Total Maximum Daily Load of Sediment in the Little Patuxent River Watershed, Howard and Anne Arundel Counties, Maryland

FINAL

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List of Abbreviations

BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practices
BSID	Biological Stressor Identification
CBP P4.3	Chesapeake Bay Program Phase 4.3
CBP P5.2	Chesapeake Bay Program Phase 5.2
cfs	Cubic feet per second
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
ESD	Environmental Site Design
ETM	Enhanced Thematic Mapper
FDC	Flow Duration Curve
FIBI	Fish Index of Biologic Integrity
GIS	Geographic Information System
HSPF	Hydrological Simulation Program – FORTRAN
IBI	Index of Biotic Integrity
LA	Load Allocation
m	Meter
MAL	Minimum Allowable IBI Limit
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
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
NRI	Natural Resources Inventory
PSU	Primary Sampling Unit
RESAC	Regional Earth Science Applications Center
SCS	Soil Conservation Service
TMDL	Total Maximum Daily Load
Ton/yr	Tons per Year
TSD	Technical Support Document
TSS	Total Suspended Solids
TM	Thematic Mapper
USDA	United States Department of Agriculture
USGS	United Stated Geological Survey
WLA	Waste Load Allocation
WQA	Water Quality Analysis
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 Little Patuxent River watershed (basin number 02131105) (2008 *Integrated Report of Surface Water Quality in Maryland Assessment Unit ID*: MD-02131105). 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 2009b).

The Maryland Department of the Environment (MDE) has identified the waters of the Little Patuxent River watershed on the State's 2008 Integrated Report as impaired by cadmium (1996), nutrients – phosphorus (1996, Centennial Lake - 1998), sediment (1996, Centennial Lake - 1998), and impacts to biological communities (2006) (MDE 2008a). The designated use of the Little Patuxent River mainstem and its tributaries downstream of Old Forge Bridge is Use I (Water Contact Recreation and Protection of Aquatic Life), upstream of US Route 1 is Use IV-P (Recreational Trout Waters), and in between US Route 1 and Old Forge Bridge is Use I-P (Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply) (COMAR 2009a,b,c,d,e,f).

The TMDL established herein by MDE will address the 1996 sediments listing, for which a data solicitation was conducted, and all readily available data from the past five years have been considered. A Water Quality Analysis (WQA) for cadmium was approved by the EPA in 2008, and a WQA for eutrophication to address the nutrient (phosphorus) listing was approved by the EPA in 2010. A TMDL of phosphorus and sediments for Centennial Lake was approved by the EPA in 2002. In the 2012 Integrated Report, the listing for impacts to biological communities will include the results of a stressor identification analysis.

The Little Patuxent River watershed aquatic life assessment 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 based on Maryland's biocriteria listing methodology. The biocriteria listing methodology assesses the condition of Maryland's 8-digit (MD 8-digit) watersheds by measuring the percentage of sites, translated into watershed stream miles, that are assessed as having BIBI and/or FIBI scores significantly lower than 3.0 (on a scale of 1 to 5), and then calculating whether this percentage differs significantly from reference conditions (i.e., unimpaired watershed <10% stream miles differ from reference conditions) (Roth et al. 2005; MDE 2008a). The objective of the TMDL established herein is to ensure that watershed sediment loads are at a level to support the Use I/I-P/IV-P designations for the Little Patuxent River watershed, and more specifically, at a level to support aquatic life.

Currently in Maryland, there are no specific numeric criteria that quantify the impact of sediment on the aquatic life of nontidal stream systems. Therefore, to determine whether aquatic life is impacted by elevated sediment loads, MDE's *Biological Stressor Identification* (BSID) methodology was applied. The BSID identifies the most probable cause(s) for observed biological impairments throughout MD's 8-digit watersheds by ranking the likely stressors affecting a watershed using a suite of physical, chemical, and land use data. The ranking of stressors was conducted via a risk-based, systematic, weight-of-evidence approach. The risk-based approach estimates the strength of association between various stressors and an impaired biological community. The BSID analysis then identifies individual stressors (pollutants) as probable or unlikely causes of the poor biological conditions within a given MD 8-digit watershed and subsequently concludes whether or not these individual stressors or groups of stressors are contributing to the impairment (MDE 2009a).

The BSID analysis for the Little Patuxent River watershed concludes that biological communities are likely impaired due to flow/sediment related stressors. Individual stressors within the sediment parameter grouping that are associated with sediment related impacts and an altered hydrologic regime were identified as being probable causes of the biological impairment. Furthermore, the degradation of biological communities in the watershed is strongly associated with urban land use and its concomitant effects (MDE 2010a).

In order to quantify the impact of sediment on the aquatic life 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; MDE 2008a). This threshold is then used to determine a watershed specific sediment TMDL.

The computational framework chosen for the Little Patuxent River watershed TMDL was the Chesapeake Bay Program Phase 5.2 (CBP P5.2) 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 P5.2 watershed model segmentation aggregates to the MD 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 2009b). 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 reflect the impacts of stressors (i.e., sediment impacts to stream biota) over the course of time (i.e., captures the impacts of all high and low flow events). Thus, critical conditions are inherently addressed. Seasonality is captured in two components. First, it is implicitly included in biological sampling as biological communities reflect the impacts of stressors over time, as described above. 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 point sources and load allocations (LAs) for nonpoint sources generated within the assessment unit, accounting for 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 2009a,b). It is proposed that the estimated variability around the reference watershed group used in this analysis already accounts for such uncertainty, and therefore the MOS is implicitly included.

The Little Patuxent River Total Baseline Sediment Load is 37,066.5 tons per year (ton/yr). This baseline load consists of upstream loads generated outside the assessment unit (i.e., MD 8-digit watershed): a Middle Patuxent River Upstream Baseline Load (BL_{MP}) of 11,899.1 ton/yr, and loads generated within the assessment unit: a Little Patuxent River Watershed Baseline Load Contribution of 25,167.4 ton/yr. The Little Patuxent River Watershed Baseline Load Contribution is further subdivided into nonpoint source baseline loads (Nonpoint Source BL_{LP}) and two types of point source baseline loads: National Pollutant Discharge Elimination System (NPDES) regulated stormwater (NPDES Stormwater BL_{LP}) and regulated process water (Process Water BL_{LP}) (see Table ES-1). Appendix D provides a detailed explanation of the upstream loads.

Table ES-1: Little Patuxent River Baseline Sediment Loads (ton/yr)

		Upstream Baseline Load[1]		Little Patuxent River Watershed Baseline Load Contribution				
Total Baseline Load (ton/yr)	=	**BL_{MP}[2]**	+	**Nonpoint Source BL_{LP}**	+	**NPDES Stormwater BL_{LP}**	+	**Process Water BL_{LP}**
37,066.5	=	11,899.1	+	6,042.1	+	17,092.5	+	2,032.8

Notes: [1] Although the Upstream Baseline Load is reported here as a single value, it could include point and nonpoint sources.
[2] For the Middle Patuxent River watershed point and nonpoint source characterization, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard County, Maryland" (MDE 2010b).

The Little Patuxent River Average Annual TMDL of Sediment/Total Suspended Solids (TSS) is 31,199.8 ton/yr. The TMDL consists of allocations attributed to loads generated outside the assessment unit referred to as Upstream Load Allocations: a Middle Patuxent River Upstream Load Allocation of 11,899.1 ton/yr (LA_{MP}), and loads generated within the assessment unit: a Little Patuxent River Watershed TMDL Contribution of 19,300.7 ton/yr. The Little Patuxent River Watershed TMDL Contribution is further subdivided into point and nonpoint source allocations and is comprised of a Load Allocation (LA_{LP}) of 6,042.1 ton/yr, an NPDES Stormwater Waste Load Allocation (NPDES Stormwater WLA_{LP}) of 11,225.8 ton/yr, and a Process Water Waste Load Allocation (Process Water WLA_{LP}) of 2,032.8 ton/yr (see Table ES-2).

Since the biological results from a Maryland Department of Natural Resources (DNR) Core/Trend station along the mainstem of the Little Patuxent River indicate that mainstem water quality can be classified as good, MDE concluded that the sediment impairment in the Little Patuxent River watershed is restricted to the lower order streams within the watershed. Therefore, sediment reductions have only been applied to the loads transported via the lower order stream network within the watershed and not the loads transported from the upstream Middle Patuxent River watershed to the Little Patuxent River mainstem.

This TMDL will ensure that the sediment loads and resulting effects are at a level to support the Use I/I-P designation for the Little Patuxent River watershed, and more specifically, at a level to support aquatic life. The TMDL, however, will not completely resolve the impairment to biological communities within the watershed. Since the BSID watershed analysis identifies other possible stressors (i.e., chlorides) as impacting the biological conditions, this impairment remains to be fully addressed through the Integrated Report listing process and the TMDL development process, such that all impairing substances identified as impacting biological communities in the watershed are reduced to levels that will meet water quality standards, as established in future TMDLs for those substances (MDE 2009a, 2010a).

Table ES-2: Little Patuxent River Average Annual TMDL of Sediment/ TSS (ton/yr)

TMDL (ton/yr)	=	LA			+	WLA			+	MOS
		LA_{MP}[1]	+	LA_{LP}		NPDES Stormwater WLA_{LP}	+	Process Water WLA_{LP}		
31,199.8	=	11,899.1	+	6,042.1	+	11,225.8	+	2,032.8	+	Implicit
		Upstream Load Allocation[2,3]		Little Patuxent River Watershed TMDL Contribution						

Notes: [1] For Middle Patuxent River watershed WLA and LA characterization, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard County, Maryland" (MDE 2010b).
[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.
[3] A delivery factor of 1 was used for the Upstream LA.

Table ES-3: Little Patuxent River Baseline Load, TMDL, and Total Reduction Percentage

Baseline Load (ton/yr)	TMDL (ton/yr)	Total Reduction (%)
37,066.5	31,199.8	15.8

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 primarily via the municipal separate storm sewer system (MS4) permitting process for medium and large municipalities. 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 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 available for local governments for implementation are available, such as 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.

1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for sediment in the Little Patuxent River watershed (basin number 02131105) (2008 *Integrated Report of Surface Water Quality in Maryland Assessment Unit ID*: MD-02131105). Section 303(d) 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 State's Integrated Report, taking into account seasonal variations, critical conditions, and a protective margin of safety (MOS) to account for uncertainty (CFR 2009b). 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.

The Maryland Department of the Environment (MDE) has identified the waters of the Little Patuxent River watershed on the State's 2008 Integrated Report as impaired by cadmium (1996), nutrients – phosphorus (1996, Centennial Lake - 1998), sediment (1996, Centennial Lake - 1998), and impacts to biological communities (2006) (MDE 2008a). The designated use of the Little Patuxent River mainstem and its tributaries downstream of Old Forge Bridge is Use I (Water Contact Recreation and Protection of Aquatic Life), upstream of US Route 1 is Use IV-P (Recreational Trout Waters), and in between US Route 1 and Old Forge Bridge is Use I-P (Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply) (COMAR 2009a,b,c,d,e,f).

The TMDL established herein by MDE will address the 1996 sediments listing, for which a data solicitation was conducted, and all readily available data from the past five years have been considered. A Water Quality Analysis (WQA) for cadmium was approved by the EPA in 2008, and a WQA for eutrophication to address the nutrient (phosphorus) listing was approved by the EPA in 2010. A TMDL of phosphorus and sediments for Centennial Lake was approved by the EPA in 2002. In the 2012 Integrated Report, the listing for impacts to biological communities will include the results of a stressor identification analysis.

The objective of the TMDL established herein is to ensure that watershed sediment loads are at a level to support the Use I/I-P/IV-P designations for the Little Patuxent River watershed, and more specifically, at a level to support aquatic life. Currently in Maryland, there are no specific numeric criteria that quantify the impact of sediment on the aquatic life of nontidal stream systems. Therefore, to determine whether aquatic life is impacted by elevated sediment loads, MDE's *Biological Stressor Identification* (BSID) methodology was applied.

The BSID identifies the most probable cause(s) for observed biological impairments throughout Maryland's 8-digit (MD 8-digit) watersheds by ranking the likely stressors affecting a watershed using a suite of physical, chemical, and land use data. The ranking of stressors was conducted via a risk-based, systematic, weight-of-evidence approach. The risk-based approach estimates the strength of association between various stressors and an impaired biological community. The BSID analysis then identifies individual stressors (pollutants) as probable or unlikely causes of the poor biological conditions within a given MD 8-digit watershed and subsequently concludes whether or not these individual stressors or groups of stressors are contributing to the impairment (MDE 2009a).

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2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Little Patuxent River is a free flowing stream that originates just north of Route 70 near the Howard County Landfill and flows 38 miles in a southeasterly direction until it joins the Patuxent River. The watershed is located in the Patuxent River sub-basin of the Chesapeake Bay watershed within both Howard and Anne Arundel Counties, Maryland and covers approximately 66,214 acres (see Figure 1). From its headwaters, the river flows southeast through the densely urban town of Columbia, crossing under Route 29 just south of Lake Kittamaqundi. The river continues southeast crossing under Route 32, where the Middle Patuxent River joins the Little Patuxent Riverin the town of Savage, thereby significantly increasing the flow. The river continues to flow southeast crossing under Route 295, through the southwest corner of the Fort Meade Military Reservation, through the northeast section of the Patuxent Research Refuge, and it finally joins the Patuxent River just southeast of the Patuxent Research Refuge, between the towns of Bowie and Crofton, just before the Route 3 and Route 450 intersection. There are no "high quality", or Tier II, stream segments (Benthic Index of Biotic Integrity (BIBI) and Fish Index of Biotic Integrity (FIBI) aquatic life assessment scores > 4 (scale 1 – 5)), located within the watershed requiring the implementation of Maryland's antidegradation policy (COMAR 2009g; MDE 2010c). Also, approximately 0.2% of the watershed area is covered by water (i.e., streams ponds, etc.). The total population in the watershed is nearly 266,000 (US Census Bureau 2000).

Geology/Soils

The Little Patuxent River watershed is situated within the Northern Piedmont and Northern Coastal Plain geologic provinces of central Maryland. The Piedmont geologic province is characterized by gentle to steep rolling topography, low hills, and ridges. The surficial geology is characterized by crystalline igneous and metamorphic rocks of volcanic origin consisting primarily of schist and gneiss. The Coastal Plan geologic province is characterized by deep sedimentary soil complexes that support broad meandering streams (DNR 2009b; MGS 2009; MDE 2000).The topography in the watershed is mostly characterized by rolling hills, gently sloping terrain, and broad valleys with small streams.

The Little Patuxent River watershed is comprised of several different soil series including the Chester, Beltsville, and Collington series. The Chester series consists of very deep, well-drained soils that are primarily located on upland divides and slopes in the Northern Piedmont geologic province. Saturated hydraulic conductivity in this soil series is moderately high to high. The Chester soils formed in materials weathered from micaceous schist. The Beltsville soil series consists of very deep, moderately well drained soils in the Northern Coastal Plain geologic province on upland and coastal plain landscapes. Saturated hydraulic conductivity in this soil series is high above the fragipan and moderately low to low in the fragipan. The Collington soil series consists of very deep, well drained soils in the Northern Coastal Plain geologic province on coastal plain landscapes. Saturated hydraulic conductivity in this soil series is low to moderate (USDA 1968, 1973).

Soil type for the Little Patuxent River watershed is also categorized by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) into four hydrologic soil groups: Group A soils have high infiltration rates and are typically deep well-drained/excessively drained sands or gravels; Group B soils have moderate infiltration rates and consist of moderately deep-to-deep and moderately well-to-well drained soils, with moderately fine/coarse textures; Group C soils have slow infiltration rates and a layer that impedes downward water movement and consist of moderately fine-to-fine textures; Group D soils have very slow infiltration rates and consist of clay soils with a permanently high water table that are often shallow over nearly impervious material. The Little Patuxent River watershed is comprised primarily of Group B soils (49%) with smaller amounts of Group D (24%), Group C (20%), and Group A soils (7%) (USDA 2006).

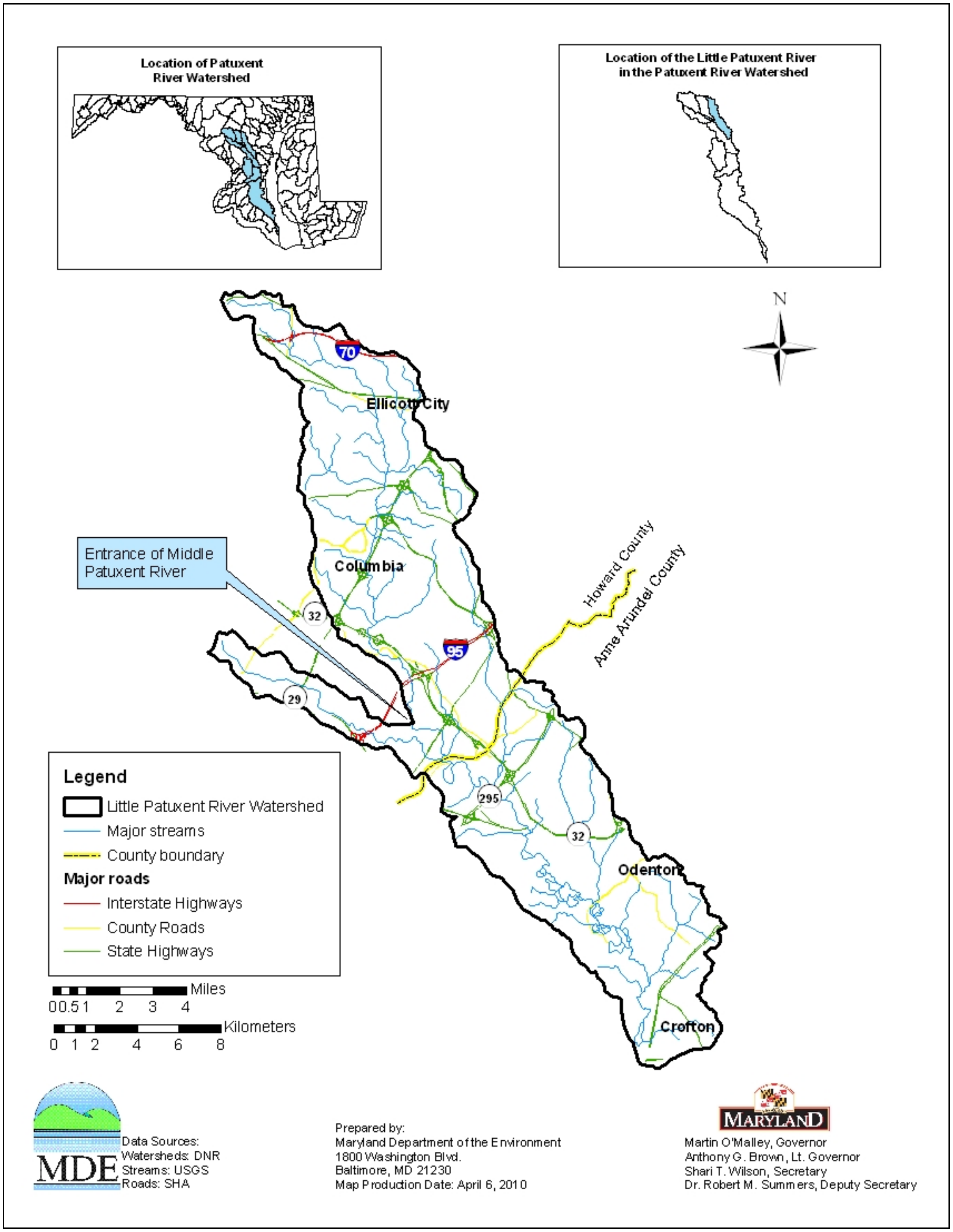

Figure 1: Location Map of the Little Patuxent River Watershed in Anne Arundel and Howard Counties, Maryland

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 5.2 (CBP P5.2) watershed model.[1] The CBP P5.2 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 2001 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 P5.2 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 P5.2 land use does not exist in a single GIS coverage; instead it is only available in a tabular format. The CBP P5.2 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 13 classes with distinct sediment erosion rates. Table 1 lists the CBP P5.2 generalized land uses, detailed land uses, which are classified by their erosion rates, and the acres of each land use in the Little Patuxent River watershed. Details of the land use development methodology have been summarized in the report entitled *Chesapeake Bay Phase 5 Community Watershed Model* (US EPA 2009).

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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.

Little Patuxent River Watershed Land Use Distribution

The Little Patuxent River watershed consists primarily of urban land use (62.5%) and forest land use (29.9%). There are also small amounts of crop (5.9%) and pasture (1.6%). A detailed summary of the watershed land use areas is presented in Table 1, and a land use map is provided in Figure 2.

Table 1: Land Use Percentage Distribution for the Little Patuxent River Watershed

General Land Use	Detailed Land Use	Area (Acres)	Percent	Grouped Percent of Total
Crop	Animal Feeding Operations	8.4	0.0	5.9
	Hay	966.3	1.5	
	High Till	943.4	1.4	
	Low Till	1,982.3	3.0	
	Nursery	4.9	0.0	
Extractive	Extractive	88.7	0.1	0.1
Forest	Forest	19,533.7	29.6	29.9
	Harvested Forest	197.3	0.3	
Pasture	Pasture	1,024.5	1.6	1.6
	Trampled Pasture	0.0	0.0	
Urban	Urban: Barren	599.1	0.9	62.5
	Urban: Impervious	11,036.9	16.7	
	Urban: Pervious	29,683.4	44.9	
Total		66,069.1	100.0	100.0

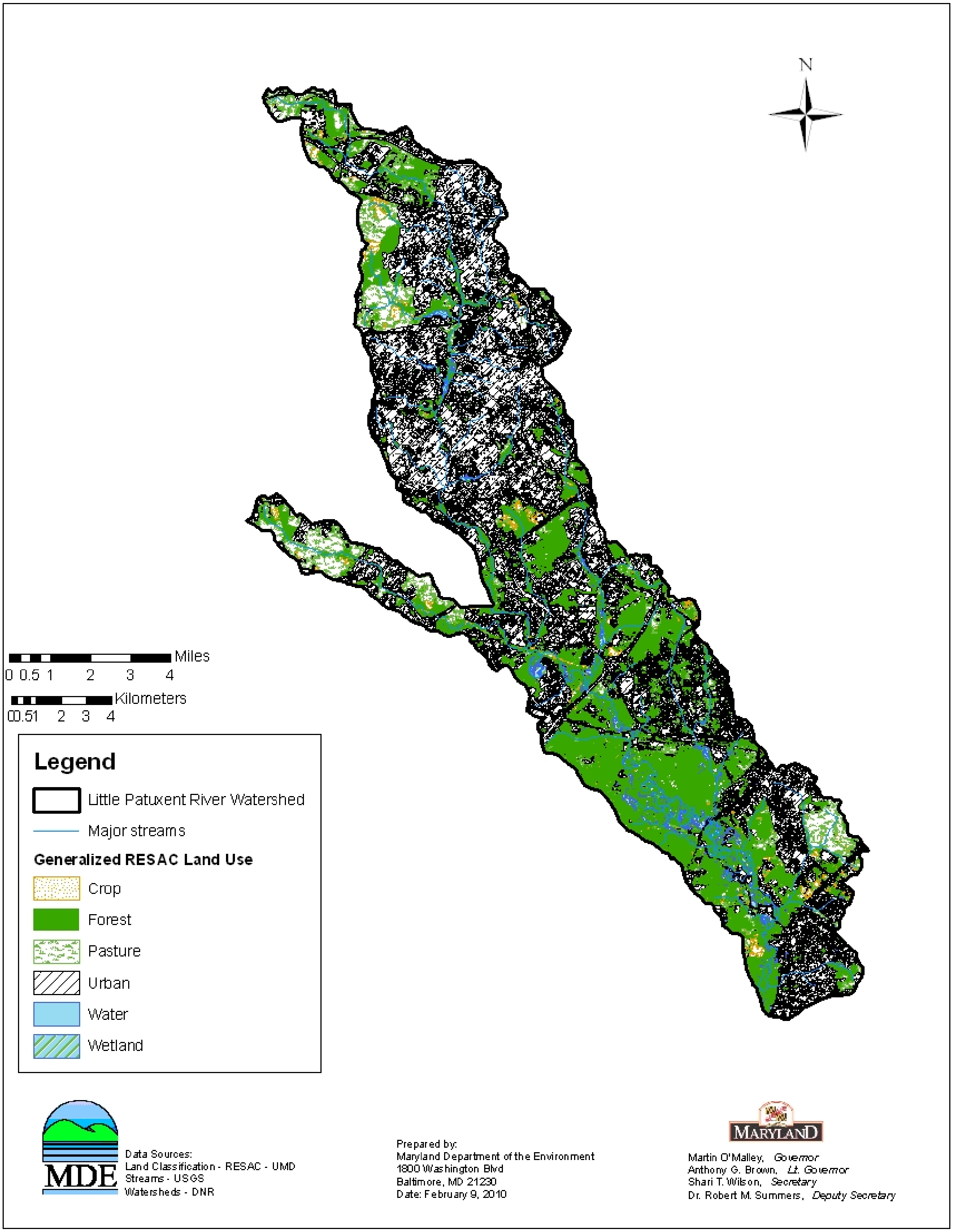

Figure 2: Land Use of the Little Patuxent River Watershed

2.2 Source Assessment

The Little Patuxent River Watershed Total Baseline Sediment Load consists of loads generated outside of the assessment unit, referred to as an Upstream Baseline Load, and loads generated within the assessment unit, referred to as the Little Patuxent River Baseline Load Contribution. The Little Patuxent River Watershed Baseline Load Contribution can be further subdivided into nonpoint and point source loads. This section summarizes the methods used to derive each of these distinct source categories.

2.2.1 Nonpoint Source Assessment

In this document, the nonpoint source loads account for sediment loads from unregulated stormwater runoff within the Little Patuxent River watershed. This section provides the background and methods for determining the nonpoint source baseline loads generated within the Little Patuxent River watershed (Nonpoint Source BL_{LP}).

General load estimation methodology

Nonpoint source sediment loads generated within the Little Patuxent River watershed are estimated based on the *edge-of-stream (EOS) calibration target loading rates* from the CBP P5.2 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* (US EPA 2009).

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 Natural Resource Inventory (NRI). NRI is a statistical survey of land use and natural resource conditions conducted by the Natural Resources Conservation Service (NRCS) (USDA 2006). 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 Chesapeake Bay Program Phase 4.3 (CBP P4.3) 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 P5.2 model.

The average value of the 1982 and 1987 surveys was used as the basis for EOF target rates for pasture and cropland. 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

P5.2. For further details regarding EOF Erosion rates, please see Section 9.2.1 of the community watershed model documentation (US EPA 2009).

Rates for urban pervious, urban impervious, extractive, 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 Little Patuxent River watershed.

Table 2: Summary of EOF Erosion Rate Calculations

Land Use	Data Source	Anne Arundel County (tons/acre/year)	Howard County (tons/acre/year)
Forest	Phase 2 NRI	0.29	0.5
Harvested Forest[1]	Average Phase 2 NRI (x 10)	3	3
Nursery	Pasture NRI (x 9.5)	4.47	30.4
Pasture	Pasture NRI (1982-1987)	0.47	3.2
Trampled pasture[2]	Pasture NRI (x 9.5)	4.47	30.4
Animal Feeding Operations[2]	Pasture NRI (x 9.5)	4.47	30.4
Hay[2]	Crop NRI (1982-1987) (x 0.32)	2.58	2.02
High Till[2]	Crop NRI (1982-1987) (x 1.25)	10.06	7.89
Low Till[2]	Crop NRI (1982-1987) (x 0.75)	6.04	4.73
Pervious Urban	Intercept Regression Analysis	0.74	0.74
Extractive	Best professional judgment	10	10
Barren	Literature survey	12.5	12.5
Impervious	100% Impervious Regression Analysis	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 P5.2 model is the same as the formula used by the NRCS (USDA 1983).

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

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 P5.2 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. The formula for the EOS loads calculation is as follows:

$$\sum_{i}^{n} EOS = Acres_i * EOF_i * SDR_i * BMP_i \qquad \text{(Equation 2.2)}$$

where:
n = number of land use classifications
i = land use classification
EOS = Edge of stream load, tons/yr
Acres = acreage for land use i
EOF = Edge-of-field erosion rate for land use i, tons/ac/yr
SDR = sediment delivery ratio for land use i, per Equation 2.1
BMP = BMP factor for land use i, as applicable

Streambank Erosion

Many studies have documented the relationship between high amounts of connected impervious surfaces, increases in storm flows, and stream degradation in the form of streambank erosion (Schueler 1994; Arnold and Gibbons 1996). In many urbanized watersheds, small stream channels have been replaced by sewer pipes. As a result, impervious surfaces such as rooftops, parking lots, and road surfaces are now directly connected to the main stream channel via the storm sewer system. During a storm event, this causes a greater amount of precipitation to flow more rapidly into a given stream channel once it reaches the surface. Furthermore, less water infiltrates into the ground both during and after a storm event, thereby limiting the amount of groundwater recharge to a stream. This altered urban hydrology typically causes abnormally high flows in streams during storms and abnormally low flows during dry periods. The high flows occurring during storm events increase sheer stress and cause excessive erosion of streambanks and streambeds, which leads to degraded stream channel conditions for biological communities (MDE 2007).

Two methods of estimating streambank erosion were presented in the *Total Maximum Daily Loads of Sediment/Total Suspended Solids for the Anacostia River Basin, Montgomery and Prince George's Counties, Maryland and The District of Columbia*. The first estimate uses the Anacostia Hydrological Simulation Program – FORTRAN (HSPF) watershed model in conjunction with the Penn State University streambank erosion equation (Evans et al. 2003). The analysis estimated that approximately 73% of the total annual sediment load within the Anacostia River watershed could be attributed to streambank erosion (MDE 2007).

The second method analyzes the long term relationship between flow and total suspended solids (TSS) concentrations to quantify the effects of an altered urban hydrology on watershed sediment loads. Changes in hydrology in the Anacostia River watershed were characterized using daily flow data from the USGS gage stations. The long-term changes over time in the flow duration curves (FDCs) for each of these stations was quantified using a type of statistical analysis known as "quantile regression". The portion of the FDC representing the highest flows was determined to have increased significantly over time, consistent with hydrologic alteration from increased impervious surfaces. Also, a "sediment rating curve" (i.e., the relationship between suspended sediment concentration and flow) was computed and combined with the FDCs to estimate annual sediment loads before and after increased development (i.e., altered hydrology). The results of the analysis indicate that approximately 75% of the total annual sediment load in the Anacostia River watershed is due to alterations in hydrology (MDE 2007).

Using CBP P5.2 urban sediment EOF target values, MDE developed a formula for estimating the percent of the urban sediment load resultant from streambank erosion (i.e., that portion of the total urban sediment load attributed to stream bank erosion) based on the amount of impervious land within the total urban land use of a watershed. The assumption is that as impervious surfaces increase, the upland sources decrease, flow increases, and the change in sediment load results from increased streambank erosion. This formula recognizes that stream bank erosion can be a significant portion of both the urban sediment load and total sediment load. The formula is as follows:

$$\%E = \frac{I * L_I}{I * L_I + (1 - I)L_P} \qquad \text{(Equation 2.3)}$$

where:
% E = Percent of urban sediment load resultant from streambank erosion
I = Percent impervious of urban land use acreage

L_I = Impervious urban land use EOF load
L_P = Pervious urban land use EOF load

The relationship demonstrated in equation 2.3 is expressed graphically in Figure 3.

While this formula only represents an empirical approximation, it is consistent with results from the Anacostia River Sediment TMDL. Using the equation, the Anacostia River watershed (31% of urban land use covered by impervious surfaces) would equate to approximately a 74% urban sediment load resultant from streambank erosion. This translates to approximately 64% of the total Anacostia River watershed sediment load resulting from streambank erosion, since total urban land use accounts for approximately 86% of the total watershed sediment load. This is slightly less, but still consistent with, the other methods used to estimate the percentage of the total watershed sediment load resultant from streambank erosion within the Anacostia River Sediment TMDL.

Per Table 1, approximately 27% of the Little Patuxent River watershed urban land use is covered by impervious surfaces. This would equate to approximately a 72% urban sediment load resultant from stream bank erosion, or 49% of the total watershed sediment load.

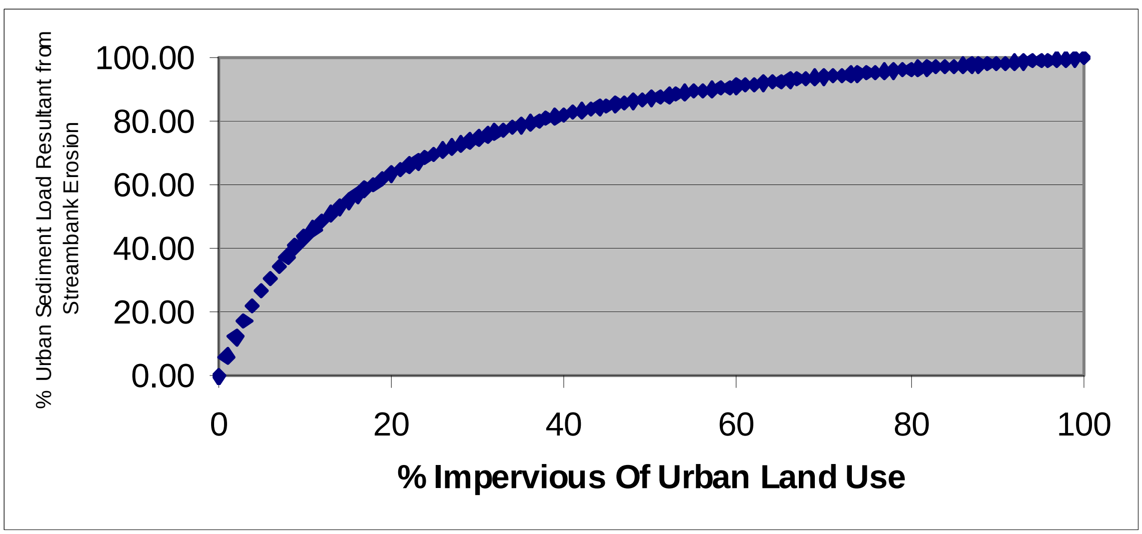

Figure 3: Percent Impervious of Urban Land Use vs. Percent of Urban Sediment Load Resultant from Streambank Erosion (Based on Equation 2.3)

For this TMDL, the urban sediment load resultant from streambank erosion represents an aggregate load within the total urban impervious EOF loads as described in the report *Chesapeake Bay Phase V Community Watershed Model* (US EPA 2009) and is not explicitly reported.

2.2.2 Point Source Assessment

A list of 51 active permitted point sources that contribute to the sediment load in the Little Patuxent River watershed was compiled using MDE's Environmental Permit

Service Center (EPSC) database. The types of permits identified include individual industrial, individual municipal, individual municipal separate storm sewer systems (MS4s), general mineral mining, and general industrial stormwater. The permits can be grouped into two categories, process water and stormwater. The process water category includes those loads generated by continuous discharge sources whose permits have TSS limits. Other permits that do not meet these conditions are considered *de minimis* in terms of the total sediment load. The stormwater category includes all National Pollutant Discharge Elimination System (NPDES) regulated stormwater discharges.

The sediment loads for the 14 process water permits (Process Water BL_{LP}) are calculated based on their TSS limits (average monthly or weekly concentration values) and corresponding flow information. The 37 NPDES Phase I or Phase II stormwater permits identified throughout the Little Patuxent 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_{LP}) is calculated using Equation 2.2 and watershed specific urban land use factors. A detailed list of the permits appears in Appendix B.

2.2.3 Upstream Loads Assessment

For the purpose of this analysis, one upstream watershed has been identified: the Middle Patuxent River watershed. Subsequently, the sediment baseline loads from this watershed will be presented as a Middle Patuxent River Upstream Baseline Load (BL_{MP}). The BL_{MP} is estimated based on the same nonpoint source load estimation methodology described in Section 2.2.1 and is presented in the WQA of Sediment for the Middle Patuxent River, Howard County, MD (MDE 2010b).

2.2.4 Summary of Baseline Loads

Table 3 summarizes the Little Patuxent River Baseline Sediment Load, reported in tons per year (ton/yr) and presented in terms of an Upstream Baseline Load and Little Patuxent River Watershed Baseline Load Contribution nonpoint and point source loadings.

Table 3: Little Patuxent River Baseline Sediment Loads (ton/yr)

		Upstream Baseline Load[1]		**Little Patuxent River Watershed Baseline Load Contribution**				
Total Baseline Load (ton/yr)	=	**BL_{MP}**[2]	+	**Nonpoint Source BL_{LP}**	+	**NPDES Stormwater BL_{LP}**	+	**Process Water BL_{LP}**
37,066.5	=	11,899.1	+	6,042.1	+	17,092.5	+	2,032.8

Notes: [1] Although the Upstream Baseline Load is reported here as a single value, it could include point and nonpoint sources.
[2] For the Middle Patuxent River watershed point and nonpoint source characterization, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard County, Maryland" (MDE 2010b).

Table 4 presents a breakdown of baseline loads generated within the Little Patuxent River watershed, detailing loads per land use. The majority of the sediment load is from urban land (68%). The next largest sediment sources are crop land (14%) and forest (7%).

Table 4: Detailed Baseline Sediment Budget Loads Generated Within the Little Patuxent River Watershed

General Land Use	Description	Load (Ton/Yr)	Percent	Grouped Percent of Total
Crop	Animal Feeding Operations	30.9	0.1	14.4
	Hay	392.5	1.6	
	High Till	1466.0	5.8	
	Low Till	1724.5	6.9	
	Nursery	20.9	0.1	
Extractive	Extractive	192.4	0.8	0.8
Forest	Forest	1636.0	6.5	7.1
	Harvested Forest	139.9	0.6	
Pasture	Pasture	439.0	1.7	1.7
	Trampled Pasture	0.0	0.0	
Urban[1]	Urban: Barren	1449.8	5.8	67.9
	Urban: Impervious	11051.3	43.9	
	Urban: Pervious	4591.4	18.2	
	Process Water	2032.8	8.1	8.1
	Total[2]	25,167.4	100.0	100.0

Notes: [1] The urban land use load represents the permitted stormwater load.
[2] The Little Patuxent River watershed receives direct upstream loads from the Middle Patuxent River watershed. The Middle Patuxent River Upstream Baseline Load of 11,899.1 ton/yr is estimated in the sediment WQA for the watershed (MDE 2010b).

2.3 Water Quality Characterization

The Little Patuxent 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. Therefore, to determine whether aquatic life is impacted by elevated sediment loads, MDE's BSID methodology was applied. The primary goal of the BSID analysis is to identify the most probable cause(s) for observed biological impairments throughout MD's 8-digit watersheds (MDE 2009a).

The BSID analysis applies a case-control, risk-based, weight-of-evidence approach to identify potential causes of biological impairment. The risk-based approach estimates the strength of association between various stressors and an impaired biological community. The BSID analysis then identifies individual stressors (pollutants) as probable or unlikely causes of the poor biological conditions, within a given MD 8-digit watershed, and subsequently reviews ecological plausibility. Finally, the analysis concludes whether or not these individual stressors or groups of stressors are contributing to the impairment (MDE 2009a).

The primary dataset for BSID analysis is Maryland Department of Natural Resources (DNR) Maryland Biological Stream Survey (MBSS) round two data (collected between 2000-2004) because it provides a broad spectrum of paired data variables, which allow for a more comprehensive stressor analysis. The MBSS is a robust statewide probability-based sampling survey for assessing the biological conditions of wadeable, non-tidal streams (Klauda et al. 1998; Roth et al. 2005). It uses a fixed length (75 meter (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). The random sample design allows for unbiased estimates of overall watershed conditions. Thus, the dataset facilitated case-control analyses because 1) in-stream biological data are paired with chemical, physical, and land use data variables that could be identified as possible stressors and 2) it uses a probabilistic statewide monitoring design.

The BSID analysis combines the individual stressors (physical and chemical variables) into three generalized parameter groups in order to assess how the resulting impacts of these stressors can alter the biological community and structure. The three generalized parameter groups include: sediment, habitat, and water chemistry. Identification of a sediment/flow stressor as contributing to the biological impairment is based on the results of the individual stressor associations within both the sediment and habitat parameters that reveal the effects of sediment related impacts or an altered hydrologic regime (MDE 2009a).

The BSID applies to 1st through 4th order streams in a MD 8-digit watershed, as assessed by the MBSS. Support of aquatic life, however, has also been evaluated for larger order rivers and streams throughout the State based on assessments from DNR's 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 integrity index, and percent *Ephemeroptera*, *Plecoptera*, and *Trichoptera* (EPT). DNR has extensive (annual) monitoring data for two stations on the mainstem of the Little Patuxent River through the Core/Trend program. These stations have between 11 and 14 years of benthic macroinvertebrate data (DNR 2009a).

Little Patuxent River Watershed Monitoring Stations

A total of 29 water quality monitoring stations were used to characterize the Little Patuxent River Watershed. Twenty-seven biological/physical habitat monitoring stations from the MBSS program round one and round two data collection were used to describe the Little Patuxent River watershed in Maryland's 2008 Integrated Report. The BSID analysis used the 13 biological/physical habitat monitoring stations from the MBSS program round two data collection collected in 2000. Additionally, two biological monitoring stations from the Maryland Core/Trend monitoring network were applied within the TMDL analysis as well. All stations are presented in Figure 4 and listed in Table 5.

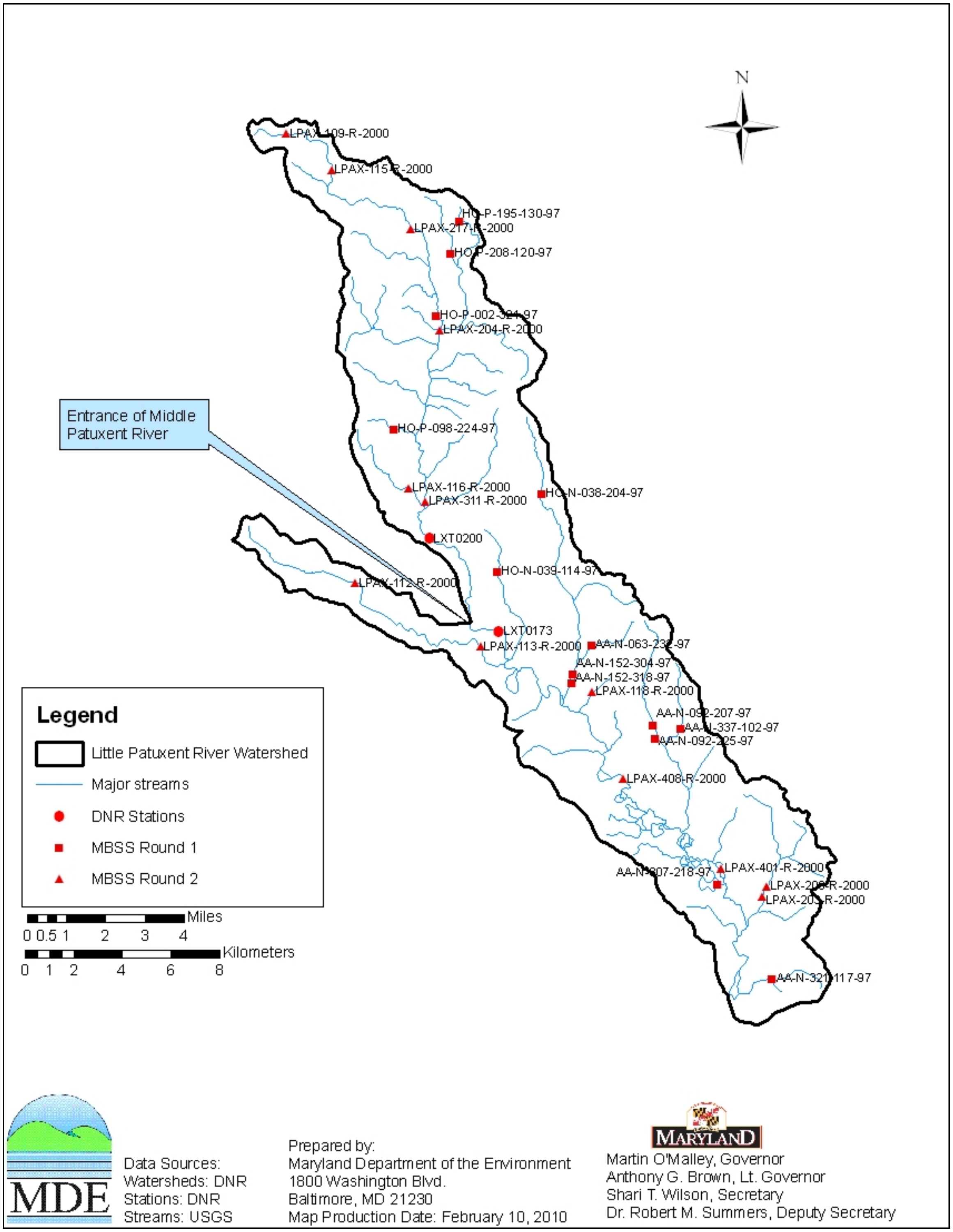

Figure 4: Monitoring Stations in the Little Patuxent River Watershed

Table 5: Monitoring Stations in the Little Patuxent River Watershed

Site Number	Sponsor	Site Type	Site Name	Latitude (dec degrees)	Longitude (dec degrees)
AA-N-063-232-97	MD DNR	MBSS, Round 1	DORSEY RUN	39.1290	-76.7740
AA-N-092-207-97	MD DNR	MBSS, Round 1	MIDWAY BRANCH	39.0990	-76.7450
AA-N-092-225-97	MD DNR	MBSS, Round 1	MIDWAY BRANCH	39.0940	-76.7440
AA-N-152-304-97	MD DNR	MBSS, Round 1	DORSEY RUN	39.1180	-76.7830
AA-N-152-318-97	MD DNR	MBSS, Round 1	DORSEY RUN	39.1150	-76.7840
AA-N-307-218-97	MD DNR	MBSS, Round 1	LITTLE PATUXENT RIVER UNNAMED TRIBUTARY 2	39.0400	-76.7150
AA-N-321-117-97	MD DNR	MBSS, Round 1	LITTLE PATUXENT RIVER UNNAMED TRIBUTARY 1	39.0050	-76.6890
AA-N-337-102-97	MD DNR	MBSS, Round 1	FRANKLIN BRANCH	39.0980	-76.7320
HO-N-038-204-97	MD DNR	MBSS, Round 1	DORSEY BRANCH TO LITTLE PATUXENT RIVER	39.1850	-76.7980
HO-N-039-114-97	MD DNR	MBSS, Round 1	LITTLE PATUXENT RIVER UNANMED TRIBUTARY 4	39.1560	-76.8190
HO-P-002-321-97	MD DNR	MBSS, Round 1	LITTLE PATUXENT RIVER	39.2510	-76.8480
HO-P-098-224-97	MD DNR	MBSS, Round 1	LITTLE PATUXENT RIVER UNNAMED TRIBUTARY 5	39.2090	-76.8680
HO-P-195-130-97	MD DNR	MBSS, Round 1	PLUMTREE BRANCH UNANMED TRIBUTARY 1	39.2860	-76.8370
HO-P-208-120-97	MD DNR	MBSS, Round 1	PLUMTREE BRANCH	39.2740	-76.8410
LPAX-109-R2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER UNAMED TRIBUTARY 3	39.3182	-76.9192
LPAX-112-R-2000	MD DNR	MBSS, Round 2	HAMMOND BRANCH	39.1519	-76.8866
LPAX-113-R-2000	MD DNR	MBSS, Round 2	HAMMOND BRANCH	39.1283	-76.8272
LPAX-115-R-2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER UNANMED TRIBUTARY 4	39.3047	-76.8978
LPAX-116-R-2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER UNANMED TRIBUTARY 1	39.1872	-76.8614
LPAX-118-R-2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER UNANMED TRIBUTARY 2	39.1115	-76.7742
LPAX-203-R-2000	MD DNR	MBSS, Round 2	TOWSERS BRANCH	39.0354	-76.6938
LPAX-204-R-2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER	39.2456	-76.8462
LPAX-206-R-2000	MD DNR	MBSS, Round 2	TOWSERS BRANCH	39.0392	-76.6916
LPAX-217-R-2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER	39.2832	-76.8600
LPAX-311-R-2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER	39.1820	-76.8533
LPAX-401-R-2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER	39.0458	-76.7133
LPAX-408-R-2000	MD DNR	MBSS, Round 2	LITTLE PATUXENT RIVER	39.0791	-76.7597
LXT0173	MD DNR	CORE/TREND	ROUTE 1	39.1339	-76.8186
LXT0200	MD DNR	CORE/TREND	ROUTE 32	39.1683	-76.1683

2.4 Water Quality Impairment

The Maryland water quality standards surface water use designation for the Little Patuxent River mainstem and its tributaries downstream of Old Forge Bridge is Use I (Water Contact Recreation and Protection of Aquatic Life), upstream of US Route 1 is Use IV-P (Recreational Trout Waters), and in between US Route 1 and Old Forge Bridge is Use I-P (Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply) (COMAR 2009a,b,c,d,e,f). The water quality impairment of the Little Patuxent River watershed addressed by this TMDL is caused by an elevated sediment load beyond a level that the watershed can sustain, thereby causing sediment related impacts that can not support aquatic life. Assessment of aquatic life is based on benthic and fish Index of Biotic Integrity (IBI) scores, as demonstrated via the BSID analysis for the watershed.

The Little Patuxent River watershed is listed on Maryland's 2008 Integrated Report as impaired for impacts to biological communities. The biological assessment is based on the combined results of MBSS round one (1995-1997) and round two (2000-2004) data, which includes 27 stations. Nineteen of the 27 stations, or 70% of the stream miles in the watershed, are assessed as having BIBI and/or FIBI scores significantly lower than 3.0 (on a scale of 1 to 5) (MDE 2008a). As mentioned in Section 2.3, however, only MBSS round two data were used in the BSID analysis. See Figure 4 and Table 5 for station locations and information.

The results of the BSID analysis for the Little Patuxent River watershed are presented in a report entitled *Watershed Report for Biological Impairment of the Little Patuxent River Watershed in Anne Arundel and Howard Counties, Maryland Biological Stressor Identification Analysis Results and Interpretation*. The report states that the degradation of biological communities in the Little Patuxent River watershed is strongly associated with urban land use and its concomitant effects (MDE 2010a).

The BSID analysis has determined that the biological impairment in the Little Patuxent River watershed is due in part to flow/sediment related stressors. Specifically, the analysis confirmed that individual stressors within the sediment parameter grouping were contributing to the biological impairment in the watershed. Overall, stressors within the sediment parameter grouping were identified as having a statistically significant association with impaired biological communities at approximately 84% of the sites with BIBI and/or FIBI scores significantly less than 3.0 throughout the watershed (MDE 2010a). Therefore, since sediment is identified as a stressor to the biological communities in the Little Patuxent River watershed, the results confirm the 1996 sediment listing, and a TMDL is required.

Additionally, the Little Patuxent River mainstem has been assessed via Maryland DNR's Core/Trend program. As shown in Table 6, the biological monitoring results from two DNR Core/Trend stations along the mainstem of the river indicate that mainstem water quality can be classified as good. Statistical analysis of the long term Core/Trend data indicates that since 1976 and 1977 respectively, the stations have shown slight improvement. The stations are ranked as having good water quality based on percent EPT, taxa number, biotic index, and diversity index (DNR 2009a).

Since the biological results from the Core/Trend stations along the mainstem of the Little Patuxent River indicate that mainstem water quality can be classified as good, MDE concluded that the sediment impairment in the Little Patuxent River watershed is restricted to the lower order streams within the watershed. Therefore, sediment reductions have only been applied to the loads within the watershed and not the loads transported from the upstream Middle Patuxent River watershed to the Little Patuxent River mainstem.

Table 6: Little Patuxent River Core/Trend Data

Site Number	Current Water Quality Status	Trend Since 1970's
LXT0173	Good	Slight improvement
LXT0200	Good	Slight improvement

3.0 TARGETED WATER QUALITY GOAL

The objective of the sediment TMDL established herein is to reduce sediment loads, and subsequent effects on aquatic life, in the Little Patuxent River watershed to levels that support the Use I/I-P/IV-P designations (Water Contact Recreation and Protection of Aquatic Life/Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply/Recreational Trout Waters) (COMAR 2009a,b,c,d,e,f). Assessment of aquatic life 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; MDE 2008a).

Reductions in 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.

The sediment TMDL, however, will not completely resolve the impairment to biological communities within the watershed. Since the BSID watershed analysis identifies other possible stressors (i.e., chlorides) as impacting the biological conditions, this impairment remains to be fully addressed through the Integrated Report listing process and the TMDL development process, such that all impairing substances identified as impacting biological communities in the watershed are reduced to levels that will meet water quality standards, as established in future TMDLs for those substances (MDE 2009a, 2010a).

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 Little Patuxent River watershed. 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 MOS. Finally, Section 4.8 summarizes the TMDL.

4.2 Analysis Framework

Since there are no specific numeric criteria that quantify the impact of sediment on the aquatic life of nontidal stream systems, a reference watershed approach will be used to establish the TMDL. Furthermore, as the BSID analysis established a link between biological impairment and sediment related stressors, the reference watershed approach will utilize a biological endpoint.

Watershed Model

The watershed model framework chosen for the Little Patuxent River watershed TMDL was the CBP P5.2 long-term average annual watershed model EOS loading rates. The spatial domain of the CBP P5.2 watershed model segmentation aggregates to the MD 8-digit watersheds, which is consistent with the impairment listing. The EOS loading rates were used because actual time variable CBP P5.2 calibration and scenario runs were not available upon development of the nontidal sediment TMDL methodology (Currey et al. 2006). These target-loading rates have been used to calibrate the land use EOS loads within the CBP P5.2 model and thus should be consistent with future CBP modeling efforts.

The nonpoint source and NPDES stormwater baseline sediment loads generated within the Little Patuxent River watershed are calculated as the sum of corresponding land use EOS loads within the watershed and represent 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 watershed (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 Little Patuxent River watershed was evaluated using one watershed TMDL segment consisting of three CBP P5.2 model segments (see Figure 5).

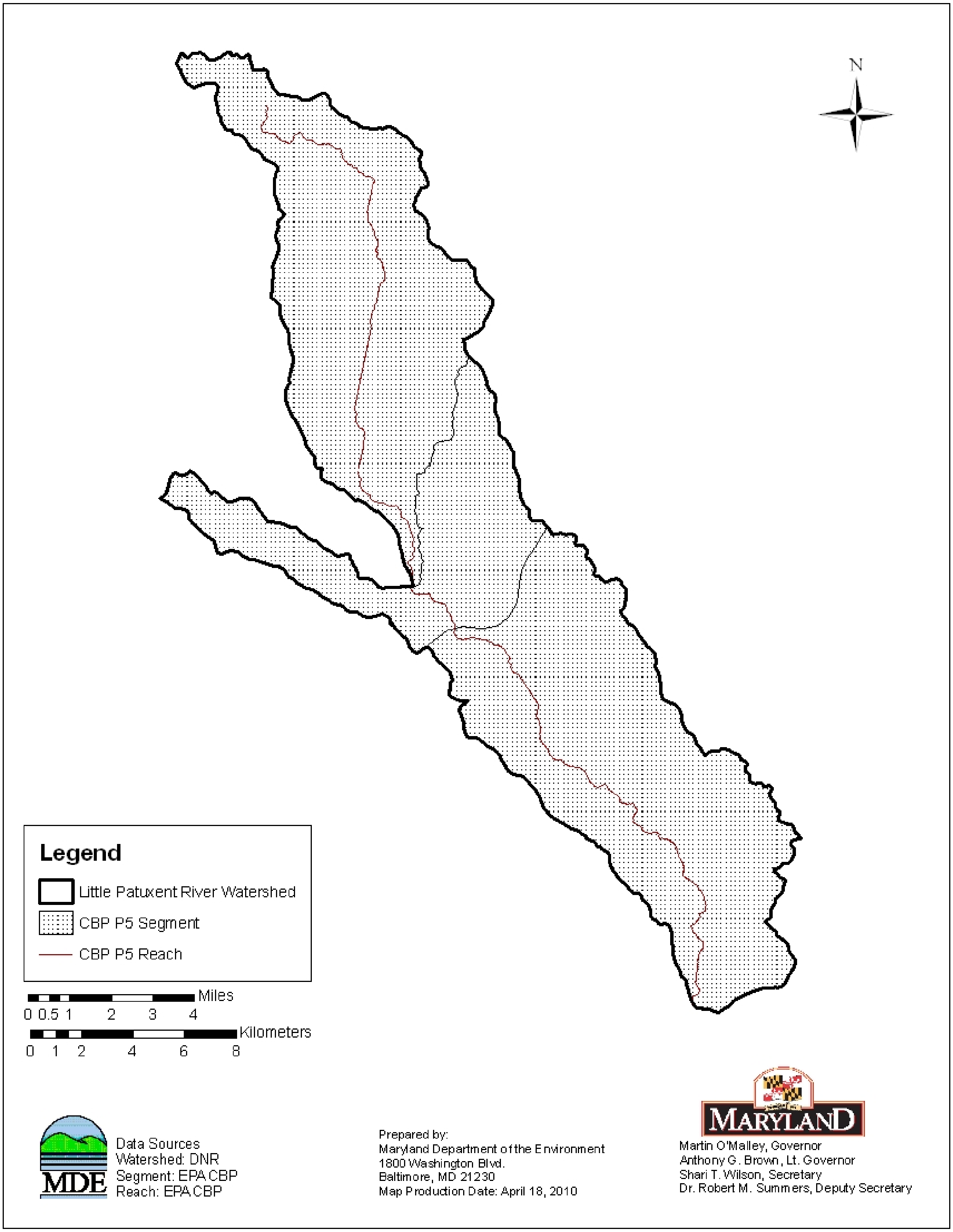

Figure 5: Little Patuxent River Watershed TMDL Segmentation

Reference Watershed Approach

Currently in Maryland, there are no specific numeric criteria that quantify the impact of sediment on the aquatic life of non-tidal stream systems. Therefore, in order to quantify the impact of sediment on the aquatic life 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). Reference watersheds were determined based on Maryland's biocriteria methodology. The biocriteria methodology assesses biological impairment at the 8-digit watershed scale based on the percentage of MBSS monitoring stations, translated into watershed stream miles, that have BIBI and/or FIBI scores lower than the Minimum Allowable IBI Limit (MAL). The MAL is calculated based on the average annual allowable IBI value of 3.0 (on a scale of 1 to 5). It accounts for variability and helps to avoid classification errors (i.e., false positives) when assessing for biological impairments (Roth et al. 1998, 2000; Stribling et al. 1998; MDE 2008a).

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 (i.e., soils, slope, etc.), 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 IX 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:

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

where:

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

Nine reference watersheds were selected from the Highland/Piedmont region. Reference watershed *forest normalized sediment loads* were calculated using CBP P5.2 2000 land use in order to maintain consistency with MBSS sampling years. The median and 75th percentile of the reference watershed *forest normalized sediment loads* were calculated and found to be 3.3 and 4.2 respectively. These values are in close agreement with more complex methods used to determine the *sediment loading threshold* in previous nontidal sediment TMDLs. Therefore, the median value of 3.3 was established as the *sediment loading threshold* as an environmentally conservative approach to develop this TMDL (see Appendix A for more details).

The *forest normalized sediment load* for the Little Patuxent River watershed (estimated as 4.0) was calculated using CBP P5.2 2005 landuse, to best represent current conditions. A comparison of the Little Patuxent River watershed *forest normalized sediment load* to the *forest normalized reference sediment load* (also referred to as the *sediment loading threshold*) demonstrates that the watershed exceeds the *sediment loading threshold*, indicating that it is receiving loads above the maximum allowable load that it can sustain and still meet water quality standards.

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.

Baseline Conditions

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 loads during the monitoring time frame, as well as estimated point source loads based on discharge data for the same period.

The Little Patuxent River watershed baseline sediment loads are estimated using the CBP P5.2 target EOS land use sediment loading rates with 2005 land use. Watershed loading calculations, based on the CBP P5.2 segmentation scheme, are often represented by multiple CBP P5.2 model segments within each TMDL segment. The sediment loads from these segments are combined to represent the baseline condition. The Little Patuxent River watershed consists of three CBP P5.2 model segments (see Figure 5). The 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 and Appendix B of this report.

TMDL Conditions

This scenario represents the future conditions of maximum allowable sediment loads that will be at a level to support aquatic life. 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 biological community) and the Little Patuxent River *all forested sediment load* (see Section 4.2). The resulting load is considered the maximum allowable load the watershed can sustain and support aquatic life.

The TMDL loading and associated reductions are averaged at the MD 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:

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

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 CBP P5.2 model segment *i* (ton /yr)
i = CBP P5.2 model segment
n = number of CBP P5.2 model segments in watershed

The Little Patuxent River watershed allowable sediment load 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 2009b). 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 reflect the impacts of stressors (i.e., sediment impacts to stream biota) over the course of time and therefore depict an average stream condition (i.e., captures all high and low flow events). Since the TMDL endpoint is based on the median of forest normalized loads from watersheds assessed as having good biological conditions (i.e., passing Maryland's biocriteria), by the nature of the biological data described above, it must inherently include the critical conditions of the reference watersheds. Therefore, since the TMDL reduces the watershed sediment load to a level compatible with that of the reference watersheds, critical conditions are inherently addressed.

Seasonality is captured in two components. First, it is implicitly included through the use of the biological monitoring data as biological communities reflect the impacts of stressors over time, as described above. Second, the MBSS dataset included benthic sampling in the spring (March 1 - April 30) and fish sampling in the summer (June 1 - September 30). Benthic sampling in the spring allows for the most accurate assessment of the benthic population, and therefore provides an excellent means of assessing the anthropogenic effects of sediment impacts on the benthic community. Fish sampling is conducted in the summer when low flow conditions significantly limit the physical habitat of the fish community, and it is therefore most reflective of the effects of anthropogenic stressors as well.

4.5 TMDL Loading Caps

This section presents the Little Patuxent River watershed average annual sediment TMDL. This load is considered the maximum allowable long-term average annual sediment load the watershed can sustain and support aquatic life.

The long-term average annual TMDL was calculated based on Equation 4.2 and set at a load 3.3 times the all forested condition. In order to attain the TMDL loading cap calculated for the watershed, reductions were applied to the only predominant controllable source (i.e., significant contributor of sediment to the stream system) identified within the watershed, independent of jurisdiction. If only this predominant (generally the largest) source is 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 could be controlled as well in order to ensure that the TMDL is attained. Urban land was identified as the only predominant controllable source in the watershed at 68% of the Baseline Sediment Load Contribution (see Table 4). Thus, reductions were only applied to this source. Additionally, all urban land in the Little Patuxent River watershed is considered to represent regulated stormwater sources (i.e., all urban stormwater is regulated via a permit).

Currently, MDE requires that Phase I MS4s retrofit 10% of their existing impervious area where there is failing, minimal, or no stormwater management (estimated to be areas developed prior to 1985) within a permit cycle (5 years) (i.e., Phase I MS4s need to install/institute stormwater management practices to treat runoff from these existing impervious areas) (MDE 2009b). Theoretically extending these permitting requirements to all urban stormwater sources (i.e., not solely those sources regulated via Phase I MS4 permits) would require that all impervious areas developed prior to 1985 be retrofit at this pace. Additionally, MDE estimates that future stormwater retrofits will have, on average, a 65% TSS reduction efficiency (Claytor and Schueler 1997; Baldwin et al. 2007; Baish and Caliri 2009). By default, these retrofits will also provide treatment of any adjacent urban pervious runoff within the applicable drainage area.

The Little Patuxent River Baseline Load and TMDL are presented in Table 7.

Table 7: Little Patuxent River Baseline Load and TMDL

Baseline Load (ton/yr)[1]	TMDL (ton/yr)[1]	Reduction (%)
37,066.5	31,199.8	15.8

Note:[1]The load summary includes the Middle Patuxent River Upstream Baseline Load/Load Allocation of 11,899.1 ton/yr.

4.6 Load Allocations Between Point and Nonpoint Sources

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, accounting for natural background, tributary, and adjacent segment loads (CFR 2009a). Consequently, the Little Patuxent River watershed TMDL allocations are presented in terms of WLAs (i.e., point source loads identified within the watershed) and LAs (i.e., the nonpoint source loads within the watershed and loads entering the watershed from outside of the assessment unit). The State reserves the right to allocate the TMDL among different sources in any manner that protects aquatic life from sediment related impacts.

As described in Section 4.5, reductions were only applied to the regulated urban stormwater sources. Furthermore, based on the current Phase I MS4 permit requirements described in Section 4.5 and the theoretical extension of these requirements to all urban stormwater sources, it is anticipated that the required reductions will be achieved by retrofitting impervious areas within the watershed developed prior to 1985 (i.e., approximate areas with failing, minimal, or no stormwater management) (MDE 2009b). Also, it is expected that these future stormwater retrofits will have an estimated 65% TSS reduction efficiency (Claytor and Schueler 1997; Baldwin et al. 2007; Baish and Caliri 2009), and by default, they will provide treatment of any adjacent urban pervious runoff within the applicable drainage area. In this watershed, no predominant controllable sediment sources were identified in addition to urban land, including typical sources such as high till crops, low till crops, hay, pasture, and harvested forest. Thus, no reductions were applied to these sources. Forest is the only non-controllable source, as it represents the most natural condition in the watershed, and no reductions were applied to permitted process water sources, since such controls would produce no discernable water quality benefit when nonpoint sources and regulated stormwater sources comprise 92% of the sediment loads generated within the Little Patuxent River watershed.

Table 8 summarizes the TMDL results for the Little Patuxent River watershed, derived by applying reductions to solely the urban sediment sources. The TMDL results in a reduction of 23.3% for the Little Patuxent River Watershed Contribution, and an overall reduction of 15.8%. For more detailed information regarding the Little Patuxent River Watershed TMDL nonpoint source LA, please see the technical memorandum to this document entitled "*Significant Sediment Nonpoint Sources in the Little Patuxent River Watershed*". The reductions required to meet this TMDL would entail that at a 65% TSS reduction efficiency, approximately 96% of the urban area (impervious and pervious) within the watershed that was developed prior to 1985 would need to be retrofit, or an equivalent reduction in sediment loads from other types of stormwater retrofits is necessary (see Section 5.0 for a detailed description of the other types of stormwater retrofits).

Table 8: Little Patuxent River TMDL Reductions by Source Category

	Baseline Load Source Categories		Baseline Load (ton/yr)	TMDL Components	TMDL (ton/yr)	Reduction (%)
Little Patuxent River Watershed Contribution	**Nonpoint Source**		6,042.1	**LA**	6,042.1	0.0
	Point Source	Urban	17,092.5	**WLA**	11,225.8	34.3
		Permits	2,032.8		2,032.8	0.0
Sub-total			**25,167.4**		**19,300.6**	**23.3**
Upstream	Middle Patuxent[1,2]		11,899.1	**Upstream LA**	11,899.1	0.0
Total			**37,066.5**		**31,199.8**	**15.8**

Notes: [1] Since the biological results from the Core/Trend stations along the mainstem of the Little Patuxent River indicate that mainstem water quality can be classified as good, MDE concluded that the sediment impairment in the Little Patuxent River watershed is restricted to the lower order streams within the watershed. Therefore, sediment reductions have only been applied to the loads transported via the lower order stream network within the watershed and not the loads transported from the upstream Middle Patuxent River watershed to the Little Patuxent River mainstem.

[2] For the Middle Patuxent River watershed point/WLA and nonpoint source/LA characterization, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard County, Maryland" (MDE 2010b).

The WLA of the Little Patuxent 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 industrial facilities
- Individual municipal facilities
- General mineral mining facilities

There are 14 process water sources with explicit TSS limits in the Little Patuxent River watershed, which include three industrial, five municipal, and six mineral mine discharges. The total estimated TSS load from all of the process water sources is based on current permit limits and is equal to 2,032.8 ton/yr. As mentioned above, no reductions were applied to this source, since such controls would produce no discernable water quality benefit when nonpoint sources and regulated stormwater sources comprise 92% of the sediment loads generated within the Little Patuxent River watershed. For a detailed description of the 14 process water sources, including information on their permit limits, please see Appendix B. For information regarding the allocations to the individual process water point sources, please see the technical memoranda to this document entitled "*Significant Sediment Point Sources in the Little Patuxent River Watershed*".

Stormwater WLA

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 Little Patuxent 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 discharges effluent limits should be expressed as BMPs or other similar requirements, rather than as numeric effluent limits" (US EPA 2002).

The Little Patuxent River NPDES stormwater WLA is based on reductions applied to the sediment load from the urban land use in 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 Little Patuxent River NPDES stormwater WLA requires an overall reduction of 34.3% (see Table 8).

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 protect aquatic life from sediment related impacts.

For more information on the methods used to calculate the baseline urban sediment load, see Section 2.2.2. For a detailed list of all of the NPDES regulated stormwater discharges within the watershed, please see Appendix B, and for information regarding the NPDES stormwater WLA distribution amongst these discharges, please see the technical memorandum to this document entitled "*Significant Sediment Point Sources in the Little Patuxent River Watershed*".

4.7 Margin of Safety

All TMDLs must include a MOS to account for any lack of knowledge and uncertainty concerning the relationship between loads and water quality (CFR 2009b). The MOS shall also account for any rounding errors generated in the various calculations used in the development of the TMDL. 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 4.2. Also, 50% of the reference watersheds have a value less than 3.3. 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 (Currey et al. 2006). This is considered an environmentally conservative estimate, since 50% of the reference watersheds have a load above this value (3.3), which when compared to the 75% value (4.2), results in an implicit MOS of approximately 18%.

4.8 Summary of Total Maximum Daily Loads

The average annual Little Patuxent River watershed TMDL is summarized in Table 9. 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 Little Patuxent River watershed and loads from upstream sources. The Maximum Daily Load (MDL) is summarized in Table 10 (See Appendix C for more details).

Table 9: Little Patuxent River Watershed Average Annual TMDL of Sediment/TSS (ton/yr)

TMDL (ton/yr)	=	LA			+	WLA			+	MOS
		LA_{MP}[1]	+	LA_{LP}		NPDES Stormwater WLA_{LP}	+	Process Water WLA_{LP}		
31,199.8	=	11,899.1	+	6,042.1	+	11,225.8	+	2,032.8	+	Implicit
		Upstream Load Allocations[2,3]		Little Patuxent River Watershed TMDL Contribution						

Notes: [1] For Middle Patuxent River watershed WLA and LA characterization, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard County, Maryland" (MDE 2010b).
[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.
[3] A delivery factor of 1 was used for the Upstream LA.

Table 10: Little Patuxent River Maximum Daily Loads of Sediment/TSS (ton/day)

MDL (ton/day)	=	LA			+	WLA			+	MOS
		LA_{MP}[1]	+	LA_{LP}		NPDES Stormwater WLA_{LP}	+	Process Water WLA_{LP}		
1,067.3	=	428.4	+	217.5	+	404.1	+	17.3	+	Implicit
		Upstream Load Allocations[2,3]		Little Patuxent River Watershed TMDL Contribution						

Notes: [1] An MDL is not calculated within the 2010 Middle Patuxent Sediment WQA. Thus, this MDL was established based off the estimated baseline loadings specified in the WQA and subsequently applied as the average annual Upstream Baseline Load and Upstream LA in this report, via the methods described in Appendix C.
[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.
[3] A delivery factor of 1 was used for the Upstream LA**.**

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 CWA and current EPA regulations require reasonable assurance that the TMDL load and WLAs can and will be implemented (CFR 2009b). 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 available for local governments for implementation include 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 BMPs for reducing sediment loads and resulting impacts can be grouped into two general categories. The first is directed toward agricultural lands and the second is directed toward urban (developed) lands. Since urban land was identified as the only predominant controllable source of sediment within the watershed (i.e., 69.3% of the Little Patuxent River Baseline Sediment Load Contribution), the entirety of the required sediment reductions within the Little Patuxent River watershed are attributed to urban (developed) land use. The various BMPs applicable to reducing urban sediment loads are discussed below.

Sediment from urban areas can be reduced by stormwater retrofits that address both water quality and flow. Examples of these retrofits include the modification of existing stormwater structural practices, the construction of new stormwater BMPs in prior development where there is none, a reduction in impervious surfaces, street sweeping, inlet cleaning, increases in the urban tree canopy, stream restoration, and any other management practice that effectively addresses water quality and flow control (i.e., riparian buffers for urban areas and watershed reforestation adjacent to the watershed stream system or within a watershed's interior). A significant portion of the sediment loading from the urban area within the Little Patuxent River watershed is attributed to streambank erosion (see section 2.2.1). Therefore, flow controls must be implemented to reduce sheer stress and limit bank erosion in order to address this portion of the urban sediment load. Additionally, impervious surface reduction results in a change in hydrology that could also reduce streambank erosion. In terms of upland urban sediment loads, stormwater retrofit reductions range from as low as 10% for dry detention to approximately 80% for wet ponds, wetlands, infiltration practices, and filtering practices (US EPA 2003). It is anticipated that the implementation of the TMDL will include the array of urban BMPs and practices outlined above. Implementation is expected to occur primarily via the Phase I MS4 permitting process for medium and large municipalities, which requires that these jurisdictions retrofit 10% of their existing impervious area within a permit cycle, or 5 years. These Phase I MS4 jurisdictions should work with the other regulated stormwater entities in the watershed (see Appendix B, Table B-5) during the implementation process to achieve the necessary reductions.

It has been estimated that the average TSS removal efficiencies for BMPs installed between the years of 1985-2002 and post 2002, which are reflective of the stormwater management regulations in place during these time periods, is 50% and 80%, respectively (Claytor and Schueler 1997; Baldwin et al. 2007; Baish and Caliri 2009). Based on these average TSS reduction efficiencies, BMP specific reduction efficiencies as estimated by CBP, and best professional judgment, MDE estimates that future stormwater retrofits, which are expected to be implemented as part of the 10% retrofit requirement to existing impervious land every 5 years for all Phase I MS4 jurisdictions (MDE 2009b), will have approximately a 65% reduction efficiency for TSS, which is subject to change over time. Additionally, any new development in the watershed will be subject to the Stormwater Management Act of 2007 and will be required to use environmental site design (ESD) to the maximum extent practicable.

In summary, through the use of the aforementioned funding mechanisms and BMPs, there is reasonable assurance that this TMDL can be implemented.

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APPENDIX A – Watershed Characterization Data

Table A-1: Reference Watersheds

MD 8-digit Name	MD 8-digit	Percent stream mile BIBI/FIBI < 3.0 (%)[1,2]	Forest Normalized Sediment Load[3]
Deer Creek	02120202	11	3.9
Broad Creek	02120205	12	4.5
Little Gunpowder Falls	02130804	15	3.3
Prettyboy Reservoir	02130806	16	3.7
Middle Patuxent River	02131106	20	3.2
Brighton Dam	02131108	11	4.2
Sideling Creek	02140510	20	1.9
Fifteen Mile Creek	02140511	4	1.6
Savage River	02141006	7	2.5
Median			**3.3**
75th			**4.2**

Notes: [1]Based on the percentage of MBSS stations with BIBI and/or FIBI scores significantly lower than 3.0 within the MD 8-digit watershed (MDE 2008a).
[2]The percent stream miles with BIBI and/or FIBI scores significantly lower than 3.0 threshold to determine if an 8-digit watershed is impaired for impacts to biological communities is based on a comparison to reference conditions (MDE 2008a).
[3]Forest normalized sediment loads based on Maryland watershed area only (consistent with MBSS random monitoring data).

APPENDIX B – MDE Permit Information

Table B-1: Permit Summary

MDE Permit #	NPDES #	Facility	City	County	Type	TMDL
01DP3368	MD0068713	JOHN RITTER TRUCKING, INC.	LAUREL	ANNE ARUNDEL	WMA1	Process Water
03DP3431	MD0068993	BBSS, INC. - TURNER PIT	GAMBRILLS	ANNE ARUNDEL	WMA1	Process Water
03DP0033	MD0000469	MARYLAND & VIRGINIA MILK PRODUCERS ASSOCIATION	LAUREL	HOWARD	WMA1M	Process Water
04DP1936	MD0059145	PINEY ORCHARD WWTP[2]	ODENTON	ANNE ARUNDEL	WMA2	Process Water
04DP2488	MD0063207	DORSEY RUN ADVANCED WWTP[2]	JESSUP	ANNE ARUNDEL	WMA2M	Process Water
06DP1421	MD0055174	LITTLE PATUXENT WATER RECLAMATION PLANT	SAVAGE	HOWARD	WMA2M	Process Water
07DP2533	MD0021717	U.S. ARMY - FORT GEORGE G. MEADE	FORT MEADE	ANNE ARUNDEL	WMA2M	Process Water
99DP0132	MD0021652	PATUXENT WATER RECLAMATION FACILITY	CROFTON	ANNE ARUNDEL	WMA2M	Process Water
00MM0344C	MDG490344	AGGREGRATE INDUSTRIES - CROFTON READY-MIX CONCRETE	CROFTON	ANNE ARUNDEL	WMA5	Process Water
00MM2410A	MDG492410	CLASSIC GROUP	ODENTON	ANNE ARUNDEL	WMA5	Process Water
00MM9709	MDG499709	CUNNINGHAM EXCAVATING, INC.	CROFTON	ANNE ARUNDEL	WMA5	Process Water
00MM9725	MDG499725	RELIABLE CONTRACTING COMPANY, INC.-ASPHALT DIV.	GAMBRILLS	ANNE ARUNDEL	WMA5	Process Water
00MM9739	MDG499739	DANIEL G. SCHUSTER INC.- JESSUP	JESSUP	HOWARD	WMA5	Process Water
00MM9860	MDG499860	LAFARGE - JESSUP CONCRETE PLANT	JESSUP	ANNE ARUNDEL	WMA5	Process Water
02SW0123		ISP PHARMA SYSTEMS	COLUMBIA	HOWARD	WMA5SW	Stormwater WLA
02SW0260		LITTLE PATUXENT WATER RECLAMATION PLANT	SAVAGE	HOWARD	WMA5SW	Stormwater WLA
02SW0331		DORSEY RUN ADVANCED WASTEWATER TREATMENT PLANT	JESSUP	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0371		CLEAN HARBORS OF LAUREL, LLC	LAUREL	ANNE ARUNDEL	WMA5SW	Stormwater WLA

MDE Permit #	NPDES #	Facility	City	County	Type	TMDL
02SW0544		GIANT OF MARYLAND, LLC - JESSUP	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW0700		U.S. ARMY - FORT GEORGE G. MEADE	FORT MEADE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0727		PINEY ORCHARD WWTP	ODENTON	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0735		CINDER & CONCRETE BLOCK CORP. - JESSUP	JESSUP	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0744		U.S. POSTAL SERVICE - COLUMBIA VMF	COLUMBIA	HOWARD	WMA5SW	Stormwater WLA
02SW0759		PATUXENT WATER RECLAMATION FACILITY	CROFTON	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0773		FLINT GROUP NORTH AMERICA LIMITED	COLUMBIA	HOWARD	WMA5SW	Stormwater WLA
02SW0776		FEDEX NATIONAL LTL, INC.	ANNAPOLIS JUNCTION	HOWARD	WMA5SW	Stormwater WLA
02SW0833		ALLIED SYSTEMS, LTD.	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW0957		TDS, INC.	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW0966		AGGREGRATE INDUSTRIES - ANNAPOLIS JUNCTION ASPHALT PLANT	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW1160		GENERAL ELECTRIC COMPANY	COLUMBIA	HOWARD	WMA5SW	Stormwater WLA
02SW1164		AMTRAK - ODENTON MAINTENANCE OF WAY BASE	ODENTON	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1168		UNITED PARCEL SERVICE - JESSUP	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW1177		ANNE ARUNDEL COUNTY - ODENTON	ODENTON	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1197		CG ENTERPRISES, INC.	ANNAPOLIS JUNCTION	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1203		CON-WAY CENTRAL EXPRESS - XJP	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW1259		DREYER'S GRAND ICE CREAM	LAUREL	HOWARD	WMA5SW	Stormwater WLA
02SW1268		TATE ACCESS FLOORS	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW1269		NATIONAL DISTRIBUTING COMPANY	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW1361		D.G.& G, INC. DBA CRAZY RAY'S	JESSUP	HOWARD	WMA5SW	Stormwater WLA
02SW1436		HOWARD COUNTY CENTRAL FLEET/GUILFORD SHOP	COLUMBIA	HOWARD	WMA5SW	Stormwater WLA
02SW1439		HOWARD COUNTY CENTRAL FLEET UTILITES SHOP	COLUMBIA	HOWARD	WMA5SW	Stormwater WLA
02SW1441		VEOLIA TRANSPORTATION - SAVAGE	SAVAGE	HOWARD	WMA5SW	Stormwater WLA

MDE Permit #	NPDES #	Facility	City	County	Type	TMDL
02SW1503		LAUREL BLOCK CORPORATION	ANNAPOLIS JUNCTION	HOWARD	WMA5SW	Stormwater WLA
02SW1697		TIPTON AIRPORT	FORT GEORGE G. MEADE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1706		WASTE MANAGEMENT OF MARYLAND - ANNAPOLIS JUNCTION TRANSFER STATION	JESSUP	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1807		MARYLAND PAVING & SEALANT, INC.	ANNAPOLIS JUNCTION	HOWARD	WMA5SW	Stormwater WLA
02SW1974		D B CONCRETE CONSTRUCTION, INC	ANNAPOLIS JUNCTION	HOWARD	WMA5SW	Stormwater WLA
04DP3316	MD0068306	ANNE ARUNDEL COUNTY MS4	COUNTY WIDE	ANNE ARUNDEL	WMA6	Stormwater WLA
99P3314	MD0068284	HOWARD COUNTY MS4	COUNTY WIDE	HOWARD	WMA6	Stormwater WLA
99DP3313	MD0068276	STATE HIGHWAY ADMINSTRATION MS4	STATE-WIDE	ALL PHASE I	WMA6	Stormwater WLA
		MDE GENERAL PERMIT TO CONSTRUCT	ALL	ALL		Stormwater WLA

Notes: [1]TMDL column identifies how the permit was considered in the TMDL allocation.
[2]WWTP = Wastewater Treatment Plant

Table B-2: Individual Industrial Permit Data

Facility Name	MDE Permit #	NPDES #	Flow (MGD)[1]	Permit Avg. Monthly Conc. (mg/l)[2]	Permit Daily Max. Conc. (mg/l)[2]
JOHN RITTER TRUCKING, INC.	01DP3368	MD0068713	0.0001	30	60
BBSS, INC. - TURNER PIT	03DP3431	MD0068993	0.1401	30	60
MARYLAND & VIRGINIA MILK PRODUCERS ASSOCIATION	03DP0033	MD0000469	0.325	12	23

Notes: [1]MGD = Millions of Gallons per Day.
[2]mg/l = Milligrams per liter.

Table B-3: Individual Municipal Permit Data

Facility Name	MDE Permit #	NPDES #	Flow (MGD)	Permit Avg. Monthly Conc. (mg/l)	Permit Weekly Max. Conc. (mg/l)
PINEY ORCHARD WWTP	04DP1936	MD0059145	1.2	30	45
DORSEY RUN ADVANCED WWTP	04DP2488	MD0063207	2	30	45
LITTLE PATUXENT WATER RECLAMATION PLANT	06DP1421	MD0055174	29	30	45
U.S. ARMY - FORT GEORGE G. MEADE	07DP2533	MD0021717	4.5	30	45
PATUXENT WATER RECLAMATION FACILITY	99DP0132	MD0021652	7.5	30	45

Table B-4: General Mine Permit Data

Facility Name	MDE Permit #	NPDES #	Flow (MGD)	Permit Avg Monthly Conc. (mg/l)	Permit Daily Max Conc. (mg/l)
AGGREGRATE INDUSTRIES - CROFTON READY-MIX CONCRETE	00MM0344C	MDG490344	0.00035	30	60
CLASSIC GROUP	00MM2410A	MDG492410	0.0457	30	60
CUNNINGHAM EXCAVATING, INC.	00MM9709	MDG499709	0.048	30	60
RELIABLE CONTRACTING COMPANY, INC.-ASPHALT DIV.	00MM9725	MDG499725	0.013	30	60
DANIEL G. SCHUSTER INC.- JESSUP	00MM9739	MDG499739	0.0008	30	60
LAFARGE - JESSUP CONCRETE PLANT	00MM9860	MDG499860	0.001	30	60

Table B-5: Stormwater Permits[1]

MDE Permit #	Facility	NPDES Group
02SW0123	ISP PHARMA SYSTEMS	Phase I
02SW0260	LITTLE PATUXENT WATER RECLAMATION PLANT	Phase I
02SW0331	DORSEY RUN ADVANCED WASTEWATER TREATMENT PLANT	Phase I
02SW0371	CLEAN HARBORS OF LAUREL, LLC	Phase I
02SW0544	GIANT OF MARYLAND, LLC - JESSUP	Phase I
02SW0700	U.S. ARMY - FORT GEORGE G. MEADE	Phase I
02SW0727	PINEY ORCHARD WWTP	Phase I
02SW0735	CINDER & CONCRETE BLOCK CORP. - JESSUP	Phase I
02SW0744	U.S. POSTAL SERVICE - COLUMBIA VMF	Phase I
02SW0759	PATUXENT WATER RECLAMATION FACILITY	Phase I
02SW0773	FLINT GROUP NORTH AMERICA LIMITED	Phase I
02SW0776	FEDEX NATIONAL LTL, INC.	Phase I
02SW0833	ALLIED SYSTEMS, LTD.	Phase I
02SW0957	TDS, INC.	Phase I
02SW0966	AGGREGRATE INDUSTRIES - ANNAPOLIS JUNCTION ASPHALT PLANT	Phase I
02SW1160	GENERAL ELECTRIC COMPANY	Phase I
02SW1164	AMTRAK - ODENTON MAINTENANCE OF WAY BASE	Phase I
02SW1168	UNITED PARCEL SERVICE - JESSUP	Phase I
02SW1177	ANNE ARUNDEL COUNTY - ODENTON	Phase I
02SW1197	CG ENTERPRISES, INC.	Phase I
02SW1203	CON-WAY CENTRAL EXPRESS - XJP	Phase I
02SW1259	DREYER'S GRAND ICE CREAM	Phase I
02SW1268	TATE ACCESS FLOORS	Phase I
02SW1269	NATIONAL DISTRIBUTING COMPANY	Phase I
02SW1361	D.G.& G, INC. DBA CRAZY RAY'S	Phase I

MDE Permit #	Facility	NPDES Group
02SW1436	HOWARD COUNTY CENTRAL FLEET/GUILFORD SHOP	Phase I
02SW1439	HOWARD COUNTY CENTRAL FLEET UTILITES SHOP	Phase I
02SW1441	VEOLIA TRANSPORTATION - SAVAGE	Phase I
02SW1503	LAUREL BLOCK CORPORATION	Phase I
02SW1697	TIPTON AIRPORT	Phase I
02SW1706	WASTE MANAGEMENT OF MARYLAND - ANNAPOLIS JUNCTION TRANSFER STATION	Phase I
02SW1807	MARYLAND PAVING & SEALANT, INC.	Phase I
02SW1974	D B CONCRETE CONSTRUCTION, INC	Phase I
04DP3316	ANNE ARUNDEL COUNTY MS4	Phase I
99P3314	HOWARD COUNTY MS4	Phase I
99DP3313	STATE HIGHWAY ADMINSTRATION MS4	Phase I
	MDE GENERAL PERMIT TO CONSTRUCT	Phase I/II

Notes: [1] Although not listed in this table, some individual process water permits incorporate stormwater requirements and are accounted for within the NPDES stormwater WLA (specifically the "Other" Regulated Stormwater Allocation in the Technical Memorandum *Significant Sediment Point Sources in the Little Patuxent River Watershed* accompanying this TMDL report) as well additional Phase II permitted MS4s, such as military bases, hospitals, etc.

APPENDIX C – Technical Approach Used to Generate Maximum Daily Loads

Summary

This appendix documents the technical approach used to define MDLs of sediment consistent with the average annual TMDL in the Little Patuxent River watershed, which is considered the maximum allowable load the watershed can sustain and support aquatic life. The approach builds upon the modeling analysis that was conducted to determine the sediment loadings and can be summarized as follows.

- The approach defines MDLs for each of the source categories.
- The approach builds upon the TMDL modeling analysis that was conducted to ensure that average annual loading targets are at a level to support aquatic life.
- The approach converts daily time-series loadings into TMDL values in a manner that is consistent with available EPA guidance on generating daily loads for TMDLs (US EPA 2007).
- The approach considers a daily load level of a resolution based on the specific data that exists for each source category.

Introduction

This appendix documents the development and application of the approach used to define MDL values. It is divided into sections discussing:

- Basis for approach
- Options considered
- Selected approach
- Results of approach

Basis for approach

The overall approach for the development of daily loads was based upon the following factors:

- **Average Annual TMDL:** The basis of the average annual sediment TMDL is that cumulative high sediment loading rates have negative impacts on the biological community. Thus, the average annual sediment load was calculated so as to ensure the support of aquatic life.
- **CBP P5 Watershed Model Sediment Loads:** There are two spatial calibration points for sediment within the CBP P5.2 watershed model framework. First, EOS loads are calibrated to long term EOS target loads. These target loads are the loads used to determine an average annual TMDL, as actual CBP P5.2 calibration and scenario runs were not available upon development of the nontidal sediment TMDL methodology (Currey et al. 2006). Since the EOS target loads applied in the TMDL remained relatively unchanged during the final calibration stages of

the CBP P5.2 model, they are consistent with the final CBP P5.2 sediment loading estimates. The CBP P5.2 model river segments were calibrated to daily monitoring information for watersheds with a flow greater that 100 cubic feet per second (cfs), or an approximate area of 100 square miles.

- **Draft EPA guidance document entitled "Developing Daily Loads for Load-based TMDLs":** This guidance document provides options for defining MDLs when using TMDL approaches that generate daily output (US EPA 2007).

The rationale for developing TMDLs expressed as *daily* loads was to accept the existing average annual TMDL, but then develop a method for converting this number to a MDL – in a manner consistent with EPA guidance and available information.

Options considered

The draft EPA guidance document for developing daily loads does not specify a single approach that must be adhered to, but rather it contains a range of acceptable options (US EPA 2007). The selection of a specific method for translating a time-series of allowable loads into the expression of a TMDL requires decisions regarding both the level of resolution (e.g., single daily load for all conditions vs. loads that vary with environmental conditions) and level of probability associated with the TMDL.

This section describes the range of options that were considered when developing methods to calculate Little Patuxent River Maximum Daily Loads.

<u>Level of Resolution</u>

The level of resolution pertains to the amount of detail used in specifying the MDL. The draft EPA guidance document on daily loads provides three categories of options for level of resolution, all of which are potentially applicable for the Little Patuxent River watershed:

1. **Representative daily load:** In this option, a single daily load (or multiple representative daily loads) is specified that covers all time periods and environmental conditions.
2. **Flow-variable daily load:** This option allows the maximum daily load to vary based upon the observed flow condition.
3. **Temporally-variable daily load:** This option allows the maximum daily load to vary based upon seasons or times of varying source or water body behavior (US EPA 2007).

<u>Probability Level</u>

All TMDLs have some probability of being exceeded, with the specific probability being either explicitly specified or implicitly assumed. This level of probability directly or indirectly reflects two separate phenomena:

1. Water quality criteria consist of components describing acceptable magnitude, duration, and frequency. The frequency component addresses how often conditions can allowably surpass the combined magnitude and duration components.
2. Pollutant loads, especially from wet weather sources, typically exhibit a large degree of variability over time. It is rarely practical to specify a "never to be exceeded value" for a daily load, as essentially any loading value has some finite probability of being exceeded.

The draft daily load guidance document states that the probability component of the MDL should be "based on a representative statistical measure" that is dependent upon the specific TMDL and the best professional judgment of the developers (US EPA 2007). This statistical measure represents how often the MDL is expected/allowed to be exceeded. The primary options for selecting this level of protection would be:

1. **The maximum daily load reflects some central tendency:** In this option, the MDL is based upon the mean or median value of the range of loads expected to occur. The variability in the actual loads is not addressed.
2. **The maximum daily load reflects a level of protection implicitly provided by the selection of some "critical" period**: In this option, the MDL is based upon the allowable load that is predicted to occur during some critical period examined during the analysis. The developer does not explicitly specify the probability of occurrence.
3. **The maximum daily load is a value that will be exceeded with a pre-defined probability:** In this option, a "reasonable" upper bound percentile is selected for the MDL based upon a characterization of the variability of daily loads. For example, selection of the 95th percentile value would result in a MDL that would be exceeded 5% of the time.

Selected Approach

The approach selected for defining a Little Patuxent River MDL was based upon the specific data that exists for each source category. The approach consists of unique methods for each of the following categories of sources:

- Approach for Nonpoint Sources and Stormwater Point Sources within the Little Patuxent River watershed
- Approach for Process Water Point Sources within the Little Patuxent River watershed
- Approach for Upstream Sources

<u>Approach for Nonpoint Sources and Stormwater Point Sources within the Little Patuxent River watershed</u>

The level of resolution selected for the Little Patuxent River MDL was a representative daily load, expressed as a single daily load for each loading source. This approach was chosen based upon the specific data that exists for nonpoint sources and stormwater point sources within the Little Patuxent River watershed. Currently, the best available data is the CBP P5.2 model daily time series calibrated to long-term average annual loads (per landuse). The CBP reach simulation results are calibrated to daily monitoring information for watershed segments with a flow typically greater than 100 cfs, but these model calibration runs were not available upon development of the average annual nontidal sediment TMDL methodology (Currey et al. 2006). Therefore, to be consistent with the average annual TMDL, it was concluded that it would not be appropriate to apply the absolute values of the reach simulation model, daily time series results to calculate the MDL. Thus, the annual loads were used instead. However, it was assumed that the distribution of the daily values was correct, in order to calculate a normalized statistical parameter to estimate the MDLs.

The MDL was estimated based on three factors: a specified probability level, the average annual sediment TMDL, and the coefficient of variation (CV) of the CBP P5.2 Little Patuxent River reach simulation daily loads. The probability level (or exceedance frequency) is based upon guidance from EPA (US EPA 1991) where examples suggest that when converting from a long-term average to a daily value, the z-score corresponding to the 99th percentile of the log-normal probability distribution should be used. The average annual sediment TMDL is estimated from the CBP P5.2 EOS target loads. The calculation of the CV is described below.

The CBP P5.2 Little Patuxent River reach simulation consisted of a daily time series beginning in 1985 and extending to the year 2005. The CV was estimated by first converting the daily sediment load values to a log distribution and then verifying that the results approximated the normal distribution (see Figure C-1). Next, the CV was calculated using the arithmetic mean and standard deviation results from the log transformation. The log-transformed values were used to reduce the possible influence of outliers. The resulting CV of 5.2 was calculated using the following equation:

$$CV = \frac{\beta}{\alpha} \qquad \text{(Equation C.1)}$$

where:
CV = coefficient of variation
$\beta = \alpha\sqrt{e^{\sigma^2} - 1}$
$\alpha = e^{(\mu + 0.5*\sigma^2)}$
α = mean (arithmetic)
β = standard deviation (arithmetic)
μ = mean of logarithms
σ =standard deviation of logarithms

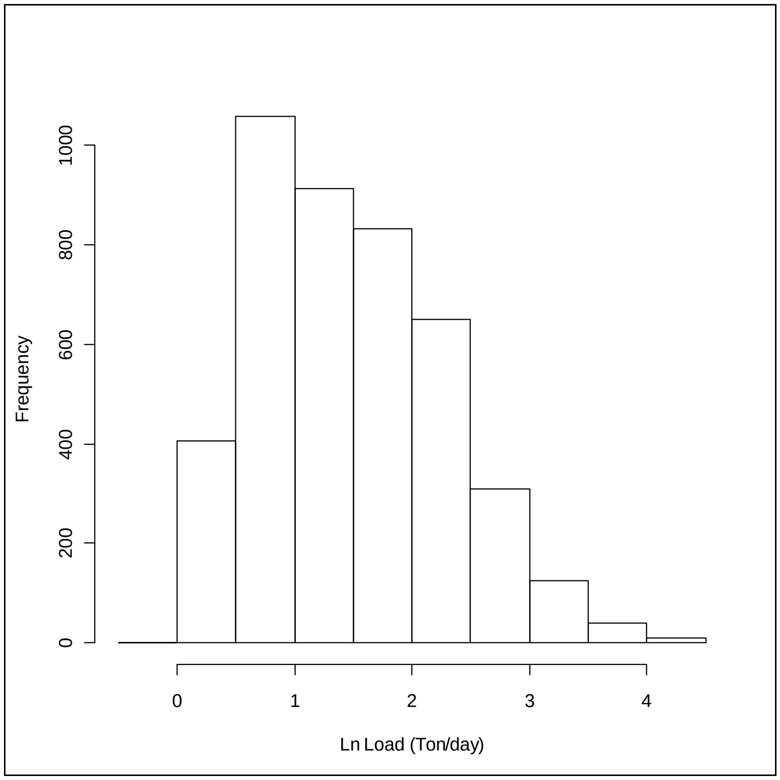

Figure C-1: Histogram of CBP River Segment Daily Simulation Results for the Little Patuxent River Watershed

The maximum "daily" load for each contributing source is estimated as the long-term average annual load multiplied by a factor that accounts for expected variability of daily loading values. The equation is as follows:

$$MDL = LTA * e^{(z\sigma - 0.5\sigma^2)} \qquad \text{(Equation C.2)}$$

where:
MDL = Maximum daily load
LTA = Long term average (average annual load)
Z = z-score associated with target probability level
$\sigma^2 = \ln(CV^2+1)$
CV = Coefficient of variation based on arithmetic mean and standard deviation

Using a z-score associated with the 99^{th} percent probability, a CV of 5.2, and consistent units, the resulting dimensionless conversion factor from long term average annual loads to a MDL is 13.2. The average annual Little Patuxent River TMDL of sediment/TSS is reported in ton/yr, and the conversion from ton/yr to a MDL in ton/day is 0.036 (e.g. 13.2/365).

Approach for Process Water Point Sources within the Little Patuxent River watershed

The TMDL also considers contributions from other point sources (i.e., sources other than stormwater point sources) in the watershed that have NPDES permits with sediment limits. As these sources are generally minor contributors to the overall sediment load, the TMDL analysis that defined the average annual TMDL did not propose any reductions for these sources and held each of them constant at their existing technology-based NPDES permit monthly (or daily if monthly was not specified) limit for the entire year.

The approach used to determine MDLs for these sources was dependent upon whether a maximum daily limit was specified within the permit. If a maximum daily limit was specified, then the reported average flow was multiplied by the daily maximum limit to obtain a MDL. If a maximum daily limit was not specified, the MDLs were calculated based on the guidance provided in the Technical Support Document (TSD) for Water Quality-based Toxics Control (US EPA 1991). The long-term average annual TMDL was converted to maximum daily limits using Table 5-2 of the TSD assuming a coefficient of variation of 0.6 and a 99^{th} percentile probability. This results in a dimensionless multiplication factor of 3.11. The average annual Little Patuxent River TMDL of sediment/TSS is reported in ton/yr, and the conversion from ton/yr to a MDL in ton/day is 0.0085 (e.g. 3.11/365).

Approach for Upstream Sources

For the purposes of this analysis, one upstream watershed has been identified: the Middle Patuxent River watershed. The MDL for this upstream source is estimated based on the same methodology applied for nonpoint source and stormwater point sources within the Little Patuxent River watershed. This MDL is calculated solely for the purposes of this analysis and is not presented in the Middle Patuxent River watershed sediment WQA report.

Results of approach

This section lists the results of the selected approach to define the Little Patuxent River MDLs.

- Calculation Approach for Nonpoint Sources and Stormwater Point Sources within the Little Patuxent River watershed

LA_{LP} (Ton/day) = Average Annual TMDL LA_{LP} (ton/yr) * 0.036

Stormwater WLA_{LP} (Ton/day) = Average Annual TMDL Stormwater WLA_{LP} (ton/yr) * 0.036

- Calculation Approach for Process Water Point Sources within the Little Patuxent River watershed
    - For permits with a daily maximum limit:

Process Water WLA_{LP} (ton/day) = Permit flow (mgd) * Daily maximum permit limit (mg/l) * 0.0042, where 0.0042 is a combined factor required to convert units to ton/day

- For permits without a daily maximum limit:

Process Water WLA_{LP} (Ton/day) = Average Annual TMDL WLA_{LP} Other (ton/yr)* 0.0085, where 0.0085 is the factor required to convert units to ton/day

- Calculation Approach for Upstream Sources

LA_{MP} (Ton/day) = Average Annual TMDL LA_{MP} (ton/yr) * 0.036

Table C-1: Little Patuxent River Maximum Daily Loads of Sediment/TSS (ton/day)

MDL (ton/day)	=	LA			+	WLA			+	MOS
		LA_{MP}[1]	+	LA_{LP}		NPDES Stormwater WLA_{LP}	+	Process Water WLA_{LP}		
1,067.3	=	428.4	+	217.5	+	404.1	+	17.30	+	Implicit
		Upstream Load Allocations[2,3]		Little Patuxent River Watershed MDL Contribution						

Notes: [1] An MDL is not calculated within the 2010 Middle Patuxent Sediment WQA. Thus, this MDL was established based off the estimated baseline loadings specified in the WQA and subsequently applied as the average annual Upstream Baseline Load and Upstream LA in this report, via the methods described here in Appendix C.
[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.
[3] A delivery factor of 1 was used for the Upstream LA**.**

APPENDIX D – Sediment Baseline Loads and TMDLs for MD 8-Digit Patuxent River Watersheds

INTRODUCTION

The purpose of this appendix is to explain the hydrologic relationship between the MD 8-Digit Middle Patuxent River, Little Patuxent River, Patuxent River Upper, Triadelphia Reservoir, Rocky Gorge Reservoir Watersheds and how this affects the sediment baseline loads and TMDLs, if applicable, for each of the respective watersheds. As illustrated in Figure D-1, the five watersheds are hydrologically connected, beginning upstream with the Middle Patuxent River watershed in the northeast and the Triadelphia Reservoir watershed in the northwest. The Middle Patuxent River watershed flows into the Little Patuxent River watershed, just south of Interstate 95. The combined flow from the Middle Patuxent River watershed and the Little Patuxent River watershed flows into the Patuxent River Upper watershed. Also, the Triadelphia Reservoir discharges to the Rocky Gorge Reservoir, which in turn discharges to the Patuxent River Upper watershed. The hydrologic connectivity of the watersheds is illustrated in Figures D-2 and D-3.

A sediment WQA, in which the baseline sediment loadings were estimated, has been developed for the Middle Patuxent River watershed, and sediment baseline loadings have been estimated, and subsequent TMDLs developed, for the Little Patuxent River watershed, Triadelphia Reservoir, and Patuxent River Upper watershed. Additionally, for the Rocky Gorge Reservoir, the baseline sediment loadings and the subsequent reduction in sediment loadings, expected to result from the implementation of the Phosphorus TMDL for the reservoir, have been estimated for the purposes of this analysis (see Section D-4).

The baseline sediment loads for the watersheds are shown in Table D-1 through D-3. The TMDL calculations are shown in Tables D-4 through D-5. Further information can be found in the individual TMDL/WQA documents for each watershed.

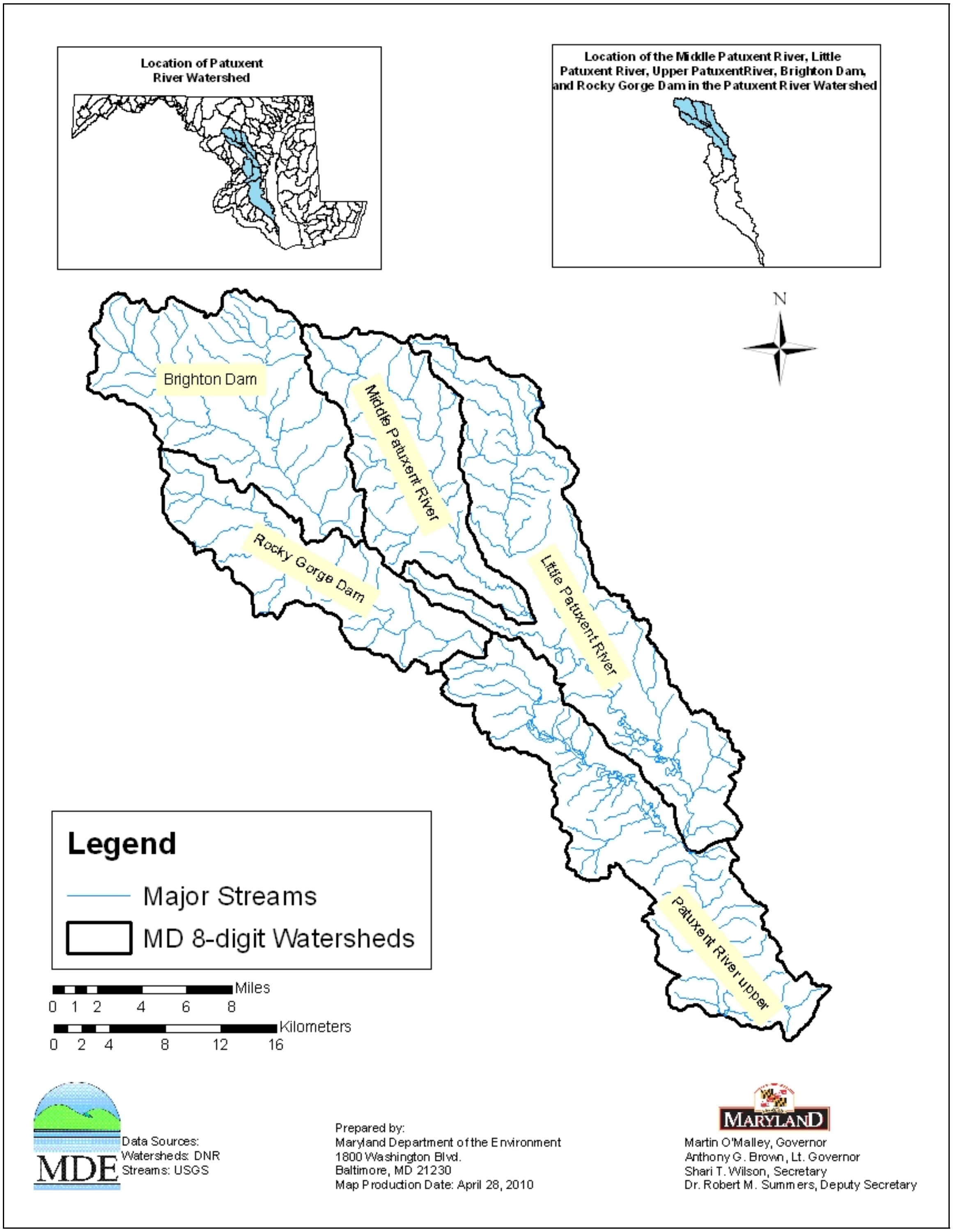

Figure D-1: Location of the Middle Patuxent River, Little Patuxent River, Triadelphia Reservoir, Rocky Gorge Reservoir, and Patuxent River Upper Watersheds

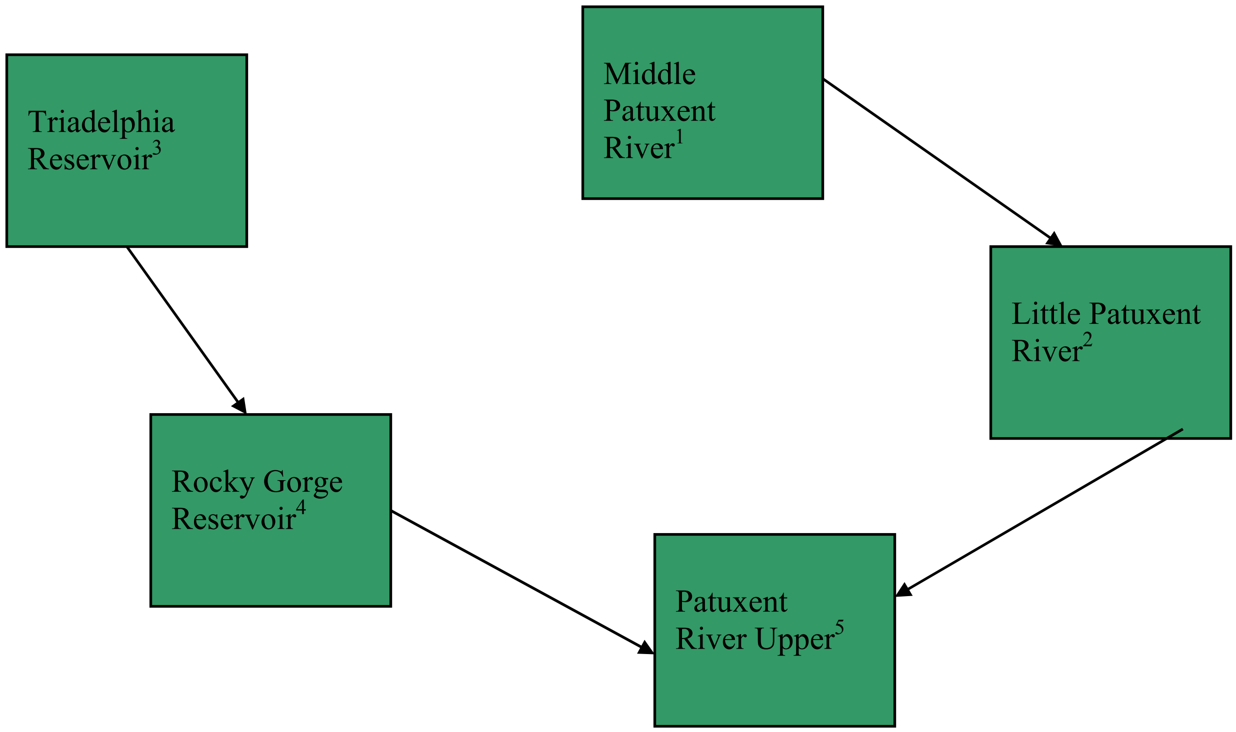

Figure D-2: Flow Schematic of the Middle Patuxent River, Little Patuxent River, Triadelphia Reservoir, Rocky Gorge Reservoir, and Patuxent River Upper Watersheds

Notes:

[1] A sediment WQA is being developed for the Middle Patuxent River watershed. For more information, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard and Anne Arundel Counties, Maryland" (MDE 2010b).

[2] A sediment TMDL is being developed for the Little Patuxent River watershed, as per this document.

[3] A sediment TMDL has been developed for the Triadelphia Reservoir. For more information, please refer to the "Total Maximum Daily Loads of Phosphorus and Sediments for Triadelphia Reservoir (Brighton Dam) and Total Maximum Daily Loads of Phosphorus for Rocky Gorge Reservoir, Howard, Montgomery, and Prince George's Counties, Maryland" (MDE 2008b).

[4] A Phosphorus TMDL only has been developed for the Rocky Gorge Reservoir. The baseline sediment load and the sediment load anticipated to result from the full implementation of the Phosphorus TMDL have been calculated within this appendix. For more information regarding the Phosphorus TMDL, please refer to the "Total Maximum Daily Loads of Phosphorus and Sediments for Triadelphia Reservoir (Brighton Dam) and Total Maximum Daily Loads of Phosphorus for Rocky Gorge Reservoir, Howard, Montgomery, and Prince George's Counties, Maryland" (MDE 2008b).

[5] A sediment TMDL is being developed for the Patuxent River Upper watershed. For more information, please refer to the "Total Maximum Daily Load of Sediment in the Patuxent River Upper Watershed, Anne Arundel, Howard, and Prince George's Counties, Maryland" (MDE 2010d).

BASELINE LOADS

Table D-1: Middle Patuxent River Baseline Sediment Loads (ton/yr)

Total Baseline Load (ton/yr)[1]
11,899.1

Notes: [1] For the Middle Patuxent River watershed point and nonpoint source characterization, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard County, Maryland" (MDE 2010b).

Table D-2: Little Patuxent River Baseline Sediment Loads (ton/yr)

		Upstream Baseline Load[1]		Little Patuxent River Watershed Baseline Load Contribution				
Total Baseline Load (ton/yr)	=	BL_{MP}[2]	+	Nonpoint Source BL_{LP}	+	NPDES Stormwater BL_{LP}	+	Process Water BL_{LP}
37,066.5	=	11,899.1	+	6,042.1	+	17,092.5	+	2,032.8

Notes: [1] Although the Upstream Baseline Load is reported here as a single value, it could include point and nonpoint sources.
[2] For the Middle Patuxent River watershed point and nonpoint source characterization, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard County, Maryland" (MDE 2010b).

Table D-3: Patuxent River Upper Baseline Sediment Loads (ton/yr)

		Upstream Baseline Loads[1]				Patuxent River Upper Watershed Baseline Load Contribution				
Total Baseline Load (ton/yr)	=	BL_{LP}[2]	+	BL_{RG}[3]	+	Nonpoint Source BL_{UP}	+	NPDES Stormwater BL_{UP}	+	Process Water BL_{UP}
66,421.1	=	37,066.5	+	7,689.0	+	11,956.1	+	9,102.0	+	607.5

Notes: [1] Although the Upstream Baseline Loads are reported here as single values, they could include point and nonpoint sources.
[2] For the Little Patuxent River watershed point and nonpoint source characterization, please refer to Section 2.0 of this document.
[3] For the Rocky Gorge Reservoir point and nonpoint source characterization, please refer to the remainder this Appendix, and for additional information regarding other sources of sediment to the reservoir (i.e., upstream sources) see the "Total Maximum Daily Loads of Phosphorus and Sediments for Triadelphia Reservoir (Brighton Dam) and Total Maximum Daily Loads of Phosphorus for Rocky Gorge Reservoir, Howard, Montgomery, and Prince George's Counties, Maryland" (MDE 2008b)..

TMDLS

Table D-4: Little Patuxent River Average Annual TMDL (ton/yr)

TMDL (ton/yr)	=	LA: LA_{MP}[1]	+	LA: LA_{LP}	+	WLA: NPDES Stormwater WLA_{LP}	+	WLA: Process Water WLA_{LP}	+	MOS
31,199.8	=	11,899.1	+	6,042.1	+	11,225.8	+	2,032.8	+	Implicit
		Upstream Load Allocations[2,3]		Little Patuxent River Watershed TMDL Contribution						

Notes: [1] For Middle Patuxent River watershed WLA and LA characterization, please refer to the "Water Quality Analysis of Sediment in the Middle Patuxent River Watershed, Howard County, Maryland" (MDE 2010b). No reductions were applied to the Middle Patuxent River watershed sediment loadings, since biological results from the DNR Core/Trend stations along the mainstem of the Little Patuxent River indicate that mainstem water quality can be classified as good, and it was therefore determined that the sediment impairment in the Little Patuxent River watershed is restricted to the lower order streams within the watershed.

[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.

[3] A delivery factor of 1 was used for the Upstream LA**.**

Table D-5: Patuxent River Upper Average Annual TMDL (ton/yr)

TMDL (ton/yr)	=	LA: LA_{LP}[1]	+	LA: LA_{RG}[2]	+	LA: LA_{UP}	+	WLA: NPDES Stormwater WLA_{UP}	+	WLA: Process Water WLA_{UP}	+	MOS
56,607.1	=	31,199.8	+	5,769.0	+	10,966.2	+	8,064.6	+	607.5	+	Implicit
		Upstream Load Allocations[3,4]				Patuxent River Upper Watershed TMDL Contribution						

Notes: [1] For Little Patuxent River watershed WLA and LA characterization, please refer to Sections 4.5 and 4.6 of this document.

[2] For Rocky Gorge Reservoir WLA and LA characterization, please refer to the remainder of this Appendix, and for additional information regarding other sources of sediment to the reservoir (i.e., upstream sources) see the "Total Maximum Daily Loads of Phosphorus and Sediments for Triadelphia Reservoir (Brighton Dam) and Total Maximum Daily Loads of Phosphorus for Rocky Gorge Reservoir, Howard, Montgomery, and Prince George's Counties, Maryland" (MDE 2008b).

[3] Although for the purposes of this analysis the 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 the Upstream LAs**.**

CALCULATION OF ROCKY GORGE RESERVOIR LOADS

The "*Total Maximum Daily Loads of Phosphorus and Sediments for Triadelphia Reservoir (Brighton Dam) and Total Maximum Daily Loads of Phosphorus for Rocky Gorge Reservoir, Howard, Montgomery, and Prince George's Counties, Maryland*" (*Reservoir TMDL*) was approved by the EPA in 2008 (MDE 2008b). Because the Rocky Gorge Reservoir was never listed as impaired for sediment, there was no calculation of its sediment loads in the *Reservoir TMDL*. However, the sediment load from the Rocky Gorge Reservoir needed to be calculated in order to be applied as an upstream load to the Patuxent River Upper Watershed. Therefore, in order to maintain consistency, a baseline sediment load was calculated using the watershed and water quality models from the *Reservoir TMDL*. Additionally, an informational sediment TMDL value was calculated for the Rocky Gorge Reservoir, based solely on the sediment reduction which naturally occurs when the phosphorus TMDL reduction is applied. The informational TMDL value is based on a ratio of 2:1 phosphorus to sediment reductions applied in Maryland reservoir TMDLs. Since the Reservoir TMDL requires a 48% phosphorus reduction, the informational TMDL for sediment would be equal to a 24% reduction from the baseline sediment load. The Rocky Gorge Reservoir is not impaired for sediment and does not require a sediment reduction to meet water quality standards.

Table D-6 summarizes the average annual baseline sediment loads (ton/yr) for the Rocky Gorge Reservoir. Table D-7 summarizes the average annual informational TMDL allocations in ton/yr for the Rocky Gorge Reservoir.

Table D-6: Rocky Gorge Reservoir Baseline Annual Sediment Loads (ton/yr), Rocky Gorge Reservoir, 1998-2003

Source	**Load (ton/yr)**
Triadelphia Reservoir	4,790
Total Edge-of-Stream	9,558
Net Scour	4,919
Total Input	**19,267**
Total Output[1]	**12,471**
Trapping Efficiency: 35.0%[2]	
Sediment Discharged to Patuxent River Upper[3]	**7,689**

Notes: [1] Total Output: The sediment load (ton/yr) that actually leaves the model. This includes sediment discharged to the Patuxent River and sediment withdrawn in water intakes.
[2] Trapping Efficiency: (Total Input –Total Output)/Total Input.
[3] Sediment Discharged: Estimate of sediment discharged to Rocky Gorge based on product of (1) sediment concentrations in outflow from reservoir and (2) daily average flow as recorded at USGS gage 01592500 (Patuxent River near Laurel).

Table D-7: Average Annual Sediment Loads (ton/yr), Rocky Gorge Reservoir, 1998-2003, Phosphorus TMDL Scenario

Source	**Load (ton/yr)**
Triadelphia Reservoir	3,401
Total Edge-of-Stream	7,422
Net Scour	3,820
Total Input	**14,643**
Total Output[1]	**9,379**
Trapping Efficiency: 36.0%[2]	
Sediment Discharged to Patuxent River Upper[3]	**5,769**

Notes: [1] Total Output: The sediment load (ton/yr) that actually leaves the model. This includes sediment discharged to the Patuxent River and sediment withdrawn in water intakes.
[2] Trapping Efficiency: (Total Input –Total Output)/Total Input.
[3] Sediment Discharged: Estimate of sediment discharged to Rocky Gorge based on product of (1) sediment concentrations in outflow from reservoir and (2) daily average flow as recorded at USGS gage 01592500 (Patuxent River near Laurel).