Total Maximum Daily Load of Polychlorinated Biphenyls in the Bush River Oligohaline Segment, Harford County, Maryland

FINAL

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Submitted to:

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1650 Arch Street
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April, 2016

EPA Submittal Date: April 6, 2016
EPA Approval Date: August 2, 2016

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Adj-SediBAF	Adjusted Sediment Bioaccumulation Factor
Adj-tBAF	Adjusted Total Bioaccumulation Factor
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
BMP	Best Management Practice
BSAF	Biota-sediment accumulation factor
CBP	Chesapeake Bay Program
CFR	Code of Federal Regulations
COMAR	Code of Maryland Regulations
CSF	Cancer Slope Factor
CV	Coefficient of Variation
CWA	Clean Water Act
DEM	Digital Elevation Model
DOC	Dissolved Organic Carbon
DRBC	Delaware River Basin Commission
EOF	Edge of Field
EOS	Edge of Stream
EPA	U.S. Environmental Protection Agency
FIBI	Fish Index of Biotic Integrity
ft	Feet
GIS	Geographic Information System
g	Gram
kg	Kilogram
km^2	Square Kilometer
K_{oc}	PCB Organic Carbon-Water Partition Coefficient
K_{ow}	PCB Octanol-Water Partition Coefficient
L	Liter
lbs	Pounds
LA	Load Allocation
LMA	Land Management Administration
LRP-MAP	Land Restoration Program Geospatial Database
m	Meter
m^2	Square meter
m^3	Cubic meter
MD	Maryland
MDE	Maryland Department of the Environment

MDL	Maximum Daily Load
mg	Milligram
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
ng	Nanogram
NOAA	National Oceanic & Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PCB	Polychlorinated Biphenyl
POC	Particulate Organic Carbon
ppb	Parts per billion
ppt	Parts per trillion
RUSLE2	Revised Universal Soil Loss Equation Version II
SediBAF	Sediment Bioaccumulation Factor
SIC	Standard Industrial Classification
TMDL	Total Maximum Daily Load
tBAF	Total Bioaccumulation Factor
tPCB	Total PCB
TSD	Technical Support Document
TSS	Total Suspended Solids
UMCES	University of Maryland Center for Environmental Science
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VA	Virginia
VCP	Voluntary Cleanup Program
WLA	Wasteload Allocation
WQA	Water Quality Analysis
WQBEL	Water Quality Based Effluent Limit
WQLS	Water Quality Limited Segment
WQS	Water Quality Standard
WWTP	Wastewater Treatment Plant
µg	Microgram

EXECUTIVE SUMMARY

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 (WQSs). For each WQLS, the State is to either establish a Total Maximum Daily Load (TMDL) for the specified substance that the waterbody can receive without violating WQSs, or demonstrate that WQSs are being met (CFR 2014a). This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a TMDL for Polychlorinated Biphenyls (PCBs) in the Bush River Oligohaline Chesapeake Bay Tidal Segment. From this point on in the Executive Summary the "Bush River Oligohaline Chesapeake Bay Tidal Segment" will be referred to as the "Bush River" (2014 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-BSHOH) and the corresponding "Bush River Oligohaline Chesapeake Bay Segmentshed" will be referred to as the "Bush River watershed."

Maryland WQSs specify that all surface waters of the State shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2014a). The designated use of the waters of the Bush River (8-digit Basin Code: 02130701) is Use II – *Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting* (COMAR 2014b). The Maryland Department of the Environment (MDE) has identified the waters of the Bush River (Integrated Report Assessment Unit ID: MD-BSHOH) on the State's 2014 Integrated Report as impaired by nitrogen (1996, Open-Water Fish and Shellfish Use; 2012, Seasonal Migratory Fish Spawning and Nursery Use), phosphorus (1996, Open-Water Fish and Shellfish Use; 2012, Seasonal Migratory Fish Spawning and Nursery Use) and PCBs in fish tissue (2002). Four 8-Digit watersheds drain to the Bush River; Bush River (Integrated Report Assessment Unit ID: MD-02130701), Lower Winters Run (MD-02130701), Atkisson Reservoir (MD-02130703), and Bynum Run (MD-02130704). The non-tidal streams of Bush River were identified as impaired by sulfates (2014), chlorides (2014) and total suspended solids (2014) on the 2014 Integrated Report (MDE 2014a). The non-tidal streams of lower Winters Run and Atkisson Reservoir watersheds were both listed for biological impairments (2002). The Bynum Run watershed was listed as impaired for sediment (2012) and an unnamed tributary of Bynum Run (MD-MD-021307041131-UTBynum_Run) was identified as being impaired due to temperature (2014). The Chesapeake Bay TMDL, which was approved by the EPA on December 29, 2010, addressed the nutrients listings for the Bush River. EPA approved a TMDL for sediment in the Bynum Run watershed on September 30, 2011. The TMDL established herein by MDE will address the total PCB (tPCB) listing for the Bush River, for which a data solicitation was conducted, and all readily available data have been considered.

PCBs are a class of man-made, carcinogenic compounds with both acute and chronic toxic effects, which are also bioaccumulative and do not readily breakdown in the natural environment There are 209 possible chemical arrangements of PCBs known as congeners, which consist of two phenyl groups and one to ten chlorine atoms. The congeners differ in the number and position of chlorine atoms along the phenyl groups. PCBs were manufactured and used for a variety of industrial applications and sold as mixtures under various trade names commonly known as Aroclors (QEA 1999). Sixteen different Aroclor mixtures were produced, each formulated based on a specific chlorine composition by mass. PCBs are a concern to human health, as regular consumption of fish containing elevated levels of PCBs will cause bioaccumulation within the fatty tissue of humans, which can potentially lead to the development of cancer.

Since the Bush River was identified as impaired for PCBs in fish tissue, the overall objective of the tPCB TMDL established in this document is to ensure that the "fishing" designated use, which is protective of human health related to the consumption of fish from this river, is supported. This objective was achieved via the use of field observations and a multi-segment water quality model. The model incorporates the influences of tide, atmospheric deposition, freshwater inputs, and exchanges between the water column and bottom sediments, thereby representing realistic dynamic transport within the area.

The water quality model is used to:

1. Estimate and predict PCB transport and fate based on observed tPCB concentrations in the water column and bottom sediments of the Bush River;
2. Simulate long-term tPCB concentrations in the water column and bottom sediments;
3. Estimate the load reductions necessary to meet the TMDL water column and sediment endpoint concentrations, which are derived from the Integrated Report fish tissue listing threshold and site specific total Bioaccumulation Factors (tBAFs);
4. Estimate the amount of time necessary for tPCB concentrations to reach the TMDL water column and sediment endpoints, given the required load reductions from the individual source sectors and an estimated rate of decline in the tPCB concentrations at the boundary between the Bush River and the Chesapeake Bay mainstem.

The CWA requires TMDLs to be protective of all the designated uses applicable to a particular waterbody. Within the Bush River, these designated uses, include "water contact recreation," "fishing," "the protection of aquatic life and wildlife," and "Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting". The TMDLs presented herein were developed specifically to be supportive of the "fishing" designated use, ensuring that the consumption of fish does not impact human health, thus addressing the impairment listings for "PCBs in fish tissue".

However, this TMDL will also ensure the protection of all other applicable designated uses within the river. The water column and sediment TMDL endpoint tPCB concentrations applied within this analysis are derived from Maryland's Integrated Report fish tissue listing threshold tPCB concentration and site specific tBAFs. In the Bush River, the tPCB endpoint concentration is lower than: 1) EPA's human health criterion tPCB water column concentration relative to fish consumption, and 2) both Maryland's freshwater and saltwater chronic criteria tPCB water column concentrations (*i.e.*, water column TMDL endpoint tPCB concentrations < saltwater chronic tPCB criterion). This indicates that the TMDL is not only protective of the "fishing" designated use but also the "aquatic life" designated use, specifically the protection of "Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting." Lastly, the designated use for "water contact recreation" is not associated with any potential human health risks due to PCB exposure. Dermal contact and consumption of water from activities associated with "water contact recreation" are not significant pathways for the uptake of PCBs. The EPA human health criterion was developed solely based on organism consumption, as drinking water consumption does not pose any risk for cancer development at environmentally relevant levels. The only human health risk associated with PCB exposure is through the consumption of aquatic organisms, which is addressed by the water column and sediment tPCB endpoint concentrations applied within this TMDL developed to be supportive of the "fishing" designated use.

As part of this analysis, both point and nonpoint sources of PCBs have been identified throughout the Bush River watershed. For the Bush River, nonpoint sources include direct atmospheric deposition to the river, runoff from non-regulated watershed areas, one contaminated site, and tidal influence from the Chesapeake Bay mainstem. Point sources include National Pollutant Discharge Elimination System (NPDES) regulated stormwater runoff within the watershed and two NPDES permitted municipal wastewater treatment plants (WWTPs).

The transport of PCBs from bottom sediments to the water column through re-suspension and diffusion can also be a major source of PCBs in estuarine systems; however, under the framework of this TMDL it is not considered a source. The water quality model developed for this TMDL simulates conditions within the water column and sediment as a single system therefore exchanges between the sediment and water column are considered an internal loading. Only external sources to the system are assigned a baseline load or allocation within a TMDL. Therefore, PCB transport from bottom sediments through re-suspension and diffusion will not be assigned a baseline load or allocation.

The transport of PCBs into the Bush River due to tidal influences from the Chesapeake Bay mainstem is a source of PCBs to the system; however, this load contribution results from other point and nonpoint source inputs (both historic and current) and is not considered to be a directly controllable source. Therefore this load will not be assigned a baseline load or allocation within the TMDL. The modeling of this TMDL does, however, account for the attenuation of PCBs in Chesapeake Bay water that is expected to occur over time due to natural processes such as the burial of contaminated sediment.

The objective of the TMDL established herein is to reduce current tPCB loads to the Bush River so that the water column and sediment TMDL endpoint tPCB concentrations are achieved. All TMDLs need to be presented as a sum of Wasteload Allocations (WLAs) for the identified point sources, Load Allocations (LAs) for nonpoint source loads generated within the assessment unit, and where applicable, natural background, tributary, and adjacent segment loads. Furthermore, all TMDLs must include a margin of safety (MOS) to account for lack of knowledge and the many uncertainties in the understanding and simulation of water quality parameters in natural systems (*i.e.*, the relationship between modeled loads and water quality) (CFR 2014a). The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection. An explicit MOS of 5% was incorporated into the analysis to account for such uncertainty.

Summaries of the baseline loads, TMDLs, and maximum daily loads (MDLs) for the Bush River are presented in Table ES-1. Additionally, the baseline loads and TMDL allocations only consider current sources of PCBs that are deemed to be directly controllable loads. When implemented, these TMDLs will ensure that the resulting tPCB concentrations in the sediment and water column are at levels supportive of the "fishing" designated use in the Bush River.

The water quality model developed for simulating ambient sediment and water column tPCB concentrations within the Bush River was used to determine the specific load reductions for each controllable source category that would result in simulated tPCB concentrations in the sediment and water column that meet the TMDL endpoints. The results of this scenario establish the load reductions per source category and the associated WLAs and LAs necessary to achieve the TMDLs. The primary source of PCBs to the atmosphere is from volatilization of PCB contaminated land sources which will be eliminated as these sources are remediated through implementation of the non-regulated watershed runoff LA and NPDES regulated stormwater WLA.

In the Bush River, the TMDL modeling scenario was used to develop the load reductions, WLAs, and LAs for all the source categories. As previously applied in other PCB TMDLs developed by Maryland in the Chesapeake Bay region (e.g., MDE 2009a, 2009b), the model assumes that water column tPCB concentration decrease at a rate of 6.5% year at the tidal boundary between the Bush River and Chesapeake Bay mainstem. The resultant TMDL scenario requires 60% load reduction of total baseline load from the point and non-point source categories in the Bush River in order to achieve the sediment and water column TMDL endpoint tPCB concentrations.

Federal regulations require that TMDL analysis take into account the impact of critical conditions and seasonality on water quality (CFR 2014b). The intent of these requirements is to ensure that load reductions required by this TMDL, when implemented, will produce water quality conditions supportive of the designated use at all times. PCB levels in fish tissue become elevated due to long term exposure primarily through consumption of lower trophic level organisms, rather than a critical condition defined by acute exposure to temporary fluctuations in water column tPCB concentrations. Therefore, the selection of the annual average tPCB water column and sediment concentrations for comparison to the TMDL endpoints adequately considers the impact of seasonal variations and critical conditions on the "fishing" designated use in the Bush River. Thus, the TMDL implicitly accounts for seasonal variations as well as critical conditions.

Despite the fact that PCB loads from re-suspension and diffusion are not considered to be directly controllable, these load contributions are still expected to decrease over time as the result of the natural attenuation of PCBs in the environment. In addition, discovering and remediating any existing PCB land sources throughout the upstream Chesapeake Bay watershed via future TMDL development and implementation will further aid in the decline of the boundary condition tPCB concentrations and in meeting water quality goals in the river. MDE also monitors and evaluates concentrations of contaminants in recreationally caught fish, shellfish, and crabs throughout Maryland. MDE will use these monitoring programs to evaluate progress towards meeting the "fishing" designated use in the Bush River.

Table ES-1: Summary of Baseline tPCB Baseline Loads, TMDL Allocations, Load Reductions, and MDLs in the Bush River

Source	Baseline Load (g/year)	Baseline Load (%)	TMDL (g/year)	Load Reduction (%)	MDL (g/day)
Direct Atmospheric Deposition	48.9	24.0%	18.58	62%	0.075
Contaminated Site	2.4	1.2%	2.37	0%	0.010
Maryland Non-regulated Watershed Runoff	82.5	40.6%	29.88	64%	0.121
Nonpoint Sources	***133.8***	***65.8%***	***50.83***	***62%***	***0.206***
NPDES Regulated Municipal WWTPs	19.9	9.8%	7.56	62%	0.064
NPDES Regulated Stormwater	49.7	24.4%	18.89	62%	0.077
Point Sources	***69.6***	***34.2%***	***26.45***	***62%***	***0.141***
MOS	-	-	4.07		0.016
Total	**203.4**	**100.0%**	**81.35**	**60%**	**0.363**

1.0 INTRODUCTION

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 (WQSs). For each WQLS, the State is to either establish a TMDL for the specified substance that the waterbody can receive without violating WQSs, or demonstrate that WQSs are being met (CFR 2014a). This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for Polychlorinated Biphenyls (PCBs) in the tidal subsegment of the Bush River Oligohaline Chesapeake Bay Tidal Segment. From this point on in the report the "Bush River Oligohaline Chesapeake Bay Tidal Segment" will be referred to as the "Bush River" (2014 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-BSHOH) and the corresponding "Bush River Oligohaline Chesapeake Bay Segmentshed" will be referred to as the "Bush River watershed."

TMDLs are established to determine the pollutant load reductions required to achieve and maintain WQSs. A WQS 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, fish and shellfish propagation and harvest, etc. 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.

Maryland WQSs specify that all surface waters of the State shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2014a). The designated use of the waters of the Bush River (8-digit Basin Code: 02130701) is Use II – *Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting* (COMAR 2014b). The Maryland Department of the Environment (MDE) has identified the waters of the Bush River (Integrated Report Assessment Unit ID: MD-BSHOH) on the State's 2014 Integrated Report as impaired by nitrogen (1996, Open-Water Fish and Shellfish Use; 2012, Seasonal Migratory Fish Spawning and Nursery Use), phosphorus (1996, Open-Water Fish and Shellfish Use; 2012, Seasonal Migratory Fish Spawning and Nursery Use) and PCBs in fish tissue (2002). Four 8-Digit watersheds drain to the Bush River; Bush River (Integrated Report Assessment Unit ID: MD-02130701), Lower Winters Run (MD-02130701), Atkisson Reservoir (MD-02130703), and Bynum Run (MD-02130704). The non-tidal streams of Bush River were identified as impaired by sulfates (2014), chlorides (2014) and total suspended solids (2014) on the 2014 Integrated Report (MDE 2014a). The non-tidal streams of lower Winters Run and Atkisson Reservoir watersheds were both listed for biological impairments (2002). The Bynum Run watershed was listed as impaired for sediment (2012) and an unnamed tributary of Bynum Run (MD-MD-021307041131-UTBynum_Run) was identified as being impaired due to temperature (2014). The Chesapeake Bay TMDL, which was approved by the EPA on December 29, 2010, addressed the nutrients listings for the Bush River. EPA approved a TMDL for sediment in the Bynum Run watershed on September 30, 2011. The TMDL established herein by MDE will address the total PCB (tPCB) listing for the Bush River, for which a data solicitation was conducted, and all readily available data have been considered.

PCBs are a class of man-made compounds that were manufactured and used for a variety of industrial applications. They consist of 209 related chemical compounds (congeners) that were manufactured and sold as mixtures under various trade names, commonly referred to as Aroclors (sixteen different Aroclor mixtures were produced, each formulated based on a specific chlorine composition by mass) (QEA 1999). Each of the 209 possible PCB compounds consists of two phenyl groups and one to ten chlorine atoms. The congeners differ in the number and position of the chlorine atoms along the phenyl group. From the 1940s to the 1970s, they were extensively used as heat transfer fluids, flame retardants, hydraulic fluids, and dielectric fluids because of their dielectric and flame resistant properties. They have been identified as a pollutant of concern due to the following:

1. They are bioaccumulative and can cause both acute and chronic toxic effects;
2. They have carcinogenic properties;
3. They are persistent organic pollutants that do not readily breakdown in the environment.

In the late 1970s, concerns regarding potential human health effects led the US government to take action to cease PCB production, restrict PCB use, and regulate the storage and disposal of PCBs. Despite these actions, PCBs are still being released into the environment through fires or leaks from old PCB containing equipment, accidental spills, burning of PCB containing oils, leaks from hazardous waste sites, or the inadvertent production during manufacturing processes. Since PCBs tend to bioaccumulate in aquatic organisms, including fish, people who consume fish may become exposed to PCBs. In fact, elevated levels of PCBs in edible parts of fish tissue are one of the leading causes of fish consumption advisories in the US.

The Bush River was originally identified as impaired by PCBs in fish tissue on Maryland's 2002 Integrated Report based on fish tissue tPCB data from MDE's monitoring program that exceeded the tPCB fish tissue listing threshold of 39 ng/g, or ppb (wet weight), based on 4 meals per month by a 76 kg individual (MDE 2014a). In addition to identifying impaired waterbodies on the State's Integrated Report, MDE also issues statewide and site specific fish consumption advisories (ranging from 0 to 4 meals per month) and recommendations (ranging from 4 to 8 meals per month). Current recreational fish consumption advisories suggest limiting the consumption of the following fish species caught in the Bush River: American eel (4 meals per month), channel catfish (1 meal every other month for children and 1 meal per month for others), sunfish (including bluegill) (8 meals per month for children), small and largemouth bass (5 meals per month for general population, 4 meals per month for women of childbearing age and 3 meals per month for children), white perch (2 meals per month for children and 3 meals per month for others) and yellow perch (1 meal per month for children and 2 meal per month for others) (MDE 2014b).

2.0 SETTING AND WATER QUALITY DESCRIPTION

1. 2.1 General Setting

Location

The Bush River is a tidal estuary in Harford County, Maryland, located about 24 km (15 miles) northeast of Baltimore. The estuary extends south from the community of Riverside, for about 14 km (9 miles) to the Chesapeake Bay. The watershed area of the tidal Bush River includes Aberdeen Proving Ground, a military facility. The Bush River watershed has two significant stream systems: Bynum Run and Winters Run. The mean tidal range of the Bush River is 0.38 meters [m] (1.25 feet) based on the United States National Oceanic and Atmospheric Administration tidal station in the Bush River: Pont Point Station (station number: 8574459) in Aberdeen, MD. The average depth of the Bush River is 1.68 m.

The watershed of the Bush River Oligohaline Chesapeake Bay Tidal Segment (MD-BSHOH) includes three watersheds: Bush River watershed (MD-02130701, with exclusion of Romney Creek drainage area), Winters Run watershed (Lower Winters Run, MD-02130702 and Atkisson Reservoir, MD-02130703) and Bynum Run watershed (MD-02130704). The total Bush River watershed area is 336 square kilometers (km^2). The location of the Bush River and Bush River subwatersheds are shown in Figure 1.

Land Use

According to the United States Geological Survey's (USGS) 2006 land cover data (USGS 2014), which was specifically developed to be applied within the Chesapeake Bay Program's (CBP) Phase 5.3.2 watershed model, urban land occupies approximately 36.9% of the Bush River watershed, while 34.5% is forest, 7.5% is water/wetland, and 21.1% is agriculture. The land use distribution is displayed and summarized in Figure 2 as well as Table 1.

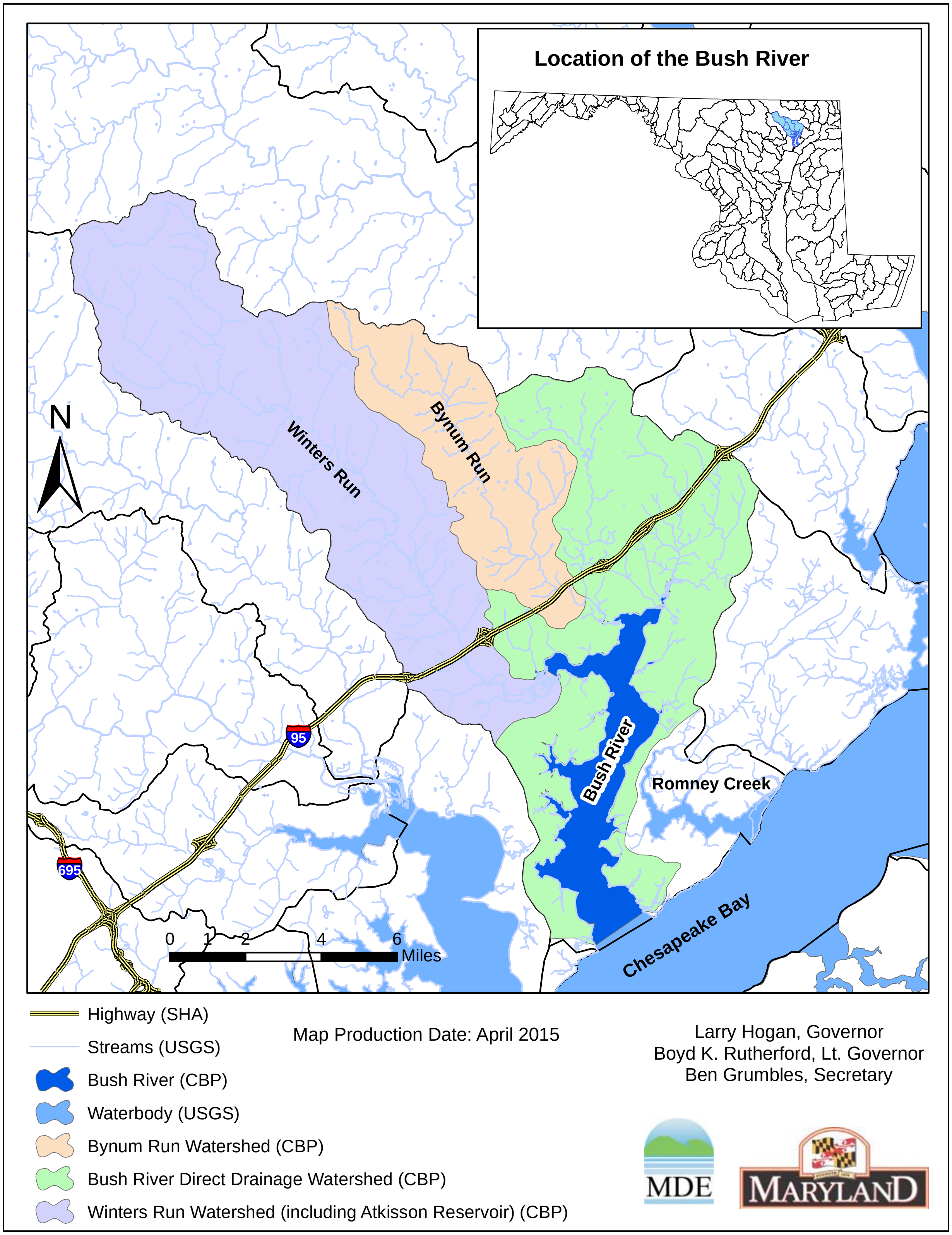

Figure 1: Location Map of the Bush River and Bush River Sub-Watersheds

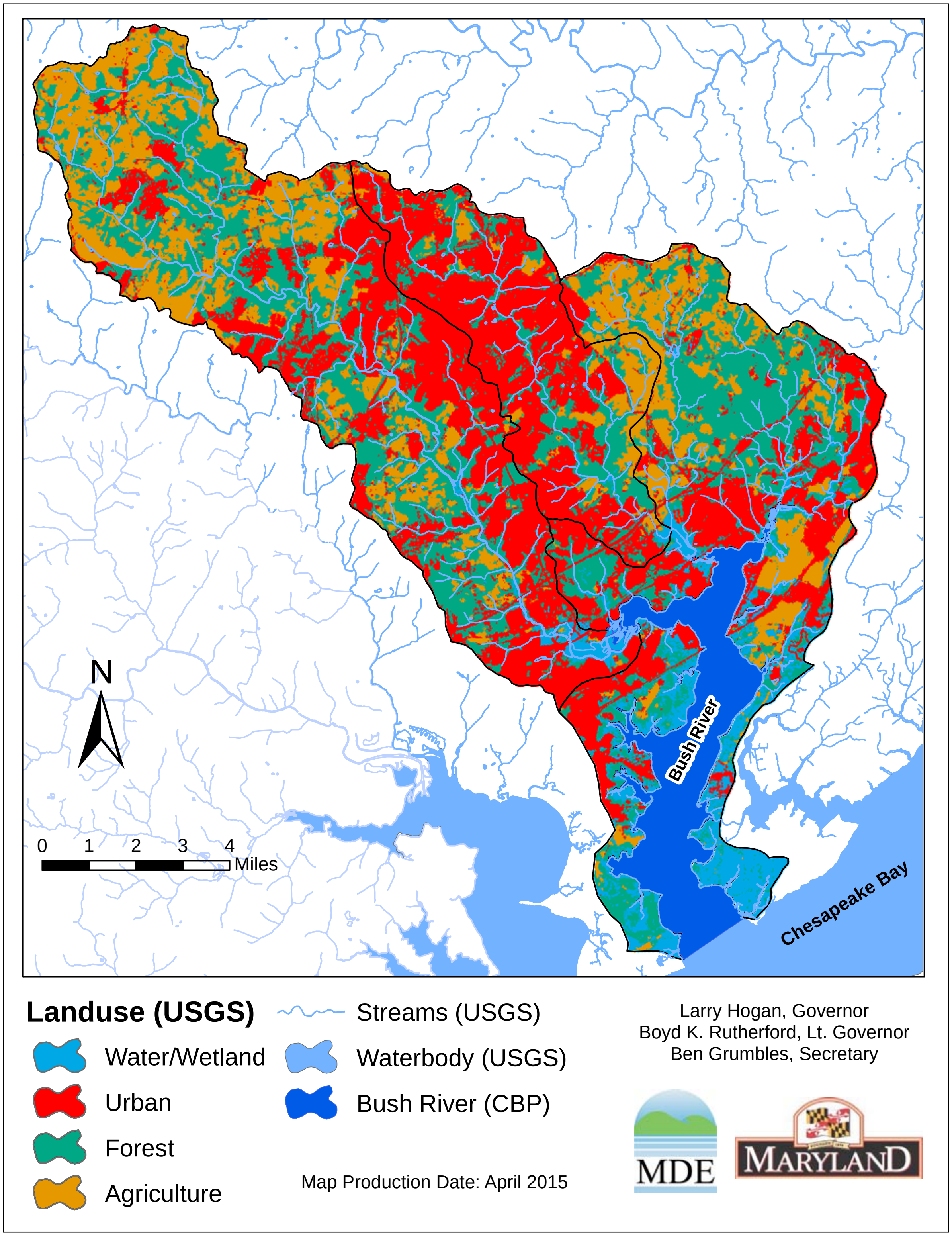

Figure 2: Land Use of the Bush River Watershed

Table 1: Land Use Distributions in the Bush River Watershed

Land Use	Urban	Forest	Water/ Wetland	Agriculture	Total
Area (km^2)	124.1	116.0	25.1	71.0	**336.2**
Percent (%)	36.9%	34.5%	7.5%	21.1%	100.0%

2.2 Water Quality Characterization and Impairment

Maryland WQSs specify that all surface waters of the State shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2014a). The designated use of the waters of the Bush River is Use II – *Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting* (COMAR 2014b). There are two "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 Bush River watershed. Within the Winters Run sub-watershed, Otter Point Creek is a Tier II stream, and in the Bynum Run sub-watershed, an unnamed tributary of Bynum Run is also a Tier II stream. (COMAR 2014c).

Water Column Characterization

The State of Maryland has adopted three separate water column tPCB criteria to account for different aspects of water quality. There is (1) a human health criterion of 0.64 nanograms/liter (ng/L) or parts per trillion (ppt) that addresses the consumption of PCB-contaminated fish, (2) a freshwater chronic criterion of 14 ng/L that is protective of aquatic life in non-tidal systems, and (3) a saltwater chronic criterion of 30 ng/L that is protective of aquatic life in tidal systems. The State defines all waters of the "Bush River Area" (MD 6-Digit Code: 021307) as fresh water, when applying numerical toxic substance criteria, so both the human health criterion and fresh water aquatic life chronic criterion are applied in assessing their waters (COMAR 2014d; US EPA 2014a). Maryland's water quality criteria are summarized in Table 2. Since the human health criterion is more stringent than the fresh water aquatic life criteria, if the human health criterion is met, all applicable water quality criteria would be satisfied.

The human health tPCB criterion is based on a cancer slope factor (CSF) of 2 milligrams/kilogram-day (mg/kg-day), a bioconcentration factor (BCF) of 31,200 liters/kilogram (L/kg), a cancer risk level of 10^{-5}, a lifetime risk level and exposure duration of 70 years, and fish intake of 17.5 g/day. A CSF is a toxicity value for evaluating the probability of an individual developing cancer from exposure to a chemical substance over a lifetime through ingestion or inhalation. A BCF is the ratio of the concentration of a chemical (i.e. tPCBs) in an aquatic organism to the concentration of the chemical in the water column. The cancer risk level provides an estimate of the additional incidence of cancer that may be expected in an exposed population. A risk level of 10^{-5} indicates a probability of one additional case of cancer for every 100,000 people exposed.

Table 2: Water Column tPCB Criteria and tPCB Fish Tissue Listing Threshold

tPCB Criteria/Threshold	Concentration
Salt Water Chronic Aquatic Life Criterion	30 ng/L
Fresh Water Chronic Aquatic Life Criterion	14 ng/L
Human Health Criterion	0.64 ng/L
Fish Tissue Listing Threshold	39 ng/g

In 2013 and 2014, monitoring surveys were conducted by MDE to measure water column tPCB concentrations in the Bush River. Tidal monitoring was conducted at five stations in the Bush River. In addition to providing assessment data, the monitoring plan was developed in order to fully characterize the impairment and inform model development. One of the tidal stations was located at the boundary between the Bush River and the main stem of the Chesapeake Bay, to evaluate the tidal influences from the Bay. Sediment samples were also collected at each tidal station, including the boundary station, to characterize tPCB sediment concentrations.

Non-tidal water column monitoring was conducted concurrently with the tidal monitoring at two stations in the direct drainage watershed of the Bush River, one station in Bynum Run and one station in Winters Run. These data were required to estimate loadings from the watersheds. Figure 3 provides a location map of the water column and sediment monitoring station locations.

An examination of the water column data revealed that on May 20, 2014 the tPCB concentrations were unusually high at the four downstream-most tidal stations in the Bush River (BuR-2, BuR-3, BuR-4 and BuR-5) and at the station in the main stem of the Bay (BuR-1). Table 3 presents the tPCB, TSS and salinity data from each of these stations measured on each of the four sampling dates. The highest recorded TSS concentrations and lowest recorded salinity concentrations for each station were also seen on May 20.

Data from this date at the USGS Station at Conowingo, MD (01578310), showed that these extreme tPCB, TSS and salinity measurements coincided with very high flows in the Susquehanna River. Daily flows on the Susquehanna River on May 20 and the two preceding days all exceeded the 99.5th-percentile flow range for the three-year period from 2012 to 2014. The Susquehanna River is the primary fresh water source in the upper Chesapeake Bay, and the position of the Bush River near its mouth means that water quality in the Bush River is strongly affected by its discharges. A large discharge from the Susquehanna River, like the one seen on May 20, would be expected to bring a large volume of turbid, fresh water into the Bush River. This matches exactly with what was observed in the monitoring data.

As PCBs have an affinity for sediment, the high TSS concentrations would be expected to coincide with higher-than average PCB concentrations, as were also seen on that date. It was concluded that the high tPCB concentrations measured on this date were a function of an extreme weather event, rather than normal variability, and that these concentrations would likely not be representative of typical conditions in the Bush River.

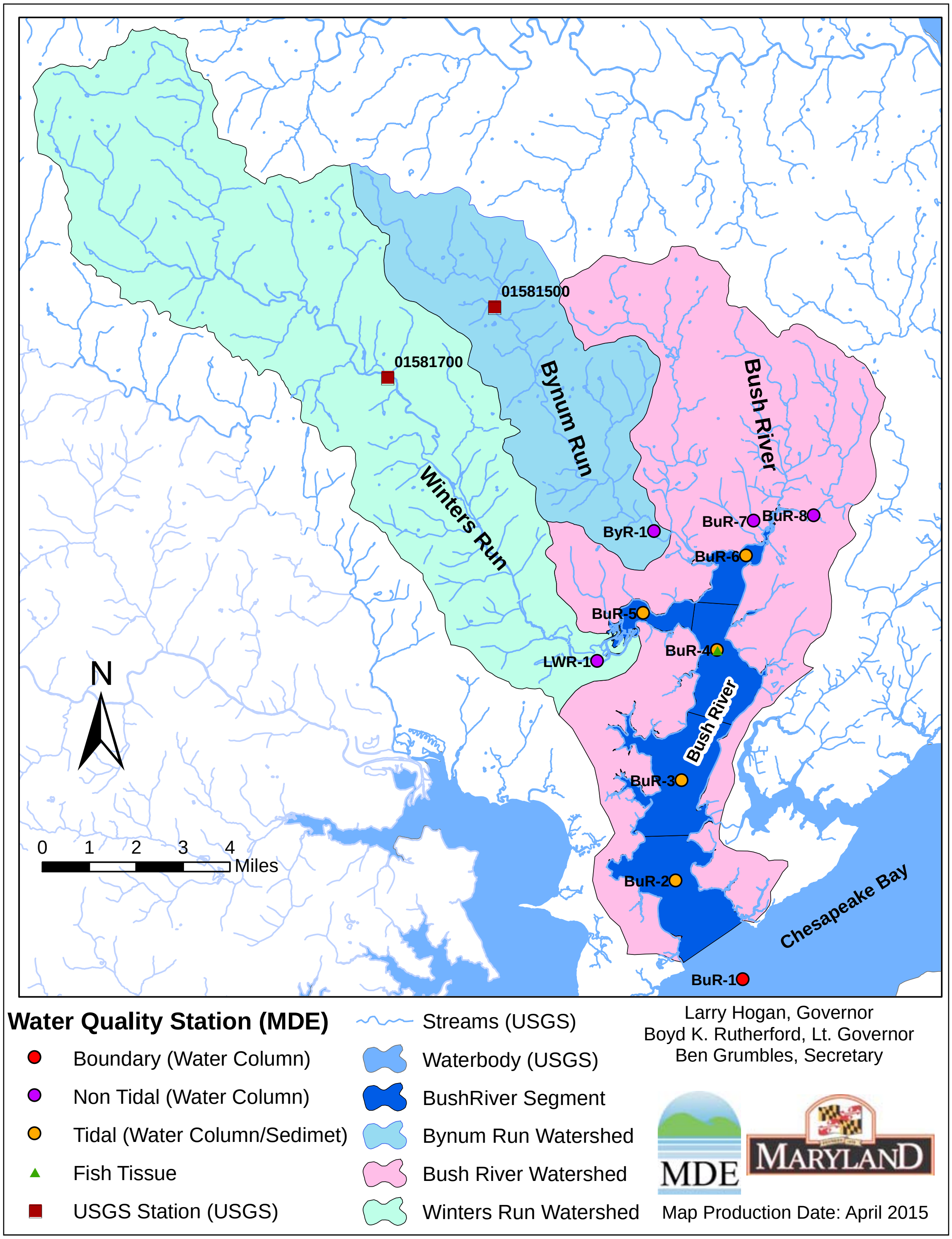

Figure 3: Water Quality Monitoring Stations in the Bush River and its Watershed

Table 3: Water Column tPCB Concentration, TSS and Salinity Data in the Bush River

Concentration	Date	BuR-1	BuR-2	BuR-3	BuR-4	BuR-5
PCB (ng/L)	8/14/2013	0.90	1.34	2.02	2.15	0.80
	10/30/2013	0.35	0.51	0.37	0.87	0.33
	3/12/2014	1.20	4.64	4.00	5.19	1.56
	5/20/2014	14.93	21.18	18.66	18.57	12.56
TSS (mg/L)	8/14/2013	16.20	17.20	21.00	16.00	14.00
	10/30/2013	16.20	17.20	21.00	16.00	14.00
	3/12/2014	13.00	8.50	8.00	8.00	10.50
	5/20/2014	38.00	42.00	48.00	32.00	42.00
Salinity (ppt)	8/14/2013	1.10	0.60	0.30	0.20	0.10
	10/30/2013	4.70	4.70	3.40	2.30	1.40
	3/12/2014	4.90	2.40	1.90	0.90	0.30
	5/20/2014	0.20	0.30	0.20	0.10	0.10

Given that bioaccumulation of PCBs is driven by long-term trends in the water column and bottom sediments, extreme, low frequency events such as this, would not be expected to significantly affect fish tissue PCB concentrations. Furthermore, since this TMDL is based on average conditions, and is presented as an annual load, it is reasonable to exclude data that would bias the results toward extreme weather events. Table 4 shows the comparison of the average tPCB water column concentrations, TSS and salinity in the Bush River with and without the data from this extreme event, along with the average water quality data in the nearby Gunpowder River. The results indicate the average water quality condition of the Bush River is more close to that of nearby Gunpowder River without the May 20 data. Based on all of this information, this TMDL will exclude the May 20 water column data to better represent the average water quality condition in the Bush River.

Table 4: Comparison of Mean Water Column tPCB Concentrations, Mean TSS Concentrations and Mean Salinity Data in the Bush River and the Gunpowder River

Bush River (with May 20, 2014 data)			
Station	**PCB (ng/L)**	**TSS (mg/L)**	**Salinity (ppt)**
BUR-1	4.12	20.85	2.73
BUR-2	6.92	21.23	2.00
BUR-3	6.26	24.50	1.45
BUR-4	6.70	18.00	0.88
BUR-5	3.81	20.13	0.48
Bush River (without May 20, 2014 data)			
Station	**PCB (ng/L)**	**TSS (mg/L)**	**Salinity**
BUR-1	0.81	15.13	3.57
BUR-2	2.16	14.30	2.57
BUR-3	2.13	16.67	1.87
BUR-4	2.74	13.33	1.13
BUR-5	0.89	12.83	0.60
Gunpowder River			
Station	**PCB (ng/L)**	**TSS (mg/L)**	**Salinity**
GR-1	0.43	17.80	4.90
GR-2	0.36	16.20	3.33
GR-3	0.52	18.15	4.23
GR-4	0.39	18.80	1.65
GR-5	0.25	14.88	1.95

The data analysis (5/20/2014 water column data excluded) indicates that the water column mean tPCB concentrations in the Bush River exceed the human health tPCB criterion of 0.64 ng/L but do not exceed the fresh water aquatic life tPCB criterion of 14 ng/L (Table 5). A summary of water column and sediment data from the Bush River is provided in Table 5.

Fish Tissue Characterization

In addition to the water column criteria described above, fish tissue monitoring is also used as an indicator of PCB water quality conditions. Maryland regularly collects and analyzes fish tissue data in order to issue fish consumption advisories and recommendations, and determine whether Maryland waterbodies are meeting the "fishing" designated use. The State's tPCB fish tissue listing threshold of 39 ng/g is based on a fish consumption limit of 4, 8-ounce meals per month, and is applied to the skinless fillet of the fish, the edible portion typically consumed by humans. When tPCB fish tissue concentrations exceed this threshold, the waterbody is listed as impaired for PCBs in fish tissue in Maryland's Integrated Report as it is not supportive of the "fishing" designated use (MDE 2012).

MDE collected 6 fish tissue composite samples (30 total fish) for PCB analysis in the Bush River in May and June 2014. The tPCB concentrations for all of the fish tissue composite samples (several species of fish including white perch, brown bullhead catfish and channel catfish) exceeded the listing threshold, demonstrating that a PCB impairment exists within the Bush River.

A location map of the fish sampling stations is shown in Figure 3. A summary of the fish tissue sampling data is provided in for the Bush River in Table 5. Appendix G contains tables of all the water column, sediment and fish tissue tPCB data in the Bush River.

Table 5: Summary of Fish Tissue, Water Column, and Sediment tPCB Data in the Bush River

Sample Media	Sample Type	Units	Sample Years	Sample Size	tPCB Concentration		
					Mean	Max.	Min.
Fish Tissue	Tidal	ng/g	2014	30*	234.6	659.0	54.2
Sediment	Tidal	ng/g	2013/2014	10	17.2	36.9	4.2
Water Column	Tidal	ng/L	2013/2014	15**	2.3	8.4	0.3
	Tidal (Boundary)		2013/2014	3**	0.8	1.2	0.3
	Non-Tidal		2013/2014	12**	0.9	7.2	0.0

***Total Fish Tissue Samples**
**** May 20, 2014 water column data excluded**

Analytical Methods

PCB analytical services were provided by the University of Maryland Center for Environmental Science (UMCES), using a slightly modified version of the PCB congener specific method described in Ashley and Baker (1999), in which the identities and concentrations of each congener in a mixed Aroclor standard are determined based on their chromatographic retention times relative to the internal standards. This approach was based on the approved EPA Method 8082 which was developed in 1996. A detailed description of this method is provided in Appendix A.

3.0 TARGETED WATER COLUMN AND SEDIMENT TMDL ENDPOINTS

As described in Section 2.2, MDE evaluates whether a waterbody meets PCB related WQSs based on three criteria: 1) the tPCB Integrated Report fish tissue listing threshold (39 ng/g, or ppb), 2) the human health tPCB water column criterion (0.64 ng/L, or ppt) and 3) the freshwater chronic tPCB criterion for protection of aquatic life (14 ng/L, or ppt). Since the Bush River was identified as impaired for PCBs in fish tissue, the overall objective of the tPCB TMDLs established in this document is to ensure that the “fishing” designated use, which is protective of human health related to the consumption of fish, is supported. However, this TMDL will also ensure the protection of all other applicable designated uses.

The tPCB fish tissue listing threshold was translated into an associated tPCB water column concentration to provide a TMDL endpoint, as the water quality model only simulates tPCB water column and sediment concentration and does not incorporate a food web model to predict tPCB fish tissue concentrations (see Equation 3.1 and Calculation 3.1). This was accomplished using an Adjusted Total Bioaccumulation Factor (Adj-tBAF) of 327,333 L/kg for the Bush River, the derivation of which follows the method applied within the Potomac River tPCB TMDLs (Haywood and Buchanan, 2007). A total Bioaccumulation Factor (tBAF) is calculated per fish species, and subsequently the tBAFs are normalized by the species median lipid content and median dissolved tPCB water column concentration in their home range to produce the Adj-tBAF per species (see Appendix B for further details regarding the calculation of the Adj-tBAF). The most environmentally conservative of the Adj-tBAFs is then selected to calculate the TMDL endpoint water column concentration. This final water column tPCB concentration was subsequently compared to the water column tPCB criteria concentrations, as described in Section 2.2, to ensure that all applicable criteria within the embayment would be attained (Calculation 3.1).

$$\text{tPCB Water Column Concentration} = \frac{\text{tPCB Fish Tissue Concentration Listing Threshold}}{\text{Adj-tBAF} \times \text{Unit Conversion}} \quad \text{(Equation 3.1)}$$

For the Bush River, substituting 39 ng/g into the equation results in:

$$\text{tPCB Water Column Concentration} = \frac{39\ \text{ng/g}}{327{,}333\ \text{L/kg} \times 0.001\ \text{kg/g}} = 0.12\ \text{ng/L}$$

(which is < 0.64 ng/L [human health tPCB water column criterion]). (Calculation 3.1)

Based on this analysis, the water column tPCB concentration of 0.12 ng/L, derived from the tPCB fish tissue listing threshold and the channel catfish tissue data, is selected as the TMDL endpoint for the Bush River. Although several species of fish tissue were collected, the channel catfish tissue was used for this calculation since it returned the most conservative BAF from the human health perspective. This endpoint is more stringent than the value of 0.64 ng/L for human health, and the fresh water chronic aquatic life tPCB criteria of 14 ng/L.

Similarly, in order to establish a tPCB TMDL endpoint for the sediment in the river, a target tPCB sediment concentration was derived from the tPCB fish tissue listing threshold, as the water quality model only simulates tPCB sediment concentrations and not tPCB fish tissue concentrations (see Equation 3.2 and Calculation 3.2). This was done using the Adjusted Sediment Bioaccumulation Factor (Adj-SediBAF) of 34.08 (unitless) for the Bush River, the derivation of which follows the method applied within the Potomac River tPCB TMDLs (Haywood and Buchanan 2007). Similar to the calculation of the water column Adj-tBAF, a sediment Bioaccumulation Factor (SediBAF) is calculated per fish species, and subsequently the SediBAFs are normalized by the median species lipid content and median organic carbon tPCB sediment concentration in their home range to produce the Adj-SediBAF per species (see Appendix B for further details regarding the calculation of the Adj-SediBAF). The most environmentally conservative of the Adj-SediBAFs is then selected to calculate the sediment TMDL endpoint tPCB concentration.

$$\text{tPCB Sediment Concentration} = \frac{\text{tPCB Fish Tissue Concentration Listing Threshold}}{\text{Adj-SediBAF}} \quad \text{(Equation 3.2)}$$

For the Bush River, substituting 39 ng/g into the equation results in:

$$\text{tPCB Sediment Concentration} = \frac{39\ \text{ng/g}}{34.08} = 1.14\ \text{ng/g} \quad \text{(Calculation 3.2)}$$

Based on this analysis, the tPCB level of 1.14 ng/g derived from the fish tissue listing threshold and the channel catfish tissue data is set as the sediment TMDL endpoint in the Bush River.

The CWA requires TMDLs to be protective of all the designated uses applicable to a particular waterbody. In addition to the "fishing" designated use, the TMDL presented herein is also supportive of the other applicable designated uses within the impaired waters, as described in the Introduction to this report and in Section 2.2. These include "marine and estuarine aquatic life", "shellfish harvesting", and "water contact recreation". The water column endpoint tPCB concentrations that will be used in this TMDL analysis and derived as described above, are more stringent than Maryland's saltwater aquatic life chronic criterion tPCB water column concentration. This indicates that the TMDLs are protective of the "aquatic life" designated use, specifically the protection of "marine and estuarine aquatic life and shellfish harvesting".

Lastly, the designated use for "water contact recreation" is not associated with any potential human health risks due to PCB exposure. Dermal contact and accidental consumption of water from activities associated with "water contact recreation" is not a significant pathway for the uptake of PCBs. The EPA human health criterion was developed solely based on aquatic organism (e.g. fish or shellfish) consumption, as drinking water consumption does not pose any risk for cancer development at environmentally relevant levels.

4.0 SOURCE ASSESSMENT

PCBs do not occur naturally in the environment. Therefore, unless existing or historical anthropogenic sources are present, their natural background levels are expected to be zero. Although PCBs are no longer manufactured in the U.S., they are still being released to the environment via accidental fires, leaks, or spills from PCB-containing equipment; potential leaks from hazardous waste sites that contain PCBs; illegal or improper dumping; and disposal of PCB-containing products (*e.g.*, transformers, old fluorescent lighting fixtures, electrical devices or appliances containing PCB capacitors, old microscope oil, and old hydraulic oil) into landfills not designed to handle hazardous waste; and through inadvertent production during manufacturing processes. Once in the environment, PCBs do not readily break down and tend to cycle between various environmental media such as air, water, and soil.

PCBs exhibit low water solubility, are moderately volatile, strongly adsorb to organics, and preferentially partition to upland and bottom sediments. The major fate process for PCBs in water is adsorption to sediment or other organic matter. Adsorption and subsequent sedimentation may immobilize PCBs for relatively long periods of time. However, desorption into the water column may also occur; PCBs contained in layers near the sediment surface may be slowly released over time, while concentrations present in the lower layers may be effectively sequestered from environmental distribution (RETEC 2002).

The linkage between the "fishing" designated use and PCB concentrations in the water column is via the uptake and bioaccumulation of PCBs by aquatic organisms. Bioaccumulation occurs when the combined uptake rate of a given chemical from food, water, and sediment by an organism exceeds the organism's ability to remove the chemical through metabolic functions, dilution, or excretion, resulting in excess concentrations of the chemical being stored in the body of the organism. Depending on the life cycle and feeding patterns, aquatic organisms can bioaccumulate PCBs via exposure to concentrations present in the water column (in dissolved and particulate form) and sediments, as well as from consumption of other organisms resulting in the biomagnification of PCBs within the food chain (RETEC 2002). Humans can be exposed to PCBs via consumption of aquatic organisms, which over time have bioaccumulated PCBs.

A simplified conceptual model of PCB fate and transport in the Bush River is diagramed in Figure 4. PCB sources, resulting primarily from historical uses of these compounds and potential releases to the environment as described above, include both point and nonpoint sources. This section provides a summary of these existing sources that have been identified as contributing tPCB loads to the impaired waters.

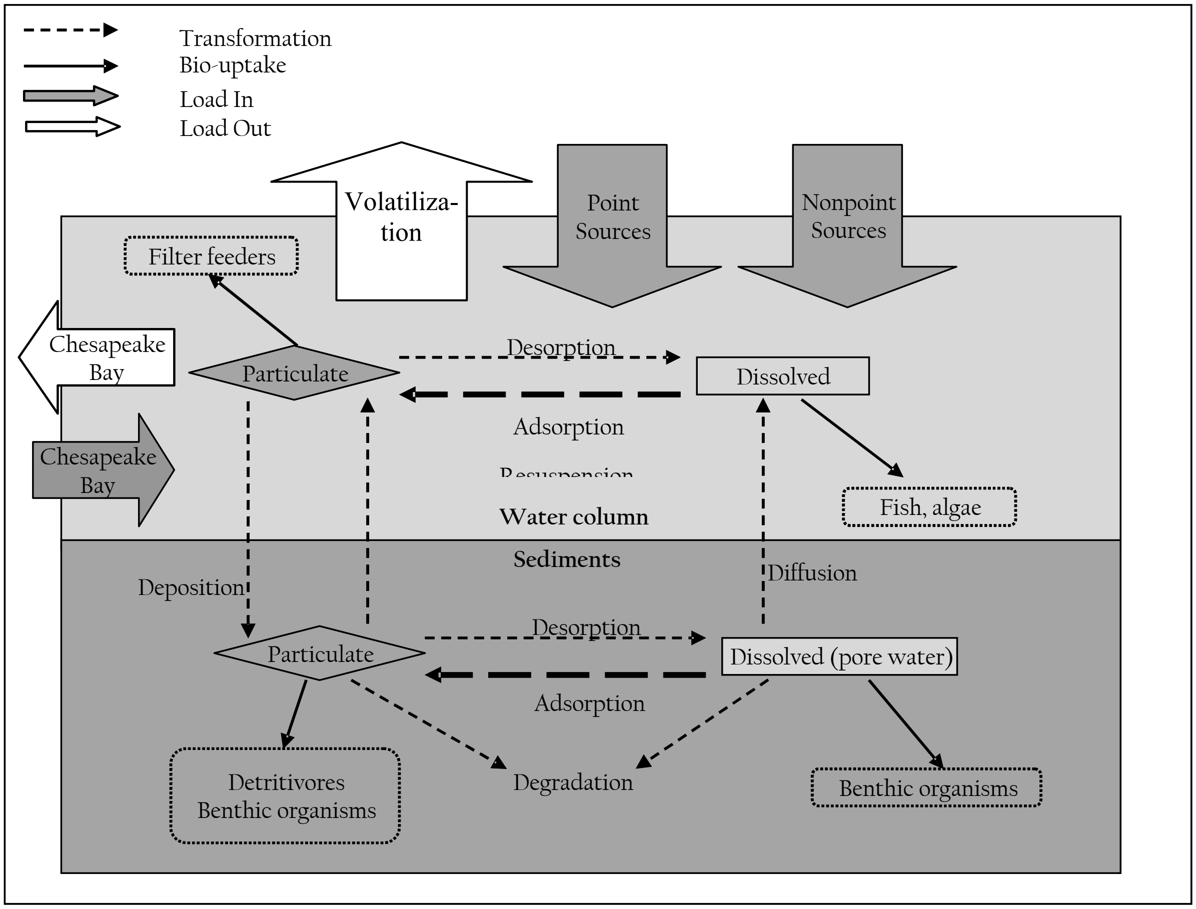

Figure 4: Conceptual Model of the Key Transport and Transformation Processes of PCBs in Surface Water and Bottom Sediments of the Bush River and Entry Points to the Food Chain

4.1 Nonpoint Sources

For the purpose of this TMDL, under current conditions, the following nonpoint sources of PCBs have been identified for the Bush River: 1) Chesapeake Bay mainstem tidal influence, 2) direct atmospheric deposition to the river, 3) contaminated sites (areas with known PCB soil contamination, as documented by state or federal hazardous waste cleanup programs), and 4) runoff from non-regulated watershed areas.

The transport of PCBs from bottom sediments to the water column through re-suspension and diffusion can also be a major source of PCBs in estuarine systems. However, under the framework of this TMDL it is not considered a source. A detailed explanation of each nonpoint source category will be presented in the following sections including additional information on re-suspension and diffusion from bottom sediments.

Chesapeake Bay Mainstem Tidal Influence

The water quality model, applying the observed tPCB concentrations measured near the mouth of the Bush River, predicts a gross tPCB input of 390 g/year from the Chesapeake Bay to the Bush River and a gross tPCB output of 1,439 g/year from the Bush River to the Bay. These loads result in a net tPCB transport of 1,049 g/year from the Bush River to the Bay. Even though the tidal influence from the Chesapeake Bay mainstem serves as a source of PCBs to the Bush River, the load contribution is resultant from other point and nonpoint source inputs (both historic and current) from the upper Chesapeake Bay watershed and is not considered to be a directly controllable (reducible) source. Therefore this load will not be assigned a baseline load or allocation within the TMDL. Although no allocation is assigned, the modeling of this TMDL does, does account for the attenuation of PCBs in Chesapeake Bay water that is expected to occur over time due to natural processes such as the burial of contaminated sediment.

Atmospheric Deposition

PCBs enter the atmosphere through volatilization. There is no recent study of the atmospheric deposition of PCBs to the surface of the Bush River. An Atmospheric Deposition Study by the Chesapeake Bay Program (CBP) (US EPA 1999) estimated a net deposition of 16.3 micrograms/square meter/year ($\mu g/m^2$/year) of tPCBs for urban areas and a net deposition of 1.6 $\mu g/m^2$/year of tPCBs for regional (non urban) areas. In the Delaware River estuary, an extensive atmospheric deposition monitoring program conducted by the Delaware River Basin Commission (DRBC) found PCB deposition rates ranging from 1.3 (non urban) to 17.5 (urban) $\mu g/m^2$/year of tPCBs (DRBC 2003). The urban deposition rate defined in CBP's study is a result of heavily urbanized areas comprised primarily of high density residential, industrial and commercial land uses.

While urban land use accounts for 37% of the Bush River watershed the land area is comprised primarily of low and medium density residential and developed land uses, so the 1.6 $\mu g/m^2$/year tPCB depositional rate for non-urban areas resultant from CBP's 1999 study will be applied in the Bush River watershed. The atmospheric deposition load to the direct watershed can be calculated by multiplying 1.6 $\mu g/m^2$/year by the watershed area of 336.2 km^2, which results in a load of 538 g/year. However, according to Totten *et al*. (2006), only a portion of the atmospherically deposited tPCB load to the terrestrial part of the watershed is expected to be delivered to the embayment. Applying the PCB pass-through efficiency estimated by Totten *et al*. (2006) for the Delaware River watershed of approximately 1%, the atmospheric deposition load to the Bush River from the watershed is approximately 5.38 g/year. This load is accounted for within the loading from the watershed and is inherently modeled as part of the non-regulated watershed runoff and the National Pollutant Discharge Elimination System (NPDES) Regulated Stormwater loads described below and in Section 4.2.

Similarly, the direct atmospheric deposition load to the surface of the Bush River of 48.9 g/year was calculated by multiplying the surface area of the river (30.5 km^2) and the deposition rate of 1.6 $\mu g/m^2$/year.

Contaminated Sites

'Contaminated sites' refer to areas with known PCB soil contamination, as documented by state or federal hazardous waste cleanup programs (*i.e.*, state or federal Superfund programs). When compared against the human health screening criteria for soil and groundwater exposure pathways, PCBs are not necessarily a contaminant of concern at these sites, but they have been screened for, reported, and detected during formal site investigations.

These sites were identified based on information gathered from the EPA's Superfund database and MDE's Land Restoration Program Geospatial Database (LRP-MAP) (US EPA 2013b; MDE 2013). Within the Bush River watershed, only one site has been identified with PCB soil concentrations at or above method detection levels, as determined via soil sample results contained within MDE Land Management Administration's (LMA) contaminated site survey and investigation records. Details about this site are presented in Table 6 and its location is shown in Figure 5.

The median tPCB concentration of the site samples was multiplied by the soil loss rate, which is a function of soil type, pervious area, and land cover, to estimate the tPCB edge of field (EOF) load. A sediment delivery ratio was applied to calculate the final edge-of-stream (EOS) load. The contaminated site tPCB baseline load is estimated to be 2.37 g/year. A detailed description of the methodology used to estimate the contaminated site tPCB baseline load is presented in Appendix H.

Table 6: Summary of Contaminated Site tPCB Baseline Loads

Site Name	Watershed	Area (acres)	EOS Load (g/year)
MD 446 Union Road Dump	Bush River	18.4	2.37

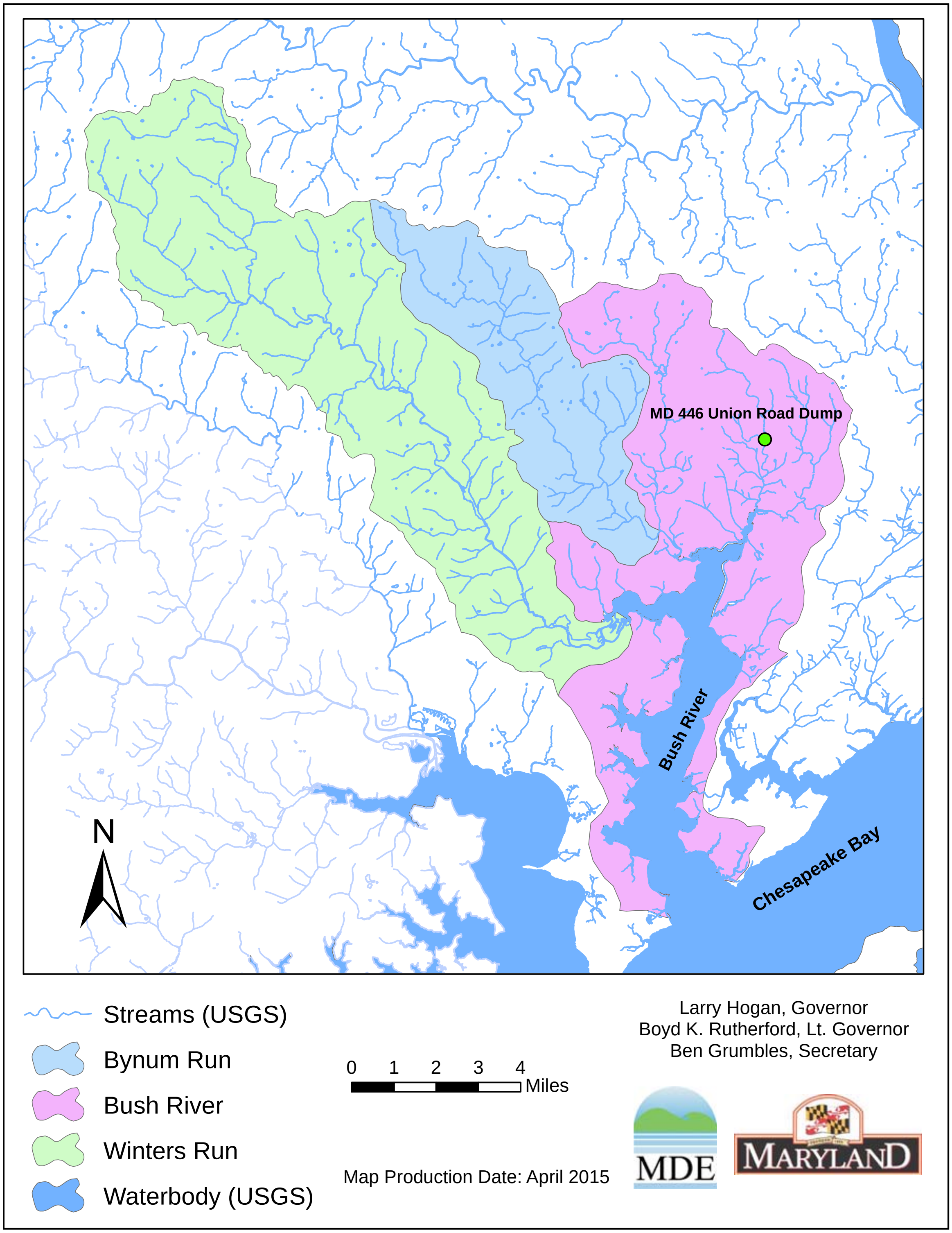

Figure 5: Location of PCB-Contaminated Site

Watershed Sources: Non-regulated Watershed Runoff

The non-regulated watershed runoff tPCB load corresponds to the non-urbanized areas (*i.e.*, primarily forest and wetland areas) of the watershed. The load associated with the urbanized area of the watershed represents the NPDES Regulated Stormwater tPCB load which is presented in Section 4.2 under Point Sources.

In August 2013, October 2013 and March 2014, MDE collected water column samples for PCB analysis at two non-tidal watershed monitoring stations in the Bush River (Stations BuR-7 and BuR-8) and one non-tidal monitoring station each in Bynum Run and Winters Run (Stations ByR-1 and LWR-1) (Appendix G).

To calculate the flow from the Bush River watershed, the daily flow rate at the nearest United States Geological Survey (USGS) station, was used. This station, USGS 01581500), is located in Bel Air, Maryland, in the Bynum Run watershed, and daily flow data at the station was available for the seven-year period from October 1, 2007 through September 30, 2014. The Bush River was divided into 5 segments and the flow from each corresponding subwatershed was calculated by multiplying the monthly mean unit area flow of the station (1.74 cubic feet per second per square mile) by the subwatershed area (Equation 4.1).

$$\text{Watershed Flow} = \text{Unit Flow} \times \text{Watershed Area} \qquad \text{(Equation 4.1)}$$

The Bush River watershed baseline tPCB loading (37g/year) is the sum of loads from each subwatershed calculated by multiplying the subwatershed flow with the average of the measured tPCB concentration (0.49 ng/L) at the two non-tidal stations located at the Bush River watershed.

Similarly, the Bynum Run watershed flow was calculated by multiplying the 7-year monthly mean unit area flow of the USGS station 01581500 (1.74 cubic feet per second per square mile) by the watershed area. The Bynum Run watershed baseline tPCB loading (85.3g/year) is calculated by multiplying the watershed flow with the average of the measured tPCB concentration (2.41 ng/L) at station ByR-1 in Bynum Run.

The Winters Run watershed flow was calculated by multiplying the watershed area by the 7-year monthly mean unit area flow (from October 1, 2007 to September 30, 2014) of the USGS station 01581700 (1.45 cubic feet per second per square mile) located near Benson, MD in the Winters Run watershed. The Winters Run watershed baseline tPCB loading (12.3g/year) is calculated by multiplying the watershed flow with the average of the measured tPCB concentration (0.16 ng/L) at station LWR-1 in Winters Run.

The total baseline tPCB load from Bush River watershed (134.6g/year) is the sum of the baseline loads from the Bush River watershed, the Bynum Run watershed and the Winters Run watershed.

As mentioned above, about 5.4 g/year of the Bush River watershed's baseline load are attributed to atmospheric deposition to the land surface of the above three watersheds, and are inherently captured within the total Bush River watershed tPCB baseline load of 134 g/year.

Using the total baseline load, the non-regulated watershed runoff tPCB load can be calculated. The load associated with the urbanized area of the Bush River watershed represents the NPDES Regulated Stormwater tPCB baseline loads. The non-regulated watershed runoff tPCB baseline load was estimated by multiplying the percentage of non-urban land use (63.1%) within the Bush River watershed by the total Bush River watershed tPCB baseline load (134.6 g/year). The non-regulated watershed runoff tPCB baseline load for the Bush River watershed is 84.9 g/year. The one contaminated site, MD 466 Union Road Dump, is located within the non-urbanized area, and so its tPCB load (2.37 g/year) is subtracted from this total load, resulting in a non-regulated watershed runoff tPCB baseline load of 82.5 g/year. The remaining load corresponds to the NPDES-regulated stormwater area of the watershed.

Resuspension and Diffusion from Bottom Sediments

The transport of PCBs from bottom sediments to the water column through re-suspension and diffusion can be a major source of PCBs in estuarine systems; however, under the framework of this TMDL it is not considered a non-point source. The water quality model developed for this TMDL simulates conditions within the water column and sediment as a single system therefore exchanges between the sediment and water column are considered an internal loading. Only external sources to the system are assigned a baseline load within the TMDL. As PCBs bind to the organic carbon fraction of the suspended sediment in the water column and settle onto the embayment floor, a large portion of the tPCB loads are delivered from various point and non-point sources to the embayment deposits within the bottom sediments. This accumulation of PCBs can subsequently become a significant source of PCBs to the water column via the disturbance and re-suspension of sediments. Dissolved tPCB concentrations in sediment pore water will also diffuse into the water column.

The water quality model, applying observed tPCB concentrations in the water column and sediment, predicts a gross tPCB load of 3,328 g/year from bottom sediment to the water column through re-suspension and diffusion in the Bush River. Although the transport of PCBs to the river from bottom sediment via re-suspension and diffusion is currently estimated to be the major source of PCBs, this load contribution is resultant from other point and nonpoint source inputs (both historic and current) and is not considered to be directly controllable source. Therefore, this load will not be assigned a baseline load or allocation.

4.2 Point Sources

Point Sources in the Bush River watershed include NPDES-regulated municipal WWTPs and industrial process water facilities, as well as stormwater discharges regulated under Phase I and Phase II of the NPDES stormwater program. This section provides detailed explanations regarding the calculation of the point source tPCB baseline loads.

Municipal WWTPs

There are no municipal WWTPs in the Bynum Run watershed and Winters Run watershed. There are two municipal WWTPs within the Bush River watershed. The outfall from one of the facilities, Sod Run WWTP, was sampled by MDE for PCB analysis. As no tPCB effluent concentration data is available for the other facility (US Army Aberdeen Proving Ground – Edgewood Area), the tPCB concentration from this facility was estimated based on the median tPCB effluent concentration from 13 WWTPs monitored by MDE in the Chesapeake Bay watershed (MDE 2006). Their baseline tPCB loadings were calculated based on their daily monitoring record (DMR) average discharge flows and the tPCB concentration. Table 7 provides information on the data used in calculating the baseline loads, and Figure 6 depicts the WWTP locations.

Table 7: Summary of Municipal WWTP tPCB Baseline Loads

Facility Name	NPDES #	Average Concentration (ng/L)	Average Flow (MGD*)	tPCB Baseline Load (g/year)
Harford County - Sod Run WWTP	MD0056545	1.00	13.4	18.4
US Army Aberdeen Proving Ground – Edgewood Area WWTP	MD0021229	0.91	1.2	1.5
Total WWTP Load in the Bush River Watershed				**19.9**

***Million gallons per day**

Industrial Process Water Facility

Industrial process water facilities are included in Maryland's PCB TMDL analyses if: 1) they are located within the applicable watershed and 2) they have the potential to discharge PCBs. Per guidance developed by the Commonwealth of Virginia for monitoring point sources in support of TMDL development, specific types of industrial and commercial operations are more likely than others to discharge PCBs based on historic or current activities. Virginia has identified specific types of permitted industrial and municipal facilities based on their Standard Industrial Classification (SIC) codes as having the potential to contain PCBs within their process water discharge (VADEQ 2009). This methodology has been previously applied within Maryland's other PCB TMDLs, which have been approved by the EPA (MDE 2011a).

Within the 8-Digit Bush River watershed, two industrial process water facilities were identified. US Army Aberdeen Proving Ground – Edgewood Area (NPDES # MD0003565) has an SIC code (9711) defined in Virginia's guidance as having no potential to discharge PCBs. Independent Can Company (NPDES # MD0064220) has an SIC code (3411) defined in the Virginia's guidance as having potential to discharge PCBs. However, the facility was considered de minimis under this analysis, as its average flow (0.0009 Million Gallons per Day [MGD]) was well below 1 MGD. Therefore no baseline load or allocation is assigned within this TMDL for this facility.

Within the Winters Run watershed, one industrial process water facility was identified. Tollgate Landfill (NPDES # MD0065765) has an SIC code (4953) defined in the Virginia guidance as having potential to discharge PCBs. However, the facility was considered de minimis under this analysis, as its average flow (0.043 Million Gallons per Day [MGD]) was well below 1 MGD. Therefore no baseline load or allocation is assigned within this TMDL for this facility.

Within the Bynum Run watershed, no industrial process water facility was identified to have potential to discharge PCBs.

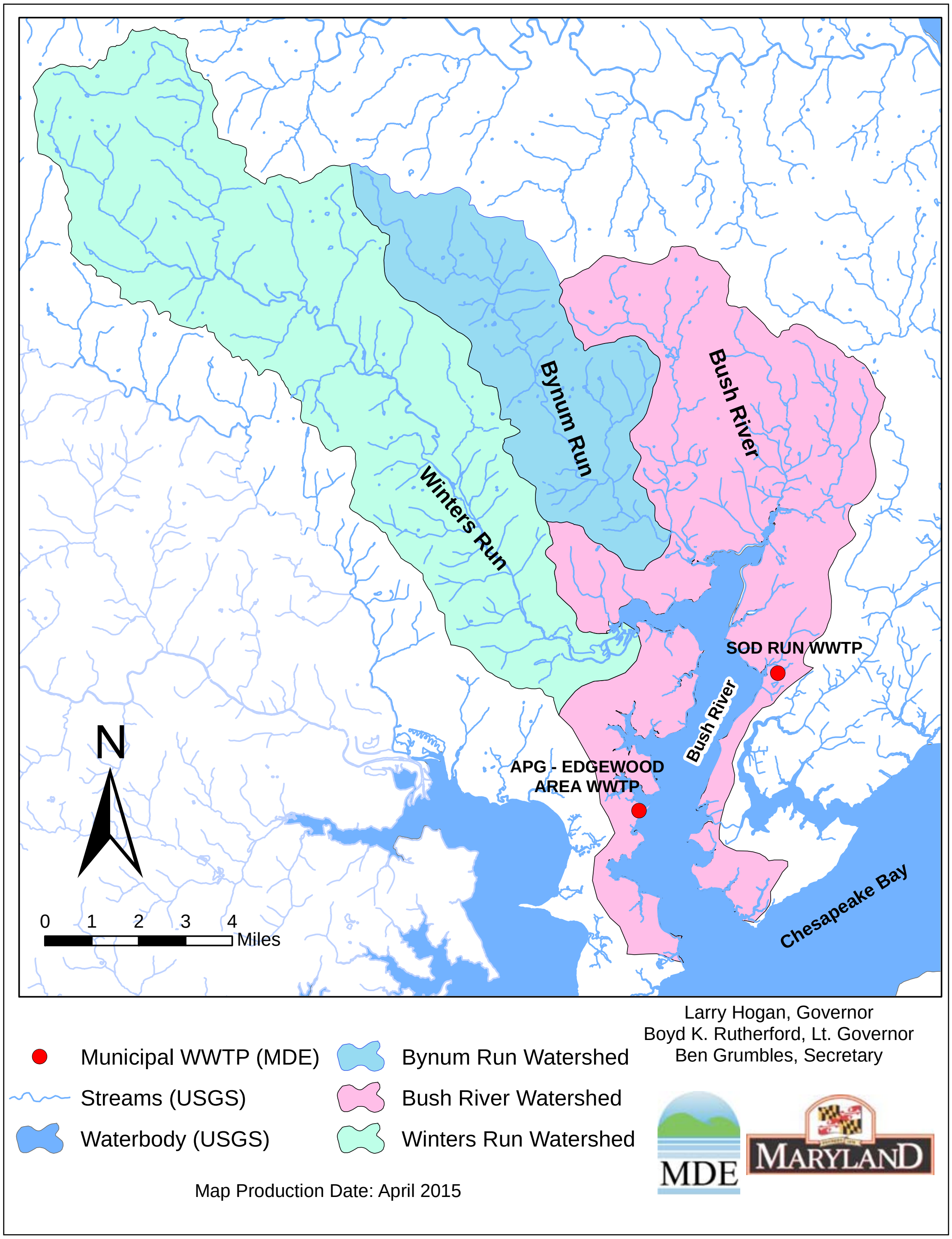

Figure 6: Municipal WWTP Locations in the Bush River Watershed

NPDES Regulated Stormwater

The Department applies EPA's requirement that "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 Wasteload Allocation (WLA) portion of a TMDL" (US EPA 2002). Phase I and II permits can include the following types of discharges:

1. Small, medium, and large Municipal Separate Storm Sewer Systems (MS4s) – these can be owned by local jurisdictions, municipalities, and state and federal entities (*e.g.*, departments of transportation, hospitals, military bases);
2. Industrial facilities permitted for stormwater discharges; and
3. Small and large construction sites.

The lists of all the NPDES regulated stormwater permits within the Bush River watershed that could potentially convey tPCB loads to the river is presented in Appendix F.

MDE estimates pollutant loads from NPDES regulated stormwater areas based on urban land use classification within a given watershed. The 2006 USGS spatial land cover, which was used to develop CBP's Phase 5.3.2 watershed model land use, was applied in this TMDL to estimate the NPDES Regulated Stormwater tPCB Baseline Load.

The Bush River watershed is entirely located within Harford County, Maryland. The NPDES stormwater permits within the watershed include: (i) the area covered under Harford County's Phase I jurisdictional MS4 permit, (ii) the State Highway Administration's Phase I MS4 permit, (iii) industrial facilities permitted for stormwater discharges, and (iv) MDE general permit to construction sites (see Appendix F for a list of all NPDES regulated stormwater permits). The load for all NPDES Stormwater permittees is presented as an aggregate load.

The NPDES regulated stormwater tPCB baseline loads of the Bush River watershed (49.7 g/year) was estimated (in section 4.1) by multiplying the percentage of urban land use (36.9%) within the Bush River watersheds by the total Bush River watershed tPCB baseline loads (134.6 g/year). Table 8 shows the result.

Table 8: Aggregate Regulated Stormwater tPCB Baseline Loads in the Bush River

Watershed	County	Stormwater tPCB load (g/year)
Bush River	Harford	49.7

4.3 Source Assessment Summary

From this source assessment, all point and nonpoint sources of PCBs to the Bush River watershed have been identified and characterized. Nonpoint sources of PCBs have been identified for the Bush River: 1) Chesapeake Bay mainstem tidal influence, 2) direct atmospheric deposition to the river, 3) contaminated site (area with known PCB soil contamination, as documented by state or federal hazardous waste cleanup programs), and 4) runoff from non-regulated watershed areas. In the Bush River watershed, point sources include NPDES regulated municipal WWTP facilities and NPDES regulated stormwater runoff. In the Bush River watershed, two NPDES regulated industrial facilities are identified to have potential to discharge PCBs. However, these facilities were considered *de minimis* under this analysis, as their average flow were well below 1 MGD. Estimated tPCB loads from these point and nonpoint sources represent the baseline conditions for the watershed.

A summary of the tPCB baseline loads for the Bush River are presented in Table 9. The total tPCB load to the Bush River embayment is 202.8 g/year. In order to address the long term PCB load variation, the watershed loads are calculated using a 7-year mean flow from October 1, 2007 to September 30, 2014 (PCB data was taken in 2013 and 2014).

As explained in Section 4.1, loads associated with re-suspension and diffusion from sediments, and tidal influences from the Chesapeake Bay mainstem are not considered to be directly controllable (reducible) within the framework of the TMDL and are thus not assigned baseline loads or allocations.

Table 9: Summary of tPCB Baseline Loads in the Bush River

Source	Baseline Load (g/year)	Baseline Load (%)
Direct Atmospheric Deposition	48.9	24.0%
Contaminated Site	2.4	1.2%
Maryland Non-regulated Watershed Runoff	82.5	40.6%
Nonpoint Sources	***133.8***	***65.8%***
NPDES Regulated Municipal WWTPs	19.9	9.8%
NPDES Regulated Stormwater	49.7	24.4%
Point Sources	***69.6***	***34.2%***
Total	**203.4**	**100.0%**

5.0 TOTAL MAXIMUM DAILY LOADS AND LOAD ALLOCATIONS

5.1 Overview

A TMDL is the total amount of an impairing substance that a waterbody can receive and still meet WQSs. The TMDL may be expressed as a mass per unit time, toxicity, or other appropriate measure and should be presented in terms of WLAs, load allocations (LAs), and either an implicit or explicit margin of safety (MOS) (CFR 2014a):

$$TMDL = WLAs + LAs + MOS \qquad \text{(Equation 5.1)}$$

This section describes how the tPCB TMDL and the corresponding LAs and WLAs have been developed for the Bush River watershed. The analysis framework for simulating PCB concentrations is described in Section 5.2. Section 5.3 addresses critical conditions and seasonality, and Section 5.4 presents the allocation of loads between point and nonpoint sources. The MOS and model uncertainties are discussed in Section 5.5, and the TMDL is summarized in Section 5.6.

5.2 Analysis Framework

A tidally-averaged multi-segment one-dimensional transport model was applied to simulate the tPCB dynamic interactions between the water column and bottom sediments within the Bush River and the Chesapeake Bay. The system was divided into 5 segments and the watershed into 5 subwatersheds (Figure D-1). In general, tidal waters are exchanged through their connecting boundaries. Within the Bush River system, the dominant processes affecting the transport of PCBs throughout the water column include: dispersion induced by tide and concentration gradient between the Bay and the embayment, fresh water discharge from upstream rivers and adjacent watershed, atmospheric exchange due to volatilization and deposition, and exchange with the bottom sediments (through diffusion, re-suspension, and settling). Burial to deeper inactive layers and the exchange with the water column (through diffusion, resuspension, and settling) are the dominant processes affecting the transport of PCBs in the bottom sediments. A technical description of the model is presented in Appendix D.

Baseline Conditions

The observed average tPCB concentrations in the water column and sediment (2013, 2014) in each segment were used to characterize the initial (baseline) model conditions (May 20, 2014 water column data excluded). If the segment did not have any PCB observations, the linear interpolation, using tPCB concentrations from the adjacent up- and down-stream segments was used. Based on the study of Ko and Baker (2004), on average the tPCB concentrations in the upper Chesapeake Bay are decreasing at a rate of 6.5% per year. All other model inputs (i.e., fresh water discharge, dispersion coefficients, sediment and water column exchange rates, atmospheric deposition, and burial rate) were kept constant. Baseline tPCB loads for the Bush River was stated in section 4. The dominant tPCB sources to the water column of the Bush River are from sediment. However, under the framework of this TMDL, the tPCB loads from sediment are considered to be internal source, therefore no baseline or load allocation is assigned to this load.

TMDL Scenarios

To determine what percent reduction of the total load is necessary for the Bush River to meet its water quality and sediment TMDL endpoints, different scenario runs were conducted (Appendix D). It was demonstrated that a minimum reduction of 60% of total baseline loads from all source categories of non-point and point sources to the Bush River is required in order to achieve the TMDL when the Bay boundary water column PCB concentration is set to decline at an annual rate of 6.5%. It will take approximately 81 years (29,744 days) to meet both the water column and sediment TMDL endpoints and thus be supportive of its designated use (Figure 7).

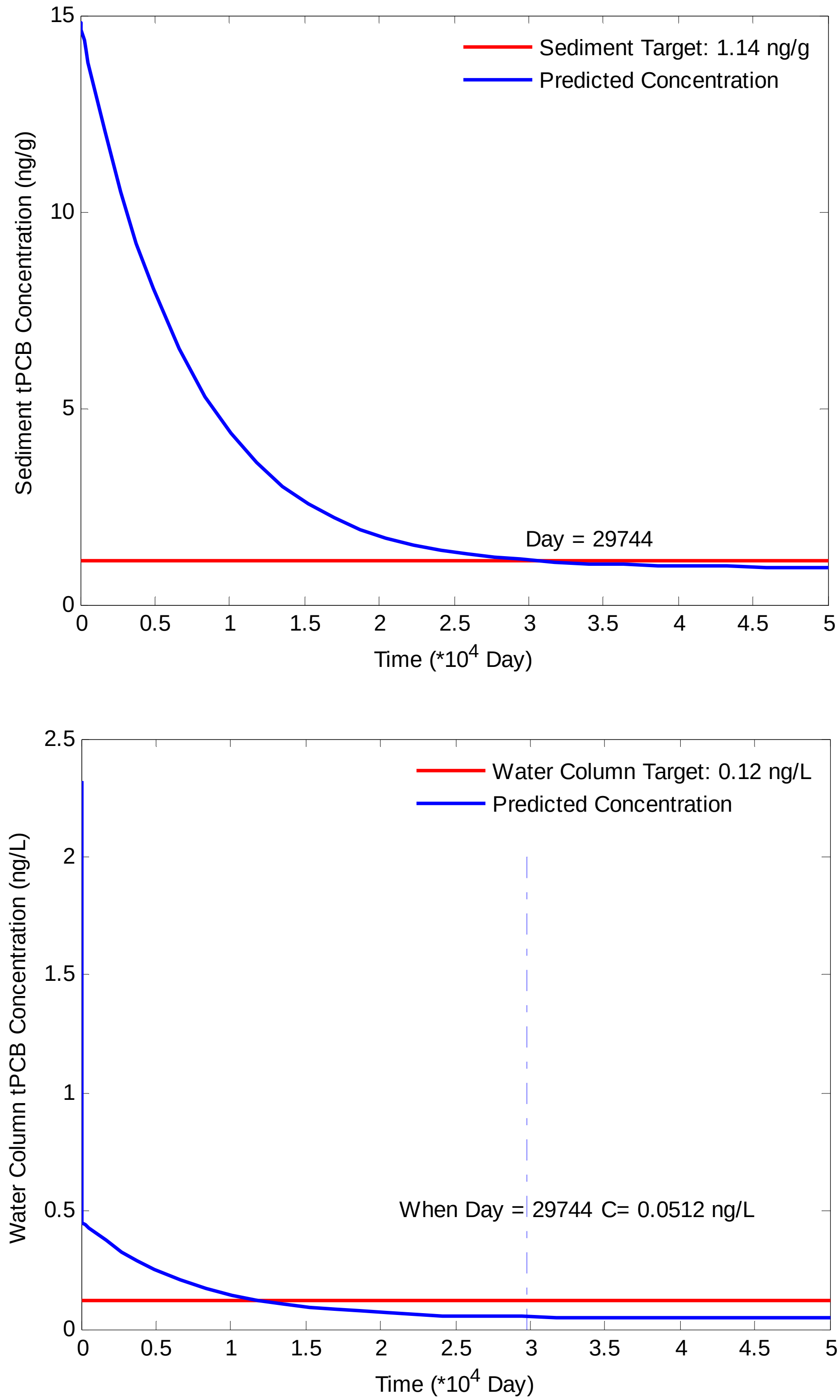

Figure 7: Change in Water Column and Bottom Sediment tPCB Concentrations over Time within the Bush River (60% load reduction from total baseline load)

5.3 Critical Condition and Seasonality

Federal regulations require TMDL analysis to take into account the impact of critical conditions and seasonality on water quality (CFR 2014a). The intent of this requirement is to ensure that water quality is protected when it is most vulnerable.

Bioaccumulation of PCBs in fish is driven by long-term exposure through respiration, dermal contact, and consumption of lower order trophic level organisms. The critical condition defined by acute exposure to temporary fluctuations in PCB water column concentrations during storm events is not a significant pathway for uptake of PCBs. Monitoring of PCBs was conducted on a quarterly basis to account for seasonal variation in establishing the baseline condition for ambient water quality in the Bush River and estimation of watershed loadings. Since PCB levels in fish tissue become elevated due to long-term exposure, it has been determined that the selection of the annual average tPCB water column and sediment concentrations for comparison to the endpoints applied within the TMDL adequately considers the impact of seasonal variations and critical conditions on the "fishing" designated use in the Bush River. Furthermore, the water column TMDL endpoint is also supportive of the "protection of aquatic life" designated use at all times as it is more stringent than the freshwater and salt water chronic tPCB criteria.

5.4 TMDL Allocations

All TMDLs need to be presented as a sum of WLAs for point sources and LAs for nonpoint source loads generated within the assessment unit, and if applicable LAs for the natural background, tributary, and adjacent segment loads (CFR 2014b). The State reserves the right to revise these allocations provided the revisions are consistent with achieving WQSs. The allocations described in this section summarize the tPCB TMDL established to meet the "fishing" designated use in the Bush River. These allocations are also supportive of the 'protection of aquatic life" designated use as explained in section 3.

5.4.1 Load Allocations

LAs have been assigned to the following nonpoint sources in order to support the "fishing" designated use: non-regulated watershed runoff from the Bush River watersheds and direct atmosphere deposition to river surface. The model demonstrates that in order to support the "fishing" designated use in the Bush River, tPCB load reduction of 62% from the total nonpoint source load is required to achieve the TMDL. The primary source of PCBs to the atmosphere is from volatilization of PCB contaminated land sources which will be eliminated as these sources are remediated through implementation of the non-regulated watershed runoff LA and NPDES regulated stormwater WLA.

As explained in Section 4.1, loads associated with re-suspension and diffusion from sediments and tidal influences from the Chesapeake Bay mainstem are not considered to be directly controllable (reducible) within the framework of the TMDL and are thus not assigned baseline loads or allocations.

5.4.2 Wasteload Allocations

Municipal WWTPs

There are two municipal WWTPs within the Bush River watershed. The outfall from one of these facilities, Sod Run WWTP, was sampled by MDE for PCB analysis. As no tPCB effluent concentration data is available for the other facility (US Army Aberdeen Proving Ground – Edgewood Area), the tPCB concentration from this facility was estimated based on the median tPCB effluent concentration from 13 WWTPs monitored by MDE in the Chesapeake Bay watershed (MDE 2006). Their baseline tPCB loadings were calculated based on their daily monitoring record (DMR) average discharge flows and the tPCB concentration. WWTPs require a 62% reduction from baseline loads to meet TMDL endpoints in the Bush River (See Table 10).

Table 10: Individual tPCB WLAs (g/day and g/year) for each Municipal WWTP

Facility Name	NPDES #	Baseline Load (g/year)	Reduction (%)	TMDL (g/year)	MDL (g/year)
Harford County - Sod Run WWTP	MD0056545	18.4	62%	6.99	0.059
US Army Aberdeen Proving Ground – Edgewood Area WWTP	MD0021229	1.5	62%	0.57	0.005

NPDES Regulated Stormwater

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." 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 allocations to the Bush River will be expressed as single, aggregate WLAs. Upon approval of the TMDL, "NPDES-regulated municipal stormwater and small construction stormwater discharges effluent limits should be expressed as Best Management Practices (BMPs) or other similar requirements, rather than as numeric effluent limits" (US EPA 2002).

The NPDES Regulated Stormwater WLA was established by reducing the NPDES Regulated Stormwater Baseline Loads the same percentages as to the Non-regulated Watershed Runoff Baseline Loads in the watershed. For more information on methods used to calculate the NPDES Regulated Stormwater PCB Baseline Load, please see Section 4.2. The NPDES Regulated Stormwater WLA may include any or all of the NPDES stormwater discharges listed in Section 4.2 (see Appendix F for a complete list of stormwater permits). As stormwater assessment or other program monitoring efforts result in a more refined source assessment, MDE reserves the right to revise the current NPDES Regulated Stormwater WLA provided the revisions are protective of the "fishing" designated use in the Bush River. The NPDES Regulated Stormwater Baseline Load requires a 62% reduction for the Bush River.

5.5 Margin of Safety

All TMDLs must include a MOS to account for the lack of knowledge and the many uncertainties in the understanding and simulation of water quality parameters in natural systems (*i.e.*, the relationship between modeled loads and water quality). The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection. Uncertainty within the model framework includes the estimated rate of decline in tPCB concentrations within the Chesapeake Bay mainstem, as well as the initial condition of mean tPCB concentrations that was selected for the model. In order to account for these uncertainties and in order to provide an adequate and environmentally protective TMDL, MDE applied an explicit 5% MOS.

5.6 Maximum Daily Loads

All TMDLs must include maximum daily loads (MDLs) consistent with the average annual TMDL. For this TMDL, tPCB MDLs are developed for each source category by converting daily time-series loads into TMDL values consistent with available EPA guidance on generating daily loads for TMDLs (US EPA 2007). The approach builds upon the TMDL modeling analysis that was conducted to ensure that average annual load targets result in compliance with the TMDL endpoint tPCB concentrations and considers a daily load level of a resolution based on specific data for each source category. The detailed calculation of MDLs is reported in Appendix E and the results are shown in Table 11.

5.7 TMDL Summary

Table 11 summarizes the tPCB baseline loads, TMDL allocations, load reductions, and maximum daily loads (MDLs) for the Bush River.

Table 11: Summary of tPCB Baseline Loads, TMDL Allocations, Associated Percent Reductions and MDLs in the Bush River

Source	Baseline Load (g/year)	Baseline Load (%)	TMDL (g/year)	Load Reduction (%)	MDL (g/day)
Direct Atmospheric Deposition	48.9	24.0%	18.58	62%	0.075
Contaminated Site	2.4	1.2%	2.37	0%	0.010
Maryland Non-regulated Watershed Runoff	82.5	40.6%	29.88	64%	0.121
Nonpoint Sources	***133.8***	***65.8%***	***50.83***	***62%***	***0.206***
NPDES Regulated Municipal WWTPs	19.9	9.8%	7.56	62%	0.064
NPDES Regulated Stormwater	49.7	24.4%	18.89	62%	0.077
Point Sources	***69.6***	***34.2%***	***26.45***	***62%***	***0.141***
MOS	-	-	4.07		0.016
Total	**203.4**	**100.0%**	**81.35**	**60%**	**0.363**

6.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurance that the tPCB TMDL for the Bush River will be achieved and maintained.

As discussed in the previous sections, the re-suspension and diffusion from the bottom sediments have been identified as the major source of PCBs to the Bush River. However, the loads from re-suspension and diffusion from bottom sediments are not considered to be directly controllable (reducible) loads and are considered as internal loads within the modeling framework of the TMDL, so they are not included in the tPCB baseline load and TMDL allocation.

Given that PCBs are no longer manufactured, and their use has been substantially restricted, it is reasonable to expect that with time tPCB concentrations in the aquatic environment will decline. In this study, it is assumed that the tPCB concentrations in the Chesapeake Bay mainstem are decreasing at a rate of 6.5% per year based on the 2004 study by Ko and Baker (Ko and Baker 2004). Given this rate of decline in the mainstem, the tPCB levels in the Bush River are expected to decline over time. Processes, such as the burial of contaminated sediments with newer, less contaminated materials, flushing of sediments during periods of high stream flow, and biodegradation will contribute to this natural attenuation. Even though tidal influence from the Chesapeake Bay mainstem serves as a source of PCBs to the Bush River, the load contribution is resultant from other point and nonpoint source inputs (both historic and current) from throughout the upper Chesapeake Bay watershed and is not considered to be a directly controllable (reducible) source. Therefore this load will not be assigned a baseline load or allocation within the TMDL.

Model scenarios predict that with the natural attenuation of tPCB concentrations in the Chesapeake Bay mainstem, and a 60% load reduction of total baseline load from the Bush River watershed, from direct atmosphere deposition to the River surface and from two municipal WWTPs, the tPCB TMDL endpoints in both water column and sediment of the Bush River embayment will be met in about 81 years. Loads from the watershed include non-regulated watershed source load and NPDES regulated stormwater load.

A new Chesapeake Bay Watershed Agreement was signed on June 16, 2014 which includes goals and outcomes for toxic contaminants including PCBs (CBP 2014). The toxic contaminant goal is to "ensure that the Bay and its rivers are free of effects of toxic contaminants on living resources and human health." Objectives for the toxic contaminant outcomes regarding PCBs include 1) characterizing the occurrence, concentrations, sources and effects of PCBs, 2) identifying BMPs that may provide benefits for reducing toxic contaminants in waterways, 3) improving practices and controls that reduce and prevent the effects of toxic contaminants, and 4) building on existing programs to reduce the amount and effects of PCBs in the Bay and its watershed. Implementation of the toxic contaminant goal and outcomes under the new Bay agreement as well as discovering and minimizing any existing PCB land sources throughout the Chesapeake Bay watershed via future TMDL development and implementation efforts could further help to meet water quality goals in the Bush River.

Aside from the processes of natural attenuation, an alternative approach that can assist in reducing the tPCB concentrations in the water column, so as to meet WQSs, is the physical removal of the PCB-contaminated sediments (*i.e.*, dredging). This process would minimize one of the primary, potential sources of tPCBs to the water column. If the PCB-contaminated sediments were removed, load reductions would still be required under the TMDL, since PCBs would continue to enter the Bush River from the mainstem of the Chesapeake Bay and from the Bush River watershed. However, the removal of these sediments could also mean that water quality supportive of the "fishing" designated use would be achieved in a shorter time frame. When considering dredging as an option, the risk versus benefit must be weighed, as the removal of contaminated sediment may potentially damage the habitat and health of the existing benthic community. The process of stirring up suspended sediments during dredging may damage the gills and sensory organs of benthic macroinvertebrates and fish. Suspended sediments can also affect the prey gathering ability of sight-feeding fish during dredging operations. In addition, the re-suspension of contaminated sediments causes additional exposure of PCBs to aquatic organisms.

PCBs are still being released to the environment via accidental fires, leaks, or spills from older PCB-containing equipment; potential leaks from hazardous waste sites that contain PCBs; illegal or improper dumping; and disposal of PCB containing products (*e.g.*, transformers, old fluorescent lighting fixtures, electrical devices, or appliances containing PCB capacitors, old microscope oil, and old hydraulic oil) into landfills that are not designed to handle hazardous waste. Due to the potential existence of unidentified sources of PCB contamination through the watershed and the significant watershed load reductions required to meet the TMDL endpoints, an adaptive approach of implementation is anticipated, with subsequent monitoring to assess the effectiveness of the ongoing implementation efforts to manage potential risks to both recreational and subsistence fish consumers.

The success of the implementation process will depend in large part on the feasibility of locating and evaluating opportunities to control on-land PCB sources, such as unidentified contaminated sites, leaky equipment, and contaminated soil or sediment. A collaborative approach involving all related jurisdictions and the identified NPDES permit holders as well as those responsible for nonpoint PCB runoff throughout the Bush River watershed will be used to work toward attaining the WLAs and LAs presented in this report.

In order to fully characterize PCB concentrations in environmental media, any future monitoring should include congener specific analytical methods. Ideally, the most current version of EPA Method 1668 should be used, or other equivalent methods capable of providing low-detection level, congener specific results. In establishing the necessity and extent of data collection, MDE will collaborate with the affected stakeholders, and take into account data that is already available, as well as the proper characterization of intake (or pass through) conditions, consistent with NPDES program "reasonable potential" determinations and the applicable provisions of the Environment Article and COMAR for permitted facilities. Similar approaches may be applicable for all upstream jurisdictions with regards to PCB monitoring and stakeholder collaboration.

Under certain conditions, EPA's NPDES regulations allow the use of non-numeric, BMP water quality based effluent limits (WQBELs). BMP WQBELs can be used where "numeric effluent limitations are infeasible; or the practices are reasonably necessary to achieve effluent limitations and standards or to carry out the purposes and intent of the CWA" (CFR 2013c).

In addition, impervious surface restoration efforts have been known to result in total suspended solids (TSS) reduction efficiencies. Since PCBs are known to adsorb to sediments and their concentrations correlate with TSS concentrations, any significant restoration requirements, which will lead to a reduction in sediment loads entering the Bush River, will also contribute toward tPCB load reductions and meeting PCB water quality goals. Other BMPs that focus on PCB source tracking and elimination at the source rather than end-of-pipe controls are also warranted.

Where necessary, the source characterization efforts will be followed with pollution minimization and reduction measures that will include BMPs for reducing runoff from urban areas, identification and termination of ongoing sources (*e.g.*, industrial uses of equipment that contain PCBs), etc. The identified NPDES regulated WWTP and stormwater control agency permits will be expected to be consistent with the WLAs presented in this report. Numerous stormwater dischargers are located in the Bush River watershed, including a Municipal Phase I MS4, the SHA Phase I MS4, industrial facilities, and any construction activities on areas greater than 1 acre (see Appendix F of this document to view the current list of known NPDES stormwater dischargers).

Given the persistent nature of PCBs, the difficulty in removing them from the environment and the significant watershed load reductions necessary in order to achieve water quality goals in the Bush River, effectiveness of the implementation effort will need to be reevaluated throughout the process to ensure progress is being made towards reaching the TMDLs. MDE also periodically monitors and evaluates concentrations of contaminants in recreationally caught fish, shellfish, and crabs throughout Maryland. MDE will use these monitoring programs to evaluate progress towards meeting the "fishing" designated use.

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Appendix A: List of Analyzed PCB Congeners

PCB analytical services were provided by the University of Maryland Center for Environmental Science (UMCES). Specific PCB congeners were identified and quantified by high resolution gas chromatography with GC-MS detection (Ayris *et al*. 1997, Holwell *et al*. 2007, Konietckka and Namiesnik 2008, Mydlová-Memersheimerová *et al* 2009). This method is based on EPA method 8082 which was developed in 1996. UMCES uses a slightly modified version of the PCB congener specific method described in Ashley and Baker (1999), in which the identities and concentrations of each congener in a mixed Aroclor standard (25:18:18 mixture of Aroclors 1232, 1248, and 1262) are determined based on their chromatographic retention times relative to the internal standards (PCB 30 and PCB 204 and ten C13 labeled standards). Based on this method, upwards of 100 chromatographic peaks can be quantified. Some of the peaks contain one PCB congener, while many are comprised of two or more co-eluting congeners. PCB congeners identified under this method are displayed in Table A-1. The PCB analysis presented in this document is based on tPCB concentrations that are calculated as the sum of the detected PCB congeners/congener groups representing the most common congeners that were historically used in the Aroclor commercial mixtures.

Table A-1: List of Analyzed PCB Congeners

1	45	110, 77	177
3	46	114	180
4, 10	47, 48	118	183
6	49	119	185
7, 9	51	123, 149	187, 182
8, 5	52	128	189
12, 13	56, 60	129, 178	191
16, 32	63	132, 153, 105	193
17	66, 95	134	194
18	70, 76	135, 144	197
19	74	136	198
22	81, 87	137, 130	199
24	82, 151	141	201
25	83	146	202, 171, 156
26	84, 92	157, 200	203, 196
29	89	158	205
31, 28	91	163, 138	206
33, 21, 53	97	167	207
37, 42	99	170, 190	208, 195
40	100	172	209
41, 64, 71	101	174	
44	107	176	

Appendix B: Derivation of Adj-tBAF and Adj-SediBAF

This appendix describes how the Adj-tBAF and Adj-SediBAF were derived. The method followed the Potomac River tPCB TMDL (Haywood and Buchanan 2007).

I. Data Description

The observation-based Adj-tBAF and Adj-SediBAF were calculated for the fish species within the Bush River from the available fish tissue, water column, and sediment tPCB data. Each fish species was assigned a trophic level and a home range (see Table B-1). The Adj-tBAF and Adj-SediBAF were calculated based on the geometric mean tPCB concentrations of all the samples within the home range for each species.

Table B-1: Species Trophic Levels and Home Ranges in the Bush River

Common Name	Scientific Name	Trophic Level (#)	Trophic Level (Description)	Home Range (miles)
White Perch	*Morone americana*	4	Predator	10
Brown Bullhead	*Ameiurus nebulosus*	3	Benthivore-Generalist	5
Channel Catfish	*Ictalurus punctatus*	3	Benthivore-Generalist	5

II. Total BAFs

First, the tBAFs were calculated using Equation B-1 (US EPA 2003):

$$tBAF = \frac{[tPCB]_{fish}}{[tPCB]_{Water}} \qquad (B\text{-}1)$$

Where: $[tPCB]_{fish}$ = tPCB concentration in wet fish tissue (ng/kg)
$[tPCB]_{water}$ = water column tPCB concentration in fish species home range (ng/L).

III. Baseline BAFs

As the tBAFs vary depending on the food habits and lipid concentration of each fish species as well as the freely-dissolved tPCB concentrations in the water column, the baseline BAFs were calculated as recommended by US EPA (2003):

$$\text{Baseline BAF} = \frac{[PCB]_{fish} \,/\, \%Lipid}{[PCB]_{Water} \times \% fd} \qquad (B\text{-}2)$$

Where: %fd = fraction of the tPCB concentration in water that is freely-dissolved
%lipid = fraction of tissue that is lipid (if the lipid content was not available for a certain fish, the average lipid content of the whole ecosystem was used.)

The freely-dissolved tPCBs are those not associated with dissolved organic carbon (DOC) or particulate organic carbon (POC). The %fd can be calculated as (US EPA 2003):

$$\%fd = \frac{1}{1 + POC \times K_{ow} + DOC \times 0.08 \times K_{ow}} \qquad (B-3)$$

Where: K_{ow} is the PCB octanol-water partition coefficient, POC and DOC are the particulate and dissolved organic carbon concentrations in the water column.

The K_{ow} of PCB congeners have large ranges. Therefore, a %fd was calculated for each PCB homolog using the midpoint of the homolog's K_{ow} range showing in Table B-2 (Hayward and Buchanan 2007).

Table B-2: K_{ow} Values of Homologs Used in the Baseline BAF Calculation

Homolog	Midpoint K_{ow}
Mono+Di	47,315
Tri	266,073
Tetra	1,011,579
Penta	3,349,654
Hexa	5,370,318
Hepta	17,179,084
Octa	39,810,717
Nona	82,224,265
Deca	151,356,125

The %fd for tPCBs (PCB %fd) was derived by dividing the freely-dissolved PCB concentrations by the water column tPCB concentrations:

$$PCB\ \%fd = \frac{\sum(\text{Homolog}\ \%fd \times \text{Homolog Concentration})}{[tPCB]_{water}} \qquad (B-4)$$

The PCB %fd was used in Equation B-2 to calculate the baseline BAFs.

IV. Adjusted Total BAFs

The baseline BAFs were normalized by the species median lipid content and a single freely-dissolved PCB concentration (*i.e.*, median %fd within the fish's home range) representative of the ecosystem, resulting in no variability attribution to differences in fish lipid content or freely-dissolved PCB concentration in the water column:

$$\text{Adj-tBAF} = (\text{Baseline BAF} \times \text{Median}\ \%\ \text{Lipid} + 1) \times \text{Median}\ \%fd \qquad (B-5)$$

The tPCB fish tissue listing threshold of 39 ng/g can then be divided by the median Adj-tBAF for each species to translate an associated tPCB water column threshold concentration. According to the data requirement for listing a waterbody as impaired by PCBs in fish tissue (http://www.mde.state.md.us/programs/Water/TMDL/Integrated303dReports/Pages/Programs/WaterPrograms/TMDL/maryland%20303%20dlist/ir_listing_methodologies.aspx), the minimum data requirement is 5 fish (individual or composite of the same resident species) for a given waterbody and all fish that comprise a composite sample must be within the same size class (i.e., the smallest fish must be within 75% of the total length of the largest fish). The lowest tPCB water column threshold concentration of all the fish species will be selected as the TMDL endpoint in order to be supportive of the “fishing” designated use. In the Bush River, the lowest threshold concentration (0.12ng/L) is associated with Channel Catfish (Table B-3). There are two fish composites for Channel Catfish with each composed of five fish. The length and weight for these fish are shown in Table B-4. For Bush River, the water column tPCB threshold concentration of 0.12ng/L for Channel Catfish was selected as the water column tPCB TMDL endpoint.

Table B-3: tBAF, Baseline BAF, Adj-tBAF, and Water Column TMDL Endpoint tPCB Concentrations for Each Species in the Bush River

Species Name	Number of Fish (Composites)	tBAF (L/kg)	Baseline BAF (L/kg)	Adj-tBAF (L/kg)	Water Column tPCB Threshold Concentration (ng/L)
White Perch	15 (3)	47,472	55,652,089	58,686	0.66
Brown Bullhead	5 (1)	90,838	9,084,919	89,944	0.43
Channel Catfish	10 (2)	333,781	55,390,682	327,333	**0.12**

Table B-4: Individual Fish Lengths and Weights in the Channel Catfish Composites in the Bush River

Station ID	Sample ID	Sample Date	Fish Species	Fish/ Composite	Length (cm)	Weight (g)
2014FTC-BUSH-E	0428_BUSH_21	6/18/2014	Channel Catfish	5	44.5	918
	0428_BUSH_22				42.5	650
	0428_BUSH_23				40.7	577
	0428_BUSH_24				39.5	575
	0428_BUSH_25				38	493
2014FTC-BUSH-F	0428_BUSH_26	5/12/2014 6/18/2014	Channel Catfish	5	55	2039
	0428_BUSH_27				47	1356
	0428_BUSH_28				48.8	1626
	0428_BUSH_29				49.8	1348
	0428_BUSH_30				49	1393

V. Biota-Sediment Accumulation Factors and Adjusted Sediment BAFs

The biota-sediment accumulation factors (BSAFs) were derived by the following equation:

$$BSAF = \frac{tPCB_{tissue} / \%\ Lipid}{tPCB_{sediment} / \%\ Oraganic\ Carbon} \quad (B\text{-}6)$$

where: % Organic Carbon is the species home range's average sediment organic carbon fraction.

Since there is no available % Organic Carbon information for some of the study sites, a default values of 1% was used (US EPA 2004). Each species' BSAF was then standardized to a common condition by normalizing them to the median lipid content of the species and a sediment organic carbon fraction representative of the ecosystem:

$$Adj\text{-}SedBAF = BSAF \times \frac{Median\ \%\ Lipid}{Median\ \%\ Oraganic\ Carbon} \quad (B\text{-}7)$$

The tPCB fish tissue listing threshold of 39 ng/g can then be divided by the median Adj-SedBAF for each species to translate an associated tPCB sediment threshold concentration. The lowest tPCB sediment threshold concentration of all the fish species will be selected as the TMDL endpoint in order to be supportive of the "fishing" designated use. In the Bush River, the lowest concentration (1.14 ng/g) is associated with channel catfish and will be selected as the sediment TMDL endpoint (Table B-5).

Table B-5: BSAF, Adj-SedBAF, and Sediment TMDL Endpoint tPCB Concentrations in the Bush River

Species Name	BSAF	Adj-SedBAF	Sediment tPCB Threshold Concentration (ng/g)
White Perch	4.84	5.38	7.25
Brown Bullhead	0.83	9.36	4.16
Channel Catfish	5.05	34.08	**1.14**

Appendix C: Method Used to Estimate Watershed tPCB Load

In August 2013, October 2013 and May 2014, MDE collected water column samples for PCB analysis at two non-tidal watershed monitoring stations in the Bush River (Stations BuR-7 and BuR-8) and one non-tidal monitoring station each in Bynum Run and Winters Run (Stations ByR-1 and LWR-1) (Figure C-1). In order to assess whether or not these samples covered all flow ranges so that they could be used to calculate watershed loads, the daily average flow rates from October 1, 2007 to September 30, 2014 of the United States Geological Survey (USGS) Station 01581500 located at Bynum Run at Bel Air, MD (Figure C1) were used to generate the flow duration curves. The flows for the dates on which the watershed samples were collected were identified on the flow duration curve (Figure C-2). This comparison indicates that the PCB samples are mainly located in the medium to high flow region. It was therefore not justifiable to use the regression method applied in the Back River tPCB TMDL (MDE 2011b) to the Bush River.

The Bush River watershed includes three sub-watersheds: Bush River watershed, Bynum Run watershed and Winters Run watershed. For the modeling purpose, the Bush River watershed was divided into 5 subwatersheds according to the Bush River modeling segmentation.

For the Bush River watershed, the flow from each subwatershed was calculated using the 7-year monthly mean flows at the USGS station located at Bynum Run watershed (USGS 1581500). The unit area flow of the station (1.74 cubic feet per second per square mile) was multiplied by the area of a subwatershed to get its flow.

The baseline tPCB loading from each subwatershed of the Bush River watershed was calculated by multiplying the average flow and mean measured tPCB concentration (0.49 ng/L) of the non-tidal monitoring stations (BuR-7 and BuR-8) in the Bush River. The flow and tPCB baseline loads from each subwatershed of the Bush River are shown in Table C-1. The Bush River watershed baseline tPCB loading (37g/year) is the sum of loads from each subwatershed.

Table C-1: Flow and tPCB baseline loads from Subwatersheds of Bush River (excluding data from May 20, 2014)

Watershed	Bush R. Tidal Segment	flow from watershed (m^3/day)	tPCB Conc from non-tidal stations(ng/L)	tPCB loads from subwatershed (ug/day)
Bush River	1	17,766.54	0.49	8,733.11
	2	21,846.44	0.49	10,738.58
	3	23,936.72	0.49	11,766.05
	4	19,478.10	0.49	9,574.43
	5	122,902.66	0.49	60,412.60

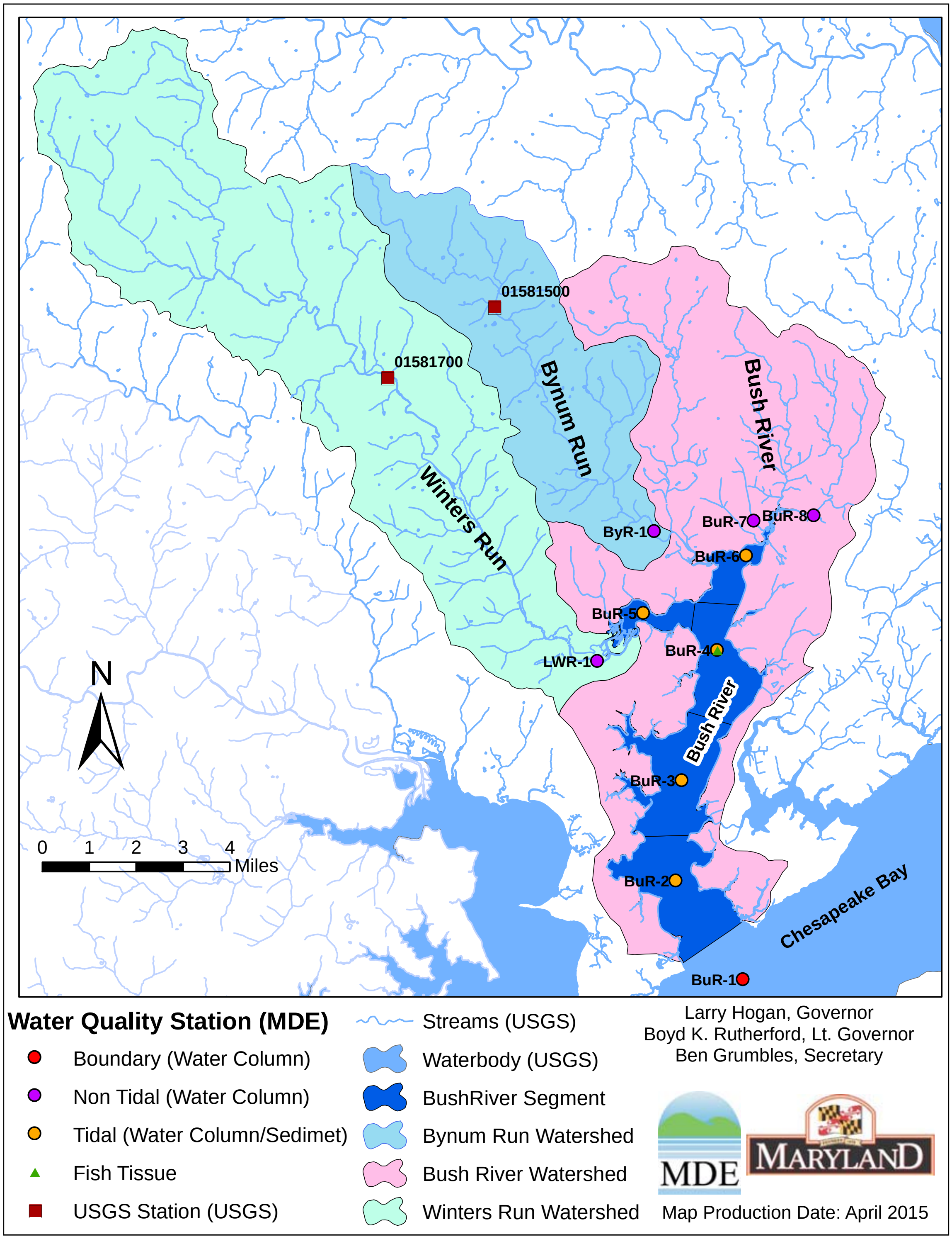
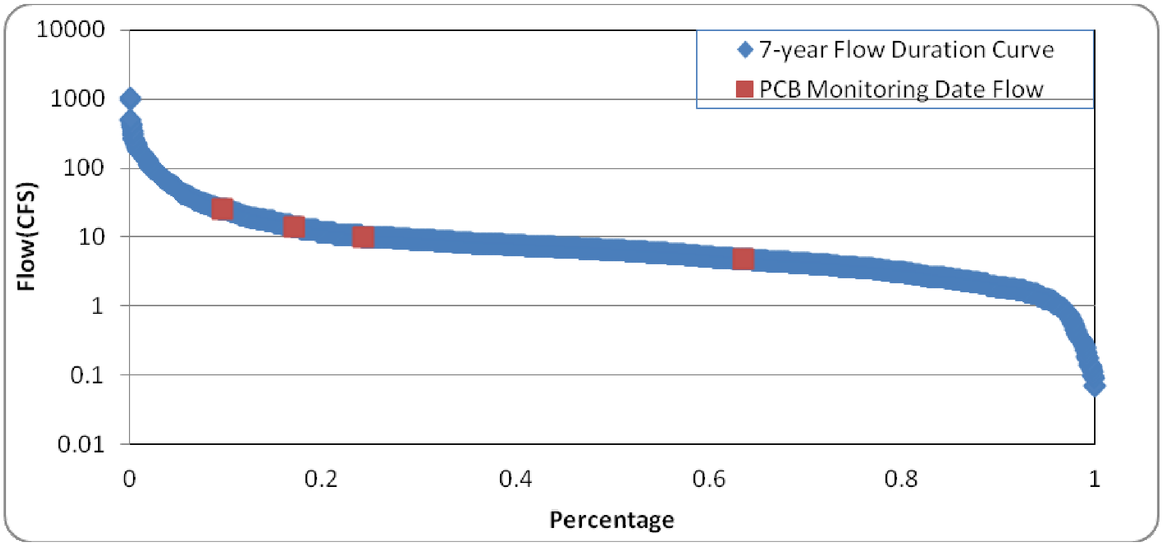


Figure C-1: PCB Water Quality Monitoring Stations/USGS Station in the Bush River Watershed



Note: The red points represent the non-tidal water quality monitoring sample flows

Figure C-2: Relative Locations of PCB Water Column Measurement Station Sampling Date Flow on the Flow Duration Curve

Similarly, the Bynum Run watershed flow was calculated by multiplying the 7-year monthly mean unit area flow of the USGS station 01581500 (1.74 cubic feet per second per square mile) by the watershed area. The Bynum Run watershed baseline tPCB loading (85.3g/year) is calculated by multiplying the watershed flow with the average of the measured tPCB concentration (2.41 ng/L) at station ByR-1 in Bynum Run.

The Winters Run watershed flow was calculated by multiplying the watershed area by the 7-year monthly mean unit area flow (from October 1, 2007 to September 30, 2014) of the USGS station 01581700 (1.45 cubic feet per second per square mile) located near Benson, MD in the Winters Run watershed. The Winters Run watershed baseline tPCB loading (12.3g/year) is calculated by multiplying the watershed flow with the average of the measured tPCB concentration (0.16 ng/L) at station LWR-1 in Winters Run.

The total baseline tPCB load from Bush River watershed (134.6g/year) is the sum of the baseline loads from Bush River watershed, Bynum Run watershed and Winters Run watershed.

Appendix D: Multi-Segment Tidally-Averaged One-Dimensional Transport Model

A tidally averaged multi-segment one-dimensional transport model was used to simulate the total polychlorinated biphenyl (tPCB) dynamic interactions between the water column and bottom sediments within the Bush River and the Chesapeake Bay. The model is based on one-dimensional tidally averaged model (Thomann and Mueller 1987) and adopts the basic assumptions and methodology of the Water Quality Analysis Simulation Program (WASP) (Di Toro *et al*. 1983, Chapra 1997). It is assumed that the pollutant is well mixed in each segment and there is no decay of PCBs. The average observed tPCB concentrations in each segment were used as the model input representing baseline conditions. If the segment did not have any PCB observation, the linear interpolation of the most adjacent up- and down-stream segments' tPCB concentrations was used. The model assumes that at the Chesapeake Bay and Bush River boundary, the water column tPCB concentration on average decreases with a rate of 6.5% per year, which is in consistent with the previous PCB TMDLs (MDE 2009a, 2009b). All other inputs (*i.e.*, freshwater inputs, dispersion coefficients, sediment and water column exchange rates, atmosphere exchange rates, and burial rates) were kept constant.

The Bush River model domain was divided into 5 segments and the Bush River watershed was divided into 5 corresponding subwatersheds (Figure D-1). In each segment, PCBs can enter the water column via loadings from adjacent watersheds and atmosphere (W_n), loadings from upstream through flow ($Q_{n+1}Cw_{n+1}$), loadings from upstream through dispersion ($D_{n+1}(Cw_{n+1}-Cw_n)CA_{n+1}/L_{n+1}$), resuspension from the sediment ($Vr_nSA_nCs_n$), and diffusion between sediment-water column interface ($VdSA_n(Fds_nCs_n - Fdw_nCw_n)$). For a mainstem segment (e.g., Segment 1) connecting to a branch, the exchange of PCBs with the branch segment is calculated in a similar way as it exchanges with the upstream segment. PCBs leave the water column via loadings to downstream segments through flow and dispersion (Q_nCw_n and $D_n(Cw_n-Cw_{n-1})CA_n/L_n$), volatilization ($VvSA_nFdw_nCw_n$), and settling ($VsetSA_nFpw_nCw_n$).

In the sediment, the PCBs enter the system via settling ($VsetSA_nFpw_nCw_n$), and leave the system via diffusion ($VdSA_n(Fds_nCs_n - Fdw_nCw_n)$), resuspension ($Vr_nSA_nCs_n$) and burial to a deeper layer ($VbSA_nCs_n$).

Specifically, the mass balance for the tPCBs in the water column of segment *n* can be written as:

$$\begin{aligned}\frac{dVw_nCw_n}{dt} &= W_n + Q_{n+1}Cw_{n+1} + Q_{nb}Cw_{nb} + D_{n+1}(Cw_{n+1} - Cw_n)CA_{n+1}/L_{n+1} \\ &+ D_{nb}(Cw_{nb} - Cw_n)CA_{nb}/L_{nb} + Vr_nSA_nCs_n + VdSA_n(Fds_nCs_n - Fdw_nCw_n) \\ &- Q_nCw_n - D_n(Cw_n - Cw_{n-1})CA_n/L_n - VvSA_nFdw_nCw_n - VsetSA_nFpw_nCw_n\end{aligned} \qquad \text{(D-1)}$$

and that in the sediment of segment *n* can be written as:

$$\frac{dVs_nCs_n}{dt} = VsetSA_nFpw_nCw_n - VdSA_n(Fds_nCs_n - Fdw_nCw_n) - Vr_nSA_nCs_n - VbSA_nCs_n \qquad \text{(D-2)}$$

Where:
n = the nth river segment;
Vw_n and Vs_n = volume of the water and sediment (m^3);
Cw_n *and* Cs_n = tPCB concentration in water and sediment (ng/L);
t = time (day);
W_n = tPCB loading from adjacent watershed (including tributaries) and atmosphere (ug/day);
Q_n = quantity of water that flows from segment n to $n-1$ (m^3/day);
Q_{nb} = quantity of water that flows from adjacent branch to segment n (m^3/day);
D_n and D_{nb} = dispersion coefficients (tidal averaged diffusivity) at the upstream and downstream sides of segment n (m^2/day);
CA_n and CA_{nb} = cross sectional area between segment n and $n-1$ and between its branch and segment n (m2);
L_n and L_{nb} = distance between center of segment n to $n-1$ and between center of its branch to segment n (m);
SA_n = surface area of segment n (m^2);
Vr_n = rate of resuspension (m/day);
Vd = diffusive mixing velocity (m/day), which is same for all the segments;
Vv = volatilization coefficient (m/day), which is same for all the segments;
$Vset$ = rate of settling (m/day);
Vb = burial rate (m/day), which is same for all the segments;
Fdw_n = fraction of truly dissolved and dissolved organic carbon (DOC) associated PCBs in the water column;
Fds_n = fraction of truly dissolved and DOC associated PCBs in the sediment;
Fpw_n = fraction of particular associated PCBs in the water column.

The values of the parameters for the Bush River are as follows:

n = 5. It was delineated in consideration of the locations of the water quality monitoring stations and the bathymetry.
Vw_n = mean water depth of segment n × surface area of segment n. The mean water depth was obtained from the bathymetry data.
Vs_n = active sediment layer thickness × surface area of segment n.
Cw_n = measured tPCB water column concentration of segment n. If the measurement was not available, the linear interpolation of the most adjacent segments' concentrations was used.
Cs_n = Measured tPCB concentration on a dry sediment base × Sediment density × (1-porosity) ÷ Fraction of particulate associated PCBs in the sediment, and the porosity (water content on a volume base) of 0.8 is selected based on reference (Thomann and Mueller 1987);
W_n = tPCB loading from the adjacent watershed of segment n and atmosphere. As showed in Figure D-1, the watershed was divided into 5 subwatersheds. The subwatershed baseline tPCB loading using the method described in Appendix C. The direct atmospheric deposition load to the surface of each segment was calculated by multiplying the surface area and the deposition rate of 1.6 µg/m^2/year.

Q_n = total flow from all the upstream subwatersheds of segment n-1. The flow was calculated using the 7-year monthly mean flows at the United States Geological Survey (USGS) stations located at Bynum Run watershed (USGS 1581500). The unit area flow of the station was multiplied by the area of a subwatershed to the get its flow.
D_n = dispersion coefficient of each segment. They are calculated based on the salinity data of the Bush River (MDE 2013, 2014). Salinity is a conservative constituent. It has no loss due to reaction, volatilization, or settling in the water and no source from the watershed. The deposition from the atmosphere is minimal and can be ignored. Therefore, the only source of salinity in the system is from the Chesapeake Bay water at the mouth. Consequently, in Equation (C1), all the terms W_n, $Vr_nSA_nCs_n$, $VdSA_n(Fds_nCs_n - Fdw_nCw_n)$, $VvSA_nFdw_nCw_n$, and $VsetSA_nFpw_nCw_n$ become zero. Dispersion coefficient can be obtained by solving the steady state, Equation (C1) providing know parameters of flow and measured salinity. D_n can be estimated for the boundary segments first (Segments 4 and 5). Then the D_n of Segments 1, 2 and 3 can be estimated in sequence.
CA_n = depth × length of the cross section.
L_n = distance between segments directly measured using ArcView GIS.
SA_n = surface area calculated from ArcView GIS.
Vd = 69.35 × Porosity × (Molecular weight of PCBs)$^{-2/3}$÷ 365 = 69.35 × 0.85 × (305.6)$^{-2/3}$ ÷ 365= 0.00356 (m/day, Thomann and Mueller 1987).
Vv = 0.251 m/day, which was derived from empirical method of Chapra (1997).
$Vset$ = 1 (m/d), a default value of settling rate used in literature (DRBC 2003).
Vb = 3.935×10^{-6} (m/day, average of the measured sedimentation rates through ^{210}Pb technology for Corsica River, Northeast River, Bohemia river, and Sassafras River).
V_{rn} can be calculated via mass balance of the sediment in the active sediment layer at steady state.

$$\frac{d\rho(1-\varphi)}{dt} = V_s \times TSS - V_r \times \rho \times (1-\varphi) - V_b \times \rho \times (1-\varphi) = 0 \qquad \text{(D-3)}$$

Where: TSS is the total suspended solid concentration (g/m^3, measured)
ρ is the sediment density (g/m^3; Thomann and Mueller, 1987)
φ is the porosity.

Rearrange Equation D-3:

$$V_r = \frac{V_s \times TSS}{\rho \times (1-\varphi)} - V_b \qquad \text{(D-4)}$$

Some physical parameters of each segment can be found in Table D-1.

Table D-1: Physical Parameters of the Model for Each Segment

n	*SA* (m^2)	*Vw* (m^3)	*CA*	*L*	*Fdw*	*Fds*	*Fpw*
1	9,407,168	19,813,005	6,982	4,079	0.6301	0.0017	0.3699
2	9,303,441	15,157,738	2,012	3,438	0.6055	0.0017	0.3945
3	6,673,763	11,537,104	4,923	4,613	0.6669	0.0017	0.3331
4	2,361,516	1,338,275	1,120	3,149	0.6261	0.0017	0.3739
5	2,812,017	2,797,304	3,087	3,381	0.5905	0.0017	0.4095

The Fdw_n, Fds_n, and Fpw_n values from Table D-1 were calculated as follows:

$$F_{p1} = \frac{TSS \times 10^{-6} K_{oc} \times f_{oc1}}{1 + (K_{oc} \times 10^{-6})(TSS \times f_{oc1} + DOC_1)} \quad \text{(D-5)}$$

$$F_{do1} = \frac{1 + (K_{oc} \times 10^{-6}) DOC_1}{1 + (K_{oc} \times 10^{-6})(TSS \times f_{oc1} + DOC_1)} \quad \text{(D-6)}$$

$$F_{do2} = \frac{\phi + \phi(K_{oc} \times 10^{-6}) DOC_2}{\phi + (K_{oc} \times 10^{-6})(f_{oc2} \times \rho \times (1-\phi) + \phi DOC_2)} \quad \text{(D-7)}$$

Where:

K_{oc} = the organic carbon/water partition coefficient of PCBs (L/kg). It describes the ratio of a compound adsorbed to solids and in solution, normalized for organic carbon content. It can be calculated via the relationship of $\log_{10} K_{oc} = 0.00028 + 0.983 \times \log_{10} K_{ow}$ (Hoke *et al*. 1994), where K_{ow} is the octanol-water partition coefficient with $\log_{10} K_{ow}$ equals to 6.261 (De Bruijn *et al*. 1989).

f_{oc1} and f_{oc2} = the fractions of organic carbon in suspended solids in the water column and the sediment solids, respectively (US EPA 2004).

DOC_1 and DOC_2 = the dissolved organic carbon concentration in water column and pore water, respectively.

φ = the porosity of the sediment.

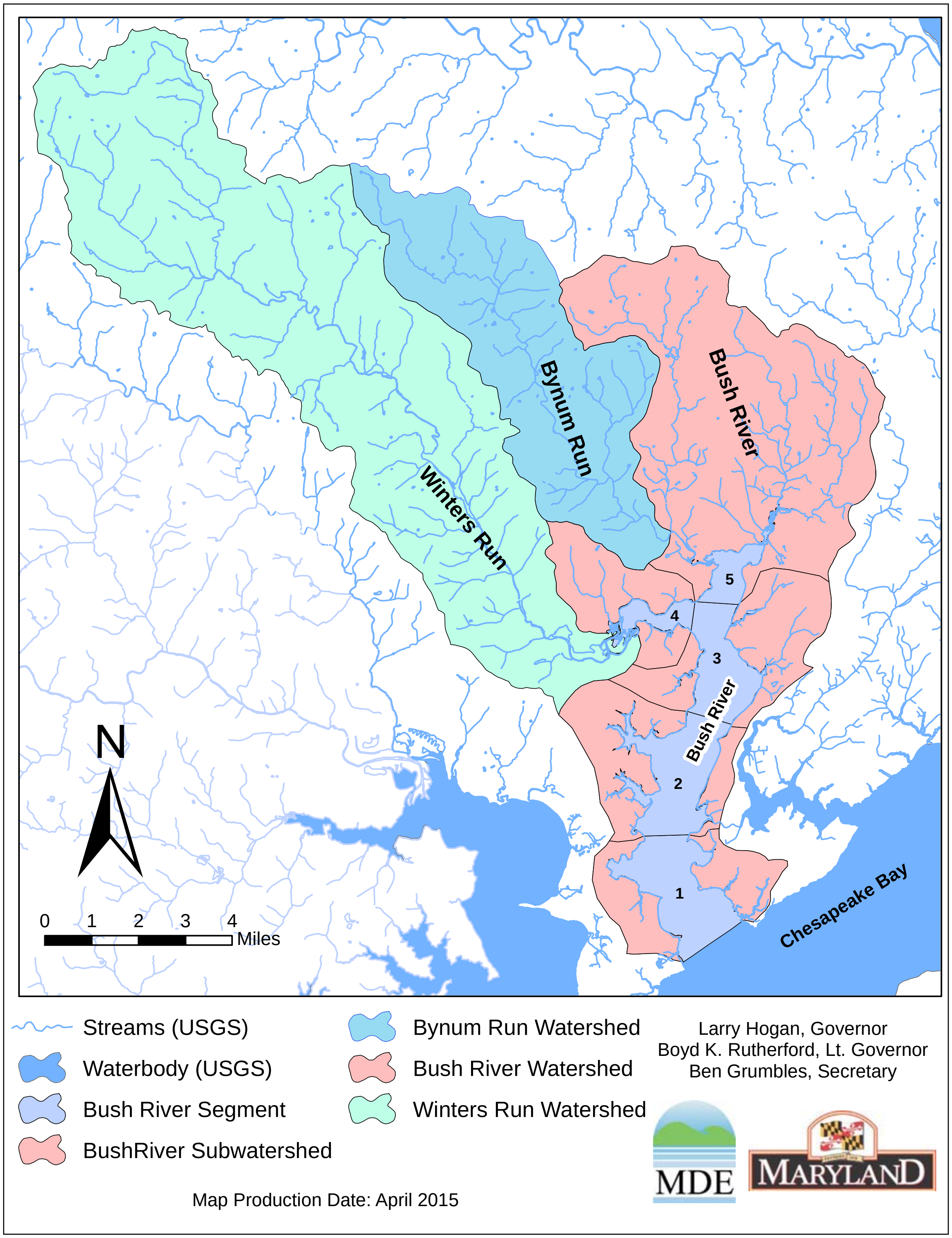


Figure D-1: Model Segments and Subwatersheds of Bush River

Appendix E: Technical Approach Used to Generate Maximum Daily Loads

I. Summary

This appendix documents the technical approach used to define MDLs of tPCBs consistent with the average annual TMDL, which is protective of the "fishing" designated use, which is protective of human health related to the consumption of fish, in the Bush River. The approach builds upon the modeling analysis that was conducted to determine the loads of tPCBs 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 load targets result in compliance with the TMDL endpoint tPCB concentrations;
- The approach converts daily time-series loads into TMDL values in a manner that is consistent with available EPA guidance on generating daily loads for TMDLs;
- The approach considers a daily load level of a resolution based on the specific data that exists for each source category.

II. Introduction

This appendix documents the development and application of the approach used to define TMDLs on a daily basis. It is divided into sections discussing:

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

III. 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 tPCB TMDL is that the baseline tPCB load rates result in tPCB levels in fish tissue that exceed the tPCB fish tissue listing threshold. Thus, the average annual tPCB TMDL was calculated to be protective of the "fishing" designated use, which is protective of human health related to the consumption of fish.
- **Draft EPA guidance document entitled *Developing Daily Loads for Load-based TMDLs***: This guidance provides options for defining MDLs when using TMDL approaches that generate daily output.

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 value to a MDL – in a manner consistent with EPA guidance and available information.

IV. 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. 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 the MDL for the Bush River.

Level of Resolution

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

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 MDL to vary based upon the observed flow condition;
3. **Temporally-variable daily load:** This option allows the MDL to vary based upon seasons or times of varying source or water body behavior.

Probability Level

All TMDLs have some probability of being exceeded, with the specific probability being 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 load 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 best professional judgment of the developers. 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 MDL 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 MDL 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 MDL 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.

V. Selected Approach

The approach selected for defining Bush River MDLs 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 NPDES Regulated Stormwater Point Sources;
- Approach for WWTPs.

VI. Approach for Nonpoint Sources and NPDES Regulated Stormwater Point Sources

The level of resolution selected for the Bush River MDLs was a representative daily load, expressed as a single daily load for each load source. This approach was chosen due to the nature of PCBs and the focus of this study on a TMDL endpoint protective of the "fishing" designated use. Daily flow and temporal variability do not affect the rate of PCB bioaccumulation in fish tissue over the long term thus establishing no influence on achievement of the TMDL endpoint. A MDL at this level of resolution is unwarranted.

The MDL was estimated based on three factors: a specified probability level, the average annual tPCB TMDL, and the coefficient of variation (CV) of the initial condition for ambient water column tPCB concentrations in the Bush River. The probability level (or exceedance frequency) is based upon guidance from 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 CV was calculated using the arithmetic mean and standard deviation of the baseline ambient water column tPCB concentrations in the Bush River. The resulting CV of 0.437 was calculated using the following equation:

$$CV = \frac{\beta}{\alpha} \qquad \text{(Equation E-1)}$$

Where,
CV = coefficient of variation
α = mean (arithmetic)
β = standard deviation (arithmetic)

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 load values. The equation is as follows:

$$MDL = LTA * e^{(z\sigma - 0.5\sigma^2)} \quad \text{(Equation G-2)}$$

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

Using a z-score associated with the 99th percent probability of 2.33, a CV of 0.437, and consistent units, the resulting dimensionless conversion factor from long-term average loads to a maximum daily value is 1.48. The average annual tPCB TMDLs in the Bush River are reported in g/year, and the conversion from g/year to a maximum daily load in g/day is 0.004 (*e.g.* 1.48/365).

VII. Approach for Municipal WWTPs

The TMDL also considers contributions from NPDES permitted municipal WWTPs that discharge quantifiable concentrations of tPCBs to the Bush River watershed. The MDLs were calculated for these facilities 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 99th percentile probability. This results in a dimensionless multiplication factor of 3.11. The average annual Bush River TMDL of PCBs is reported in g/year, and the conversion from g/year to a maximum daily load in g/day is 0.0085 (i.e. 3.11/365).

VIII. Results of Approach

Table E-1 lists the results of the selected approach to define the Bush River MDLs

Table E-1: Summary of tPCB Maximum Daily Loads in the Bush River

Source	TMDL (g/year)	MDL (g/day)
Direct Atmospheric Deposition	18.58	0.075
Contaminated Site	2.37	0.010
Maryland Non-regulated Watershed Runoff	29.88	0.121
Nonpoint Sources	***50.83***	***0.206***
Municipal WWTPs	7.56	0.064
NPDES Regulated Stormwater	18.89	0.077
Point Sources	***26.45***	***0.141***
MOS	4.07	0.016
Total	**81.35**	**0.363**

Appendix F: List of NPDES Regulated Stormwater Permits

Table F-1: NPDES Regulated Stormwater Permit Summary for the Bush River[1]

MDE Permit	NPDES	Facility	County	Type	TMDL	Watershed
11-DP-3313	MD0068276	State Highway Administration(MS4)	All Phase I (Harford)	WM6	Stormwater WLA	Bush River
14-GP-0000	MDRC	MDE General Permit to Construct	All		Stormwater WLA	Bush River
11-DP-3310	MD0068268	Harford County Phase I MS4	Harford	WM6	Stormwater WLA	Bush River
03-IM-5500	MDR055500	Aberdeen Phase II MS4	Harford		Stormwater WLA	Bush River
03-IM-5500	MDR055500	Bel Air Phase II MS4	Harford		Stormwater WLA	Bush River
02-SW-2190	MDR002190	American Auto Recyclers	Harford	WMA5	Stormwater WLA	Bush River
02-SW-0164	MDR000164	American Color Graphics	Harford	WMA5	Stormwater WLA	Bush River
02-SW-0935	MDR000935	Crouse Construction Co., Inc.	Harford	WMA5	Stormwater WLA	Bush River
12-SW-1597	MDR001597	Crown Specialty Packaging	Harford	WMA5	Stormwater WLA	Bush River
02-SW-0188	MDR000188	Citrus And Allied Essences, Ltd.	Harford	WMA5	Stormwater WLA	Bush River
12-SW-1727	MDR001727	Harford County - Sod Run Wastewater Treatment Plant	Harford	WMA5	Stormwater WLA	Bush River
12-SW-1271	MDR001271	Harford County Transportation Services Facility	Harford	WMA5	Stormwater WLA	Bush River
12-SW-2042	MDR002042	MDTA - JFK Memorial Highway Maintenance Facility #1	Harford	WMA5	Stormwater WLA	Bush River
12-SW-1714	MDR001714	Harford County Hickory II Highway Maintenance Facility	Harford	WMA5	Stormwater WLA	Bynum Run

MDE Permit	NPDES	Facility	County	Type	TMDL	Watershed
02-SW-0738	MDR000738	Modular Components National Inc	Harford	WMA5	Stormwater WLA	Bynum Run
12-SW-0016	MDR000016	Town of Bel Air - DPW	Harford	WMA5	Stormwater WLA	Bynum Run
12-SW-2095	MDR002095	Harford County Dept of Parks and Recreation	Harford	WMA5	Stormwater WLA	Atkisson Reservoir
12-SW-2094	MDR002094	Parks & Recreation Jarrettsville Maintenance Facility	Harford	WMA5	Stormwater WLA	Atkisson Reservoir
02-SW-0539	MDR000539	Auto Wreckers Of Edgewood	Harford	WMA5	Stormwater WLA	Lower Winters Run
02-SW-1470	MDR001470	Smiths Detection Edgewood, Inc.	Harford	WMA5	Stormwater WLA	Lower Winters Run

Note: [1] Although not listed in this table, some individual process water permits incorporate stormwater requirements and are accounted for within the NPDES Stormwater WLA, as well as additional Phase II permitted MS4s, such as military bases, hospitals, etc.

Appendix G: Total PCB Concentrations and Locations of the PCB Monitoring Stations

Tables G-1 through G-3 list the tPCB concentrations for sediment, fish tissue, and water column samples collected in the Bush River.

Table G-1: Sediment tPCB Concentrations (ng/g) in the Bush River

Station	Date	Station Type	Concentration (ng/g)
BUR-2	10/3/2013	Tidal	32.2
BUR-2	5/20/2014	Tidal	18.9
BUR-3	10/3/2013	Tidal	36.9
BUR-3	5/20/2014	Tidal	10.1
BUR-4	10/3/2013	Tidal	12.6
BUR-4	5/20/2014	Tidal	12.5
BUR-5	10/3/2013	Tidal	14.2
BUR-5	5/20/2014	Tidal	4.2
BUR-6	10/3/2013	Tidal	16.5
BUR-6	5/20/2014	Tidal	14.1

Table G-2: Fish Tissue tPCB Concentrations (ng/g) in the Bush River

Station	Date	Fish Species	Fish/ Composite (#)	Mean Length (cm)	Mean weight (g)	Concentration (ng/g)	Lipid
BUR-4	5/12/14, 6/18/14	White Perch	5	20.9	117.6	135.34	1.32%
BUR-4	5/12/14, 6/18/14	White Perch	5	19.2	83.0	63.80	1.11%
BUR-4	5/12/14, 6/18/14	White Perch	5	18.6	77.6	54.22	0.76%
BUR-4	5/12/14, 6/18/14	Brown Bullhead	5	26.2	295.0	138.27	11.30%
BUR-4	5/12/14, 6/18/14	Channel Catfish	5	41.0	642.6	357.18	4.97%
BUR-4	5/12/14, 6/18/14	Channel Catfish	5	49.9	1,552.4	658.96	8.52%

Table G-3: Water Column tPCB Concentrations (ng/L) in the Bush River

Station	Date	Station Type	tPCB Conc. (ng/L)
BUR-1	8/14/2013	Tidal Boundary	0.00
BUR-1	10/30/2013	Tidal Boundary	0.35
BUR-1	3/12/2014	Tidal Boundary	1.20
BUR-1	5/20/2014	Tidal Boundary	14.93
BUR-2	8/14/2013	Tidal	1.34
BUR-2	10/30/2013	Tidal	0.51
BUR-2	3/12/2014	Tidal	4.64
BUR-2	5/20/2014	Tidal	21.18
BUR-3	8/14/2013	Tidal	2.02
BUR-3	10/30/2013	Tidal	0.37
BUR-3	3/12/2014	Tidal	4.00
BUR-3	5/20/2014	Tidal	18.66
BUR-4	8/14/2013	Tidal	2.15
BUR-4	10/30/2013	Tidal	0.87
BUR-4	3/12/2014	Tidal	5.19
BUR-4	5/20/2014	Tidal	18.57
BUR-5	8/14/2013	Tidal	0.80
BUR-5	10/30/2013	Tidal	0.33
BUR-5	3/12/2014	Tidal	1.56
BUR-5	5/20/2014	Tidal	12.56
BUR-6	8/14/2013	Tidal	1.46
BUR-6	10/30/2013	Tidal	1.16
BUR-6	3/12/2014	Tidal	8.43
BUR-6	5/20/2014	Tidal	2.47
BUR-7	8/14/2013	Non-tidal	0.01
BUR-7	10/30/2013	Non-tidal	0.03
BUR-7	3/12/2014	Non-tidal	1.15
BUR-7	5/20/2014	Non-tidal	0.97
BUR-8	8/14/2013	Non-tidal	0.00
BUR-8	10/30/2013	Non-tidal	0.03
BUR-8	3/12/2014	Non-tidal	1.72
BUR-8	5/20/2014	Non-tidal	2.08
BYR-1	8/14/2013	Non-tidal Boundary	0.02
BYR-1	10/30/2013	Non-tidal Boundary	0.01

Station	Date	Station Type	tPCB Conc. (ng/L)
BYR-1	3/12/2014	Non-tidal Boundary	7.20
BYR-1	5/20/2014	Non-tidal Boundary	2.69
LWR-1	8/14/2013	Non-tidal Boundary	0.02
LWR-1	10/30/2013	Non-tidal Boundary	0.03
LWR-1	3/12/2014	Non-tidal Boundary	0.44
LWR-1	5/20/2014	Non-tidal Boundary	1.05

Appendix H: Contaminated Site Load Calculation Methodology

The term PCB contaminated site used throughout this report refers to areas with known PCB soil contamination, as documented by state or federal hazardous waste cleanup programs (i.e., state or federal Superfund programs). When compared against the human health screening criteria for soil and groundwater exposure pathways, PCBs are not necessarily a contaminant of concern at these sites, but they have been screened for, reported, and detected during formal site investigations. Within the Bush River watershed, only one site - MD 446 Union Road Dump, has been identified with PCB soil concentrations at or above method detection levels. Figure 6 depicts its location. This site (see Table H-1) was identified based on information gathered from MDE's LRP-MAP database (MDE 2013), and has tPCB soil concentrations at or above method detection levels, as determined via soil sample results contained within MDE-LMA's records of contaminated site surveys and investigations.

The tPCB EOF load from the site has been calculated, and subsequently, the EOF load would usually be converted to EOS load using methods applied within Maryland's nontidal sediment TMDLs, thirteen of which have been approved by the EPA since 2006. The modeling assumption behind the conversion to EOS load is that not all of the contaminated site tPCB loads are expected to reach the impaired waterbody. Thus, EOS load is thought to be a more accurate representation of tPCB loads from the site. Various delivery factors were applied.

The purpose of this appendix is to describe the detailed procedures used to calculate the Contaminated Site tPCB Baseline Load.

I. tPCB Soil Concentration Data Processing

The Contaminated Site tPCB Baseline Load was only characterized for the site (contained within MDE's LRP-MAP database and located within the Bush River watershed) with samples where tPCB concentrations were found to be at or above the method detection limits used in the soil sampling analyses conducted as part of site investigations. Only one property (See Table G-1) was identified as PCB contaminated site. For the most part, these soil sampling analyses employed an Aroclor based analytical method. Thus, when a given sample was analyzed for multiple Aroclors and more than one mixture was detected (e.g., 1232, 1248, 1262, etc.), the results were added together to represent tPCB concentrations. Next, the median values of the tPCB concentrations from these sites were calculated.

II. Revised Universal Soil Loss Equation Version II Soil Loss Calculation Procedures

The Revised Universal Soil Loss Equation Version II (RUSLE2)[1] was run for the site with the use of the Maryland state climate database, county soil databases, and management databases that can be downloaded from the following website: http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm. The site characteristics (e.g.,

[1] RUSLE2 is an advanced, user-friendly software model developed by the University of Tennessee Biosystems Engineering & Soil Science Department, in cooperation with the United States Department of Agriculture (USDA) – Agricultural Research Service (ARS), the National Sedimentation Laboratory, USDA – Natural Resources Conservation Service (NRCS), and the Bureau of Land Management.

soil types, land cover, slope, etc.) were selected from drop down menus provided in the RUSLE2 worksheet. Input parameters were selected via the following decision rules:

1. **Location:** The appropriate county name was selected from the Maryland state climate database in the RUSLE2 *location* field. This resulted in an automatic selection of the appropriate climatic factors.

2. **Soil:** Soil types were identified per site via Geographic Information System (GIS) analysis using a digitized site area and soils data acquired from the USDA-NRCS. The soil types were then subsequently selected from the appropriate county's soils database in the RUSLE2 worksheet.

3. **Slope Length:** Slope length (length of the site), which was identified via GIS analysis using flow direction grids generated from Digital Elevation Models (DEMs) from the USGS, and/or digital USGS quadrangles (i.e., topographic maps), was manually inserted into the *slope length* field. The maximum slope length permitted by the soil loss equation was 2000 feet. If the site has a length greater than 2000 feet, 2000 feet was used.

4. **Percent Slope:** Percent slope, or slope steepness (the difference between maximum and minimum site elevations/slope length), which was identified via GIS analysis, was manually inserted into the *percent slope* field. Percent slope was calculated using GIS analysis by calculating the slope per DEM grid cell within the digitized site area and subsequently taking the average of the cell values.

5. **Management:** The *management option* field was used to represent a site's land cover (i.e., forest, grass, barren, etc.), which was identified via GIS analysis (i.e., agricultural management options were used to approximate the soil loss characteristics of the land covers present at these non-agricultural sites). For example, for sites covered by grass, the warm season grass – not harvested management option was selected; for wooded sites, the established orchard - full cover option was selected; and for sites with bare soil, the bare ground management option was selected. Land cover classification areas were estimated using GIS analysis by digitizing the various land cover areas within the site's boundaries using the State of Maryland's 2007 6-inch resolution orthophotography. This includes impervious areas of the site; however, these areas were left out of the soil loss calculations, since there is no potential for soil runoff. Please see Section III below for more information on how impervious areas were removed from the total site soil loss calculation.

For sites with multiple soil types and land cover classifications present, soil loss was first calculated for each unique soil type-land cover combination based on the entire site's parameters (e.g. slope and slope length). Then, the soil loss values for each soil type-land cover combination were weighted based on the percentage of the site that the unique combination occupied (determined by the GIS intersection between the soil type data layer and digitized land cover data layer). Finally, the summation of the weighted soil loss values was calculated to produce a total soil loss for the entire site.

III. Calculating EOF tPCB loads

The RUSLE2 generated soil loss values, reported in tons/acre/year, were used in conjunction with adjusted pervious area estimates and median tPCB soil concentrations to determine the EOF contaminated site PCB loads. As discussed previously, the various land cover types per site were digitized. The land cover types include: impervious, barren, grass, and forest classifications. Barren, grass, and forest all constitute pervious areas. The area of these pervious land covers were calculated and summed to produce a total pervious area. Then, the total pervious area estimates were adjusted for at each site based on the percent of samples that were above the method detection limit (e.g., if only 25% of the samples had tPCB concentrations above the method detection limit, only 25% of the previous area of the site was used in the calculations). These total adjusted pervious areas were then used in conjunction with the RUSLE2 generated soil loss values to produce a total soil loss value for each site in tons/year. To be consistent with the RUSLE2 soil loss units, the median tPCB soil concentration of the identified site was converted to pounds of tPCBs per pound of soil (lbs/lb). The EOF contaminated site tPCB load is reported in Table H-1 in g/year.

IV. Calculating EOS tPCB loads

The EOF load is expected to be delivered to the system with some losses expected to occur over land. The identified contaminated site happens to be located immediately adjacent to an upstream branch of the Bush River. Therefore, the entire edge of field load is expected to be delivered directly to the system, with no losses expected to occur over land, and a delivery factor of one is consequently applied to the EOF loads. The resultant EOS load is therefore equivalent to the initial EOF load (Table H-1).

Table H-1: Summary of Contaminated Site Soil Loss Value and EOS tPCB Loads

Site Name	Median tPCB (µg/kg)	Soil Loss (lbs/year)	EOF Load (g/year)	Delivery Factor	EOS Load (g/year)
MD 466 Union Road Dump	113	4.62×10^4	2.37	1	2.37

V. Contaminated Site Baseline Load Summary

The total Contaminated Site tPCB Baseline Load from the identified site in the Bush River watershed is estimated to be 2.37 g/year.