge-of-Field
EOS	Edge-of-Stream
EPA	Environmental Protection Agency
EPSC	Environmental Permit Service Center
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ETM	Enhanced Thematic Mapper
FIBI	Fish Index of Biologic Integrity
GIS	Geographic Information System
IBI	Index of Biotic Integrity
Ind.	Indeterminate
LA	Load Allocation
MACS	Maryland Agriculture water quality cost share program
MBSS	Maryland Biological Stream Survey
MD 8-digit	Maryland 8-digit Watershed
MDE	Maryland Department of the Environment
MDL	Maximum Daily Load
MGD	Millions of Gallons per Day
mg/l	Milligrams per liter
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
N/A	Not Applicable
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service

NRI	Natural Resources Inventory
NS	No Sample
PSU	Primary Sampling Unit
RESAC	Regional Earth Science Applications Center
SSDI	Sediment Stream Disturbance Index
TMDL	Total Maximum Daily Load
ton/yr	Tons per Year
TSD	Technical Support Document
TSS	Total Suspended Solids
TM	Thematic Mapper
USGS	United Stated Geological Survey
WLA	Waste Load Allocation
WTP	Water Treatment Plant
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for sediment in the Maryland 8-digit (MD 8-digit) Upper Monocacy River watershed (basin number 02140303). Section 303(d) of the federal Clean Water Act (CWA) and the EPA's implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, the State is required to either establish a TMDL of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met (CFR 2007b).

The Maryland Department of the Environment (MDE) has identified the waters of the MD 8-digit Upper Monocacy River watershed on the State's 303(d) List as impaired by sediments (1996), nutrients (1996), bacteria (2002), and impacts to biological communities (2002, 2004, and 2006) (MDE 2007). The designated use of the MD 8-digit Upper Monocacy River and its tributaries is Use IV-P (Recreational Trout Waters and Public Water Supply) except for Fishing Creek, Hunting Creek, Owens Creek, and Friends Creek, which are designated as Use III-P (Nontidal Cold Water and Public Water Supply) (COMAR 2007a,b,c).

A data solicitation for sediments was conducted by MDE, and all readily available data from the past five years have been considered. A TMDL for fecal bacteria was submitted to the EPA in 2007. The listings for nutrients and impacts to biological communities will be addressed separately at a future date.

The MD 8-digit Upper Monocacy River watershed aquatic health scores, consisting of the Benthic Index of Biotic Integrity (BIBI) and Fish Index of Biotic Integrity (FIBI), indicate that the biological metrics for the watershed exhibit a significant negative deviation from reference conditions (Roth et al. 2005). The objective of the TMDL established herein is to ensure that there will be no sediment impacts affecting aquatic health, thereby establishing a sediment load that supports the Use IV-P/III-P designations for the MD 8-digit Upper Monocacy River watershed.

Currently in Maryland, there are no specific numeric criteria that quantify the impact of sediment on the aquatic health of non-tidal stream systems. To determine whether aquatic health is impacted by elevated sediment loads, a weight-of-evidence stressor identification approach was used. This approach applies a composite stressor indicator, defined as the *sediment stream disturbance index* (SSDI). Similar to the Index of Biotic Integrity (IBI), the SSDI is based on a comparison of specific watershed parameters with those from streams with a healthy aquatic community (i.e., reference watersheds) and is scored separately for the benthic and fish communities. Watershed specific SSDI values indicate whether sediment is one of the stressors affecting the biological community.

In order to quantify the impact of sediment on the aquatic health of non-tidal stream systems, a reference watershed TMDL approach was used and resulted in the establishment of a *sediment loading threshold* (Currey et al. 2006). This threshold is based on a detailed analysis of sediment loads from watersheds that are identified as supporting aquatic life (i.e., reference watersheds) based on Maryland's biocriteria (Roth et al. 1998, 2000; Stribling et al. 1998). This threshold is then used to determine a watershed specific sediment TMDL.

The computational framework chosen for the MD 8-digit Upper Monocacy River watershed TMDL was the Chesapeake Bay Program Phase 5 (CBP P5) watershed model target *edge-of-field* (EOF) land use sediment loading rate calculations combined with a *sediment delivery ratio*. The *edge-of-stream* (EOS) sediment load is calculated per land use as a product of the land use area, land use target loading rate, and loss from the EOF to the main channel. The spatial domain of the CBP P5 watershed model segmentation aggregates to the Maryland 8-digit watersheds, which is consistent with the impairment listing.

EPA's regulations require TMDLs to take into account seasonality and critical conditions for stream flow, loading, and water quality parameters (CFR 2007b). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The biological monitoring data used to determine the reference watersheds integrates the stress effects over the course of time and thus inherently addresses critical conditions. Seasonality is captured in two components. First, it is implicitly included in biological sampling. Second, the Maryland Biological Stream Survey (MBSS) dataset included benthic sampling in the spring and fish sampling in the summer.

All TMDLs need to be presented as a sum of waste load allocations (WLAs) for permitted point sources and load allocations (LAs) for nonpoint sources generated within the assessment unit, natural background, tributary, and adjacent segment loads. Furthermore, all TMDLs must include a margin of safety (MOS) to account for any lack of knowledge and uncertainty concerning the relationship between loads and water quality (CFR 2007a,b). It is proposed that the estimated variability around the reference watershed group used in this analysis already accounts for such uncertainty. This results in an implicit margin of safety of approximately 8%.

The MD 8-digit Upper Monocacy River Total Baseline Sediment Load is 98,728.7 tons per year (ton/yr). This baseline load consists of upstream loads generated outside the assessment unit (i.e., MD 8-digit watershed): a Pennsylvania Upstream Baseline Load (BL_{PA}) of 20,511.9 ton/yr and a Double Pipe Creek Upstream Baseline Load (BL_{DP}) of 35,224.3 ton/yr, and loads generated within the assessment unit: an MD 8-digit Upper Monocacy River Watershed Baseline Load Contribution of 42,992.5 ton/yr. The MD 8-digit Upper Monocacy River Watershed Baseline Load Contribution is further subdivided into nonpoint source baseline loads (Nonpoint Source BL_{UM}) and two types of point source baseline loads: National Pollutant Discharge Elimination System (NPDES) regulated stormwater (NPDES Stormwater BL_{UM}) and regulated process water (Process Water BL_{UM}) (see Table ES-1). Appendix D provides a detailed explanation of the upstream loads.

Table ES-1: MD 8-digit Upper Monocacy River Baseline Sediment Loads (ton/yr)

		Upstream Baseline Load[1]				MD 8-digit Upper Monocacy River Watershed Baseline Load Contribution				
Total Baseline Load (ton/yr)	=	**BL_{PA}**	+	**BL_{DP}[2]**	+	**Nonpoint Source BL_{UM}**	+	**NPDES Stormwater BL_{UM}**	+	**Process Water BL_{UM}**
98,728.7	=	20,511.9	+	35,224.3	+	38,679.3	+	4,129.1	+	184.1

Notes: [1] Although the Upstream Baseline Loads are reported here as single values, they could include point and nonpoint sources.
[2] For Double Pipe Creek watershed point and nonpoint source characterization, please refer to the "Total Maximum Daily Load of Sediment in the Double Pipe Creek Watershed, Frederick and Carroll Counties, Maryland" (MDE 2008).

The MD 8-digit Upper Monocacy River Average Annual TMDL of Sediment/Total Suspended Solids (TSS) is 66,707.3 ton/yr. Biological results from the Maryland Department of Natural Resources (DNR) Core/Trend stations along the mainstem of the MD 8-digit Upper Monocacy River indicate that mainstem water quality can be classified as good. Based on this information, MDE concluded that the sediment impairment in the Maryland portion of the Upper Monocacy River watershed is restricted to the lower order streams within Segment 2 of the watershed. Consequently, sediment reductions have been applied to the loads transported via the lower order stream network within Segment 2 (located mostly in Maryland) and not the loads transported from Segment 1 (located mostly in Pennsylvania) via the main channel. The TMDL consists of allocations attributed to loads generated outside the assessment unit referred to as Upstream Load Allocations: a Pennsylvania Upstream Load Allocation (LA_{PA}) of 19,362.0 ton/yr and a Double Pipe Creek Upstream Load Allocation (LA_{DP}) of 24,199.1 ton/yr, and allocations attributed to loads generated within the assessment unit: a MD 8-digit Upper Monocacy River Watershed TMDL Contribution of 23,146.2 ton/yr. The MD 8-digit Upper Monocacy River Watershed TMDL Contribution is further subdivided into point and nonpoint source allocations and is comprised of a Load Allocation (LA_{UM}) of 20,820.6 ton/yr, an NPDES Stormwater Wasteload Allocation (NPDES Stormwater WLA_{UM}) of 2,141.5 ton/yr, and a Process Water Waste Load Allocation (Process Water WLA_{UM}) of 184.1 ton/yr (see Table ES-2). This TMDL will ensure that the sediment loads and resulting effects are at a level to support the Use IV-P/III-P designations for the MD 8-digit Upper Monocacy River watershed, and more specifically, at a level to support aquatic health.

Table ES-2: Average Annual MD 8-digit Upper Monocacy River TMDL of Sediment/TSS (ton/yr)

TMDL (ton/yr)	=	LA					+	WLA			+	MOS
		LA_{PA}[1]	+	LA_{DP}[2]	+	LA_{UM}		NPDES Stormwater WLA_{UM}	+	Process Water WLA_{UM}		
66,707.3	=	19,362.0	+	24,199.1	+	20,820.6	+	2,141.5	+	184.1	+	Implicit
		Upstream Load Allocations[3, 4]				MD 8-digit Upper Monocacy River Watershed TMDL Contribution						

Notes:[1] LA_{PA} was determined to be necessary in order to meet Maryland water quality standards within the MD 8-digit Upper Monocacy River watershed.
[2] For Double Pipe Creek watershed WLA and LA characterization, please refer to the "Total Maximum Daily Load of Sediment in the Double Pipe Creek Watershed, Frederick and Carroll Counties, Maryland" (MDE 2008).
[3] Although for the purpose of this analysis upstream loads are referred to as LAs, they could include loads from point and nonpoint sources.
[4] A delivery factor of 1 was used for all of the Upstream Load Allocations.

Table ES-3: MD 8-digit Upper Monocacy River Baseline Load, TMDL, and Total Reduction Percentage

Baseline Load (ton/yr)	TMDL (ton/yr)	Total Reduction (%)
98,728.7	66,707.3	32.4

In addition to the TMDL value, a Maximum Daily Load (MDL) is also presented in this document. The calculation of the MDL, which is derived from the TMDL average annual loads is explained in Appendix C and presented in Table C-1.

Once the EPA has approved this TMDL and it is known what measures must be taken to reduce pollution levels, implementation of best management practices (BMPs) is expected to take place. MDE intends for the required reduction to be implemented in an iterative process that first addresses those sources with the largest impact to water quality, with consideration given to ease and cost of implementation.

Maryland has several well-established programs to draw upon, including the Water Quality Improvement Act of 1998 (WQIA) and the Federal Nonpoint Source Management Program (§ 319 of the Clean Water Act). Several potential funding sources for implementation are available, such as the Buffer Incentive Program (BIP), the State Water Quality Revolving Loan Fund, and the Stormwater Pollution Cost Share Program.

1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for sediments in the Maryland 8-digit (MD 8-digit) Upper Monocacy River watershed (basin number 02140303). Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the EPA's implementing regulations direct each state to develop a TMDL for each impaired water quality limited segment (WQLS) on the Section 303(d) List, taking into account seasonal variations, critical conditions, and a protective margin of safety (MOS) to account for uncertainty (CFR 2007b). A TMDL reflects the total pollutant loading of the impairing substance a waterbody can receive and still meet water quality standards.

TMDLs are established to determine the pollutant load reductions needed to achieve and maintain water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include activities such as swimming, drinking water supply, protection of aquatic life, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

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The objective of the TMDL established herein is to ensure that there will be no sediment impacts affecting aquatic health, thereby establishing a sediment load that supports Use IV-P/III-P designations for the MD 8-digit Upper Monocacy River watershed. Currently in Maryland, there are no specific numeric criteria that quantify the impact of sediment on the aquatic health of non-tidal stream systems. To determine whether aquatic health is impacted by elevated sediment loads, a weight-of-evidence stressor identification approach was used. This approach applies a composite stressor indicator, defined as the *sediment stream disturbance index* (SSDI). Similar to the Index of Biotic Integrity (IBI), the SSDI is based on a comparison of specific watershed parameters with those from streams with a healthy aquatic community (i.e., reference watersheds) and is scored separately for the benthic and fish communities. Watershed specific SSDI values indicate whether sediment is one of the stressors affecting the biological community.

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2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Monocacy River is a free flowing stream that originates in Pennsylvania and flows 58 miles within Maryland where it finally empties into the Potomac River. The watershed covers approximately 966 square miles, with approximately 224 square miles located in Pennsylvania and 742 square miles in Maryland. The basin can be subdivided into three distinct watersheds: the Upper Monocacy River, Lower Monocacy River, and Double Pipe Creek.

The Upper Monocacy River watershed encompasses areas within both Maryland and Pennsylvania; however, the assessment unit identified on the Maryland 303(d) list and consequently addressed by this TMDL consists only of the Maryland portion of the watershed, otherwise referred to as the MD 8-digit Upper Monocacy River watershed. Sediment loads generated within the Pennsylvania portion of the watershed as well as the sediment load transported via Double Pipe Creek, a tributary to the Upper Monocacy River, are included in the analysis, but will be referred to as upstream loads. The hydrological relationship amongst the three Monocacy River basin watersheds and the subsequent effect on sediment loads are further explained in Appendix D.

The MD 8-digit Upper Monocacy River watershed is located within Frederick and Carroll Counties, Maryland (see Figure 1). It lies to the west of the town of Westminster. The Upper Monocacy River and its tributaries flow through several small towns, including Thurmont, Taneytown, and Emmitsburg. The total Upper Monocacy River watershed spans 472 square miles, with 5% of the total watershed area covered by water (i.e., streams, ponds, etc.). The total population in the MD 8-digit Upper Monocacy River watershed is estimated to be approximately 42,500 (US Census Bureau 2000).

Geology/Soils

The MD 8-digit Upper Monocacy River lies within both the Piedmont and Blue Ridge physiographic provinces of Maryland. The Piedmont Plateau Province is composed of hard, crystalline igneous and metamorphic rocks and extends from the inner edge of the Coastal Plain westward to Catoctin Mountain, the eastern boundary of the Blue Ridge Province. The Piedmont Province is an area of rolling uplands with elevations ranging from 100 to 500 feet above sea level. Soils of the Piedmont were derived from granite rock and consist of loams and clays with rock fragments and gravel. The Blue Ridge Province is underlain primarily by folded and faulted sedimentary rocks. The rocks of the Blue Ridge Province in western Frederick County are exposed in a large anticlinal fold whose limbs are represented by Catoctin Mountain and South Mountain. (DNR 2007b; MGS 2007; MDE 2000). The soils in the watershed are in the Klinesville, Catoctin, Athol, and Codorus Associations, which are all loamy, mixed, and methic soil types (USDA 1960, 1969).

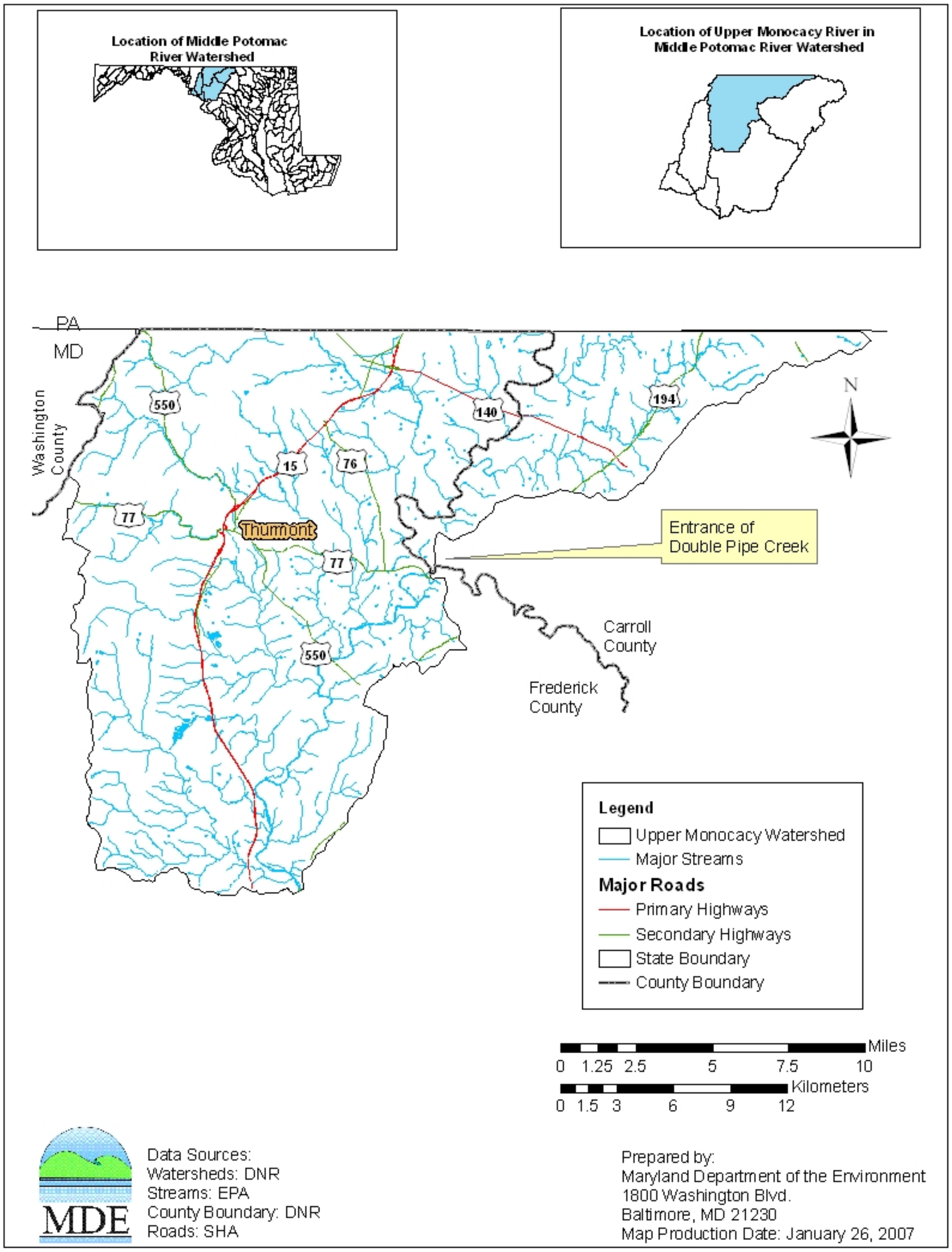

Figure 1: Location Map of the MD 8-digit Upper Monocacy River Watershed in Frederick and Carroll Counties, Maryland

2.1.1. Land Use

Land Use Methodology

The land use framework used to develop this TMDL was originally developed for the Chesapeake Bay Program Phase 5 (CBP P5) watershed model.[1] The CBP P5 land use Geographic Information System (GIS) framework was based on two distinct layers of development. The first GIS layer was developed by the Regional Earth Science Applications Center (RESAC) at the University of Maryland and was based on satellite imagery (Landsat 7-Enhanced Thematic Mapper (ETM) and 5-Thematic Mapper (TM)) (Goetz et al. 2004). This layer did not provide the required level of accuracy that is especially important when developing agricultural land uses. In order to develop accurate agricultural land use calculations, the CBP P5 used county level U.S. Agricultural Census data as a second layer (USDA 1982, 1987, 1992, 1997, 2002).

Given that land cover classifications based on satellite imagery are likely to be least accurate at edges (i.e., boundaries between covers), the RESAC land uses bordering agricultural areas were analyzed separately. If the agricultural census data accounted for more agricultural use than the RESAC's data, appropriate acres were added to agricultural land uses from non-agricultural land uses. Similarly, if census agricultural land estimates were smaller than RESAC's, appropriate acres were added to non-agricultural land uses.

Adjustments were also made to the RESAC land cover to determine developed land uses. RESAC land cover was originally based on the United States Geological Survey (USGS) protocols used to develop the 2000 National Land Cover Database. The only difference between the RESAC and USGS approaches was RESAC's use of town boundaries and road densities to determine urban land covered by trees or grasses. This approach greatly improved the accuracy of the identified urban land uses, but led to the misclassification of some land adjacent to roads and highways as developed land. This was corrected by subsequent analysis. To ensure that the model accurately represented development over the simulation period, post-processing techniques that reflected changes in urban land use have been applied.

The result of this approach is that CBP P5 land use does not exist in a single GIS coverage; instead it is only available in a tabular format. The CBP P5 watershed model is comprised of 25 land uses. Most of these land uses are differentiated only by their nitrogen and phosphorus loading rates. The land uses are divided into 14 classes with distinct sediment erosion rates. Table 1 lists the CBP P5 generalized land uses, detailed land uses, which are classified by their erosion rates, and the acres of each land use in the Upper Monocacy River watershed. Details of the land use development methodology have been summarized in the report entitled "Chesapeake Bay Phase 5 Community Watershed Model: Tracking Nutrient and Sediment Loads on a Regional and Local Scale" (US EPA 2007).

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[1] The EPA Chesapeake Bay Program developed the first watershed model in 1982. There have been many upgrades since the first phase of this model. The CBP P5 was developed to estimate flow, nutrient, and sediment loads to the Bay.

Upper Monocacy River Watershed Land Use Distribution

The Upper Monocacy River watershed land use was evaluated separately for Maryland and Pennsylvania. The land use distribution in Maryland consists primarily of forest (45.3%) and crop (29.5%) land uses, with urban (14.8%) and pasture (10.4%) land use classifications making up the remainder of the distribution. In Pennsylvania, the land use also consists primarily of forest (43.9%) and crop (33.1%) land use, with smaller amounts of urban (12.9%) and pasture (10.0%).

A land use map is provided in Figure 2 and a summary of the watershed land use areas is presented in Table 1.

Table 1: Land Use Percentage Distribution for Upper Monocacy River Watershed

		Maryland			Pennsylvania		
General Land Use	**Detailed Land Use**	**Area (Acres)**	**Percent**	**Grouped Percent of Total**	**Area (Acres)**	**Percent**	**Grouped Percent of Total**
Crop	Animal Feeding Operations	36.3	0.0		55.4	0.0	
	Hay	16,054.2	10.8		24,595.7	17.7	
	High Till	12,365.6	8.3		9,866.7	7.1	
	Low Till	14,790.6	9.9		10,891.2	7.8	
	Nursery	639.1	0.4	29.5	563.4	0.4	33.1
Extractive	Extractive	13.2	N/A[1]	N/A[1]	39.0	N/A[1]	N/A[1]
Forest	Forest	66,810.6	44.9		60,382.6	43.5	
	Harvested Forest	674.9	0.5	45.3	609.9	0.4	43.9
Pasture	Natural Grass	961.4	0.6		3,743.5	2.7	
	Pasture	14,400.6	9.7		10,070.8	7.3	
	Trampled Pasture	75.4	0.1	10.4	52.7	0.0	10.0
Urban	Urban: Barren	231.1	0.2		276.2	0.2	
	Urban: Imp	2,686.7	1.8		3,241.2	2.3	
	Urban: perv	19,145.1	12.9	14.8	14,433.0	10.4	12.9
	Total	148,884.8	100.0	100.0	138,821.4	100.0	100.0

Note: [1] Percentage of total land area is minimal.

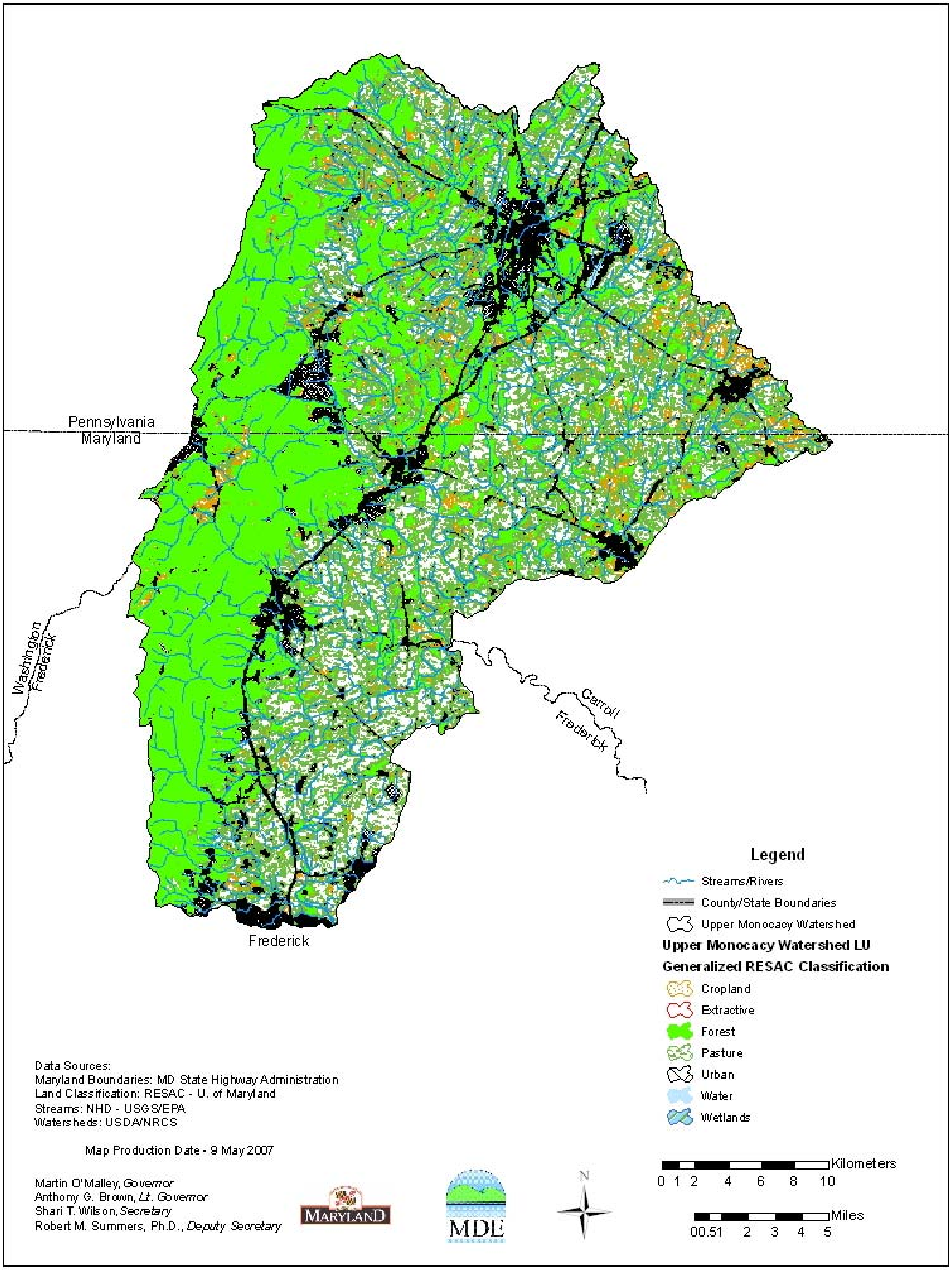


Figure 2: Land Use of the Upper Monocacy River Watershed

2.2 Source Assessment

The MD 8-digit Upper Monocacy River Total Baseline Sediment Load consists of loads generated outside the 8-digit assessment unit, referred to as Upstream Baseline Loads, and loads generated within the assessment unit, referred to as the MD 8-digit Upper Monocacy River Watershed Baseline Load Contribution. The MD 8-digit Upper Monocacy River Watershed Baseline Load Contribution can be further subdivided into nonpoint and point source loads. This section summarizes methods used to derive each of these three distinct source categories.

2.2.1 Nonpoint Sources Assessment

In this document, the nonpoint source loads account for sediment loads from unregulated storm water runoff within the MD 8-digit watershed. This section provides background and methods used to characterize the nonpoint source baseline loads generated within the MD 8-digit Upper Monocacy River watershed (Nonpoint Source BL_{UM}). This approach was also used to estimate the Pennsylvania Upstream Baseline Load.

General load estimation methodology

Nonpoint source sediment loads generated within the MD 8-digit watershed are estimated based on the *edge-of-stream (EOS) calibration target loading rates* from the CBP P5 model. This approach is based on the fact that not all of the *edge-of-field* (EOF) sediment load is delivered to the stream or river (some of it is stored on fields down slope, at the foot of hillsides, or in smaller rivers or streams that are not represented in the model). To calculate the actual EOS loads, a *sediment delivery ratio* (the ratio of sediment reaching a basin outlet compared to the total erosion within the basin) is used. Details of the methods used to calculate sediment load have been summarized in the report entitled "Chesapeake Bay Phase 5 Community Watershed Model: Tracking Nutrient and Sediment Loads on a Regional and Local Scale" (US EPA 2007).

Edge-of-Field Target Erosion Rate Methodology

EOF target erosion rates for agricultural land uses and forested land use were based on erosion rates determined by the National Resource Inventory (NRI). NRI is a statistical survey of land use and natural resource conditions conducted by the Natural Resources Conservation Service (NRCS) (USDA 2007). Sampling methodology is explained by Nusser and Goebel (1997).

Estimates of average annual erosion rates for pasture and cropland are available on a county basis at five-year intervals, starting in 1982. Erosion rates for forested land uses are not available on a county basis from NRI; however, for the purpose of the CBP Phase 2 watershed model, NRI calculated average annual erosion rates for forested land use on a watershed basis. These rates are still being used as targets in the CBP P5 model.

The average value of the 1982 and 1987 surveys was used as the basis for EOF target loads. The erosion rates from this period do not reflect best management practices (BMPs) or other soil conservation policies introduced in the wake of the effort to restore the Chesapeake Bay. To compensate for this, a BMP factor was included in the loading estimates using best available "draft" information from the CBP. However, the effect of these factors was minimal, as most of the anticipated reductions are expected to result from land use changes (e.g. high till to low till). Rates for urban pervious, urban impervious, and barren land were based on a combination of best professional judgment, literature analysis, and regression analysis. Table 2 lists erosion rates specific to the Upper Monocacy River watershed.

Table 2: Summary of EOF Erosion Rate Calculations

Land Use	Data Source	Carroll County (MD) (Ton/Acre/Yr)	Frederick County (MD) (Ton/Acre/Yr)	Franklin County (PA) (Ton/Acre/Yr)	Adams County (PA) (Ton/Acre/Yr)
Forest	Phase 2 NRI	0.34	0.21	0.33	0.29
Harvested Forest[1]	Average Phase 2 NRI (x 10)	3	3	3	3
Natural Grass	Average NRI Pasture (1982-1987)	1.5	1.5	1.5	1.5
Pasture	Pasture NRI (1982-1987)	0.85	1.48	0.74	0.17
Trampled pasture[2]	Pasture NRI (x 9.5)	8.08	14.06	7.03	1.62
Animal Feeding Operations[2]	Pasture NRI (x 9.5)	8.08	14.06	7.03	1.62
Hay[2]	Crop NRI (1982-1987) (x 0.32)	1.05	2.46	2	1.44
High Till Without Manure[2]	Crop NRI (1982-1987) (x 1.25)	4.09	9.59	7.82	5.61
High Till With manure[2]	Crop NRI (1982-1987) (x 1.25)	4.09	9.59	7.82	5.61
Low till With Manure[2]	Crop NRI (1982-1987) (x 0.75)	2.45	5.76	4.69	3.36
Pervious Urban	Intercept Regression Analysis	0.74	0.74	0.74	0.74
Extractive	Best professional judgment	10	10	10	10
Barren	Literature survey	12.5	12.5	12.5	12.5
Impervious	100% Impervious Regression Analysis	5.18	5.18	5.18	5.18

Notes: [1] Based on an average of NRI values for the Chesapeake Bay Phase 5 segments.
[2] NRI score data adjusted based on land use.

Sediment Delivery Ratio: The base formula for calculating *sediment delivery ratio*s in the CBP P5 model is the same as the formula used by the NRCS (USDA 1983).

$$DF = 0.417762 * A^{-0.134958} - 0.127097 \qquad (2.1)$$

where
DF (delivery factor) = the sediment delivery ratio
A = drainage area in square miles

In order to account for the changes in sediment loads due to distance traveled to the stream, the CBP P5 model uses the *sediment delivery ratio*. Land use specific *sediment delivery ratios* were calculated for each river segment using the following procedure:

(1) mean distance of each land use from the river reach was calculated;

(2) *sediment delivery ratio*s for each land use were calculated (drainage area in Equation 2.1 was assumed to be equal to the area of a circle with radius equal to the mean distance between the land use and the river reach).

Edge-of-Stream Loads

Edge-of-stream loads are the loads that actually enter the river reaches (i.e., the mainstem of a watershed). Such loads represent not only the erosion from the land but all of the intervening processes of deposition on hillsides and sediment transport through smaller rivers and streams.

2.2.2 Point Source Assessment

A list of 36 active permitted point sources that contribute to the sediment load in the MD 8-digit Upper Monocacy River watershed was compiled using MDE's Environmental Permit Service Center (EPSC) database. The types of permits identified include individual industrial, individual municipal, general mineral mining, general industrial stormwater, individual municipal separate storm sewer systems (MS4s), and general MS4s. The permits can be grouped into two categories, process water and stormwater. The stormwater category includes all National Pollutant Discharge Elimination System (NPDES) regulated stormwater discharges. The process water category includes those loads generated by continuous discharge sources whose permits have total suspended solids (TSS) limits. Other permits that do not meet these conditions are considered *de minimis* in terms of the total sediment load.

The sediment loads for the 16 process water permits (Process Water BL_{UM}) are calculated based on their TSS limits and corresponding flow information. The 20 NPDES Phase I or Phase II stormwater permits identified throughout the MD 8-digit Upper Monocacy River watershed are regulated based on BMPs and do not include TSS limits. In the absence of TSS limits, the NPDES regulated stormwater baseline load (NPDES Stormwater BL_{UM}) is calculated using methods described in Section 2.2.1 and watershed specific urban land use sediment delivery factors. A detailed list of the permits appears in Appendix B.

2.2.3 Upstream Loads Assessment

For the purpose of this analysis two upstream watersheds have been identified: (1) the Pennsylvania portion of the Upper Monocacy River watershed and (2) the Double Pipe Creek watershed. Subsequently, sediment baseline loads from these watersheds will be presented as a Pennsylvania Upstream Baseline Load (BL_{PA}) and a Double Pipe Creek Upstream Baseline Load (BL_{DP}). The BL_{PA} is estimated based on land use specific sediment delivery ratios (this method is described in Section 2.2.1). The BL_{DP} is based on the same approach and is presented in a separate Double Pipe Creek TMDL document (MDE 2008).

2.2.4 Summary of Baseline Loads

Table 3 summarizes the MD 8-digit Upper Monocacy River Baseline Sediment Load, reported in tons per year (ton/yr) and presented in terms of Upstream Baseline Loads and MD 8-digit Upper Monocacy River Watershed Baseline Load Contribution nonpoint and point source loadings.

Table 3: MD 8-digit Upper Monocacy River Baseline Sediment Loads (ton/yr)

		Upstream Baseline Load[1]				MD 8-digit Upper Monocacy River Watershed Baseline Load Contribution				
Total Baseline Load (ton/yr)	=	**BL_{PA}**	+	**BL_{DP}[2]**	+	**Nonpoint Source BL_{UM}**	+	**NPDES Stormwater BL_{UM}**	+	**Process Water BL_{UM}**
98,728.7	=	20,511.9	+	35,224.3	+	38,679.3	+	4,129.1	+	184.1

Notes: [1] Although the Upstream Baseline Loads are reported here as single values, they could include point and nonpoint sources.
[2] For Double Pipe Creek watershed point and nonpoint characterization, please refer to the "Total Maximum Daily Load of Sediment in the Double Pipe Creek Watershed, Frederick and Carroll Counties, Maryland" (MDE 2008).

Table 4 presents a breakdown of the baseline loads generated within the Upper Monocacy River watershed, detailing loads per land use and state. The majority of the sediment load in both Maryland and Pennsylvania is from cropland (77.5% of the total sediment budget in Maryland and 66.8% in Pennsylvania). In Maryland, the next largest sediment sources are urban (9.6%), pasture (6.4%), and forest (6.1%). In Pennsylvania, the next largest sediment sources are urban (17.3%), forest (10.6%), and pasture (5.2%).

Table 4: Detailed Baseline Sediment Budget Loads Generated within the Upper Monocacy River Watershed

General Land Use	Description	Maryland			Pennsylvania		
		Load (ton/yr)	Percent	Grouped Percent of Total	Load (ton/yr)	Percent	Grouped Percent of Total
Crop	Animal Feeding Operations	70.2	0.2	77.5	10.2	0.0	66.8
	Hay	5,447.8	12.7		4,274.9	20.8	
	High Till	15,994.4	37.2		4,989.8	24.3	
	Low Till	10,555.4	24.6		4,315.3	21.0	
	Nursery	1,230.0	2.9		110.2	0.5	
Extractive	Extractive	21.3	N/A[3]	N/A[3]	32.5	0.2	0.2
Forest	Forest	2,393.0	5.6	6.1	1,959.2	9.6	10.6
	Harvested Forest	225.0	0.5		213.8	1.0	
Pasture	Natural Grass	175.5	0.4	6.4	820.2	4.0	5.2
	Pasture	2,435.6	5.7		234.8	1.1	
	Trampled Pasture	131.1	0.3		11.8	0.1	
Urban[1]	Urban: Barren	431.0	1.0	9.6	413.3	2.0	17.3
	Urban: Imp	1,855.7	4.3		1,954.1	9.5	
	Urban: Perv	1,842.4	4.3		1,171.8	5.7	
N/A	Process Water	184.1	0.4	0.4	N/A	N/A	N/A
	Total	**42,992.5**	**100.0**	**100.0**	**20,511.9**[2]	**100.0**	**100.0**

Notes: 1 The Maryland urban land use load represents the permitted stormwater load.
2 MD 8-digit Upper Monocacy River watershed receives loads from two upstream waterbodies: (1) the Pennsylvania portion of the Upper Monocacy River watershed and (2) the Double Pipe Creek watershed. The Pennsylvania baseline load is estimated based methods described in Section 2.2.1. The Double Pipe Creek baseline load of 35,224.3 ton/yr is based on the same approach summarized in a separate Double Pipe Creek TMDL document (MDE 2008).
3 Percentage of total load is minimal.

2.3 Water Quality Characterization

The MD 8-digit Upper Monocacy River watershed was originally listed on Maryland's 1996 303(d) List as impaired by elevated sediments from nonpoint sources, with supporting evidence cited in Maryland's 1996 305(b) report. The 1996 305(b) report did not directly state that elevated sediments were a concern, and it has been determined that the sediment listing was based on best professional judgment (MDE 2004; DNR 1996).

Currently in Maryland, there are no specific numeric criteria for suspended sediments. However, the Maryland 2004 303(d) report states that degraded stream water quality resulting in a sediment impairment is characterized by erosional impacts, depositional impacts, and decreased water clarity (MDE 2004). Therefore, the evaluation of suspended sediment loads will be based on how the sediment related impacts are influencing the designated use of supporting aquatic health, as defined by Maryland's biocriteria (Roth et al. 1998, 2000; Stribling et al. 1998).

Recently, MDE developed a stressor identification methodology entitled "Using MBSS Data to Identify Stressors for Streams that Fail Biocriteria in Maryland" (Southerland et al. 2007). This document proposes a conceptual model (see Figure 3) that establishes a link between sediment loads and aquatic health. Specifically, it identifies whether current sediment loads have a negative impact on a watershed's aquatic health based on the observed sediment impacts. This linkage between sediment loads, sediment impacts, and aquatic health is used to evaluate a sediment impairment.

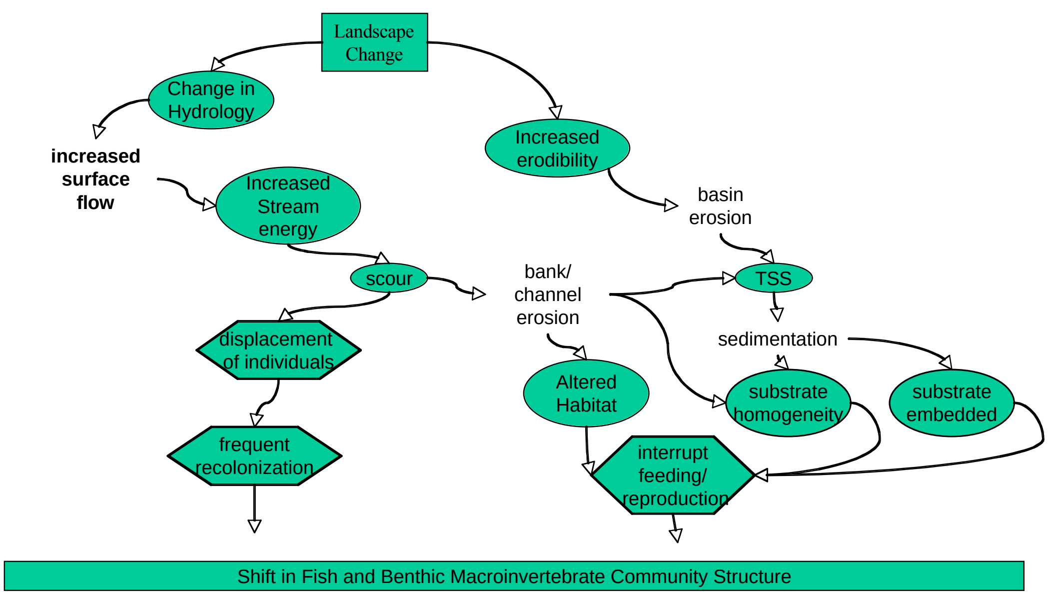


Figure 3: Sediment Stressor Conceptual Model

The sediment stressor conceptual model (adapted from Southerland et al. 2007) illustrates that changes in the landscape result in two possible paths, one triggered by changes in hydrology and the other triggered by increased land erodibility. Both paths ultimately result in changes in TSS and sediment loads, which, if increased, will result in a negative shift in the structure of the biological community.

Furthermore, the stressor conceptual model identifies water column TSS as the most direct measure of sediment loadings. Therefore, TSS was chosen as the most appropriate parameter for the sediment TMDL analysis. While an effective TSS concentration threshold would include both exposure duration and concentration magnitude, due to natural variations in geology, topography, and episodic flows, such a threshold would be extremely difficult to quantify (Rowe et al. 2003). In addition, the collection of sufficient instantaneous TSS concentration and flow data would be difficult due to high cost and limited site access during high flow events. Thus, MDE has not established a specific TSS water column concentration criteria. As a result, the water quality characterization of TSS impacts to aquatic life will be based on the cumulative impacts identified from observed streambed measures. Upon identification of sediment impacts, the TMDL will be estimated as a cumulative loading based on a comparison of the current watershed sediment loads with the acceptable levels derived from reference watersheds.

The streambed measures used to determine the water quality characterization were gathered from the Maryland Biological Stream Survey (MBSS) dataset. The MBSS uses a fixed length (75 m) randomly selected stream segment for collecting site level information within a primary sampling unit (PSU), also defined as a watershed. The randomly selected stream segments, from which field data are collected, are selected using either stratified random sampling with proportional allocation, or simple random sampling (Cochran 1977). This allocation ensures that all sites in a PSU stream network have the same probability of being selected. The random sample design allows for unbiased watershed estimates of mean conditions by averaging results at multiple stations. The average watershed estimates are then used to determine if streams within a watershed have a degraded biology (fish or benthic) and subsequently whether or not sediment is contributing to the observed degradation (Roth et al. 2005).

MD 8-digit Upper Monocacy River Watershed Monitoring Stations

A total of 20 water quality monitoring stations were used to characterize the MD 8-digit Upper Monocacy River Watershed. There were 18 biological/physical habitat monitoring stations from the MBSS program and 2 biological monitoring stations from the Maryland Core/Trend monitoring network. The stations are presented in Figure 4 and listed in Table 5.

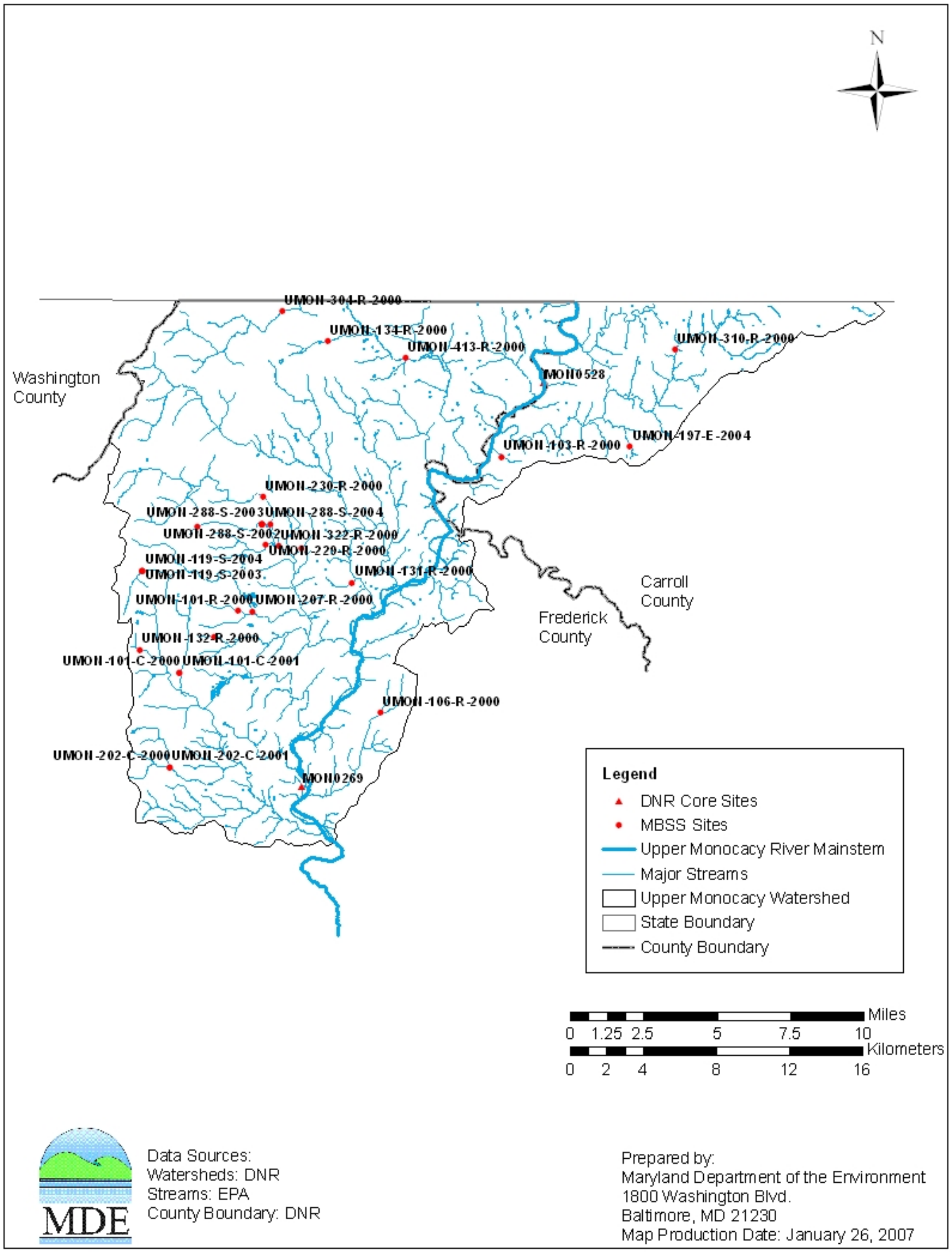


Figure 4: Monitoring Stations in the MD 8-digit Upper Monocacy River Watershed

Table 5: Monitoring Stations in the MD 8-digit Upper Monocacy River Watershed

Site Number	Sponsor	Site Type	Site Name	Latitude (dec degrees)	Longitude (dec degrees)
UMON-101-R-2000	MD DNR	MBSS	Little Hunting Creek, unnamed tributary	39.56690	-77.43050
UMON-103-R-2000	MD DNR	MBSS	Monocacy River, unnamed tributary	39.64340	-77.26296
UMON-106-R-2000	MD DNR	MBSS	Glad Creek	39.51701	-77.33965
UMON-115-R-2000	MD DNR	MBSS	Sandy Run	39.55377	-77.44600
UMON-117-R-2000	MD DNR	MBSS	Graceham Run	39.59785	-77.39072
UMON-119-R-2000	MD DNR	MBSS	Buzzard Bridge	39.58636	-77.49148
UMON-128-R-2000	MD DNR	MBSS	High Run	39.60833	-77.45667
UMON-131-R-2000	MD DNR	MBSS	Creagers Bridge	39.58113	-77.35790
UMON-132-R-2000	MD DNR	MBSS	Steep Creek, unnamed tributary	39.54739	-77.49303
UMON-134-R-2000	MD DNR	MBSS	Turkey Creek	39.70000	-77.37445
UMON-207-R-2000	MD DNR	MBSS	Little Hunting Creek	39.56674	-77.42117
UMON-221-R-2000	MD DNR	MBSS	Hunting Creek	39.60948	-77.41047
UMON-229-R-2000	MD DNR	MBSS	Muddy Run	39.59967	-77.41290
UMON-230-R-2000	MD DNR	MBSS	Hunting Creek	39.62291	-77.41478
UMON-304-R-2000	MD DNR	MBSS	Friends Creek	39.71475	-77.40314
UMON-310-R-2000	MD DNR	MBSS	Piney Creek	39.69634	-77.15239
UMON-322-R-2000	MD DNR	MBSS	Hunting Creek	39.59881	-77.40523
UMON-413-R-2000	MD DNR	MBSS	Toms Creek	39.69182	-77.32469
MONO269	MD DNR	CORE	Biggs Ford Road	39.48027	-77.38972
MONO528	MD DNR	CORE	Route 140	39.67972	-77.23611

<u>MD 8-digit Upper Monocacy River MBSS Monitoring Stations</u>

The MBSS program monitored 18 locations in the MD 8-digit Upper Monocacy River watershed in 2000 (see Figure 4 and Table 5). The MBSS parameters recommended from the stressor identification model for determining a sediment stressor were: percent embeddedness, epifaunal substrate score, instream habitat score, bank stability index, and number of benthic tolerant species. These specific parameters were chosen based on their ecological and statistical significance (Southerland et al. 2007) as well as their linkage to increased terrestrial and/or instream erosion. High percent embeddedness indicates that fine particulates are filling the spaces between cobbles, thus covering habitat and limiting food supply. Low epifaunal substrate is an indication of either stream erosion or excess deposition limiting the quality of the streambed to support a benthic community. Decreased in-stream habitat is an indication of potential erosion removing woody debris and is primarily linked with the Fish Index of Biotic Integrity (FIBI). The bank stability index is a composite score that indicates the lack of channel erosion, based on the presence or absence of riparian vegetation and other stabilizing bank materials. The number of benthic tolerant species is an indicator of frequent stream scouring, which prevents more sensitive species from colonizing the streambed.

Observed values of the above parameters, along with Benthic Index of Biotic Integrity (BIBI) and FIBI scores, are presented in Table 6.

Table 6: MD 8-digit Upper Monocacy River MBSS Data

Site	FIBI	BIBI	Epifaunal Substrate	Percent embeddedness	Instream Habitat	Bank Stability Index	Benthic Tolerant Species
UMON-101-R-2000	1.00	2.00	12	35	10	19.67	5.38
UMON-103-R-2000	1.33	1.75	11	35	11	20.00	5.18
UMON-106-R-2000	1.00	1.75	7	90	12	10.00	6.38
UMON-115-R-2000	2.00	3.00	17	25	12	20.00	4.29
UMON-117-R-2000	2.67	2.50	11	65	11	19.67	5.44
UMON-119-R-2000	3.00	3.75	18	25	17	19.67	3.47
UMON-128-R-2000	NS	1.50	NS	NS	NS	NS	6.40
UMON-131-R-2000	1.33	1.75	10	45	9	20.00	6.50
UMON-132-R-2000	2.00	1.25	9	20	8	20.00	6.60
UMON-134-R-2000	1.50	2.50	18	35	13	19.67	4.00
UMON-207-R-2000	4.00	3.00	16	NS	18	20.00	4.53
UMON-221-R-2000	4.67	3.75	16	30	17	20.00	4.72
UMON-229-R-2000	2.50	3.25	11	45	12	18.33	3.73
UMON-230-R-2000	4.33	4.25	20	20	18	20.00	3.77
UMON-304-R-2000	4.67	3.50	16	30	19	20.00	4.50
UMON-310-R-2000	4.00	1.75	8	45	12	12.83	6.75
UMON-322-R-2000	4.67	2.50	18	10	19	19.33	5.61
UMON-413-R-2000	5.00	2.50	17	20	17	16.93	5.50

Note: NS = No sample

MD 8-digit Upper Monocacy River Core Monitoring Stations

Additional data for the MD 8-digit Upper Monocacy River watershed was obtained from the Maryland Department of Natural Resources (DNR) Core/Trend Program. The program collected benthic macroinvertebrate data between 1976 and 2006. This data was used to calculate four benthic community measures: total number of taxa, the Shannon-Weiner diversity index, the modified Hilsenhoff biotic index, and percent Ephemeroptera, Plecoptera, and Trichoptera (EPT). DNR has extensive monitoring information for two stations in the mainstem of the MD 8-digit Upper Monocacy River through the CORE Program. The stations are located on Biggs Ford Road (MONO269) and on Route 140 (MONO528) (see Figure 4 and Table 5). These stations have between 21 and 28 years of benthic macroinvertebrate data (DNR 2007a). A summary of the results for each of the stations is presented in Table 7.

Table 7: MD 8-digit Upper Monocacy River DNR Core Data

Site Number	Current Water Quality Status	Trend Since 1970's
MONO269	GOOD/VERY GOOD	NO CHANGE
MONO528	GOOD/VERY GOOD	MODERATE IMPROVEMENT

2.4 Water Quality Impairment

The Maryland water quality standards surface water use designation for the MD 8-digit Upper Monocacy River mainstem and its tributaries is Use IV-P (Recreational Trout Waters and Public Water Supply) except for Fishing Creek, Hunting Creek, Owens Creek, and Friends Creek, which are designated as Use III-P (Nontidal Cold Water and Public Water Supply) (COMAR 2007a,b,c). The water quality impairment of the MD 8-digit Upper Monocacy River watershed addressed by this TMDL is caused by an elevated sediment load beyond a level that is supportive of aquatic health, where aquatic health is evaluated based on BIBI and FIBI scores (BIBI and FIBI ≥ 3).

To determine whether aquatic health is impacted by elevated sediment loads, a weight-of-evidence stressor identification approach was used. This approach applies a composite stressor indicator, defined as the *sediment stream disturbance index*. Similar to the Index of Biotic Integrity, the SSDI is based on a comparison of specific watershed parameters with those from streams with a healthy aquatic community (i.e., reference watersheds) and is scored separately for the benthic and fish communities. The benthic SSDI includes benthic tolerant species, embeddedness, bank stability, and epifaunal substrate condition. The fish SSDI includes embeddedness, epifaunal substrate, and instream habitat condition. Watershed specific SSDI values indicate whether sediment is one of the stressors affecting the biological community.

The SSDI is developed by scoring each parameter result (see Section 2.3) and then calculating the average of the scores to form an index value. Each parameter result is scored a value of 1, 3, or 5, depending on whether the parameter value at a site approximates (5), deviates slightly from (3), or deviates greatly from (1) conditions at reference sites (Karr et al. 1986). This discrete scoring approach was based on Maryland's IBI methodology, so that a direct comparison could be made between the SSDI and the IBI thresholds. Per Maryland's biocriteria, FIBI and BIBI scores less than 3 are indicative of water quality conditions that are not protective of aquatic life (Roth et al. 1998, 2000; Stribling et al. 1998). Similarly, an SSDI score less than 3 provides evidence of a sediment stressor or sediment impact to the aquatic community. An SSDI score significantly greater than 3 indicates that there is no evidence of adverse sediment impacts to the aquatic community.

The threshold values for each selected parameter were established based on how they compared to the values observed at the reference sites (i.e., sites with FIBI & BIBI>3.0). For parameters expected to decrease with degradation, values below the 10th percentile were scored as 1. Values between the 10th and 50th percentiles were scored as 3. Values above the 50th percentile were scored as 5. Scoring was reversed for metrics expected to increase with degradation (i.e., values below the 50th percentile were scored as 5, and values above the 90th percentile were scored as 1). In this method, both the upper and lower thresholds are independently derived from the distribution of reference site values. This approach is based on the assumption that in Maryland, and most other states, even reference sites are expected to have some degree of anthropogenic impact (Southerland et al. 2005). Thresholds used for scoring the SSDI are summarized in Table 8. Further details are found in Appendix A.

Table 8: Sediment Stream Disturbance Index Scoring

Parameter	Score		
	1	3	5
Benthic Tolerant Species Limits	x ≥ 5.3	5.3 > x ≥ 4.2	x <4.2
Bank Stability	x < 12	12 ≤ x < 19	x ≥ 19
Embeddedness Limits	x > 40	40 ≥ x > 25	x ≤ 25
Epifaunal Substrate Limits	x < 10	10 ≤ x < 15	x ≥ 15
Instream Habitat Condition Limits	x < 10	10 ≤ x < 16	x ≥ 16

The MD 8-digit Upper Monocacy River watershed average BIBIs, FIBIs, and corresponding SSDIs are listed in Table 9. The BIBIs and FIBIs indicate that the watershed is exhibiting a negative deviation from reference conditions. Both the benthic and fish based SSDIs indicate that sediment is a stressor to the aquatic community. Therefore, it is concluded that a sediment TMDL is required.

Table 9: MD 8-digit Upper Monocacy River IBI and SSDI Scores

Site	BIBI	Benthic SSDI	FIBI	Fish SSDI
UMON-101-R-2000	2.00	3.00	1.00	3.00
UMON-103-R-2000	1.75	3.50	1.33	3.00
UMON-106-R-2000	1.75	1.00	1.00	1.67
UMON-115-R-2000	3.00	4.50	2.00	4.33
UMON-117-R-2000	2.50	2.50	2.67	2.33
UMON-119-R-2000	3.75	5.00	3.00	5.00
UMON-128-R-2000	1.50	1.00	NS	NS
UMON-131-R-2000	1.75	2.50	1.33	1.67
UMON-132-R-2000	1.25	3.00	2.00	2.33
UMON-134-R-2000	2.50	4.50	1.50	3.67
UMON-207-R-2000	3.00	4.33	4.00	5.00
UMON-221-R-2000	3.75	4.00	4.67	4.33
UMON-229-R-2000	3.25	3.00	2.50	2.33
UMON-230-R-2000	4.25	5.00	4.33	5.00
UMON-304-R-2000	3.50	4.00	4.67	4.33
UMON-310-R-2000	1.75	1.50	4.00	1.67
UMON-322-R-2000	2.50	4.00	4.67	5.00
UMON-413-R-2000	2.50	3.50	5.00	5.00
Average	**2.57 ± 0.34**	**3.32 ± 0.49**	**2.92 ± 0.58**	**3.51 ± 0.53**

Note: NS = No sample

Biological results from the two DNR Core/Trend stations along the mainstem of the MD 8-digit Upper Monocacy River indicate that mainstem water quality can be classified as good to very good. Statistical analysis of the long-term Core/Trend data indicates that since 1976, both stations have shown improvement and are ranked as having good water quality based on percent EPT, taxa number, biotic index, and diversity index (DNR 2007a).

Since both Core station biological monitoring results on the MD 8-digit Upper Monocacy River mainstem indicate good conditions, it is concluded that sediment loads from Pennsylvania and Maryland located upstream of station MON0528, are not impacting water quality in the MD 8-digit Upper Monocacy River mainstem. Thus, MDE concludes that the sediment impairment is within the lower order (smaller) streams in the Maryland portion of the watershed, extending up to station MON0528, and is subsequently dividing the watershed into two TMDL segments. TMDL Segment 1, upstream of MON0528, is not impaired but will receive an informational allocation based on current conditions. TMDL Segment 2, downstream of MON0528, will require a TMDL and a reduction in sediment loads to correct the impairment.

3.0 TARGETED WATER QUALITY GOAL

The objective of the sediment TMDL established herein is to reduce sediment loads, and subsequent effects on aquatic health, in the MD 8-digit Upper Monocacy River watershed to levels that support the Use IV-P/III-P designations (Recreational Trout Waters and Public Water Supply) (Nontidal Cold Water and Public Water Supply) (COMAR 2007a,b,c). Assessment of aquatic health is based on Maryland's biocriteria protocol, which evaluates both the amount and diversity of the benthic and fish community through the use of the IBI (Roth et al. 1998, 2000; Stribling et al. 1998).

Reductions of sediment loads are expected to result from decreased watershed and streambed erosion, which will then lead to improved benthic and fish habitat conditions. Specifically, sediment load reductions are expected to result in an increase in the number of benthic sensitive species present, an increase in the available and suitable habitat for a benthic community, a possible decrease in fine sediment (fines), and improved stream habitat diversity, all of which will result in improved water quality.

4.0 TOTAL MAXIMUM DAILY LOADS AND SOURCE ALLOCATION

4.1 Overview

This section describes how the sediment TMDL and the corresponding allocations were developed for the MD 8-digit Upper Monocacy River. Section 4.2 describes the analysis framework for estimating sediment loading rates and the assimilative capacity of the watershed stream system. Section 4.3 summarizes the scenarios that were used in the analysis and presents results. Section 4.4 discusses critical conditions and seasonality. Section 4.5 explains the calculations of TMDL loading caps. Section 4.6 details the load allocations, and Section 4.7 explains the rationale for the margin of safety. Finally, Section 4.8 summarizes the TMDL.

4.2 Analysis Framework

The stressor identification methodology (see Section 2.3) identifies the most direct measure of sediment pollutant loading as water column TSS concentrations. Elevated TSS loads are linked with negative sediment impacts to stream geomorphology and aquatic health. Since TSS numeric criterion is not available, a reference watershed approach will be used to establish the TMDL.

Watershed Model

The watershed model framework chosen for the MD 8-digit Upper Monocacy River TMDL was the CBP P5 long-term average annual watershed model EOS loading rates. The spatial domain of the CBP P5 watershed model segmentation aggregates to the Maryland 8-digit watersheds, which is consistent with the impairment listing. The EOS loading rates were used because actual time variable CBP P5 calibration and scenario runs are currently being developed and are not yet available. These target-loading rates are used to calibrate the land use EOS loads within the CBP P5 model and thus should be consistent with future CBP modeling efforts.

The nonpoint source and NPDES stormwater baseline sediment loads generated within the MD 8-digit Upper Monocacy River watershed are calculated as the sum of corresponding land use EOS loads within the watershed and represents a long-term average loading rate. Individual land use EOS loads are calculated as a product of the land use area, land use target loading rate, and loss from the EOF to the main channel. The loss from the EOF to the main channel is the *sediment delivery ratio* and is defined as the ratio of the sediment load reaching a basin outlet to the total erosion within the basin. A *sediment delivery ratio* is estimated for each land use type based on the proximity of the land use to the main channel. Thus, as the distance to the main channel increases, more sediment is stored within the channels (i.e., *sediment delivery ratio* decreases). Details of the data sources for the unit loading rates can be found in Section 2.2 of this report.

The MD 8-digit Upper Monocacy River watershed was evaluated using two TMDL segments, both of which include loads from Maryland and Pennsylvania (see Figure 5). TMDL Segment 1 represents the sediment loads transported from Pennsylvania to the

Maryland state line via the Upper Monocacy River mainstem and also includes a small area within the Maryland portion of the watershed. TMDL Segment 2 represents the sediment loads generated in Maryland and also includes the sediment loads from Pennsylvania that flow into Maryland in the northeast and northwest portions of the watershed. Based on the analysis in Section 2.4, TMDL Segment 1 of the watershed is not impaired, but to protect downstream water quality will be given an informational allocation equivalent to its current baseline loads. TMDL Segment 2 will require a reduction in sediment loads.

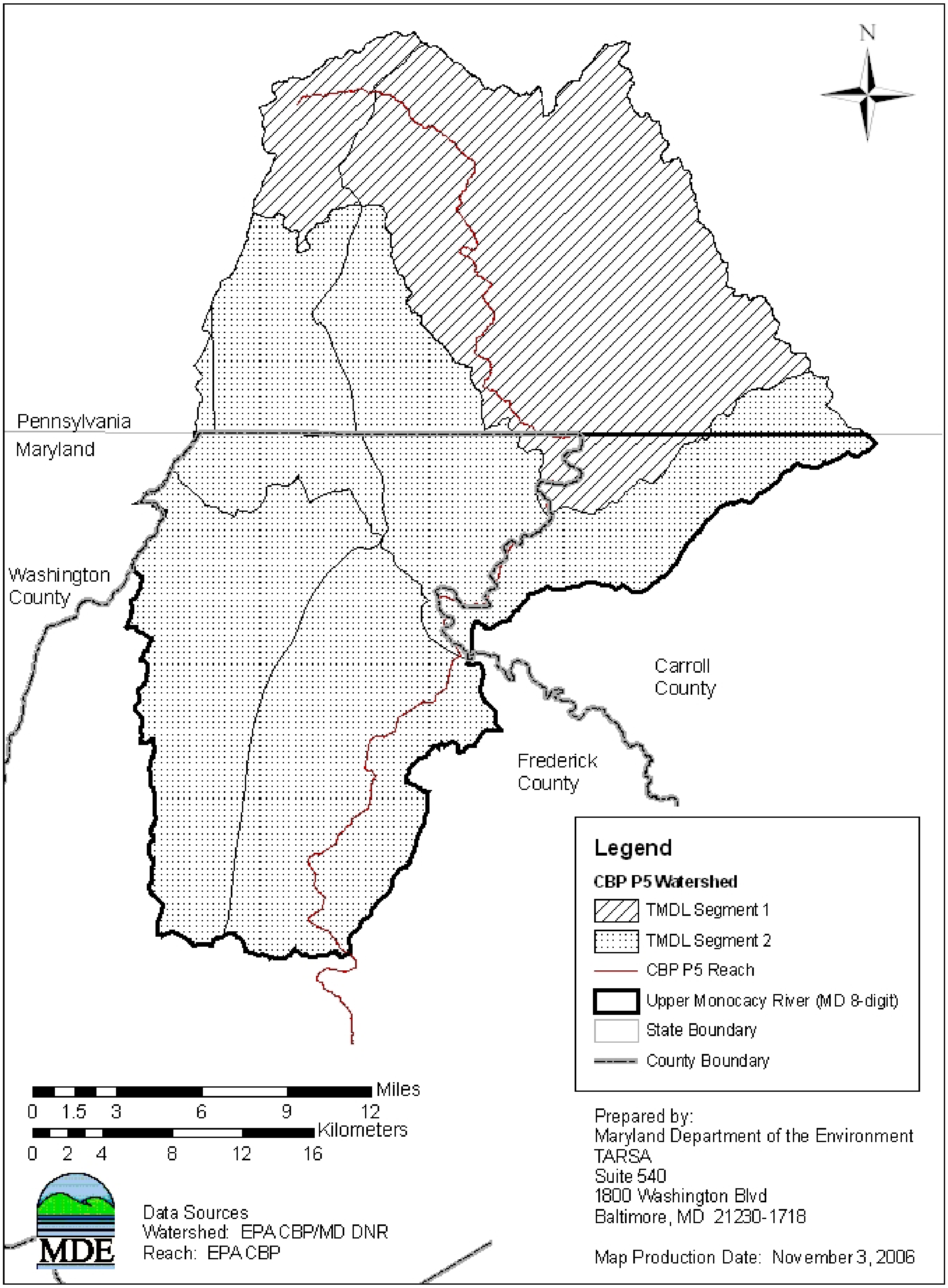


Figure 5: Upper Monocacy River Watershed Segmentation

Reference Watershed Approach

Currently in Maryland, there are no specific numeric criteria that quantify the impact of sediment on the aquatic health of non-tidal stream systems. Therefore, in order to quantify the impact of sediment on the aquatic health of non-tidal stream systems, a reference watershed TMDL approach was used and resulted in the establishment of a *sediment-loading threshold* for watersheds within the Highland and Piedmont physiographic regions (Currey et al. 2006). In summary, reference watersheds were determined based on the BIBI/FIBI average watershed scores significantly greater than 3.0 (based on a scale of 1 to 5). A threshold of 3.0 was selected because this is the level indicative of satisfactory water quality per Maryland's biocriteria (Roth et al. 1998, 2000; Stribling et al. 1998). In determining if the average watershed score is significantly greater than 3.0, a 90% confidence interval was calculated for each watershed based on the individual MBSS sampling results.

Comparison of watershed sediment loads to loads from reference watersheds requires that the watersheds be similar in physical and hydrological characteristics. To satisfy this requirement, Currey et al. (2006) selected reference watersheds only from the Highland and Piedmont physiographic regions (see Appendix A for the list of reference watersheds). This region is consistent with the non-coastal region that was identified in the 1998 development of FIBI and subsequently used in the development of BIBI (Roth et al. 1998; Stribling et al. 1998).

To reduce the effect of the variability within the Highland and Piedmont physiographic regions, the watershed sediment loads were then normalized by a constant background condition, the all forested watershed condition. This new normalized term, defined as the *forest normalized sediment load* (Y_n), represents how many times greater the current watershed sediment load is than the *all forested sediment load*. A similar approach was used by EPA Region 9 for sediment TMDLs in California (e.g., Navarro River or Trinity River TMDLs), where the loading capacity was based on an analysis of the amount of human-caused sediment delivery that can occur in addition to natural sediment delivery, without causing adverse impacts to aquatic life. The *forest normalized sediment load* for this TMDL is calculated as the current watershed sediment load divided by the *all forested sediment load*. The equation for the *forest normalized sediment load* is as follows:

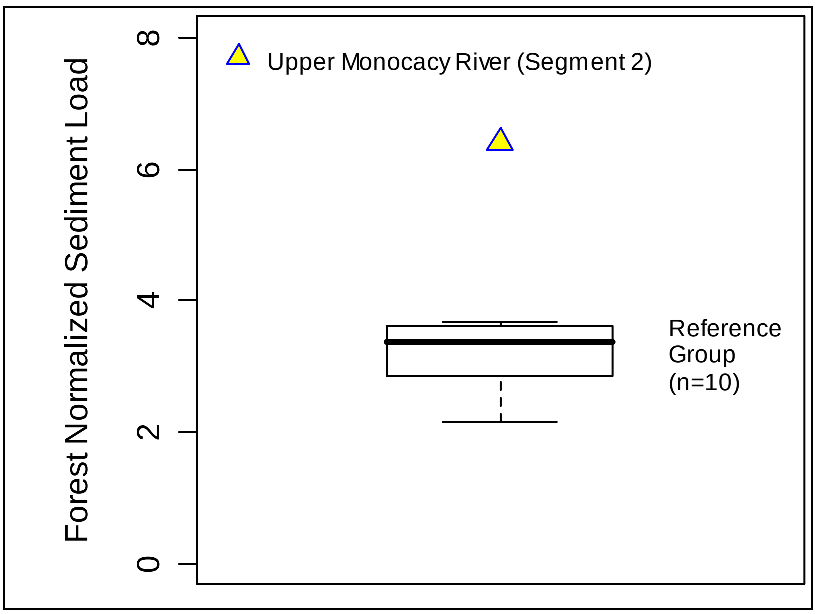
$$Y_n = \frac{y_{ws}}{y_{for}} \qquad (4.1)$$

where:

Y_n = forest normalized sediment load
y_{ws} = current watershed sediment load (ton/yr)
y_{for} = all forested sediment load (ton/yr)

An average *sediment loading threshold* of approximately 3.6 was established in Currey et al. (2006) with an 80% confidence interval ranging from 3.3 to 4.1. The lower confidence interval of 3.3, which also represents the median value of the reference watersheds, was chosen as an environmentally conservative approach to develop this TMDL (see Appendix A for more details).

A comparison of the Upper Monocacy River watershed *forest normalized sediment load* to the *forest normalized reference sediment load* (also referred to as the *sediment loading threshold*) is shown in Figure 6. The comparison was only completed for TMDL Segment 2 because TMDL Segment 1 has been previously identified as not impaired. As seen in Figure 6, the TMDL Segment 2 *forest normalized sediment load* exceeds the *sediment loading threshold*, indicating that it is receiving loads that are above the maximum allowable load that the watershed can sustain and still meet water quality standards.



Note: The *forest normalized sediment load* is unitless and represents how many times greater the current watershed sediment load is than the *all forested sediment load.*

Figure 6: Upper Monocacy River (TMDL Segment 2) Forest Normalized Sediment Load Compared to Reference Watershed Group

4.3 Scenario Descriptions and Results

The following analyses allow a comparison of baseline conditions (under which water quality problems exist) with future conditions, which project the water quality response to various simulated sediment load reductions. The analyses are grouped according to baseline conditions and future conditions associated with TMDLs. Sediment loads are calculated for TMDL Segments 1 and 2 separately.

<u>Baseline Conditions</u>

The baseline conditions are intended to provide a point of reference by which to compare the future scenario that simulates conditions of a TMDL. The baseline conditions typically reflect an approximation of nonpoint source and upstream loads during the monitoring time frame, as well as estimated point source loads based on discharge data for the same period.

The Upper Monocacy River watershed baseline sediment loads are estimated using the CBP P5 target EOS land use sediment loading rates with the CBP P5 2000 land use. Watershed loading calculations, based on the CBP P5 segmentation scheme, are represented by multiple CBP P5 model segments within each TMDL analysis segment. The TSS loads from these segments are combined to represent the baseline condition. The Maryland point source sediment loads are estimated based on the existing permit information. Details of these loading source estimates can be found in Section 2.2, Section 4.6, and Appendix B of this report.

<u>Future (TMDL) Conditions</u>

This scenario represents the future conditions of maximum allowable sediment loads that will support a healthy biological community. In the TMDL calculation, the allowable load for the impaired watershed is calculated as the product of the *sediment loading threshold* (determined from watersheds with a healthy benthic community) and the Upper Monocacy River *all forested sediment load* (see Section 4.3). The resulting load is considered the maximum allowable load the watershed can receive and still meet water quality standards.

The TMDL loading and associated reductions are first estimated at the model segment scale (see Figure 5) and then partitioned at the Maryland 8-digit watershed scale, which is consistent with the original listing scale. It is important to recognize that some subwatersheds may require higher reductions than others, depending on the distribution of the land use.

The formula for estimating the TMDL is as follows:

$$TMDL = \sum_{i=1}^{n} Yn_{ref} \cdot y_{forest\ i} \qquad (4.2)$$

where
TMDL = allowable load for impaired watershed (ton/yr)
Yn_{ref} = sediment loading threshold = forest normalized reference sediment load (3.3)
$y_{forest\ i}$ = all forested sediment load for segment *i* (ton/yr)
i = CBP P5 model segment
n = number of CBP P5 model segments in watershed

The allocation for the Upper Monocacy River TMDL Segment 1 is equivalent to its baseline load because it was identified as not impaired. The allocation for the Upper Monocacy River TMDL Segment 2 is estimated using equation 4.2.

4.4 Critical Condition and Seasonality

EPA's regulations require TMDLs to take into account seasonality and critical conditions for stream flow, loading, and water quality parameters (CFR 2007b). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The biological monitoring data used to determine the reference watersheds integrates the stress effects over the course of time and thus inherently addresses critical conditions. Seasonality is captured in two components. First, it is implicitly included in biological sampling. Second, the MBSS dataset included benthic sampling in the spring and fish sampling in the summer.

4.5 TMDL Loading Caps

This section presents the average annual MD 8-digit Upper Monocacy River TMDL of TSS. This load is considered the maximum allowable long-term average annual load the watershed can receive and still meet water quality standards.

TMDL allocations were developed for TMDL Segments 1 and 2 independently. The TMDL Segment 1 allocation is equivalent to its baseline conditions and is considered informational since no Maryland water quality impact from sediment was identified. As described in Section 2.4, the DNR Core monitoring data demonstrates that the MD 8-digit Upper Monocacy River mainstem exhibits good aquatic health conditions. Based on this information, it was concluded that loads from TMDL Segment 1 do not have a negative impact on the aquatic health of the MD 8-digit Upper Monocacy River mainstem.

The TMDL Segment 2 allocation was based on equation 4.2 and set at a load 3.3 times the all forested condition. A constant reduction was estimated for the predominant controllable sources (i.e., significant contributors of sediment to the stream system) in TMDL Segment 2, independent of jurisdiction. If only these predominant (generally the largest) sources are controlled, water quality standards can be achieved in the most effective, efficient, and equitable manner. Predominant sources typically include urban land, high till crops, low till crops, hay, pasture, and harvested forest, but additional sources might need to be controlled in order to ensure that the water quality standards are attained.

The MD 8-digit Upper Monocacy River Baseline Load and TMDL are presented in Table 10.

Table 10: MD 8-digit Upper Monocacy River Baseline Load and TMDL

	Baseline Load (ton/yr)	TMDL (ton/yr)	Reduction (%)
TMDL Segment 1 [1]	21,039.3	21,039.3	0.0
TMDL Segment 2 [2]	77,689.4	45,668.1	41.2
Total	98,728.7	66,707.4	32.4

Notes: [1] The allocation presented for TMDL Segment 1 is informational only. It is equivalent to the current baseline load of the Segment.
[2] TMDL Segment 2 load summary includes Double Pipe Creek upstream baseline load of 35,224.3 ton/yr and TMDL of 24,199.1 ton/yr presented in a separate Double Pipe Creek TMDL document (MDE 2008).

4.6 Load Allocations Between Point and Nonpoint Sources

The allocations described in this section summarize a TMDL of TSS established to meet the water quality standards in the MD 8-digit Upper Monocacy River watershed. Per EPA regulation, all TMDLs need to be presented as a sum of waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint source loads generated within the assessment unit, as well as natural background, tributary, and adjacent segment loads (CFR 2007a). Consequently, MD 8-digit Upper Monocacy River TMDL allocations are presented in terms of WLAs (i.e., point source loads identified within the assessment unit) and LAs (i.e., the assessment unit's nonpoint source loads and loads entering the watershed from outside of the assessment unit boundary). The State reserves the right to revise these allocations provided the revisions are consistent with achieving water quality standards.

As described in Section 4.5, a constant reduction was applied to the predominant controllable sources in TMDL Segment 2, independent of jurisdiction. In this watershed, crop, pasture, and urban land were identified as the predominant controllable sources. Forest is the only non-controllable source, as it represents the most natural condition in the watershed. No reductions were applied to permitted process load sources because at 0.2% of the total load, such controls would produce no discernable water quality benefit.

Table 11 summarizes the TMDL reductions derived by applying the reduction equally to the predominant controllable sediment sources within TMDL Segment 2. The source categories in Table 11 represent aggregates of multiple sources (e.g., crop source is an aggregate of high till, low till, hay, animal feeding operations, and nursery sources). The TMDL results in a 46.2% reduction for the MD 8-digit Upper Monocacy River Watershed Contribution, a 31.3% reduction from the Double Pipe Creek Upstream Baseline Load, and a 5.6% reduction from the Pennsylvania Upstream Based Load.

Table 11: MD 8-digit Upper Monocacy River TMDL Reductions by Source Category

	Baseline Load Source Categories		Baseline Load (ton/yr)	TMDL Components	TMDL (ton/yr)	Reduction (%)
MD 8-digit Upper Monocacy River Watershed Contribution	**Nonpoint Source**	Crop	33,297.8	**LA**	16,643.8	50.0
		Extractive	21.3		21.3	0.0
		Forest	2,618		2,618.0	0.0
		Pasture	2742.2		1,537.5	43.9
	Point Source	Urban	4,129.1	**WLA**	2,141.5	48.1
		Permits	184.1		184.1	0.0
Sub-total			**42,992.5**		**23,146.2**	**46.2**
Upstream	Pennsylvania		20,511.9	**Upstream LAs**	19,362.0	5.6
	Double Pipe[1]		35,224.3		24,199.1	31.3
Total			**98,728.7**		**66,707.3**[2]	**32.4**

Note: [1] Background relating to the Double Pipe Creek upstream baseline load and TMDL are presented in the Double Pipe Creek TMDL document (MDE 2008).

[2] Biological results from both the DNR Core/Trend and MBSS stations along the mainstem of the MD 8-digit Upper Monocacy River indicate that mainstem water quality can be classified as good. Based on this information, MDE concluded that the sediment impairment in the Maryland portion of the Upper Monocacy River watershed is restricted to the lower order streams within Segment 2 of the watershed. Consequently, sediment reductions have been applied to the loads transported via the lower order stream network within Segment 2 (located mostly in Maryland) and not the loads transported via the main channel from Segment 1 (located mostly in Pennsylvania).

The waste load allocation generated within the MD 8-digit Upper Monocacy River watershed is allocated to two permitted source categories, Process Water WLA and Stormwater WLA. The categories are described below.

<u>Process Water WLA</u>

Process Water permits with specific TSS limits and corresponding flow information are assigned to the WLA. In this case, detailed information is available to accurately estimate the WLA. If specific TSS limits are not explicitly stated in the process water permit, then TSS loads are expected to be *de minimis.* If loads are *de minimis*, then they pose little or no risk to the aquatic environment and are not a significant source

Process Water permits with specific TSS limits include:

- Individual municipal facilities,
- Individual industrial facilities
- General mineral mining facilities.

There are 16 process water sources with explicit TSS limits (see Appendix B), which include 3 industrial sources, 10 municipal sources, and 3 mineral mines. The total estimated TSS load from all of the process water sources is based on current permit limits and is equal to 184.1 ton/yr. As mentioned above, no reductions were applied to this source because at 0.2% of the total load, such controls would produce no discernable water quality benefit.

<u>NPDES Stormwater WLA</u>

Per EPA requirements, "stormwater discharges that are regulated under Phase I or Phase II of the NPDES stormwater program are point sources that must be included in the WLA portion of a TMDL" (US EPA 2002). Phase I and II permits can include the following types of discharges:

- Small, medium, and large MS4s – these can be owned by local jurisdictions, municipalities, and state and federal entities e.g., departments of transportation, hospitals, military bases),
- Industrial facilities permitted for stormwater discharges, and
- Small and large construction sites.

EPA recognizes that available data and information are usually not detailed enough to determine WLAs for NPDES regulated stormwater discharges on an outfall-specific basis (US EPA 2002). Therefore, NPDES regulated stormwater loads within the MD 8-digit Upper Monocacy River watershed will be expressed as a single NPDES stormwater WLA. Upon approval of the TMDL, "NPDES-regulated municipal stormwater and small construction storm water discharge effluent limits should be expressed as BMPs or other similar requirements, rather than as numeric effluent limits" (US EPA 2002).

The Upper Monocacy River NPDES stormwater WLA is based on reductions applied to the sediment load from the urban land use of the watershed and may include legacy or other sediment sources. Some of these sources may also be subject to controls from other management programs. The Upper Monocacy River NPDES stormwater WLA requires an overall reduction of 48.1% (see Table 11). The NPDES stormwater WLA distribution between Frederick County and Carroll County is presented in Appendix B. It constitutes a proportional allocation of the stormwater load to the entire urban land area of each county and may include any or all of the NPDES stormwater discharges listed above.

As stormwater assessment and/or other program monitoring efforts result in a more refined source assessment, MDE reserves the right to revise the current NPDES stormwater WLA provided the revisions are consistent with achieving water quality standards.

For more information on the methods used to calculate the baseline urban sediment load see Section 2.2.2. Additionally, Appendix B provides a detailed summary of all point source allocations.

4.7 Margin of Safety

All TMDLs must include a margin of safety to account for any lack of knowledge and uncertainty concerning the relationship between loads and water quality (CFR 2007b). It is proposed that the estimated variability around the reference watershed group used in this analysis already accounts for such uncertainty. Analysis of the reference group *forest normalized sediment loads* indicates that approximately 75% of the reference watersheds have a value of less than 3.6, consistent with the recommended value reported by Currey et al. (2006). Also, 50% of the reference watersheds have a value less than 3.3, consistent with the lower confidence interval value reported in Currey et al. (2006). Based on this analysis the *forest normalized reference sediment load* (also referred to as the *sediment loading threshold*) was set at the median value of 3.3. This is considered an environmentally conservative estimate, since 50% of the reference watersheds have a load above this value, which when compared to the 75% value, results in an implicit margin of safety of approximately 8%.

4.8 Summary of Total Maximum Daily Loads

The average annual MD 8-digit Upper Monocacy River TMDL is summarized in Table 12. The TMDL is the sum of the LAs, NPDES Stormwater WLA, Process Water WLA, and MOS. The LAs include nonpoint source loads generated within the MD 8-digit Upper Monocacy River watershed and loads from upstream sources. The Maryland Maximum Daily Load (MDL) is summarized in Table 13 (see Appendix C for more details).

Table 12: Average Annual MD 8-digit Upper Monocacy River TMDL of Sediment/TSS (ton/yr)

TMDL (ton/yr)	=	LA					+	WLA			+	MOS
		LA_{PA}[1]	+	LA_{DP}[2]	+	LA_{UM}		NPDES Stormwater WLA_{UM}	+	Process Water WLA_{UM}		
66,707.3	=	19,362.0	+	24,199.1	+	20,820.6	+	2,141.5	+	184.1	+	Implicit

Upstream Load Allocation[3, 4] (covers LA_{PA} + LA_{DP})

MD 8-digit Upper Monocacy River Watershed TMDL Contribution (covers LA_{UM} through Process Water WLA_{UM})

Notes:[1] LA_{PA} was determined to be necessary in order to meet Maryland water quality standards within the MD 8-digit Upper Monocacy River watershed.
[2] For Double Pipe Creek watershed WLA and LA characterization, please refer to the "Total Maximum Daily Load of Sediment in the Double Pipe Creek Watershed, Frederick and Carroll Counties, Maryland" (MDE 2008).
[3] Although for the purpose of this analysis upstream loads are referred to as LAs, they could include loads from point and nonpoint sources.
[4] A delivery factor of 1 was used for all of the Upstream Load Allocations.

Table 13: MD 8-digit Upper Monocacy River Maximum Daily Load of Sediment/TSS (ton/day)

MDL (ton/day)	=	Max. Daily LA					+	Max. Daily WLA			+	MOS
		LA_{PA}[1]	+	LA_{DP}[2]	+	LA_{UM}		NPDES Stormwater WLA_{UM}	+	Process Water WLA_{UM}		
2,513.2	=	754.7	+	860.8	+	812.3	+	83.8	+	1.4	+	Implicit

Upstream MDL[3,4] (covers LA_{PA} + LA_{DP})

MD 8-digit Upper Monocacy River Watershed MDL Contribution (covers LA_{UM} through Process Water WLA_{UM})

Notes:[1] LA_{PA} was determined to be necessary in order to meet Maryland water quality standards within the MD 8-digit Upper Monocacy River watershed.
[2] For Double Pipe Creek watershed WLA and LA characterization, please refer to the "Total Maximum Daily Load of Sediment in the Double Pipe Creek Watershed, Frederick and Carroll Counties, Maryland" (MDE 2008).
[3] Although for the purpose of this analysis upstream loads are referred to as LAs, they could include loads from point and nonpoint sources.
[4] A delivery factor of 1 was used for all of the Upstream Load Allocations.

5.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurances that the sediment TMDL will be achieved and maintained. Section 303(d) of the Clean Water Act and current EPA regulations require reasonable assurance that the TMDL load and wasteload allocations can and will be implemented (CFR 2007b). Maryland has several well-established programs to draw upon, including the Water Quality Improvement Act of 1998 (WQIA) and the Federal Nonpoint Source Management Program (§ 319 of the Clean Water Act).

Potential funding sources for implementation include the Buffer Incentive Program (BIP) and the Maryland Agriculture water quality cost share program (MACS). Other funding available for local governments includes the State Water Quality Revolving Loan Fund and the Stormwater Pollution Cost Share Program. Details of these programs and additional funding sources can be found at: http://www.dnr.state.md.us/bay/services/summaries.html.

Potential best management practices for reducing sediment loads and resulting impacts can be grouped into three general categories. The first is directed toward agricultural lands, the second to urban (developed) land, and the third applies to all land uses.

In agricultural areas comprehensive soil conservation plans can be developed that meet criteria of the USDA-NRCS Field Office Technical Guide (USDA 1983). Soil conservation plans help control erosion by modifying cultural practices or structural practices. Cultural practices may change from year to year and include changes to crop rotations, tillage practices, or use of cover crops. Structural practices are long-term measures that include, but are not limited to, the installation of grass waterways (in areas with concentrated flow), terraces, diversions, sediment basins, or drop structures. The reduction percentage attributed to cultural practices is determined based on changes in land use, while structural practices have a reduction percentage of up to 25%. In addition, livestock can be controlled via stream fencing and rotational grazing. Sediment reduction efficiencies of methods applicable to pasture land use range from 40% to 75% (US EPA 2004).

Sediment from urban areas can be reduced by stormwater retrofits, impervious surface reduction, and stream restoration. Stormwater retrofits include modification of existing stormwater structural practices to address water quality. Reductions range from as low as 10% for dry detention to approximately 80% for wet ponds, wetlands, infiltration practices, and filtering practices. Impervious surface reduction results in a change in hydrology that could reduce stream erosion (US EPA 2003).

All non-forested land uses can benefit from improved riparian buffer systems. A riparian buffer reduces the effects of upland sediment sources through trapping and filtering. Riparian buffer efficiencies vary depending on type (grass or forested), land use (urban or agriculture), and physiographic region. The CBP estimates riparian buffer sediment reduction efficiencies in the Upper Monocacy River region to be approximately 50% (US EPA 2006).

While a portion of the sediment loads that contribute to the MD 8-digit Upper Monocacy River watershed impairment originate in the Pennsylvania portion of the watershed, implementation actions in this area of the watershed are beyond the jurisdictional and regulatory authority of the Maryland Department of the Environment. MDE looks forward to working with the Commonwealth of Pennsylvania and the EPA to ensure that the Upstream Load Allocations presented in this document are achieved to meet Maryland's downstream water quality standards.

In summary, through the use of the aforementioned funding mechanisms and best management practices and assuming the cooperation of upstream jurisdictions, there is reasonable assurance that this TMDL can be implemented.

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