Total Maximum Daily Loads of Polychlorinated Biphenyls in the Bohemia River, Oligohaline Segment, Cecil County, Maryland

FINAL

MARYLAND

DEPARTMENT OF THE ENVIRONMENT

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List of Abbreviations

Adj-SediBAF	Adjusted Sediment Bioaccumulation Factor
Adj-tBAF	Adjusted Total Bioaccumulation Factor
BAF	Bioaccumulation Factor
BSAF	Biota-sediment accumulation factor
C&D Canal	Chesapeake and Delaware Canal
CBP P5	Chesapeake Bay Program Phase 5
CFR	Code of Federal Regulations
CI	Confidence Interval
COMAR	Code of Maryland Regulations
CV	Coefficient of Variation
DOC	Dissolved Organic Carbon
DRBC	Delaware River Basin Commission
g	Gram
kg	Kilogram
km	Kilometer
Kow	PCB Octanol-Water Partition Coefficient
L	Liter
LA	Load Allocation
m	Meter
MDE	Maryland Department of the Environment
MDL	Maximum Daily Load
MDP	Maryland Department of Planning
mg/kg	Milligrams/kilogram, ppm
MGD	Million gallons per day
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer Systems
ng/g	Nanograms per gram, ppb

ng/kg	Nanograms per kilogram, ppt
ng/L	Nanograms per liter, ppt
NPDES	National Pollutant Discharge Elimination System
PCB	Polychlorinated Biphenyl
POC	Particulate Organic Carbon
ppb	Parts per billion
ppm	Parts per million
ppt	Parts per trillion
QEA	Quantitative Environmental Analysis
RUSLE2	Revised Universal Soil Loss Equation Version II
TMDL	Total Maximum Daily Load
tPCB	Total PCB
TSD	Technical Support Document
TSS	Total Suspended Solid
UMCES	University of Maryland Center for Environmental Science
US EPA	U. S. Environmental Protection Agency
USGS	U. S. Geological Survey
WLA	Waste Load Allocation
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WQS	Water Quality Standard
WWTP	Waste Water Treatment Plant
yr	Year

EXECUTIVE SUMMARY

Section 303(d) of the federal Clean Water Act and the U.S. Environmental Protection Agency's (US EPA) 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) of the specified substance that the waterbody can receive without violating WQSs, or demonstrate that WQSs are being met (CFR 2007).

The Maryland water quality regulations state that all surface waters of Maryland shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2007a). The specific designated use for Bohemia River Oligohaline segment (also referred to as the Bohemia River embayment) is Use II – Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting (COMAR 2007b). The Maryland Department of the Environment (MDE) has identified the waters of the Bohemia River Oligohaline segment (Integrated Report Assessment Unit Identification: MD-BOHOH) on the State's Integrated Report as impaired by the following pollutants (listing years in parentheses): sediments (1996 – later changed to a total suspended solids (TSS) listing), nutrients (1996), and polychlorinated biphenyls (PCBs) in fish tissue (2002) (MDE 2008).

A nutrient TMDL has been approved by the US EPA in January 2001. In 2008 the TSS impairment was moved from Category 5 of the Integrated Report (i.e., *water body is impaired, does not attain the water quality standard, and a TMDL is required*) to Category 2 (*water body is meeting some* [in this case TSS] *water quality standards but with insufficient data to determine if other water quality standards are being met*) (MDE 2008). This document, upon EPA approval, establishes a total PCB (tPCB) TMDL for the Bohemia River Oligohaline segment. Data solicitation for PCB related information was conducted by MDE and all readily available data have been considered.

The objective of the tPCB TMDL established in this document is to ensure that the "fishing" designated use in the Bohemia River embayment is supported to allow consumption of fish protective of human health. This objective was achieved with the use of a tidal prism model and the Maryland tPCB fish tissue listing threshold of 39 nanogram/gram (ng/g, ppb) – wet weight (MDE 2008, 72-74). The tidal prism model incorporates the influences of fresh water discharge, tidal flushing, and exchanges between the water column and bottom sediments, thereby representing the dynamic transport within the Bohemia River embayment. The tidal prism model was used to:

1. Estimate and predict tPCB transport and fate based on the measured tPCB concentrations in the water column and sediment of the Bohemia River embayment.
2. Simulate the long-term tPCB concentrations in the water column and bottom sediments of the Bohemia River embayment.
3. Based on the available literature, the TMDL methodology assumes that on average the tPCB concentrations at the Bohemia River open boundary with the Lower Elk River are decreasing at a rate of 6.5% per year (Appendix I). Given this rate of decline, the model estimates that the time needed for the tPCB concentrations to meet the site-specific water

column and sediment TMDL endpoints of 0.18 nanograms/liter (ng/L) and 1.5 ng/g, respectively is approximately 47 years.

As part of this analysis, point and nonpoint PCB sources have been identified throughout the Bohemia River watershed. Two nonpoint sources (i.e., resuspension and diffusion from the bottom sediments and the Lower Elk River influence) were determined to be the major sources of tPCBs to the Bohemia River embayment. The Lower Elk River tPCB loads (conveying tPCB loads from the Upper Chesapeake Bay and Delaware River Estuary) are transported via flood tides into the Bohemia River embayment and tend to accumulate in the bottom sediments. Other nonpoint sources include atmospheric deposition to the embayment and runoff from watershed sources in Maryland and upstream in Delaware. Point sources include one wastewater treatment plant (WWTP) and National Pollutant Discharge Elimination System (NPDES) regulated stormwater.

The Total Baseline (i.e., 2003) Load of tPCBs to the Bohemia River embayment is 14,544 g/year. It can be further subdivided into a Nonpoint Source Baseline Load and Point Source Baseline Load. The tPCB TMDL for the Bohemia River embayment is 876 g/year with a reduction of 94.0% from the Total Baseline Load (see Table ES- 1). This TMDL when implemented will ensure that the tPCB loads are at a level expected to support the "fishing" designated use in the Bohemia River embayment that is protective of human health.

Table ES- 1: Summary of tPCB Baseline Loads, TMDL Allocations, and Associated Percent Reductions

Source	Baseline (g/year)	Baseline (%)	TMDL (g/year)	Load Reduction (%)
Lower Elk River Influence	11,879.0	81.67	500.8	95.8
Bottom Sediment (Resuspension and Diffusion)	2,560.8	17.61	183.2	92.8
Direct Atmospheric Deposition (to the Surface of the Embayment)	43.6	0.30	43.6	0.0
Maryland Watershed Nonpoint Sources*	47.4	0.33	47.4	0.0
Delaware Upstream	10.7	0.07	10.7	0.0
Nonpoint Sources/Load Allocations	***14,541.5***	***99.98***	***785.7***	***94.6***
WWTP*△	0.06	0.00	0.06	0.0
NPDES Regulated Stormwater*	2.8	0.02	2.8	0.0
Point Sources/Waste Load Allocations*	***2.86***	***0.02***	***2.86***	***0.0***
MOS	-	-	***87.6***	-
Total	**14,544**	100	**876**	**94.0**

Notes: *These sources were characterized only for the Maryland portion of the watershed.
△WWTP Baseline Load was considered to be *de minimis*.

All TMDLs need to be presented as a sum of waste load allocations (WLAs) for the identified point sources and load allocations (LAs) for nonpoint source loads generated within the assessment unit, and where applicable LAs for natural background, tributary, and adjacent segment loads. WLAs were assigned to NPDES regulated stormwater sources and WWTPs. The WWTP Baseline Load was considered to be *de minimis*, therefore no appreciable environmental benefit would be gained by reducing this load (see Appendix K for details). There are currently no effluent PCB limits established in the discharge permits for WWTPs. The sensitivity analysis provided in this document (Appendix K) suggests that there is no "reasonable potential" for PCBs to exceed water quality even at 100 times the current WWTP loadings. Inclusion of a WLA in this document does not reflect any determination to impose an effluent limit.

Furthermore, all TMDLs must include a margin of safety (MOS) to account for uncertainty in the relationship between pollutant loads and water quality as well as the scientific and technical understanding and simulation of water quality parameters in natural systems (CFR 2007). An explicit MOS of 10% or 87.6 grams/year (g/year) was incorporated into the analysis to account for such uncertainty. The State reserves the right to revise these allocations provided the revisions are consistent with achieving WQSs.

The TMDL presented in this document is protective of human health at all times and in this way implicitly accounts for seasonal variations as well as critical conditions. Since tPCB levels in fish become elevated due to long-term exposure, rather than temporary spikes in water column tPCB concentration, it has been determined that the selection of the average tPCB concentrations as representing the baseline conditions adequately considers the impact of seasonal variations and critical conditions on the “fishing” designated use in the Bohemia River embayment. Furthermore, the site-specific tPCB water column TMDL endpoint used to develop this TMDL is lower than the Maryland fresh and salt water chronic aquatic life tPCB criteria protective of fish and wildlife as well as the Maryland water column human health tPCB criterion protective of human health associated with consumption of PCB contaminated fish.

Lower Elk River influence (conveying tPCB loads from the Upper Chesapeake Bay and Delaware River Estuary) and resuspension and diffusion from the bottom sediments have been identified as the two major sources of tPCBs to the Bohemia River embayment. The tPCB levels in the Bohemia River embayment are expected to decline over time (Appendix I). Discovering and remediating any existing PCB land sources throughout the Upper Chesapeake Bay watershed via future TMDL development and implementation efforts will further help to meet water quality goals in the Bohemia River embayment.

Once US EPA has approved this TMDL, MDE will begin an iterative process of implementation, focusing first on those sources with the largest impact on water quality and giving consideration to the relative cost and ease of implementation. MDE’s Water Quality Standards Section will continue to monitor PCB levels in fish. This information will be used to evaluate the PCB impairment in the Bohemia River embayment on an ongoing basis.

1.0 INTRODUCTION

Section 303(d) of the federal Clean Water Act and the U.S. Environmental Protection Agency's (US EPA) 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) of the specified substance that the waterbody can receive without violating WQSs, or demonstrate that WQSs are being met (CFR 2007).

TMDLs are established to determine the pollutant load reductions needed 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, fish and shellfish propagation and harvest, etc. Water quality criteria can be either narrative statements or numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

The Maryland water quality regulations state that all surface waters of Maryland shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2007a). The specific designated use for Bohemia River Oligohaline segment (also referred to as the Bohemia River embayment) is Use II – Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting (COMAR 2007b). The Maryland Department of the Environment (MDE) has identified the waters of the Bohemia River Oligohaline segment (Integrated Report Assessment Unit Identification: MD-BOHOH) on the State's Integrated Report as impaired by the following pollutants (listing years in parentheses): sediments (1996 – later changed to a total suspended solids (TSS) listing), nutrients (1996), and polychlorinated biphenyls (PCBs) in fish tissue (2002) (MDE 2008).

A nutrient TMDL has been approved by the US EPA in January 2001. In 2008 the TSS impairment was moved from Category 5 of the Integrated Report (i.e., *water body is impaired, does not attain the water quality standard, and a TMDL is required*) to Category 2 (*water body is meeting some* [in this case TSS] *water quality standards but with insufficient data to determine if other water quality standards are being met*) (MDE 2008). This document, upon EPA approval, establishes a total PCB (tPCB) TMDL for the Bohemia River Oligohaline segment. Data solicitation for PCB related information was conducted by MDE 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 (QEA, 1999). Each of the 209 possible PCB compounds consists of two phenyl groups and one or more 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 United States 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, etc. As PCBs tend to bioaccumulate in aquatic organisms including fish, people who ingest fish may become exposed to PCBs. In fact, elevated levels of PCBs in fish are one of the leading causes of fish consumption advisories in the United States.

The Bohemia River Oligohaline segment is identified as impaired by PCBs on the State's Integrated Report based on fish tissue PCB data from MDE's monitoring program that exceeded the tPCB fish tissue listing threshold of 39 nanogram/gram (ng/g, ppb) – wet weight (MDE 2008, 72-74). Besides 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 fish consumption advisories within the Bohemia River embayment suggest limiting the consumption of the following fish species: channel catfish and white perch.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1. General Setting

The Bohemia River watershed is located within Cecil County with the eastern most portion of the watershed extending through Delaware. It drains to the Lower Elk River, which eventually drains to the Upper Chesapeake Bay (see Figure 2). Additionally, Bohemia River embayment also exchanges water and the associated PCBs with the Delaware River Estuary via the Chesapeake and Delaware (C&D) Canal which is hydrologically connected with the Elk River. The tidal influence extends as far east as Bohemia Mills. The tidal range is 1.6 feet (0.49 meters (m)) based on the United States National Oceanic and Atmospheric Administration tidal station in Betterton, MD. The depths of the river range from about 6 inches (0.15 m) at the headwaters of the tidal embayment to greater than 7 feet (2.1 m) at the confluence of the Lower Elk River and Bohemia River (MDE 2001).

There are no Tier II (i.e., high quality) stream segments (Benthic Index of Biotic Integrity/Fish Index of Biotic Integrity aquatic health scores > 4 – scale 1 to 5) located within the watershed requiring the implementation of Maryland's antidegradation policy procedures (COMAR 2007d; MDE 2009b). The total population in the Maryland portion of the Bohemia River watershed is approximately 7,000 (US Census Bureau 2000).

The entire Bohemia River watershed stretches over approximately 55 square miles (143 square kilometers (km^2)). The length of the river is approximately 8.7 miles (14 km). The watershed is predominately rural in nature consisting of 54.8% agricultural land and 25.8% forest (see Figure 1, Figure 3, and Table 1).

Table 1: Land Use Distribution in the Bohemia River Watershed

Land Use	Area (km^2)	Percent of Total
Water	10.7	7.5
Urban	5.5	3.8
Residential	3.8	2.7
Barren	0.6	0.4
Forest	36.9	25.8
Agriculture	78.4	54.8
Natural grass	0.1	0.1
Wetland	7.0	4.9
Totals	**143**	**100**

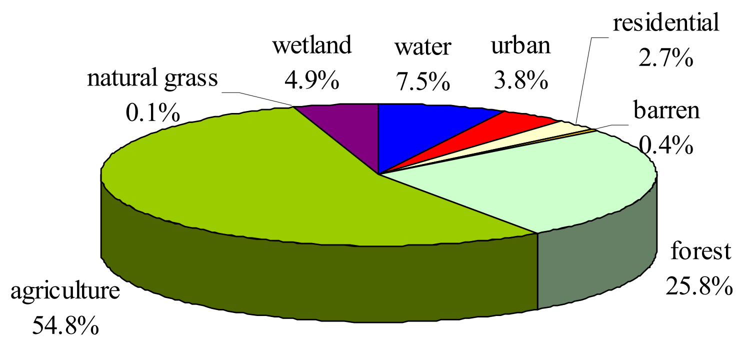

Figure 1: Land Use Distribution in the Bohemia River Watershed

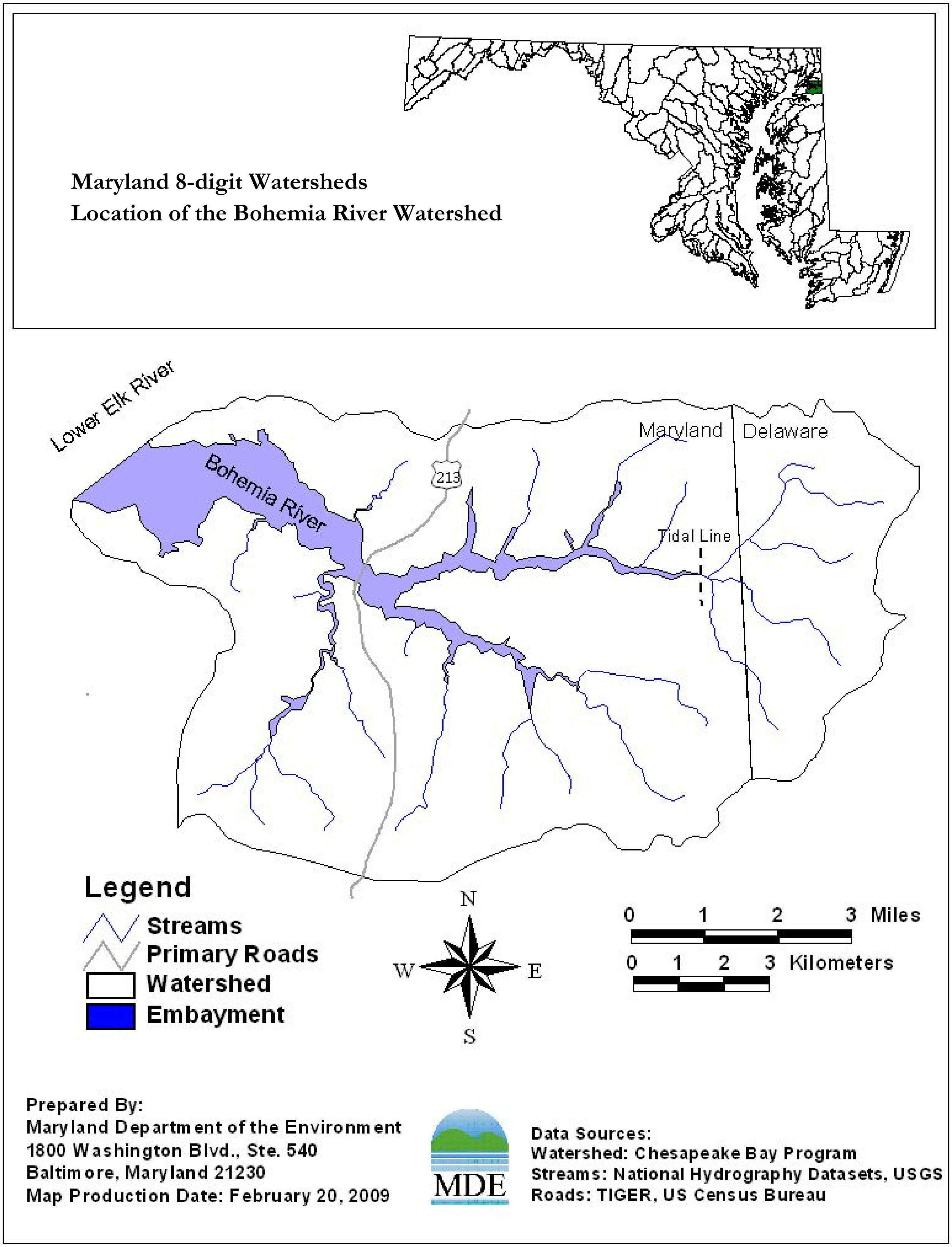

Figure 2: Location Map of the Bohemia River Watershed and Embayment

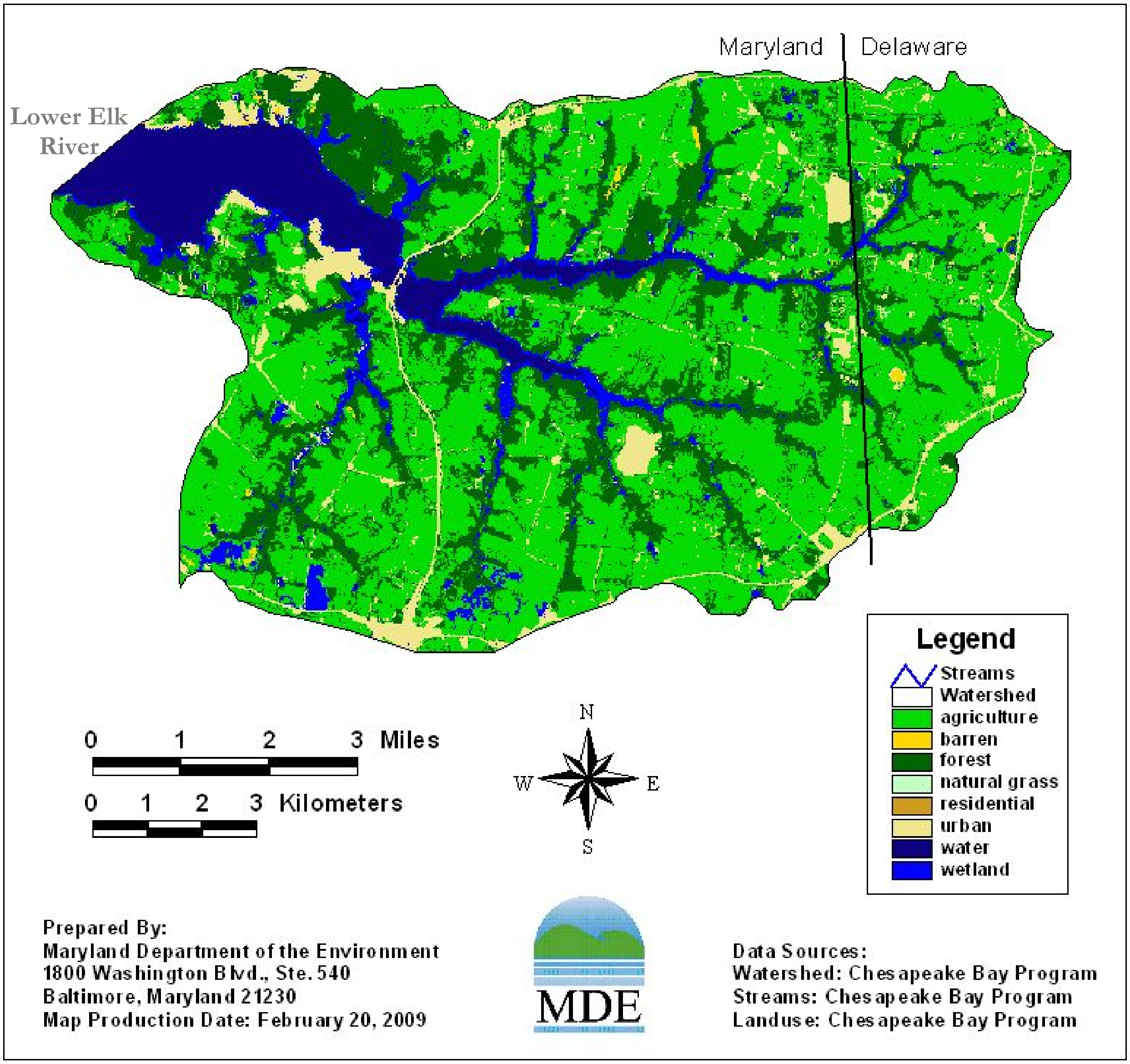

Figure 3: Land Use in the Bohemia River Watershed

2.2 Water Quality Characterization and Impairment

The Maryland water quality regulations state that all surface waters of Maryland shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2007a). The specific designated use for Bohemia River Oligohaline segment is Use II – Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting (COMAR 2007b). The State of Maryland adopted three separate water column tPCB criteria: human health criterion for protection of human health associated with consumption of PCB contaminated fish, as well as fresh and salt water chronic tPCB criteria for protection of aquatic life. The Maryland human health tPCB criterion is set at 0.64 nanograms/liter (ng/L, ppt) (COMAR 2007c, US EPA 2006). This criterion is based on a cancer slope factor of 2 milligrams/kilogram-day $^{-1}$ (mg/kg-day)$^{-1}$, bioconcentration factor of 31,200 liters/kilogram (L/kg), risk level of 10^{-5}, lifetime risk level and exposure duration of 70 years, and fish intake of 17.5 grams/day (g/day). A 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. The Maryland fresh and salt water chronic aquatic life tPCB criteria are set at 14 ng/L and 30 ng/L, respectively (COMAR 2007c; US EPA 2006). A sediment tPCB criterion has not been established within Maryland water quality standards.

In addition to the water column criteria described above, fish tissue monitoring data can serve as an indicator of PCB water quality conditions. The Maryland fish tissue monitoring data is used to issue fish consumption advisories/recommendations and determine whether Maryland waterbodies are meeting the "fishing" designated use. Currently Maryland applies 39 ng/g as the tPCB fish tissue listing threshold (MDE 2008, 72-74). MDE has collected fish tissue samples in the Bohemia River embayment in September 2000 (see Table 2). The average concentration for each of the indicator fish species exceeds the tPCB listing threshold, indicating PCB impairment.

Table 2: Fish Tissue tPCB Concentrations in the Bohemia River Embayment (2000)

Species Name (Composite #)	Mean Lipid Content (%)	tPCBs* (ng/g wet weight)	Number of Individual Fish in a Composite	Exceed Maryland Threshold
White Perch (1)	2.0	167.49	5	Yes
White Perch (2)	2.0	194.79	5	Yes
Channel Catfish (1)	3.0	330.70	3	Yes
Channel Catfish (2)	1.0	389.41	1	Yes

Note: *Actual values (i.e., not lipid normalized).

In 2003, sampling surveys were conducted by MDE to measure sediment and water column tPCB concentrations throughout the embayment. Water column samples were also collected in the Bohemia River nontidal watershed in 2003 (Stations BOR9 and BOR10), 2008, and 2009 (Stations GOB 0050, UUU 0011, and UXP 0010). While none of the total averaged water column tPCB concentrations (particulate + dissolved) exceed the 30 ng/L Maryland salt water chronic aquatic life tPCB criterion, all of them exceeded the 0.64 ng/L Maryland water column human health tPCB criterion (see Table 3). Figure 4 displays the locations of the Bohemia River monitoring stations. Detailed tPCB results for each measurement are presented in Appendix A.

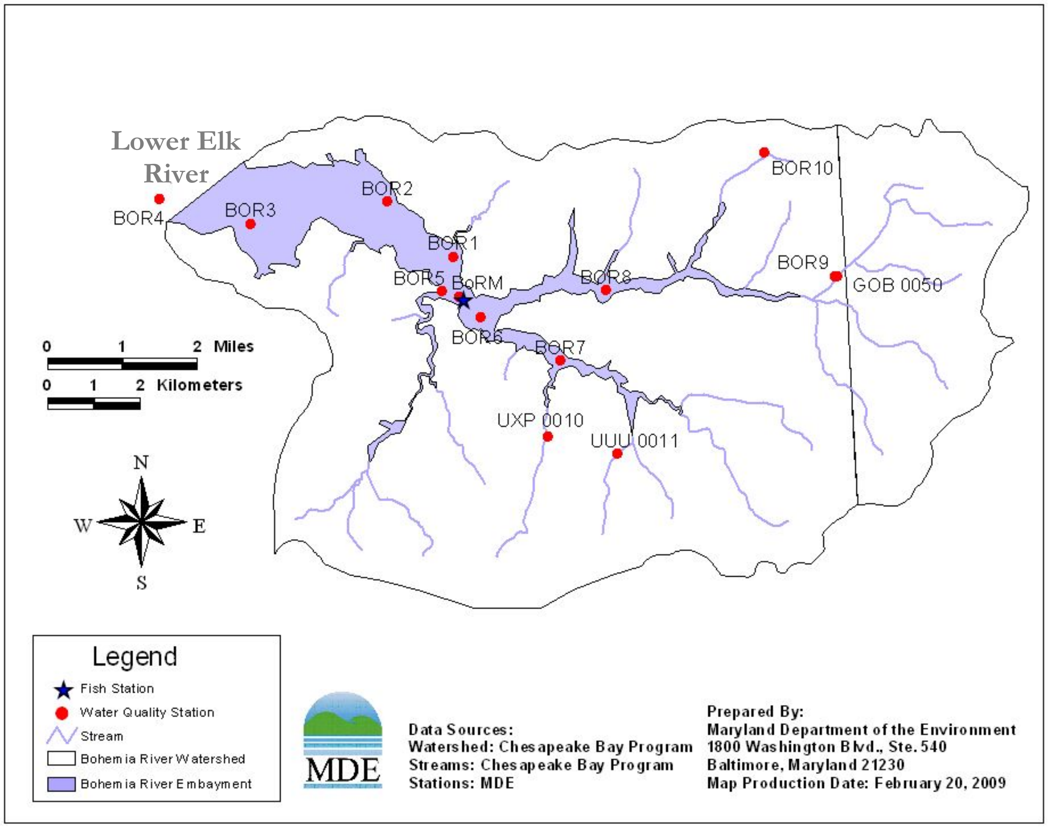

Figure 4: Water Quality Monitoring Stations in the Bohemia River Watershed

Table 3: Water Quality Monitoring Stations and Average tPCB Concentrations in the Bohemia River Embayment, Watershed, and River Boundary (2003, 2008, 2009)

Station Name	Latitude	Longitude	Average Water Column Concentration (ng/L)			Sediment Concentration (ng/g dry weight)
			Dissolved	Particulate	Total	
BOR1	39.4684	-75.9570	0.74	3.06	3.79	22.79
BOR2	39.4790	-75.9564	0.19	2.59	2.78	10.77
BOR3	39.4745	-75.9656	0.25	1.35	1.59	44.93
BOR4	39.4791	-75.9792	1.05	2.69	3.74	38.37
BOR5	39.4617	-75.9958	0.29	3.24	3.53	5.37
BOR6	39.4568	-75.9496	1.11	1.78	2.89	23.09
BOR7	39.4485	-75.9832	0.49	2.62	3.11	NA
BOR8	39.4623	-75.9499	0.83	1.84	2.67	18.96
BOR9	39.4654	-75.9426	0.19	0.48	0.67	NA
BOR10	39.4893	-75.7943	0.62	0.41	1.03	NA
GBO 0050	39.4654	-75.7759	0.62	0.60	1.22	NA
UUU 0011	39.4306	-75.8303	0.55	0.13	0.67	NA
UXP 0010	39.4337	-75.8477	0.28	0.47	0.75	NA

PCB analytical services were provided by the University of Maryland Center for Environmental Science (UMCES). PCB congeners were identified and quantified by high resolution gas chromatography with electron capture detection. 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). Based on this method, 86 chromatographic peaks can be quantified (see Appendix J). Some of the peaks contain one PCB congener, while others are comprised of two or more co-eluting congeners. 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 most common congeners that were historically used in the Aroclor commercial mixtures.

2.3 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. However, although PCBs are no longer manufactured in the United States, they 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 not designed to handle hazardous waste. Once in the environment, PCBs do not readily break down and tend to cycle between various environmental media such as air, water, and soil. This section provides a detailed description of the existing nonpoint and point sources that have been identified as contributing tPCB loads to the Bohemia River embayment.

2.3.1 Nonpoint Sources

Nonpoint sources do not have a single discharge point, but rather can occur over a part of or the entire length of a waterbody. For the purpose of this TMDL, the following nonpoint sources have been identified: the Lower Elk River influence (conveying tPCB loads from the Upper Chesapeake Bay and Delaware River Estuary), resuspension and diffusion from the bottom sediments, watershed runoff (including runoff associated with atmospheric deposition to the watershed), and direct atmospheric deposition to the embayment.

Lower Elk River Influence

Based on the tPCB concentration measured at the mouth of Bohemia River and the relatively high quantity of water flowing from the Lower Elk River to the embayment during the flood tides (conveying tPCB loads from the Upper Chesapeake Bay and Delaware River Estuary), the Lower Elk River tPCB Baseline Load of 11,879.0 g/year is the major source of tPCBs to the Bohemia River embayment (see Table 6, Appendix C, and Appendix D).

The Susquehanna River is the major source of flow and PCBs to the Upper Chesapeake Bay (Ko and Baker 2004). In order to determine the temporal changes in tPCB loads from the Susquehanna River to the Upper Chesapeake Bay, Ko and Baker (2004) measured tPCB concentration downstream of the Susquehanna River and compared their results with those reported by Foster et al. (2000) and

Godfrey et al. (1995). According to this analysis, flow normalized tPCB loadings decreased from 37 kg/m^3/year in 1992 to 24 kg/m^3/year in 1998. Based on these results, it is estimated that on average the tPCB concentrations in the Upper Chesapeake Bay are decreasing at a rate of 6.5% per year (Appendix I). As Bohemia River also exchanges water and sediment with the Delaware River Estuary through the C&D Canal, the PCB decreasing rate in the Delaware River Estuary was also considered. According to the Delaware River Basin Commission, the water column tPCB concentrations in Delaware River region have been decreasing at a rate of around 18% per year from 1970 to 2002 (Hellweger 2009). The smaller of the two PCB rates of decline (i.e., 6.5% per year) was used in the model simulation to account for the expected temporal changes in tPCB concentrations at the Bohemia River embayment boundary.

Bottom Sediments (Resuspension and Diffusion)

Because PCBs tend to bind to sediments, a large portion of the tPCB loads delivered to the embayment from various sources will quickly end up in the bottom sediments. This accumulation of PCBs can subsequently become a significant source of PCBs to the water column in the embayment. Based on the measured tPCB concentrations in the water column and bottom sediments, the Bottom Sediment tPCB Baseline Load of 2,560.8 g/year is the second largest source of tPCBs to the Bohemia River embayment (see Table 6, Appendix C, and Appendix D).

Atmospheric Deposition

Based on previous research conducted in the Chesapeake Bay area, a relatively small portion of the tPCB load to the Bohemia River embayment can be attributed to atmospheric deposition. However, it should be pointed out that overall a net loss of tPCB occurs due to volatilization of the dissolved PCBs in the water column to the atmosphere (Totten et al, 2006). The TMDL analysis accounts for both atmospheric deposition and volatilization. The observed annual atmospheric tPCB loading to the entire surface of the Chesapeake Bay is approximately 38 ± 7 kg/year (Leister and Baker 1994). Based on the Chesapeake Bay surface area of 1.15×10^{10} m^2 and Bohemia River embayment surface area of 1.320×10^7 m^2, the estimated direct tPCB atmospheric deposition to the surface of the Bohemia River embayment is:

$$\frac{38}{(1.15\times10^{10})} \times (1.320\times10^{7}) \approx \mathbf{43.6\ g/year} \qquad \text{(Calculation 1)}$$

Using the same method, the atmospheric loading to the entire land surface of the watershed (1.298×10^8 m^2) is:

$$\frac{38}{(1.15\times10^{10})} \times (1.298\times10^{8}) \approx \mathbf{429.0\ g/year} \qquad \text{(Calculation 2)}$$

However, according to Totten et al. (2006) not all of the atmospheric deposition to the terrestrial part of the watershed is expected to be delivered to the embayment. Considering that the PCB pass-through efficiency, estimated by Totten et al. for the Delaware River watershed, is about 1%, the atmospheric tPCB loading to the Bohemia River embayment from the watershed is approximately 4.3 g/year. The watershed runoff calculation below accounts for this load due to atmospheric deposition. Compared to other sources (see Table 6), atmospheric deposition constitutes a relatively small portion of the tPCB load delivered to the Bohemia River embayment.

Watershed Runoff

The Total Watershed tPCB Baseline Load of the Bohemia River was estimated by multiplying the mean ambient water column tPCB concentration (0.87 ng/L) observed at the nontidal watershed stations by the average watershed stream flow.

Using the 7-year monthly mean flow at the United States Geological Survey (USGS) station located at Silver Lake Tributary at Middletown (USGS 01483155) (see Figure 5), and ratio of the Bohemia River watershed area to the USGS station drainage area, the Bohemia River watershed average stream flow was estimated to equal to 2.22 m^3/s (78.48 cubic feet per second). The average stream flow was then distributed between Delaware (0.39 m^3/s) and Maryland (1.83 m^3/s) portions of the watershed, according to their respective areas, and used to calculate the watershed tPCB baseline loads (Calculation 3).

Delaware Load = 0.39 $m^3/s \times 0.87$ ng/L $\times$ 1,000 $L/m^3 \times 10^{-9}$ g/ng $\times$ 60 minutes/hour $\times$ 60 seconds/minute $\times$ 24 hours/day $\times$ 365 days/year = **10.7 g/year**

(Calculation 3)

Maryland Load = 1.83 $m^3/s \times 0.87$ ng/L $\times$ 1,000 $L/m^3 \times 10^{-9}$ g/ng $\times$ 60 minutes/hour $\times$ 60 seconds/minute $\times$ 24 hours/day $\times$ 365 days/year = **50.2 g/year**

While the Delaware Upstream Baseline Load is presented as a single load, the Maryland Watershed Baseline Load is further subdivided into:

- *Point Source Load*: National Pollutant Discharge Elimination System (NPDES) Regulated Stormwater Baseline Load and
- *Nonpoint Source Load*: Maryland Watershed Nonpoint Source Baseline Load (see Table 4 and Table 6).

Table 4: Breakdown of the Total Watershed tPCB Baseline Load

Source	Baseline (g/year)
Maryland Watershed Nonpoint Sources	47.4
NPDES Regulated Stormwater	2.8
Maryland Watershed Baseline Loads	*50.2*
Delaware Upstream Baseline Loads	*10.7*
Total Watershed Baseline Load	**60.9**

About 4.3 g/year of the Bohemia River Total Watershed tPCB Baseline Load is attributed to atmospheric deposition to the entire land surface of the watershed. The watershed runoff calculation

accounts for this load due to atmospheric deposition. The remaining load is due to unidentified sources of PCB contamination from historical uses and releases. However, when compared with the Lower Elk River and Bottom Sediment Baseline Loads, the Total Watershed tPCB Baseline Load is insignificant and even its complete elimination would not result in noticeable decrease in the tPCB concentrations in the Bohemia River embayment. Based on the information gathered from the US EPA's Superfund Database (US EPA 2007a) and MDE's Environmental Restoration and Redevelopment Program (MDE 2007a), no known contaminated sites have been identified throughout the watershed.

2.3.2 Point Sources

The Department applies US EPA's requirement that "stormwater discharges that are regulated under Phase I or Phase II of the NPDES storm water program are point sources that must be included in the WLA portion of a TMDL" (US EPA 2002). Other point sources in the Bohemia River watershed include one wastewater treatment plant (WWTP). While, for the purpose of this TMDL, the WWTP Baseline Load has been estimated, it has been considered to be *de minimis* (see Appendix K). This section provides detailed explanation about how the point source baseline loads have been estimated.

<u>Waste Water Treatment Plant</u>

Cecilton WWTP (MD0020443) is the only WWTP located in the watershed (see Figure 5). As no PCB data for Cecilton WWTP have been identified, the tPCB concentration for this facility was estimated as the median tPCB concentration of 31 samples from 13 WWTPs monitored by MDE in the Chesapeake Bay watershed. The baseline tPCB loading was calculated based on the permit design flow and the estimated median tPCB concentration of 0.906 ng/L. Thus, the estimated tPCB baseline load is 0.06 g/year (see Table 5 and Table 6), which for the purpose of this analysis is treated as a separate model input.

Table 5: WWTP tPCB Baseline Load

WWTP	tPCB Concentration (ng/L)	Design Flow (MGD)	Baseline Load (g/year)
Cecilton WWTP	0.906	0.05*	0.06

Note: * It should be noted that this plant is due for an expansion. However, since the permit has not been yet approved, the current design flow has been used in the TMDL analysis. As demonstrated in Appendix K, a possible future increase in this load (e.g., due to potential future development or expansion of plant capacity) is not expected to have any significant impact on meeting the tPCB water quality endpoints; even a 100-fold increase in WWTP load (up to 1% of the TMDL) is expected to increase the time it takes to reach the TMDL endpoints by only 0.27% or 45 days.

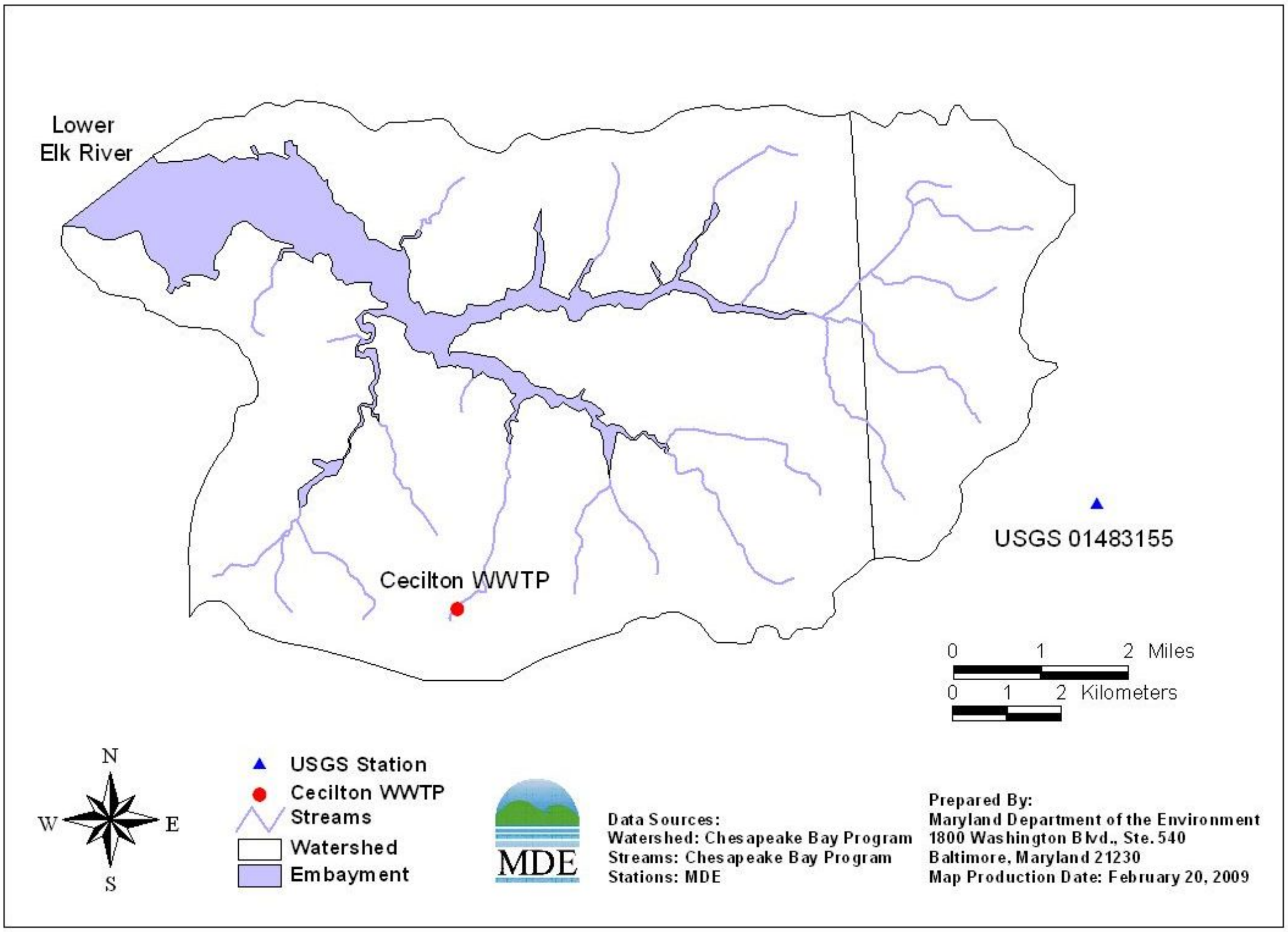

Figure 5: Locations of the WWTP in the Bohemia River Watershed and the USGS Stations Used for Flow Estimation

NPDES Regulated Stormwater

MDE estimates pollutant loadings from NPDES regulated stormwater areas based on urban land use classification within a watershed. This methodology assumes certain relationships between specific Maryland Department of Planning (MDP) urban land use classification (as modified by MDE; for further details please see MDE 2009a) and various categories of NPDES regulated stormwater permits, whereby the identification of the existing permits determines what portion of the urban land use is considered regulated. Based on this information, the Chesapeake Bay Program Phase 5 (CBP P5) land use applied in this TMDL analysis can be refined into more detailed classifications associated with specific categories of NPDES regulated stormwater permits, which can subsequently be used to estimate the NPDES Regulated Stormwater Baseline Load.

The Maryland portion of the Bohemia River watershed is located in Cecil County, Maryland. The NPDES stormwater permits within the Bohemia River watershed include: (i) the area covered under Cecil County's Phase II jurisdictional municipal separate storm sewer system (MS4) permit, and (ii) state and federal general MS4s, industrial facilities, and construction sites, collectively termed "Other NPDES Regulated Stormwater."

Applying MDE's methodology, the areas regulated by the NPDES stormwater permits are represented by the CBP P5 urban land use associated with MDP residential, commercial, open urban, industrial, and institutional land use classifications (MDE 2009a). The resulting NPDES Regulated Stormwater tPCB Baseline Load of 2.8 g/year (see Table 6) was estimated by multiplying the proportion of the CBP P5 urban land use area within the watershed that is considered regulated out of the total watershed land use area (5.5%) by the Total Maryland Watershed Baseline Load (50.2 g/year). A list of all the NPDES regulated stormwater permits within the Bohemia River watershed that could potentially convey tPCB loads to the embayment has been presented in Appendix H.

2.3.3 Summary

In summary, the Lower Elk River influence and resuspension and diffusion from the bottom sediments are the two major tPCB sources to the Bohemia River embayment. The remaining nonpoint sources (i.e., watershed runoff and atmospheric deposition to the embayment) and point sources (i.e., WWTP and NPDES regulated stormwater) comprise a relatively small portion of the Total Baseline Load. Table 6 summarizes the estimated Total tPCB Baseline Load from all identified source categories.

Table 6: Summary of the Total tPCB Baseline Load

Source	Baseline (g/year)	Baseline (%)
Lower Elk River Influence	11,879.0	81.67
Bottom Sediment (Resuspension and Diffusion)	2,560.8	17.61
Direct Atmospheric Deposition (to the Surface of the Embayment)	43.6	0.30
Maryland Watershed Nonpoint Sources*	47.4	0.33
Delaware Upstream	10.7	0.07
Nonpoint Sources	***14,541.5***	***99.98***
WWTP*	0.06	0.00
NPDES Regulated Stormwater*	2.8	0.02
Point Sources*	***2.86***	***0.02***
Total	**14,544**	**100**

Note: *These sources were characterized only for the Maryland portion of the watershed.

3.0 WATER COLUMN AND SEDIMENT TMDL ENDPOINTS

The overall objective of the tPCB TMDL established in this document is to ensure that the "fishing" designated use in the Bohemia River embayment is protected. As described in Section 2.2, MDE evaluates PCB water quality conditions with the use of either the tPCB fish tissue listing threshold (39 ng/g) or the Maryland water column human health tPCB criterion (0.64 ng/L). In order to determine which one of these targets is more environmentally protective, the tPCB fish tissue listing threshold was converted to a corresponding tPCB water column concentration (see Equation 1 and Calculation 4). This was done with the use of a site-specific Adjusted Total Bioaccumulation Factor (Adj-tBAF) of 214,790 L/kg following the method of the Tidal Potomac River PCB TMDLs (see Appendix B for the derivation of the Adj-tBAF) (MDE 2007b).

$$\text{Water Column Target} = \text{Fish Tissue Concentration} \div \text{Adj-tBAF} \times \text{Unit} \qquad \text{(Equation 1)}$$

$$\text{Water Column Target} = 39\ \text{ng/g} \div 214{,}790\ \text{L/kg} \times \frac{1{,}000\ \text{g}}{1\ \text{kg}} = 0.18\ \text{ng/L} < 0.64\ \text{ng/L} \qquad \text{(Calculation 4)}$$

Based on this analysis, the water column tPCB target of 0.18 ng/L derived from the tPCB fish tissue listing threshold is the more environmentally protective than the Maryland water column human health tPCB criterion of 0.64 ng/L, and therefore will be applied in this analysis as the site-specific tPCB water column TMDL endpoint.

Similarly, in order to establish whether levels of PCBs in the sediment are protective of the "fishing" designated use, a site-specific tPCB sediment target for the Bohemia River embayment was derived based on the tPCB fish tissue listing threshold (see Equation 2 and Calculation 5). This was done with the use of the site-specific adjusted sediment bioaccumulation factor (Adj-SediBAF) of 25.9 (unitless) following the method of the Tidal Potomac River PCB TMDLs (see Appendix B for the derivation of the Adj-SediBAF) (MDE 2007b).

$$\text{Sediment Target} = \frac{\text{Fish Tissue Threshold}}{\text{Adj} - \text{SediBAF}} \qquad \text{(Equation 2)}$$

$$\text{Sediment Target} = \frac{39\ \text{ng/g}}{25.9} = 1.5\ \text{ng/g} \qquad \text{(Calculation 5)}$$

Both the site-specific tPCB water column and sediment targets will be used as TMDL endpoints and the more restrictive one will determine the actual TMDL (Section 4.2).

4.0 TOTAL MAXIMUM DAILY LOADS AND LOAD ALLOCATIONS

4.1 Overview

A TMDL is the total amount of 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 wasteload allocations (WLAs), load allocations (LAs), and either implicitly or explicitly margin of safety (MOS) (CFR 2007):

$$\text{TMDL} = \text{WLAs} + \text{LAs} + \text{MOS} \qquad \text{(Equation 3)}$$

This section describes how the tPCB TMDL and the corresponding LAs and WLAs have been developed for the Bohemia River Oligohaline segment. The analysis framework for simulating tPCB concentrations is described in Section 4.2, Section 4.3 addresses critical conditions and seasonality, and Section 4.4 presents the allocation of loads between point and nonpoint sources. The MOS is discussed in Section 4.5. Finally, the TMDL is summarized in Section 4.6.

4.2 Analysis Framework

A tidal prism model, which incorporates the influences of both fresh water discharge and tidal flushing, was used to simulate the dynamic interactions between the water column and bottom sediments within the Bohemia River embayment and the Lower Elk River (MDE 2005, Kuo et al. 2005). In general, tidal waters are exchanged through their connecting boundaries. Within the Bohemia River embayment, the dominant processes affecting the transport of PCBs throughout the water column include: the tidal influence, fresh water discharge, atmospheric exchange (i.e., volatilization and deposition), and exchange with the bottom sediments. Burial to the 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. Technical description of the model is presented in Appendix C and Appendix D.

The observed average tPCB concentrations were used as inputs to the model representing baseline (2003) conditions. Based on the available literature, the TMDL methodology assumes that on average the tPCB concentrations at the Bohemia River boundary are decreasing at a rate of 6.5% per year (see Section 2.3.1 and Appendix I). All other inputs (i.e., fresh water inputs, tidal exchange rates, sediment and water column exchange rates, atmosphere deposition, and burial rate) were kept constant.

The model was initially run for 35,000 days to predict the time needed for the water column tPCB concentration to meet the site-specific tPCB water column TMDL endpoint. The results indicated that when the site-specific water column TMDL endpoint (0.18 ng/L) was met, the tPCB sediment concentration was still higher than the site-specific sediment TMDL endpoint (1.5 ng/g). Consequently, the model was run again for 35,000 days to predict the time needed for the sediment concentrations to reach the TMDL endpoint. Figure 6 and Figure 7 show the simulated results: after 17,196 days (about 47 years) the tPCB sediment concentration reached 1.5 ng/g (see Figure 6), at which time the water column tPCB concentration was equal to 0.17 ng/L (see Figure 7).

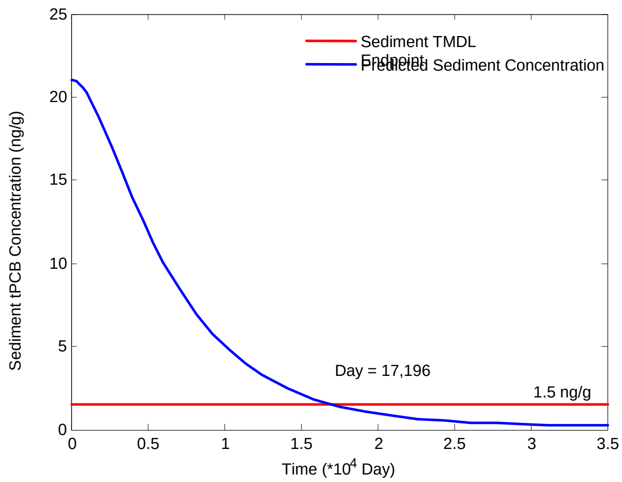

Figure 6: Changes in Sediment tPCB Concentration with Time

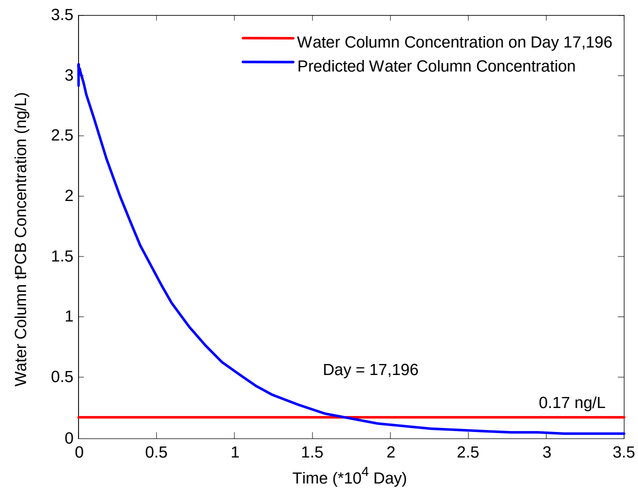

Figure 7: Changes in Water Column tPCB Concentration with Time

As presented in Table 6, the Lower Elk River (conveying tPCB loads from the Upper Chesapeake Bay and Delaware River Estuary) as well as resuspension and diffusion from the bottom sediments are the two primary sources of tPCB baseline loads resulting in the PCB impairment in the Bohemia River embayment. Attainment of the site-specific tPCB water quality TMDL endpoints will only be possible with significant reduction in these primary loadings (see Table 7), which is expected to take place over time as the Upper Chesapeake Bay and Delaware River Estuary concentrations continue to decline resulting also in natural attenuation of tPCB levels in the legacy sediments (i.e., the covering of contaminated sediments with newer, less contaminated materials, flushing of sediments during periods of high stream flow, and biodegradation). Assuming that the tPCB concentrations in the Upper Chesapeake Bay and Delaware River Estuary will continue to decline, at or above the current rate (see Section 2.3.1 and Appendix I), no additional tPCB reductions will be necessary to meet the "fishing" designated use in the Bohemia River embayment.

4.3 Critical Conditions and Seasonality

Federal regulations require TMDL determinations to take into account the impact of critical conditions and seasonality on water quality (CFR 2007). The intent of this requirement is to ensure that the water quality is protected during the most vulnerable times. Figure 8 illustrates seasonal variation in terms of water column tPCB concentrations in the Bohemia River embayment.

At the two water quality stations (BOR6 and BOR8) where samples were collected during various times of the year, the tPCB water column concentrations were lower during the spring sampling than during the summer sampling. This indicates that in the spring, due to the high river flow, water column PCBs are likely diluted by the increased river discharge more so than during the low flow period of summer and fall. However, since tPCB levels in fish become elevated due to long-term exposure, rather than temporary spikes in water column tPCB concentration, it has been determined that the selection of the average tPCB concentration as representing the baseline conditions adequately considers the impact of seasonal variations and critical conditions on the "fishing" designated use in the Bohemia River embayment. Furthermore, the site-specific tPCB water column

TMDL endpoint used to develop this TMDL is lower than the Maryland fresh and salt water chronic aquatic life tPCB criteria protective of fish and wildlife as well as the Maryland water column human health tPCB criterion protective of human health associated with consumption of PCB contaminated fish.

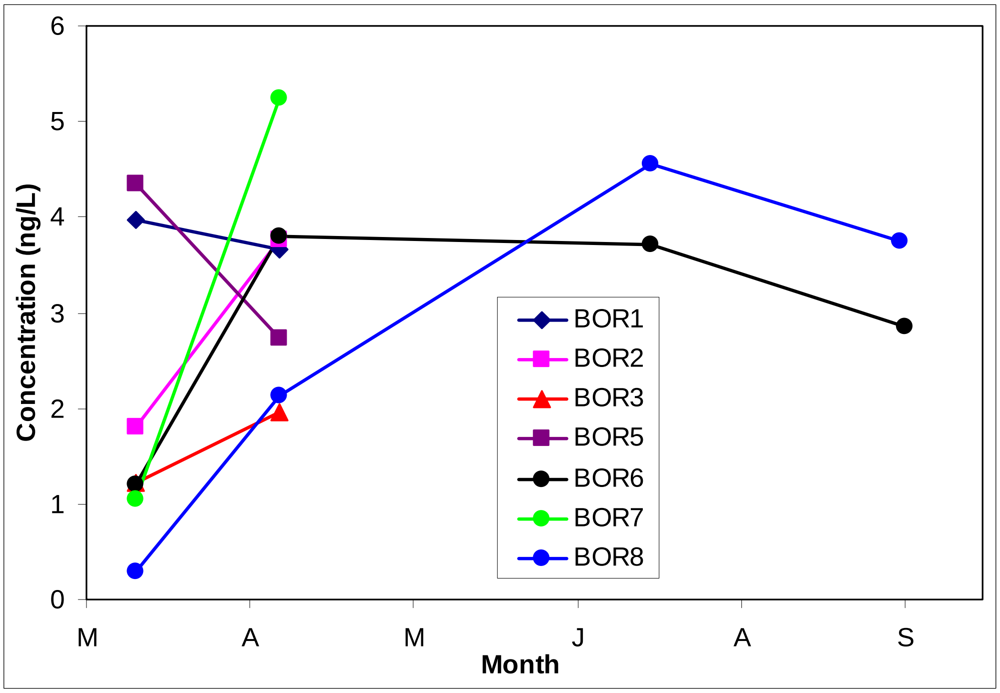

Figure 8: Seasonal Variations of Water Column tPCB Concentrations in Bohemia River Embayment

Selection of the average tPCB concentrations to represent the baseline model conditions will not affect the TMDL, which was established to meet the site-specific tPCB water column and sediment TMDL endpoints at all times. However, the length of time required to reach the TMDL endpoints will depend on the selection of the baseline conditions. To better understand this concept, the upper and lower 95% confidence intervals (CIs) of the mean water quality tPCB concentrations were estimated and used in the analysis. The time duration required to reach the TMDL endpoints increased by about 14 percent (7 years) when the upper CI (vs. the mean) was used as the baseline condition. Detailed results are presented in Appendix E.

4.4 TMDL Allocations

All TMDLs need to be presented in terms 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 2007). The State reserves the right to revise these allocations provided the revisions are consistent with achieving WQSs. This section summarizes the tPCB allocations established to meet the "fishing" designated use in the Bohemia River embayment.

4.4.1 Point Sources

Waste Water Treatment Plant

Cecilton WWTP (MD0020443) is the only WWTP located in the watershed. The estimated WWTP tPCB Baseline Load is 0.06 g/year (see Table 7). For more information on methods used to calculate this load see Section 2.3.2. At less than 0.01% of the TMDL, the Bohemia River WWTP Baseline Load was considered *de minimis*, therefore no appreciable environmental benefit would be gained by reducing this load (see Appendix K). The elevated tPCB concentrations in wastewater are believed to be primarily due to external sources (e.g., source water, atmospheric deposition, and stormwater runoff) infiltrating the waste water collection system through broken sewer lines and connections. There are currently no effluent PCB limits established in the discharge permits for WWTPs. The sensitivity analysis provided in this document (Appendix K) suggests that there is no "reasonable potential" for PCBs to exceed water quality even at 100 times the current WWTP loadings. Inclusion of a WLA in this document does not reflect any determination to impose an effluent limit.

NPDES Regulated Stormwater

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

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

US 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 Bohemia River embayment will be expressed as a single WLA. Upon approval of the TMDLs, "NPDES-regulated municipal stormwater and small construction storm water discharges effluent limits should be expressed as BMPs or other similar requirements, rather than as numeric effluent limits" (US EPA 2002).

The NPDES Regulated Stormwater WLA constitutes a proportional allocation of the Watershed tPCB Baseline Load to the regulated portion of CBP P5 urban land use within Cecil County (see Section 2.3.2). This NPDES Regulated Stormwater WLA may include any or all of the NPDES stormwater discharges listed above (see Appendix H for a list of specific stormwater permits within the watershed). As stormwater assessment and/or other program monitoring efforts result in a more refined source assessment, MDE reserves the right to revise the current NPDES Regulated Stormwater WLA provided the revisions are consistent with achieving WQSs.

The NPDES Regulated Stormwater tPCB Baseline Load to the Bohemia River embayment was considered to be insignificant relative to the resuspension and diffusion from the bottom sediments and loads from the Lower Elk River. Therefore, no reductions were applied to this source category, and the NPDES Regulated Stormwater WLA was set as equivalent to the Baseline Load (see Table

7). For more information on methods used to calculate the NPDES Regulated Stormwater tPCB Baseline Loads, please see Section 2.3.2.

4.4.2 Nonpoint Sources

Load allocations have been assigned to the following nonpoint sources: the Lower Elk River influence, bottom sediment, direct atmospheric deposition to the surface of the embayment, Maryland watershed nonpoint sources, and Delaware upstream sources. PCB loadings from the Lower Elk River (conveying tPCB loads from the Upper Chesapeake Bay and Delaware River Estuary) and bottom sediments are the most significant sources of tPCBs to the Bohemia River embayment and as such are the only ones requiring reductions in order to meet the “fishing” designated use in the Bohemia River embayment. These reductions are expected to take place over time as the Upper Chesapeake Bay and Delaware River Estuary concentrations continue to decline resulting also in natural attenuation of tPCB levels in the legacy sediments. Assuming that the tPCB concentrations in the Upper Chesapeake Bay and Delaware River Estuary will continue to decline at or above the current rate, no additional tPCB load reductions should be required for the remaining nonpoint sources. The remaining LAs were set as equivalent to the corresponding baseline loads (see Table 7).

4.5 Margin of Safety

All TMDLs must include a margin of safety to account for the lack of knowledge and the many uncertainties in the understanding and simulation of water quality parameters in natural systems. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection. Considering the uncertainty surrounding the estimated rate at which PCB concentrations are decreasing in the Upper Bay region and the variation in tPCB concentrations within the 95% CIs, MDE decided to apply a 10% MOS in order to provide an adequate and environmentally protective TMDL (see Table 7).

4.6 Summary of Total Maximum Daily Loads

Table 7 summarizes the tPCB TMDL allocations for the Bohemia River embayment as well as the corresponding baseline loads, the maximum daily load (MDL) (see Appendix G), and the associated load reductions.

**Table 7: Summary of tPCB Baseline Loads,
TMDL Allocations, MDL, and Associated Percent Reductions**

Source	Baseline Load (g/year)	TMDL (g/year)	Load Reduction (%)	MDL[a] (g/day)
Lower Elk River Influence	11,879.0	500.8	95.8	2.313
Bottom Sediment (Resuspension and Diffusion)	2,560.8	183.2	92.8	0.846
Direct Atmospheric Deposition (to the Surface of the Embayment)	43.6	43.6	0.0	0.201
Maryland Watershed Nonpoint Sources*	47.4	47.4	0.0	0.219
Delaware Upstream	10.7	10.7	0.0	0.049
Nonpoint Sources/Load Allocations	***14,541.5***	***785.7***	***94.6***	***3.628***
WWTP*△	0.06	0.06	0.0	0.0005
NPDES Regulated Stormwater*	2.8	2.8	0.0	0.013
Point Sources/Waste Load Allocations*	***2.86***	***2.86***	***0.0***	***0.014***
MOS	**-**	***87.6***	**-**	***0.405***
Total	**14,544**	**876**	**94.0**	**4.05**

Notes: * These sources were characterized only for the Maryland portion of the watershed.
△ WWTP Baseline Load was considered to be *de minimis*.
[a] For details see Appendix G.

5.0 ASSURANCE OF IMPLEMENTATION

As discussed in the previous sections, the Lower Elk River influence (conveying tPCB loads from the Upper Chesapeake Bay and Delaware River Estuary) and resuspension and diffusion from the bottom sediments have been identified as the two major sources of tPCBs to the Bohemia River embayment. As described in Section 2.3.1, it has been estimated that on average the tPCB concentrations in the Upper Chesapeake Bay are decreasing at a rate of 6.5% per year. Given this rate of decline, the tPCB levels in the Bohemia River embayment are expected to decline over time due to natural attenuation, such as the burial of contaminated sediments with newer, less contaminated materials, flushing of sediments during periods of high stream flow, and biodegradation.

Aside from the processes of natural attenuation, there are two alternatives that can assist in reducing the tPCB concentrations in the water column so as to meet WQSs. First, the physical removal of the PCB-contaminated sediments (i.e., dredging) would minimize one of the primary sources of tPCB to the water column. Second, a reduction in the Chesapeake Bay and Delaware River Estuary's tPCB loads would greatly accelerate the process of attenuation.

In this particular situation, dredging is the least desirable alternative because of its potential biological destruction. It damages the habitat of benthic macroinvertebrates and may directly kill some organisms. The process of stirring up suspended sediments during dredging may damage the gills and/or sensory organs of benthic macroinvertebrates and fish. Suspended sediments can also affect the prey gathering ability of sight-feeding fish. In addition, the resuspension of contaminated sediments provides organisms with additional exposure to PCBs.

In the case of the Bohemia River Oligohaline segment natural attenuation is a better implementation method because it involves less habitat disturbance/destruction and is less costly. Discovering and minimizing any existing PCB land sources throughout the Upper Chesapeake Bay watershed via future TMDL development and implementation efforts will further help to meet water quality goals in the Bohemia River watershed. MDE's Water Quality Standards Section will continue to monitor PCB levels in fish. This information will be used to evaluate the PCB impairment in the Bohemia River embayment on an ongoing basis.

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Appendix A. List of Individual tPCB Measurements

The Bohemia River polychlorinated biphenyl (PCB) data were collected in 2000, 2003, 2008, and 2009. The observed total PCB (tPCB) concentrations in fish tissue, sediment, and water column are listed in Table A-1, Table A-2, and Table A-3.

Table A-1: Fish Tissue tPCB Concentrations

Station	Fish Species	Date	tPCB* (ng/g – wet weight)
BORM	White Perch	9/7/2000	167.79
BORM	White Perch	9/7/2000	194.79
BORM	Channel Catfish	9/11/2000	330.70
BORM	Channel Catfish	9/11/2000	389.41

Note: *Actual values (i.e., not lipid normalized).

Table A-2: Sediment tPCB Concentrations

Station	Date	tPCB (ng/g – wet weight)
BOR1	7/17/2003	22.786
BOR2	7/17/2003	10.774
BOR3	7/17/2003	44.933
BOR4	7/17/2003	38.370
BOR5	7/17/2003	5.3730
BOR6	7/17/2003	23.085
BOR8	7/17/2003	18.958

Table A-3: Water Column tPCB Concentrations

Station	Date	Particulate (ng/L)	Dissolved (ng/L)	Total (ng/L)
BOR1	3/13/2003	2.617	1.317	3.934
BOR1	4/17/2003	3.501	0.154	3.655
BOR2	3/13/2003	1.680	0.129	1.809
BOR2	4/17/2003	3.501	0.253	3.754
BOR3	3/13/2003	0.880	0.340	1.220
BOR3	4/17/2003	1.813	0.151	1.964
BOR4	3/13/2003	0.524	0.346	0.871
BOR4	4/17/2003	3.762	0.190	3.952
BOR4	7/17/2003	4.466	0.969	5.436
BOR4	9/16/2003	2.091	1.930	4.021
BOR4	10/1/2003	2.598	1.801	4.399
BOR5	3/13/2003	3.969	0.350	4.319
BOR5	4/17/2003	2.510	0.222	2.732
BOR6	3/13/2003	0.744	0.456	1.200
BOR6	4/17/2003	3.470	0.330	3.800
BOR6	7/17/2003	1.694	2.011	3.704
BOR6	9/17/2003	1.215	1.639	2.854
BOR7	3/13/2003	0.664	0.392	1.056
BOR7	4/17/2003	4.576	0.592	5.168
BOR8	3/13/2003	0.107	0.180	0.287
BOR8	4/17/2003	1.679	0.434	2.113
BOR8	7/17/2003	3.192	1.345	4.537
BOR8	9/16/2003	2.392	1.359	3.752
BOR9	3/13/2003	0.294	0.165	0.459
BOR9	4/16/2003	0.657	0.224	0.882
BOR10	3/13/2003	0.420	0.089	0.508
BOR10	4/16/2003	0.398	1.154	1.552
GBO 0050	12/2008	0.094	0.086	0.180
GBO 0050	3/2009	1.108	1.151	2.259
UUU 0011	12/2008	0.052	0.108	0.160
UUU 0011	3/2009	0.201	0.986	1.187
UXP 0010	12/2008	0.497	0.116	0.613
UXP 0010	3/2009	0.444	0.451	0.895

Appendix B. Derivation of Adj-tBAFs and Adj-SediBAFs

This appendix describes how the site-specific Adjusted Total Bioaccumulation Factor (Adj-tBAF) and Adjusted Sediment Bioaccumulation Factor (Adj-SediBAF) were derived. These values are then used to convert the total Polychlorinated Biphenyl (tPCB) fish tissue listing threshold to the corresponding site-specific tPCB water column and sediment concentrations protective of the "fishing" designated use in the Bohemia River embayment. These methods are based on the approach used in the development of the Tidal Potomac River PCB TMDLs (MDE 2007b).

I. Data Description

The site-specific observation-based Adj-tBAFs and Adj-SediBAFs were calculated based on the available tPCB concentrations for the various fish species and accompanying water column and sediment samples collected in the Bohemia River embayment. Each fish species was assigned a trophic level and home range (Table B-1). The Adj-tBAFs and Adj-SediBAFs were calculated based on the geometric mean tPCB concentrations of all the water quality samples within each species' home range.

Table B-1: Trophic Levels and Home Ranges of Sampled Fish Species

Common Name	Scientific Name	Trophic Level	Home Range (Mile)
Channel Catfish	*Ictalurus punctatus*	Benthivore-generalist	5
White Perch	*Morone americana*	Predator	10

II. Total BAFs

The Total Bioaccumulation Factors (BAFs) for each fish sample (individual or composited) was calculated using Equation B1 (US EPA 2003):

$$\text{Total BAF} = \frac{[\text{tPCB}]_{\text{fish}}}{[\text{tPCB}]_{\text{water}}} \qquad \text{(B1)}$$

Where: $[\text{tPCB}]_{\text{fish}}$ = fish tissue tPCB concentration (ng/kg – wet weight)
$[\text{tPCB}]_{\text{water}}$ = geometric mean of water column tPCB concentrations within fish species' home range (ng/L).

Next, for fish species with more than one sample, a single Total BAF was calculated as the median of the applicable total BAFs.

III. Baseline BAFs

As the Total BAFs vary depending on the food habits and lipid concentration of each fish species and on the freely-dissolved tPCB concentrations in ambient water, it was determined that for the purpose of the TMDL analysis, Adj-tBAFs should be used. To calculate the site-specific Adj-tBAFs, first Baseline BAFs were calculated as recommended by US EPA (2000):

$$\text{Baseline BAF} = \frac{[\text{tPCB}]_{\text{fish}} \div \%\text{Lipid}}{[\text{tPCB}]_{\text{water}} \times \% fd} \qquad \text{(B2)}$$

Where: $[tPCB]_{fish}$ = fish tissue tPCB concentration (ng/kg – wet weight)
$[tPCB]_{water}$ = geometric mean of water column tPCB concentrations within fish species' home range (ng/L)
%lipid = fraction of fish tissue that is lipid
%fd = fraction of tPCB concentration in ambient water that is freely-dissolved.

Again, the above calculation was done for each fish sample (individual or composited). Next, for fish species with more than one sample, a single Baseline BAF was calculated as the median of the applicable Baseline BAFs.

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):

$$\%fd = \frac{1}{1 + POC \times K_{ow} + DOC \times 0.08 \times K_{ow}} \qquad (B3)$$

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

The K_{ow} of different PCB congeners vary widely. Therefore, the %fd value was first calculated for each PCB homolog (Homolog %fd) using the midpoint of the homolog's K_{ow} range (Table B-2; MDE 2007b page D-10).

Table B-2: K_{ow} Values of PCB Homologs

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 tPCB freely dissolved fraction (tPCB %fd) for each water sample within fish species' home range was derived as described in Equation B4 and multiplied by the appropriate water column tPCB concentration. The geometric mean of all of the results within fish species' home range was then used in Equation B2 (in place of $[tPCB]_{water} \times$ %fd) to calculate the Baseline BAFs for each fish sample.

$$tPCB\ \%fd = \frac{\sum (Homolog\ \%fd \times Homolog\ Concentration)}{[tPCB]_{water}} \qquad (B4)$$

The freely dissolved tPCB, POC, and DOC concentrations for each water sample are listed in Table B-3.

Table B-3: Freely Dissolved tPCB, POC, and DOC Concentrations

Station	Sample Date	Freely-Dissolved tPCB (ng/L)	POC (kg/L)*	DOC (kg/L)*
BOR1	13-Mar-03	1.4E+00	1.5E-06	3.6E-06
BOR1	17-Apr-03	5.0E-01	3.3E-06	4.0E-06
BOR2	13-Mar-03	5.9E-01	1.3E-06	3.3E-06
BOR2	17-Apr-03	4.4E-01	3.3E-06	3.9E-06
BOR3	13-Mar-03	3.5E-01	9.5E-07	3.2E-06
BOR3	17-Apr-03	5.0E-01	1.7E-06	2.9E-06
BOR4	13-Mar-03	2.7E-01	1.1E-06	3.2E-06
BOR4	17-Apr-03	7.7E-01	2.5E-06	4.7E-06
BOR4	17-Jul-03	1.7E+00	2.1E-06	4.2E-06
BOR4	16-Sep-03	1.9E+00	7.2E-07	4.4E-06
BOR4	01-Oct-03	1.8E+00	1.3E-06	3.8E-06
BOR5	13-Mar-03	1.1E+00	1.6E-06	3.5E-06
BOR5	17-Apr-03	3.6E-01	4.7E-06	4.2E-06
BOR6	13-Mar-03	4.0E-01	1.5E-06	3.4E-06
BOR6	17-Sep-03	1.0E+00	2.0E-06	9.9E-06
BOR6	17-Apr-03	6.2E-01	4.2E-06	3.7E-06
BOR6	17-Jul-03	1.7E+00	2.7E-06	5.1E-06
BOR7	13-Mar-03	2.2E-01	2.3E-06	3.2E-06
BOR7	17-Apr-03	1.0E+00	2.1E-06	6.1E-06
BOR8	13-Mar-03	8.4E-02	1.8E-06	2.9E-06
BOR8	17-Apr-03	3.0E-01	8.0E-06	3.7E-06
BOR8	17-Jul-03	1.3E+00	4.8E-06	5.3E-06
BOR8	16-Sep-03	1.0E+00	4.1E-06	1.5E-05
ELR2	13-Mar-03	6.4E-01	1.3E-06	2.4E-06
ELR2	17-Apr-03	7.4E-01	1.9E-06	3.3E-06
ELR2	16-Jul-03	2.3E+00	1.5E-06	4.3E-06
ELR2	01-Oct-03	2.0E+00	1.0E-06	3.9E-06
ELR3	13-Mar-03	1.0E+00	7.6E-07	3.4E-06
ELR3	17-Apr-03	5.4E-01	3.7E-06	3.4E-06
ELR4	13-Mar-03	9.9E-01	7.9E-07	3.3E-06
ELR4	17-Apr-03	8.4E-01	1.3E-06	4.4E-06
ELR12	13-Mar-03	1.2E+00	7.3E-07	3.4E-06
ELR12	17-Apr-03	7.8E-02	1.7E-06	4.9E-06

Note: * When the POC or DOC data were not available, the averaged value within the range was used instead.

IV. Adjusted Total BAFs

Next, the Baseline BAFs was normalized by the species median lipid content and a median freely-dissolved water column tPCB concentration within species' home range, thus minimizing variability associated with the differences in fish lipid content or freely-dissolved water column tPCB concentrations:

$$\text{Adj-tBAF} = (\text{Baseline BAF} \times \text{Median \% Lipid} + 1) \times \text{Median \%fd} \qquad \text{(B5)}$$

Finally, the tPCB fish tissue listing threshold of 39 ng/g was divided by the site-specific Adj-tBAF calculated for each fish species (Table B-4). To be environmentally protective, the lowest value (i.e., 0.18 ng/L – channel catfish) was used as the site-specific tPCB water column TMDL endpoint protective of the "fishing" designated use in the Bohemia River embayment.

Table B-4: Site-Specific Total BAF, Baseline BAF, Adj-tBAF, and Water Column Target, as well as Median %fd and Median Lipid Content for Each Fish Species

Species Name	Total BAF (L/kg)	Baseline BAF (L/kg)	Adj-tBAF (L/kg)	Water Column Target (ng/L)	Median %fd	Median Lipid Content
Channel Catfish	138,044	38,515,973	214,790	**0.18**	0.28	0.02
White Perch	80,214	14,465,779	90,018	0.43	0.29	0.02

V. BSAFs and Adj-SedBAFs

Similarly as in the case of the Baseline BAF calculation, the biota-sediment accumulation factors (BSAFs) for each fish sample (individual or composited) were derived using the following equation:

$$\text{BSAF} = \frac{\text{tPCB}_{\text{tissue}} \div \text{\% Lipid}}{\text{tPCB}_{\text{sediment}} \div \text{\%Oraganic Carbon}} \qquad \text{(B6)}$$

Where: $[\text{tPCB}]_{\text{fish}}$ = fish tissue tPCB concentration (ng/kg – wet weight)
$[\text{tPCB}]_{\text{sediment}}$ = geometric mean of sediment tPCB concentrations within fish species' home range (ng/L)
%lipid = fraction of fish tissue that is lipid
%Organic Carbon = sediment organic carbon fraction within fish species' home range.

As the %Organic Carbon data were not available for the Bohemia River embayment, a default value of 1% was used (US EPA 2004).

For fish species with more than one result, a single BSAF was calculated as the median of the applicable total BSAFs. Each species' BSAF was then normalized with the use of the median lipid content (Table B-4) and the sediment organic carbon fraction:

$$\text{Adj-SedBAF} = \text{BSAF} \times \frac{\text{Median \% Lipid}}{\text{\% Oraganic Carbon}} \qquad \text{(B7)}$$

The tPCB fish tissue listing threshold of 39 ng/g was then divided by the Adj-SedBAF calculated for each species (Table B-5). To be environmentally protective, the lowest value (i.e., 1.5 ng/g – channel catfish) was used as the site-specific tPCB sediment TMDL endpoint protective of the "fishing" designated use in the Bohemia River embayment.

Table B-5: Site-Specific BSAF, Adj-SedBAF, and Sediment Target for Each Fish Species

Species Name	BSAF	Adj-SedBAF	Sediment Target (ng/g)
Channel Catfish	12.95	25.9	**1.5**
White Perch	4.44	8.9	4.4

Appendix C. Tidal Prism Model

A description of the tidal prism model is presented in this appendix. Detailed information about tidal prism model and its applications can be found at Kuo et al. (1998) and Kuo et al. (2005). It is assumed that a single volume can represent a waterbody and that the pollutant is well mixed in the waterbody, as shown in Figure C-1.

The mass balance of water can be written as follows (Guo and Lordi, 2000):

$$\frac{dV}{dT} = Q_0(1-a) - Q_b + Q_f \qquad \text{(C1)}$$

Where:
V is the volume of the bay (m3);
T is the dominant tidal period (hours);
Q_0 = quantity of water that enters the embayment through the open boundary (m3/d);
Q_b = quantity of water that leaves the embayment through the open boundary (m3/d);
Q_f = the volume of water that enters the embayment from the Bohemia River watershed;
α = return ratio, which is the percentage of water that flowed to the Lower Elk River during the previous ebb tide and flows back to the embayment during the following flood tide;

In a steady-state condition, the mass balance equations for the water can be written as follows:

$$Q_b = Q_0(1-a) + Q_f \qquad \text{(C2)}$$

Knowing Q_0, Q_f, and α , Q_b can be estimated (see Appendix D).

Assuming no decay, the polychlorinated biphenyls (PCBs) can enter the water column via loading from upstream and the atmosphere (L_f), loading from the Lower Elk River (Q_0C_0), resuspension from the sediment (V_rAC_2), and diffusion between sediment-water column interface ($V_dA(F_{do2}C_2 - F_{do1}C_1)$). PCBs leave the water column via volatilization ($V_vAF_{do1}C_1$), flow to the Lower Elk River (Q_bC_1) and sedimentation ($V_sAF_{p1}C_1$). In the sediment, the PCBs enter the system via settling ($V_sAF_{p1}C_1$) and leave the system via diffusion ($V_dA(F_{do2}C_2 - F_{do1}C_1)$), resuspension ($V_rAC_2$) and burial to a deeper layer (V_bAC_2). Specifically, the mass balance for the PCBs in the water column (Equation C3) and sediment (Equation C4) can be written as (Chapra, S.C. 1997):

$$\frac{dV_1C_1}{dt} = L_f - V_vAF_{do1}C_1 + (1-\alpha)Q_0C_0 - Q_bC_1 + V_rAC_2 - V_sAF_{p1}C_1 + V_dA(F_{do2}C_2 - F_{do1}C_1) \qquad \text{(C3)}$$

$$\frac{dV_2C_2}{dt} = -V_rAC_2 + V_sAF_{p1}C_1 - V_dA(F_{do2}C_2 - F_{do1}C_1) - V_bAC_2 \qquad \text{(C4)}$$

Where:
L_f = tPCB loading from upstream (point and nonpoint sources) and atmosphere;
V_v = volatilization coefficient (m/d);
A = area of the embayment (m^2);
C_0 = tPCB concentrations in the water column of the Lower Elk River (ng/L);
C_1 = tPCB concentrations in the water column of the embayment (ng/L);
C_2 = tPCB concentrations in the sediment of the embayment (ng/L);
V_1 = volume of the water column in the embayment (m^3);
V_2 = volume of the active sediment layer of the embayment (m^3);

V_d = diffusive mixing velocity;
F_{p1} = fraction of particular-associated PCBs in the water column;
F_{do1}= fraction of truly dissolved and dissolved organic carbon (DOC)-associated PCBs in the water column;
F_{do2}= fraction of truly dissolved and DOC-associated PCBs in the sediment;
V_r = rate of resuspension (m/d);
V_s = rate of settling (m/d);
V_b = rate of burial (m/d).

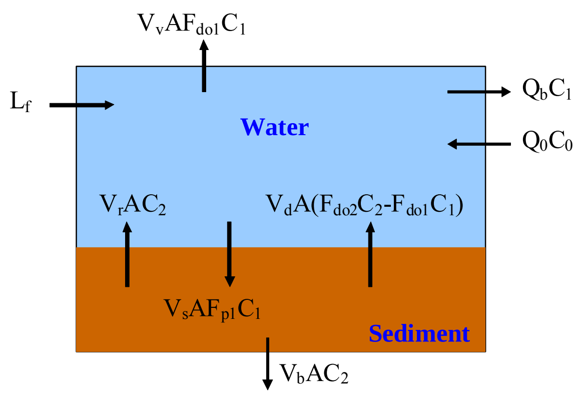

Figure C-1: The Schematic Diagram for the Tidal Prism Model and the tPCB Budget

Appendix D. Tidal Prism Model Calculation for Bohemia River

For Bohemia River, the parameter values are as follows:

L_f = 286,466 μg/day. It was obtained by summing all the upstream point and nonpoint source loads and the load from the atmosphere.

V_v = 90 m/year = 0.25 m/day. It was derived using the method of Chapra (1997) assuming a wind speed of 1 m/s and a temperature of 10 ℃.

α = 0.3. In general, the exchange ratio varies from 0.3 to 0.7 (Kuo et al. 1998; Shen et al. 2002).

A = 13,196,975 m^2 estimated from GIS layer.

Q_0 = A × Tidal range ÷ Tidal circle × 24 hrs = 13,196,975 × 0.488 ÷ 12.42 × 24 = 12,444,684 m^3.

Q_b = $Q_f + Q_0 \times (1-\alpha)$ = 192,010 + 12,444,684 × (1-0.3) = 8,903,288 m^3.

Q_f is obtained by dividing the mean flow recorded at the closest U.S. Geological Survey gage station (Silver Lake Tributary at Middletown, USGS 01483155) by its drainage area, and multiplying by the drainage area of the Bohemia River watershed.

C_0 = 3.74 × $(0.935)^t$ ng/L. The measurement at the station BOR4 was used as the baseline boundary condition of the model. The TMDL methodology assumes that on average the tPCB concentrations at the Bohemia River boundary are decreasing at a rate of 6.5% per year (also see Section 2.3.1 and Appendix I).

C_1 = 2.91 ng/L (measured).

C_2 = Measured tPCB concentration on a dry sediment base × Sediment density × (1-porosity) ÷ Fraction of particular-associated tPCBs in the sediment = 21 × 2,500 × (1-0.85) ÷ 0.9976 = 7,894 ng/L; the porosity (water content on a volume base) of 0.85 is selected based on observations and reference (Thomann and Mueller 1987).

V_1 = 28,604,661 m^3 estimated from GIS

V_2 = A × Active sediment layer thickness = 13,196,975 × 0.10 = 1,319,698 m^3. The Active sediment layer thickness value of 0.10 m is a default value and frequently used in water quality models.

V_d = 69.35 × Porosity × (Molecular weight of PCBs)$^{-2/3}$ ÷ 365 = 69.35 × 0.85 × $(305.6)^{-2/3}$ ÷ 365 = 0.00356 m/d (Thomann and Mueller 1987).

F_{p1} = 0.5350; F_{do1} = 0.4650; F_{do2} = 0.0024 (see Appendix F for derivation).

V_s = 0.35 m/d, normally the range of settling rate is from 0.1 to 1 m/d (DRBC 2003).

V_b = 4.685 × 10^{-6} m/d (average of the measured sedimentation rates through ^{210}Pb technology).

V_r = 5.934 × 10^{-5} m/d. It was first calculated via mass balance of the sediment in the active sediment layer at steady state:

$$\frac{d\rho(1-\varphi)}{dt} = V_s \times TSS - V_r \times \rho \times (1-\varphi) - V_b \times \rho \times (1-\varphi) = 0 \qquad \text{(D1)}$$

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.

The V_r value was then calibrated assuming the initial equilibrium has been reached in the water column and sediment.

Substituting all the necessary parameters in equations (C3) and (C4) results in the changes of C_1 and C_2 through time.

Appendix E. Calculation of 95% CIs

The 95% Confidence Intervals (CIs) for the baseline mean total polychlorinated biphenyl (tPCB) concentration were calculated as follows:

$$\text{Upper 95\% CI} = \text{Mean} + \frac{\text{t - Value} \times \text{Standard Deviation}}{\sqrt{\text{Sample Size}}}$$

$$\text{Lower 95\% CI} = \text{Mean} - \frac{\text{t - Value} \times \text{Standard Deviation}}{\sqrt{\text{Sample Size}}}$$

Where: t-value is a tabulated value that can be found in a basic statistics textbook.

The model was run with the mean as well as the upper and lower 95% CIs set as the baseline conditions in the embayment and at the boundary. The results are presented in Figures E-1 and E-2. Time duration required to meet the site-specific tPCB sediment TMDL endpoint and the corresponding water column concentrations are listed in Table E-1. Time duration required to meet the water quality TMDL endpoint in the embayment increased by approximately 14 percent (7 years) when the upper CI (vs. the mean) was used as the baseline.

Table E-1: Values for the Mean and its 95% CIs of tPCB Concentration

	Time (days) to Meet Sediment TMDL Endpoint	Water Column tPCB Concentration (ng/L) When Sediment TMDL Endpoint is Met
Mean	17196	0.169
Upper 95% C.I.	19609	0.169
Lower 95% C.I.	12572	0.169

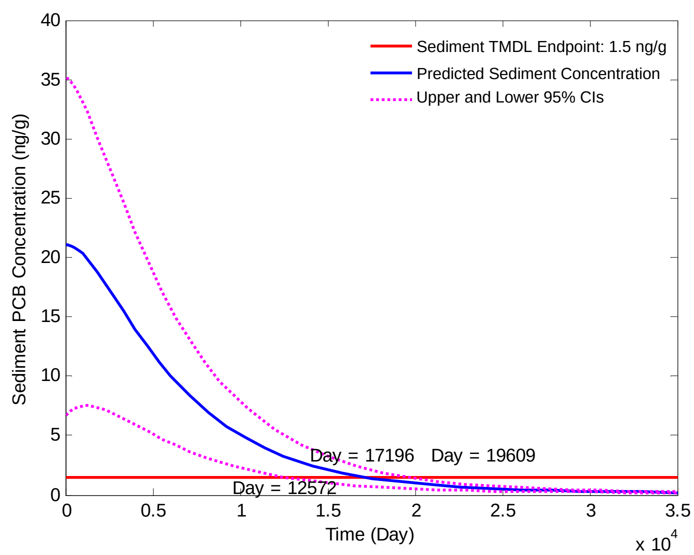

Figure E-1: Predicted Sediment tPCB Concentration in ng/L (Blue Line) and its 95% CIs (Magenta Lines)

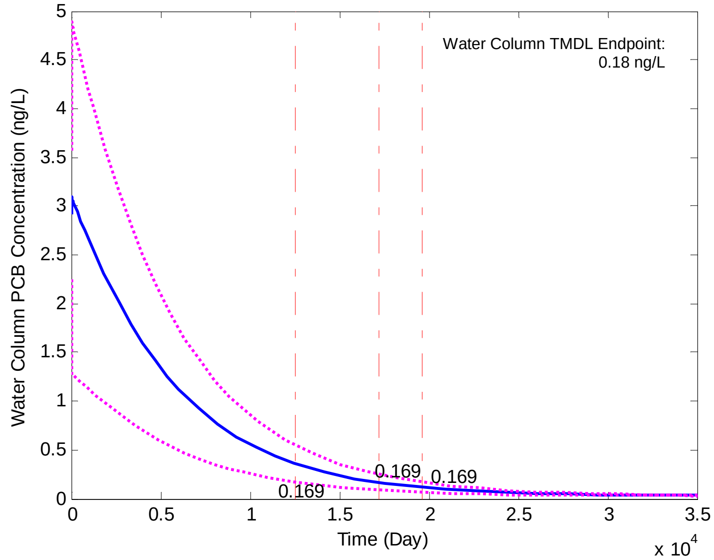

Figure E-2: Predicted Water Column tPCB Concentration in ng/L (Blue Line) and Its 95% CIs (Magenta Lines). The Red Vertical Lines Indicate the Times When the Sediment TMDL Endpoint Was Met

Appendix F. Calculation of Fraction of Different PCB Forms

The fractions in equations (C1) and (C2) can be calculated as follows:

$$F_{p1} = \frac{TSS \times 10^{-6} K_{oc} \times f_{oc1}}{1 + (K_{oc} \times 10^{-6})(TSS \times f_{oc1} + DOC_1)} \quad \text{(F1)}$$

$$F_{do1} = \frac{1 + (K_{oc} \times 10^{-6}) DOC_1}{1 + (K_{oc} \times 10^{-6})(TSS \times f_{oc1} + DOC_1)} \quad \text{(F2)}$$

$$F_{do2} = \frac{\phi + \phi(K_{oc} \times 10^{-6}) DOC_2}{\phi + (K_{oc} \times 10^{-6})(f_{oc2} \times \rho \times (1-\phi) + \phi DOC_2)} \quad \text{(F3)}$$

Where:

K_{oc} is 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} are 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 are the dissolved organic carbon concentrations in water column and pore water, respectively.

φ is the porosity of the sediment.

Appendix G. Technical Approach Used to Generate Maximum Daily Load

Summary

This appendix documents the technical approach used to define the maximum daily load (MDL) of total polychlorinated biphenyls (tPCBs) consistent with the average annual Total Maximum Daily Load (TMDL), which is protective of the "fishing" designated use in the Bohemia River embayment. The approach builds upon the modeling analysis that was conducted to determine the average annual tPCB TMDL and can be summarized as follows:

- The approach defines an MDL for each of the source categories;
- The approach builds upon the TMDL modeling analysis that was conducted to ensure that the average annual TMDL results in compliance with water quality standards;
- The approach considers a daily load level of a resolution based on the specific data that exists for each source category.

Introduction

This appendix documents the development and application of the approach used to present the average annual tPCB TMDL allocations in terms of daily loads. It is divided into sections discussing:

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

Basis for Approach

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

- **Average Annual TMDL:** The basis of the average annual tPCB TMDL is that the Baseline Load to the Bohemia River embayment results in fish tissue concentrations that exceed the tPCB fish tissue listing threshold. Thus, the average annual tPCB TMDL was calculated to be protective of the "fishing" designated use.
- **Draft U.S. Environmental Protection Agency (US EPA) guidance document entitled *Options for the Expression of Daily Loads in TMDLs*** (US EPA 2007b).

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

Options Considered

The draft US EPA guidance document for developing daily loads does not specify a single approach that must be adhered to, but rather it contains a range of acceptable options (US EPA 2007b). The selection of a specific method for translating a time-series of allowable loads into the expression of an MDL 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 exceedance of the TMDL.

This section describes the options that were considered when developing methods to calculate the Bohemia River embayment MDL.

Level of Resolution

The level of resolution pertains to the amount of detail used in specifying the MDL. The draft US EPA guidance on daily loads (US EPA 2007b) provides three categories of options for level of resolution, all of which are potentially applicable to the Bohemia 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 conditions.
3. **Temporally-variable daily load:** This option allows the MDL to vary based upon seasons or times of varying source or water body behavior (US EPA 2007b).

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 loading value has some finite probability of being exceeded.

The draft daily load guidance document states that the probability component of the MDL should be “based on a representative statistical measure” that is dependent upon the specific TMDL and best professional judgment of the developers (US EPA 2007b). 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 an MDL that would be exceeded 5% of the time.

Selected Approach

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

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

- Approach for Nonpoint Sources and National Pollutant Discharge Elimination System (NPDES) Regulated Stormwater Point Sources within the Bohemia River watershed;
- Approach for NPDES permitted waste water treatment plant (WWTP) Point Sources within the Bohemia River watershed; and
- Approach for Upstream Sources.

<u>Approach for Nonpoint Sources and NPDES Regulated Stormwater Point Sources within the Bohemia River Watershed</u>

The Nonpoint Source and NPDES Regulated Stormwater Point Source MDLs were estimated based on three factors: a specified probability level, the average annual tPCB TMDL allocations, and the coefficient of variation (CV) of the baseline condition for ambient water column concentrations in the Bohemia River embayment. 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 of 0.24 was calculated using the arithmetic mean and standard deviation of the baseline ambient water column concentrations in the Bohemia River embayment (see Equation G1).

$$CV = \frac{\beta}{\alpha} \qquad \text{(G1)}$$

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

The MDL for each contributing source is estimated as the appropriate average annual load allocation multiplied by a conversion factor that accounts for expected variability of daily loading values. The equation is as follows:

$$MDL = LTA * e^{(z\sigma - 0.5\sigma^2)} \qquad \text{(G2)}$$

Where:
MDL = Maximum daily load
LTA = Long-term average (average annual load allocation)
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 (z value of 2.326), a CV of 0.24, and an appropriate unit conversion (i.e., from long-term average load (g/yr) to an MDL (g/day)) results in a conversion factor of 0.0046.

Approach for WWTP Point Sources within the Bohemia River Watershed

The TMDL also considers contributions from NPDES permitted WWTP point sources that discharge quantifiable concentrations of tPCBs in the Bohemia River watershed. The MDL was calculated based on the guidance provided in the Technical Support Document (TSD) for Water Quality-based Toxics Control (US EPA 1991). The average annual TMDL allocation was converted to maximum daily limits using Table 5-2 of the TSD assuming a coefficient of variation of 0.6, a 99th percentile probability (z valueof 2.326), and an appropriate unit conversion (i.e., from long-term average load (g/yr) to an MDL (g/day)). This results in a conversion factor of 0.0085. It should be noted, however, that the WWTP Baseline Load was considered to be *de minimis*, therefore no appreciable environmental benefit would be gained by reducing this load (see Appendix K for details).

Approach for Upstream Sources

For the purpose of this analysis only one upstream watershed has been identified: the Delaware portion of the Bohemia River watershed. Delaware MDL was calculated based on the same approach as was used for nonpoint sources and NPDES regulated stormwater point sources within the Bohemia River watershed (see above).

Results of Approach

This section lists the results of the selected approaches to define the Bohemia River embayment MDL.

- Calculation Approach for Nonpoint Sources (Lower Elk River influence, Bottom Sediment, Direct Atmospheric Deposition, and Maryland Watershed Nonpoint Sources) and NPDES Regulated Stormwater Point Sources within the Bohemia River watershed:

  Nonpoint Source MDL (g/day) = Average Annual Nonpoint Source LA (g/yr) × 0.0046

  NPDES Regulated Stormwater MDL (g/day) = Average Annual NPDES Regulated Stormwater WLA (g/yr) × 0.0046

- Calculation Approach for WWTP Point Source within the Bohemia River watershed:

  WWTP MDL (g/day)$^{\triangle}$ = Average Annual WWTP WLA (g/yr) × 0.0085

- Calculation Approach for Upstream Sources:

  Delaware Upstream MDL (g/day) = Average Annual Delaware Upstream LA (g/yr) $\times 0.0046$

Table G-1: Summary of tPCB Maximum Daily Load

Source	MDL (g/day)
Lower Elk River Influence	2.313
Bottom Sediment (Resuspension and Diffusion)	0.846
Direct Atmospheric Deposition (to the Surface of the Embayment)	0.201
Maryland Watershed Nonpoint Sources*	0.219
Delaware Upstream	0.049
Total Nonpoint Sources	***3.628***
WWTP*△	0.0005
NPDES Regulated Stormwater*	0.0013
Total Point Sources*	***0. 014***
MOS	***0.405***
Total	**4.05**

Notes: * These sources were characterized only for the Maryland portion of the watershed.
△ WWTP Baseline Load was considered to be *de minimis*.

Appendix H. MDE Permit Information

Table H-1: NPDES Regulated Stormwater Permit Summary for Bohemia River Watershed[1]

Facility	City	County	Type	TMDL
Cecil County MS4	ALL	Cecil	-	Stormwater WLA
MDE General Permit to Construct	ALL	ALL	-	Stormwater WLA

Note: [1] Although not listed in this table, some individual process water permits for municipal and industrial discharges may also incorporate stormwater requirements. Loads from such facilities as well as from general Phase II state and federal MS4s (i.e., military bases, hospitals, etc.) are inherently accounted for within the NPDES stormwater WLA presented in this document.

Appendix I. Derivation of the Boundary tPCB Concentration

Bohemia River exchanges waters with the Chesapeake Bay and Delaware River Estuary via the Lower Elk River. The Susquehanna River is the major source of flow and polychlorinated biphenyls (PCBs) to the Upper Chesapeake Bay (Ko and Baker 2004) including Elk and Bohemia rivers. According to Ko and Baker (2004), the tPCB loads of Susquehanna River from 1992 to 1998 are as follows:

Table I-1: The Flow Normalized tPCB loads of Susquehanna River (kg/m^3/year)

Year	Years Since 1992	Load (kg/m^3/year)	Log ($Load_{Current}/Load_{1992}$)
1992	0	37	0
1993	1	37	0
1994	2	35	-0.02413
1995	3	35	-0.02413
1997	5	24	-0.18799
1998	6	24	-0.18799

A linear regression was developed for *Years Since 1992* vs. *Log ($Load_{Current}/Load_{1992}$)*, the slope of -0.0292 stands for log of current year's load as a percentage of the previous year's load. The current year's load as a percentage of the previous year's load is $10^{-0.0292} = 0.935$. Thus, on average the tPCB concentrations in the Upper Chesapeake Bay are decreasing at a rate of 1 - 0.935 = 6.5% per year (Figure I-1). According to the Delaware River Basin Commission (Hellweger 2009), the water column tPCB concentrations in the Delaware River region have been decreasing at a rate of around 18% per year from 1970 to 2002. The smaller of the two tPCB rates of decline (i.e., 6.5% per year) was used in the model simulation to account for the expected temporal changes in tPCB concentration at the Bohemia River boundary.

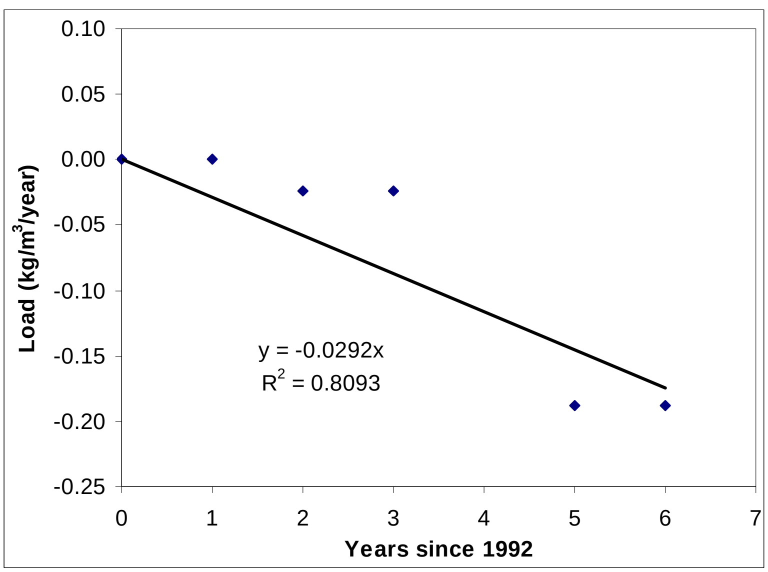

Figure I-1: The Regression Line of the Ko and Baker tPCB Loading Data

Appendix J. List of Analyzed PCB Congeners

Polychlorinated biphenyl (PCB) analytical services were provided by the University of Maryland Center for Environmental Science (UMCES). PCB congeners were identified and quantified by high resolution gas chromatography with electron capture detection. 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). Based on this method, 86 chromatographic peaks can be quantified (see Table J-1). Some of the peaks contain one PCB congener, while many are comprised of two or more co-eluting congeners. The PCB analysis presented in this document is based on total PCB 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 J-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 K. WWTP Load Evaluation

This appendix evaluates the significance of the Waste Water Treatment Plant (WWTP) Total Polychlorinated Biphenyl (tPCB) Baseline Load and whether a reduction is necessary in order to meet the TMDL resulting in the attainment of water quality standards. Assigning reductions to loads that are considered *de minimis* (i.e., insignificant or negligible) would produce no appreciable environmental benefit and would require regulated facilities to implement burdensome regulatory requirements.

At 0.01% of the TMDL (Table K-1), the Bohemia River WWTP Baseline Load is considered *de minimis* because even its complete elimination would not result in any discernible improvement in water quality (Table K-2). Moreover, a possible future increase in this load (e.g., due to potential future development or expansion of plant capacity) is also not expected to have any significant impact on meeting the site-specific tPCB water quality TMDL endpoints; even a 100-fold increase in WWTP load (up to 1% of the TMDL) is expected to increase the time it takes to reach the TMDL endpoints by only 0.27% or 45 days (Table K-3, Figure K-1 and K-2). Therefore, given that even a possible future increase in this load would not have any impact on meeting TMDL endpoints, no appreciable environmental benefit would be gained by reducing this load.

Table K-1. WWTP tPCB Loads as Percent of TMDL

Sources	Allowable Load (g/year)	Percent of TMDL
WWTP	0.06	0.01%
Other	875.9	99.99%
Total	**876**	**100%**

Table K-2. Effect of Eliminating WWTP Baseline Load on Time Needed to Reach the TMDL Endpoints

Allowable Load	Nr. of Days Needed to Reach the TMDL Endpoints
Including WWTP Baseline Load	17,196
Reducing WWTP Baseline Load by 100%	17,196

Loadings from the Lower Elk River (conveying tPCB loads from the Upper Chesapeake Bay and Delaware River Estuary) as well as resuspension and diffusion from the bottom sediments are the primary source of the tPCB loads resulting in the PCB impairment in the Bohemia River embayment (see Section 2.3). Attainment of the site-specific tPCB water quality TMDL endpoints will only be possible with the decline of these primary loadings, which is expected to take place over time as the Upper Chesapeake Bay and Delaware River Estuary concentrations continue to decline resulting also in natural attenuation of tPCB levels in the legacy sediments. In the future, if WWTPs are discovered to discharge PCBs at levels that threaten water quality, the assessment of the appropriate WLA will be revisited.

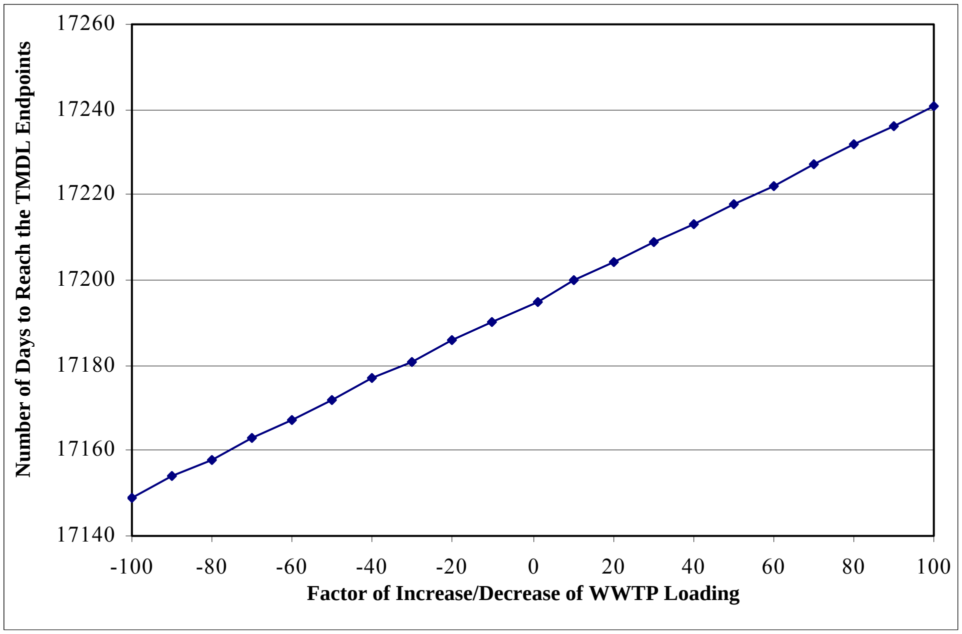

Figure K-1. Effect of Increasing/Decreasing Loads as Factor of WWTP Baseline Load on Time Needed to Reach the TMDL Endpoints (days)

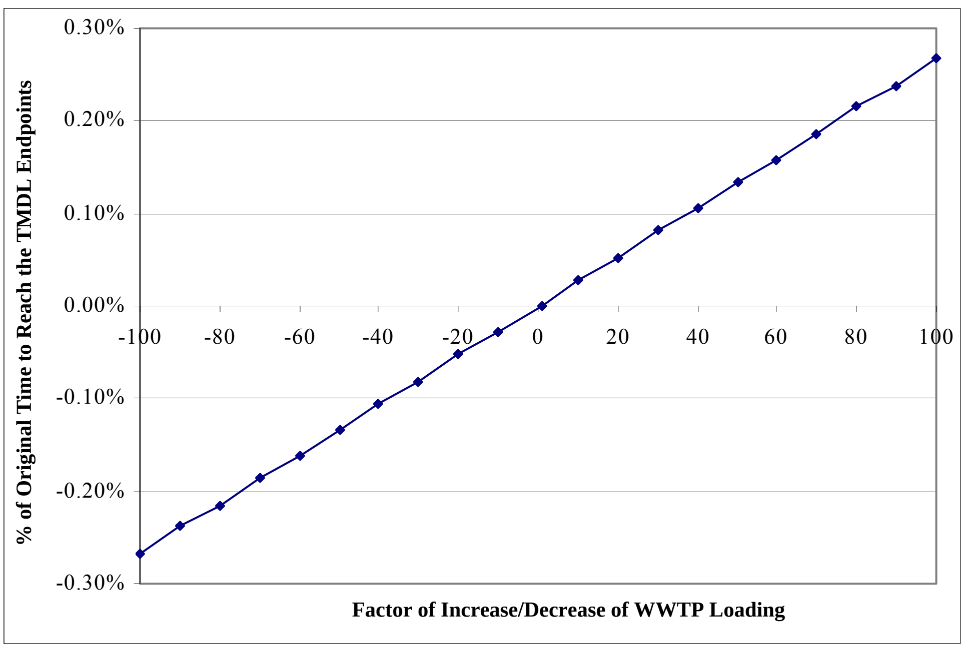

Figure K-2. Effect of Increasing/Decreasing Loads as Factor of WWTP Baseline Load on Time Needed to Reach the TMDL Endpoints (% of time)

Table K-3. Effect of Increasing/Decreasing Loads as Factor of WWTP Baseline Load on Time Needed to Reach the TMDL Endpoints

Factor of Increase/ Decrease of WWTP Loading	Nr. of Days Needed to Reach the TMDL Endpoints	Percent Change
100	17241	0.27%
90	17236	0.24%
80	17232	0.22%
70	17227	0.19%
60	17222	0.16%
50	17218	0.13%
40	17214	0.10%
30	17210	0.08%
20	17205	0.05%
10	17200	0.03%
1	17196	0.00%
-10	17190	-0.03%
-20	17186	-0.05%
-30	17181	-0.08%
-40	17177	-0.10%
-50	17172	-0.13%
-60	17167	-0.16%
-70	17163	-0.19%
-80	17158	-0.22%
-90	17154	-0.24%
-100	17149	-0.27%