Draft Final Anacostia River Toxic Constituents TMDL Modeling Report

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PRESENTED TO

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and

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ARSP	Anacostia River Sediment Project
ATSDR	Agency of Toxic Substances and Disease Registry
AWRP	Anacostia Watershed Restoration Partnership
BAF	Bioaccumulation Factor
BSAF	Bio-sediment accumulation factor
CCC	Criteria Continuous Concentration
CMC	Criteria Maximum Concentration
COC	Contaminant of Concern
CSO	Combined Sewer Outfall
CSS	Combined Sanitary Sewer
CWA	Clean Water Act
DEM	Digital Elevation Model
DMR	Discharge Monitoring Report
DOEE	District Department of Energy and the Environment
EFDC	Environmental Fluid Dynamics Code
EPA	Environmental Protection Agency
ET	Evapotranspiration
FTABLE	Function Table
GHCN	Global Historical Climate Network
GIS	Geographic Information System
HE	Heptachlor Epoxide
HH	Human Health
HRU	Hydrologic Response Unit
HSG	Hydrologic Soil Group
HSPF	Hydrologic Simulation Program - FORTRAN
IR	Integrated Report
LA	Load Allocation
LCD	Local Climatological Data
LSPC	Loading Simulation Program C++
MDE	Maryland Department of the Environment
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
MSGP	Multi-Sector General Permit
NCDC	National Climactic Data Center
NED	National Elevation Dataset

Acronyms/Abbreviations	Definition
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSE	Nash Sutcliffe Coefficient of Model Fit Efficiency
PAH	Polyaromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PET	Potential Evapotranspiration
SWS	Subwatershed
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WLA	Waste Load Allocation
WQC	Water Quality Criteria

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) Region 3 is coordinating with the District of Columbia Department of Energy and Environment (DOEE), and the Maryland Department of the Environment (MDE) to replace existing total maximum daily loads (TMDLs) for toxic impairments (metals, organochlorine pesticides, and polycyclic aromatic hydrocarbons [PAHs]) in the Anacostia River, its tributaries, and Kingman Lake and to develop new TMDLs to address organochlorine pesticide listings in the Maryland portion of the Anacostia River. The Anacostia River was originally listed as impaired on the District of Columbia's (DC's) 1998 Clean Water Act (CWA) Section 303(d) list. TMDLs were developed for those listings in 2003, but they were later challenged in court because they did not include a daily load expression. A subsequent court order set a date for the vacatur of EPA's approval of the existing TMDLs in 2017 the court order was amended to extend that deadline twice: first, until January 31, 2020, and then until September 30, 2021, to allow for further investigation into the impairment extent and potential sources. In addition, during that time a Remedial Investigation conducted under the Anacostia River Sediment Project (ARSP) has resulted in the development of a large monitoring dataset to better characterize surface waters, bed sediment, pore water, manhole sediment quality, and tributary loading of sediment and contaminants in the watershed. Further, DOEE has published an interim Record of Decision to reduce sediment contamination at 11 different sites in the Anacostia River.

This report describes modeling undertaken by Tetra Tech for EPA, DOEE, and MDE to support toxic constituents TMDL development for the Anacostia River, its impaired tributaries, and Kingman Lake.

2.0 WATERSHED BACKGROUND

2.1 WATERBODY AND WATERSHED OVERVIEW

The 170-square-mile Anacostia River watershed originates in Montgomery and Prince George's counties, Maryland, and terminates at the confluence with the Potomac River in DC. Approximately 80% of the watershed is in Maryland and 20% is in DC. The main subwatersheds include the Northwest Branch, Paint Branch, Little Paint Branch, Indian Creek, Upper and Lower Beaverdam Creeks, the Northeast Branch, Still Creek, Brier Ditch, Fort Dupont, Pope Branch, Watts Branch, Hickey Run and Sligo Creek. The upper tributaries are nontidal freshwater, while the mainstem of the Anacostia River is tidally influenced.

The watershed's population is more than 850,000 in DC and Maryland. The upper portions of the watershed are in the Piedmont Plateau, which is characterized by gently rolling hills. The remainder of the watershed is in the Coastal Plain, which is somewhat flatter, but can also contain gently rolling hills. Elevations in the watershed range from sea level to about 400 feet above sea level.

Figure 2-1 is a map of the Anacostia River watershed illustrating the assessment units addressed by the TMDL and the areas draining to them. Note that the areas draining to the tidal segments Anacostia #2 and Anacostia #1 (listed in order upstream to downstream) include some tributaries that are depicted with their own unique color. The legend also indicates whether an area ultimately drains to Anacostia #2 or Anacostia #1.

The Anacostia River watershed is highly urbanized. According to the Anacostia Watershed Restoration Partnership (AWRP), established by the Metropolitan Washington Council of Governments (MWCOG), about 45% of the watershed is residential, the dominant land use in the watershed. Undeveloped land covers just under 30% of the watershed. That undeveloped land is primarily forests and parks. Commercial and institutional land uses compose more than 15% of the watershed. Agriculture land use makes up 4.5% of the watershed. Industrial land use makes up less than 4% of the watershed. Finally, water and wetlands cover an additional 1%.

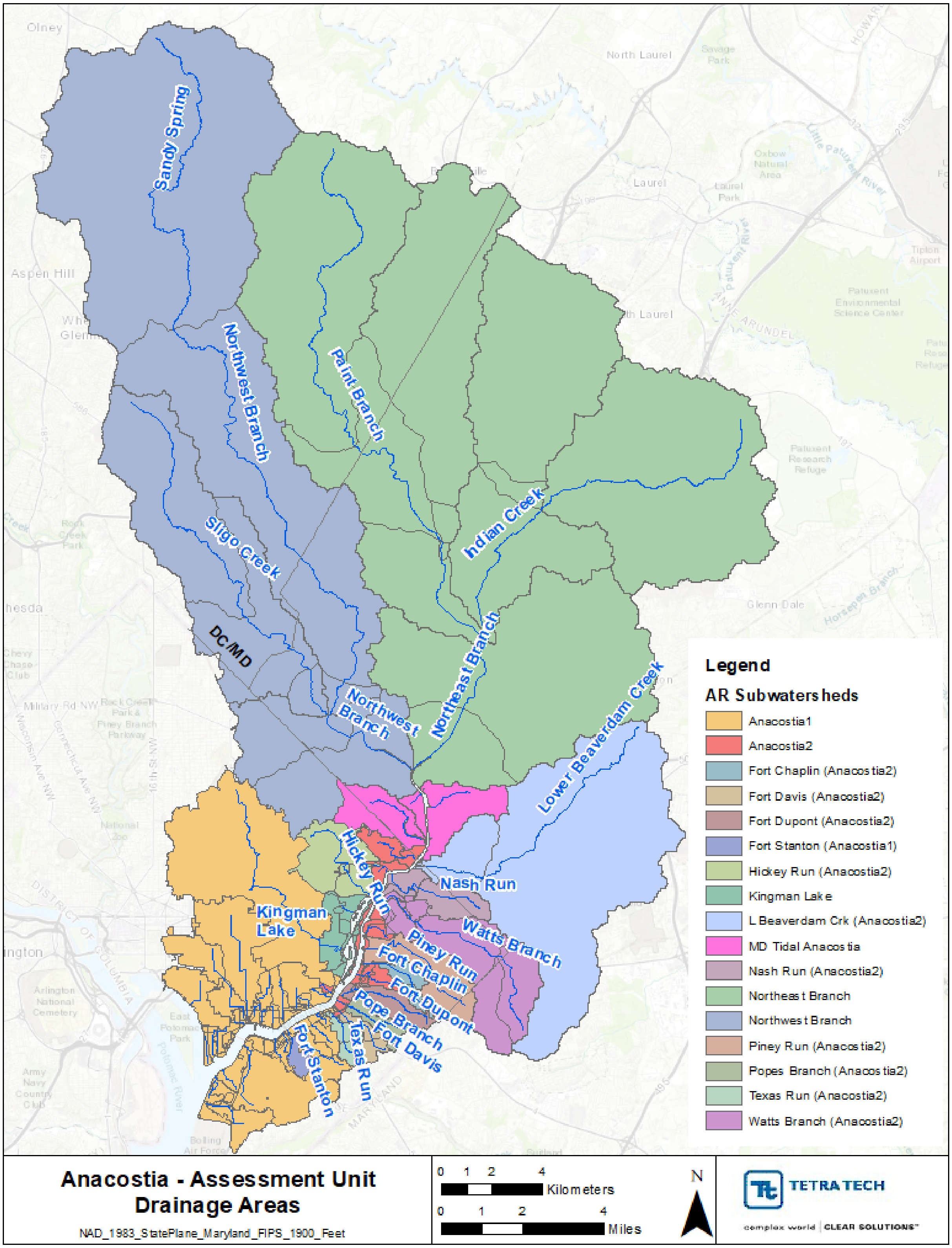


Figure 2-1. Anacostia River watershed assessment unit drainage areas.

According to the Anacostia River Watershed Implementation Plan (DC Health, 2005), the overall imperviousness of the watershed is 22.5%, although that varies among subwatersheds. The Upper Beaverdam Creek subwatershed has the lowest level of imperviousness at 6%, largely because of the presence of the U.S. Department of Agriculture, Beltsville Agricultural Research Center, which occupies most of the subwatershed (AWRP, 2010). The highest levels of imperviousness are in the Hickey Run (41%) and the Northeast Branch (37%) subwatersheds (AWRP 2009). Land use in Hickey Run is 30% industrial and 29% residential, while Northeast Branch is 51% residential and 10% commercial (AWRP 2009). Some areas of the tidal mainstem of the Anacostia River in DC, such as the northwest bank, have significantly higher levels of imperviousness (48%) (DC Health 2005).

2.2 IMPAIRMENTS AND LISTINGS

CWA sections 303(d) and 305(b) include requirements and responsibilities for states and DC related to identifying impaired waters and conducting water quality inventories, respectively. Both Maryland and DC submit Integrated Reports (IRs) to EPA, which fulfill the requirements of both those sections.

CWA section 305(b) reports provide the framework for section 303(d) impairment listings as a comprehensive inventory of water quality for surface waters within a jurisdiction. Failure to meet the applicable water quality criteria (WQC) generally results in that water body being included on the section 303(d) list of impaired waters for the violating pollutant.

The nomenclature and definition of designated uses adopted by the DOEE and MDE are slightly different as shown in Table 2-1. Where DOEE uses *Designated Use* as a description of that water use, an MDE *Use* is a code for the designated use description. DOEE uses a *Class* code for each *Designated Use*, while MDE gives a *Description* of each *Use*. For the purposes of this document *Use Code* will be used to refer to the *Class* and *Use* codes used by DOEE and MDE, respectively.

Table 2-1. Waterbody designated uses for the District of Columbia and the state of Maryland.

Jurisdiction	Designated use	Class	Listing criteria[a]
DC	Primary contact recreation	A	*Escherichia coli*, pH, turbidity
	Secondary contact recreation and aesthetic enjoyment	B	Aesthetics, pH, turbidity
	Protection and propagation of fish, shellfish, and wildlife	C	CCC, CMC
	Protection of human health related to consumption of fish and shellfish	D	Human health (fish tissue)
	Navigation	E	Presence/absence of unmarked fully/partially submerged man-made objects
Jurisdiction	**Description**	**Use[b]**	**Listing criteria[a]**
MD	Water contact recreation and protection of nontidal warmwater aquatic life	I	CCC, CMC, human health (water and fish tissue)
	Support of estuarine and marine aquatic life and shellfish harvesting	II	CCC, CMC, human health (water and fish tissue)
	Nontidal cold water	III	CCC, CMC, human health (water and fish tissue)
	Nontidal recreational trout waters	IV	CCC, CMC, human health (water and fish tissue)

Notes:
[a] CCC = Criteria Continuous Concentration; CMC = Criteria Maximum Concentration
[b] Each Maryland *Use* can also have a "-P" suffix indicating use as a public water supply; however, no water bodies in the Anacostia River watershed fall under this designation.

In addition to the nomenclature differences between DC and Maryland, the two jurisdictions also use a different methodology for assigning Use Codes to a water body. In DC, multiple Use Codes can be assigned to a water body, and each can either support or be impaired for associated criteria. In the state of Maryland, a water body is assigned one Use Code, which is either supported or impaired according to associated criteria. Current metals and toxic constituents impairments in the Anacostia River watershed are presented in Table 2-2 and Figure 2-2.

Table 2-2. Current Anacostia River water quality toxic constituents[a] impairment listings being addressed through TMDLs.

Waterbody	Uses supporting	Uses not supporting	Arsenic	Copper	Zinc	4,4 DDD	4,4 DDE	4,4 DDT	Chlordane	Dieldrin	Heptachlor epoxide	PAHs	Jurisdiction[b,c]
Anacostia #1	E	A, B, C, D	D	D	D	D	D	D	D	D	D	D	DC
Anacostia #2	E	A, B, C, D	D	D	D	D	D	D	D	D	D	D	DC
Kingman Lake	E	A, B, C, D	D					D	D			D	DC
Nash Run		A, B, C, D	D						D	D	D	D	DC
Popes Branch		A, B, C, D					D		D		D	D	DC
Watts Branch		A, B, C, D							D	D			DC
Hickey Run		A, B, C, D					D		D			D	DC
Fort Dupont		A, B, C, D	D										DC
Fort Chaplin		A, B, C, D	D										DC
Fort Davis		A, B, C, D	D										DC
Fort Stanton		A, B, C, D	D									D	DC
Texas Run		A, B, C, D	D			D	D	D	D	D	D	D	DC
MD Tidal Anacostia River		II									II		MD
MD Northwest Branch		I									I		MD

Notes:

DDD = dichlorodiphenyldichloroethane; DDE = Dichlorodiphenyldichloroethylene; DDT = dichlorodiphenyltrichloroethane

[a] Header shading color indicates type of toxin: Teal blue = metals, yellow = organochlorine pesticides, green = 1-6 ring PAHs

[b] DC uses: A = Primary contact recreation; B = secondary contact recreation and aesthetic enjoyment; C = protection and propagation of fish, shellfish, and wildlife; D = protection of human health related to consumption of fish and shellfish; E = navigation

[c] MD uses: I = Water contact recreation and protection of nontidal warmwater aquatic life; II = support of estuarine and marine aquatic life and shellfish harvesting

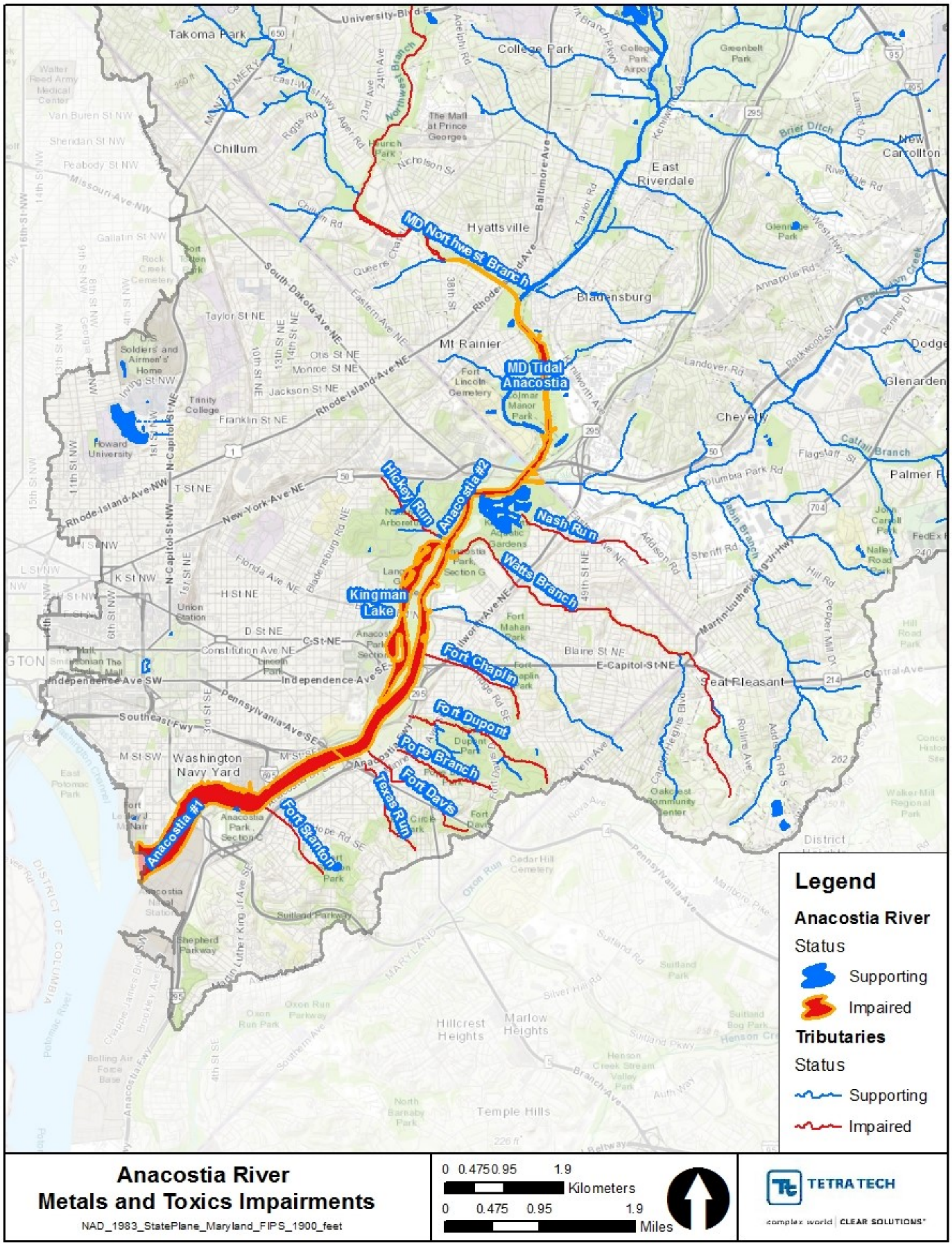


Figure 2-2. Anacostia River Watershed segments impaired by metals and toxic constituents.

The majority of DC toxic constituents impairments are the result of not supporting Use Code D (fish consumption). The original impairment listings were based on fish tissue data, which were only collected on the Anacostia mainstem, exceeding fish consumption advisory levels. The data collected on the Anacostia mainstem in DC was also used to originally list the tributaries as impaired. Maryland's heptachlor epoxide impairment in the tidal Anacostia River is also the result of fish tissue monitoring data that exceeded applicable screening levels.

In 2013–2014, EPA and Tetra Tech performed water column monitoring in the Anacostia tributaries to confirm/refute the historic listings that were based on mainstem fish tissue data. Where monitoring data showed exceedance of a criterion, the impairment remained in category 4a (i.e., where a state-developed TMDL has been approved by EPA or a TMDL has been established by EPA for any segment-pollutant combination). If there were no exceedances of criteria, the impairment was moved to category 3 (i.e., where there is insufficient available data and/or information to make a use-support determination) or completely delisted depending on the hydrologic connection. For more information on this process, see the DC 2014 Integrated Report (DDOE, 2014). Impairment of a fish consumption use can be addressed using applicable human health (HH) water column criteria, which are developed to be protective of fish consumption. Maryland's heptachlor epoxide listing in the Northwest Branch of the Anacostia River is a result of water quality monitoring data exceeding HH criteria.

TMDL development generally uses applicable WQC as endpoints for impaired water bodies. WQC are available for all current impairment listings in the Anacostia River watershed (Table 2-2); thus, the applicable WQC were applied as TMDL endpoints as they were for the original Anacostia River TMDLs developed by DC in 2003. However, the original impairment listings in the Anacostia mainstem for both DC and Maryland waters were based on fish tissue contamination data, which suggests that those screening levels *could* be evaluated as TMDL endpoints, as well. To do so, fish tissue screening levels (in micrograms [µg] per kilogram [kg]) would have to be converted to water column concentrations (in µg per liter [L]) and bed sediment concentrations (in µg/kg) using bioaccumulation factors (BAFs) (in L/kg) because the water quality model simulates water column and bed sediment concentrations only—not fish tissue concentrations. Because the water column endpoints developed using BAFs could be less stringent than existing WQC, a BAF-based endpoint would need to be compared to the existing WQC and the most stringent value chosen, where appropriate. For impairment listings based on fish tissue exceedances, MDE opted to calculate a BAF-based water column endpoint, compare it to the associated water column criteria, and then choose the most stringent of the two as the TMDL endpoint. In addition, MDE calculated a BAF-based bed sediment endpoint. Alternatively, for all the impairment listings in DC and the impairment listings in Maryland that were based on water column exceedances (as opposed to fish tissue exceedances), the associated WQC were directly chosen as TMDL endpoints.

2.3 CRITERIA

To support the selection of the TMDL endpoints for the Anacostia River metals and toxic constituents impairments, media (i.e., fresh water, fish tissue) quality criteria for the TMDL pollutants were compiled from responsible agencies, including:

Fresh Water

- DC (2020): DOEE WQC (21 DCMR §1104.8).
- EPA: Updated CWA section 304(a) WQC recommendations that have been published since May 30, 2000. DOEE has already adopted EPA's updated HH criteria for organochlorine pesticides and PAHs (2015). Although MDE also intends to adopt EPA's updated HH criteria for organochlorine pesticides and PAHs (2015), adoption may occur after TMDLs are finalized.
- Maryland (2018): MDE WQC (COMAR 26.08.02.03-2). In addition, Maryland COMAR 26.08.02.03-1 states that the waters of the Washington Metropolitan Area (Sub-Basin 02-14-02), including the Tidal Anacostia, are designated as freshwater; thus, the freshwater numeric criteria are applicable.

Fish Tissue

- EPA: Fish tissue screening guidelines from EPA Office of Water (U.S. EPA 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1, Fish Sampling and Analysis, Third edition. EPA 823-B-00-007, Office of Water, Washington DC). DOEE uses these values to evaluate waters using fish tissue data.

- Maryland: MDE Risk-Based Screening of Pollutant in Maryland Finfish Tissue.

Because both DC and Maryland have adopted EPA-approved WQC, those standards are in effect for the jurisdictions and supersede EPA's nationally recommended WQC. Both DC and Maryland have adopted WQC for all pollutants (metals, organochlorine pesticides, and PAHs) targeted in the current TMDLs. EPA's recommended criteria are included for comparison purposes and because Maryland intends to adopt EPA's 2015 recommended HH WQC with a 10^{-5} cancer risk level. The TMDLs are protective of MDE's current WQC and anticipated future criteria based on EPA's recommendations. Maryland's adoption of EPA's recommendations will occur after TMDL finalization. Drinking water (DW) criteria are presented for comparison purposes; however, no surface waters in the Anacostia watershed are used for drinking water withdrawals.

2.3.1 Fresh Water Criteria

2.3.1.1 Metals

Available metals WQC are listed in Table 2-3; they include aquatic life (Criteria Continuous Concentration [CCC] and Criteria Maximum Concentration [CMC]) criteria and HH criteria for the consumption of an organism. The most stringent *applicable* criteria are highlighted yellow for each Criteria Period (4-day average [aquatic life CCC], 1-hour average [aquatic life CMC], and 30-day average [HH]), where DC standards take precedence over Maryland standards because only DC waters are currently listed as impaired for metals. The only condition under which Maryland metals criteria would be selected as an endpoint for DC's impaired waters would be in the event that there are no applicable DC criteria, though that condition does not exist.

Current metals impairments are exclusive to waters in DC, but upstream contributions from Maryland will have to meet DC standards at the state boundary. Blue highlighted cells in the following table indicate where applicable Maryland criteria is less stringent than will be required at the boundary with DC. Maryland criteria that are more protective than the downstream criteria are highlighted in green.

Table 2-3. Applicable numeric WQC for metals.

Criteria class	Criteria period	Criteria class category	Jurisdiction	Extent	Arsenic, dissolved (µg/L)	Copper, dissolved (µg/L)	Zinc, dissolved (µg/L)
Aquatic life	4-day avg.	CCC	DC [a]	N/A	150	8.96[b]	118.14[c]
			EPA	N/A	150	—	120
			MD	N/A	150[d]	9[d]	120[d]
	1-hr avg.	CMC	DC [a]	N/A	340	13.44[b]	117.18[c]
			EPA	N/A	340	[e]	120
			MD	N/A	340[d]	13[d]	120[d]
Human health	30-day Avg. or 10 sample mean[k]	Organism	DC [a, f]	N/A	0.14[g]	—	26000
			EPA	N/A	0.14[g]	—	26000[h]
			MD	N/A	1.4[g, i]	—	26000
		DW + organism	EPA	N/A	0.018[g]	1300[g]	7400[h]
			MD	N/A	0.18[g]	1300	7400
		DW	MD	N/A	100	1300[j]	

Notes:
hr = hour; avg = average; µg/L = micrograms per liter

Header shading color indicates type of applicable criteria: Yellow = The most stringent applicable criteria for each Criteria Period; Medium blue = Applicable MD criteria that are less stringent than the downstream DC criteria; Green = Applicable MD criteria that are more protective than the downstream DC criteria
[a] DC Water Quality Standards (Effective August 5, 2020). The criteria for the hardness dependent constituents (copper and zinc) calculated using the applicable formulas below.
[b] CCC CF=0.960; CMC CF=0.960; CCC=$e^{(0.8545[\ln(hardness)]-1.702)}$x0.960; CMC=$e^{(0.9422[\ln(hardness)]-1.700)}$x0.960; assuming mean hardness 100 mg/L.
[c] CCC CF=0.986; CMC CF=0.978; CCC=$e^{(0.8473[\ln(hardness)]+0.884)}$x0.986; CMC=$e^{(0.8473[\ln(hardness)]+0.844)}$x0.978; assuming mean hardness 100 mg/L.
[d] The toxicity of these substances is increased or decreased by hardness or pH and are subject to §D of MD regulation for determining site specific criteria.
[e] Freshwater criteria calculated using the biotic ligand method.
[f] DC Class D HH criteria for metals based on total recoverable metals.
[g] This criterion is based on carcinogenicity of 10^{-6} risk.
[h] This chemical has a criterion for organoleptic (taste and order) effects. In some cases, the organoleptic criterion may be more stringent.
[i] Criterion will be applied against the actual measurement of inorganic arsenic (As+3), rather than total arsenic.
[j] Copper is regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps.
[k] The long-term exposure component of applicable HH criteria is expressed as a 30-day average for DC and as a mean of 10 samples collected over a representative temporal period and spatial extent for MD criteria.

Observations from the freshwater metals WQC comparison include:

- Applicable DC aquatic life CCC for all three metals are the most stringent currently applicable criteria for that use category. Maryland criteria for arsenic are the same as DC. The DC CCC WQC for copper (8.96 µg/L) and zinc (118.14 µg/L) were applied to Maryland waters to meet the downstream DC WQC.
- The most stringent applicable aquatic life CMC WQC for metals are the DC criteria. While the Maryland copper criterion (13 µg/L) is more stringent, it is likely not applicable due to the lack of waters listed as impaired for metals in Maryland. Maryland criteria for arsenic are the same as DC. The DC CMC WQC for zinc (117.18 µg/L) were applied to Maryland waters to meet the downstream DC water quality standard.
- The most stringent applicable HH organism WQC for arsenic and zinc are the DC criteria. Maryland criteria for zinc is the same as DC. The DC HH criteria for arsenic (0.18 µg/L) were applied to Maryland waters to meet the downstream DC WQC. There are currently no applicable HH organism WQC for copper.

2.3.1.2 Organochloride Pesticides

Available organochlorine pesticide WQC are listed in Table 2-4 and include aquatic life (CCC and CMC) standards and HH organism standards. The most stringent *applicable* criteria are highlighted yellow for each Criteria Period, where DC criteria take precedence over Maryland criteria for all constituents except heptachlor epoxide, for which there are both DC and Maryland impairment listings.

Current toxic constituents impairments in DC include all six constituents, while Maryland impairments are limited to heptachlor epoxide. Upstream contributions from Maryland will have to meet the DC criteria at the DC/Maryland state line for the other five pollutants to protect the downstream condition. Applicable Maryland criteria for each Criteria Period that will have to meet DC criteria due to more stringent downstream criteria are highlighted blue. There are no Maryland criteria that are more protective than the downstream DC criteria.

Table 2-4. Applicable Numeric Organochloride Pesticide WQC.

Criteria class	Criteria period	Criteria class category	Juris.	4,4 DDD (µg/L)	4,4 DDE (µg/L)	4,4 DDT (µg/L)	Chlordane (µg/L)	Dieldrin (µg/L)	Heptachlor epoxide (µg/L)
Aquatic life	4-day avg.	CCC	DC	0.001	0.001	0.001	0.0043	0.056	0.0038
			EPA	—	—	0.001	0.0043	0.056	0.0038
			MD	—	—	—	0.0043	0.056	0.0038
	1-hr avg.	CMC	DC	1.1	1.1	1.1	2.4	0.24	0.52
			EPA	—	—	1.1	2.4	0.24	0.52
			MD	—	—	—	2.4	0.24	0.52
Human health	30-day Avg. or 10 sample mean[a]	Organism[a]	DC	0.00012	0.000018	0.000030	0.00032	0.0000012	0.000032
			EPA (2015)	0.00012	0.000018	0.000030	0.00032[b]	0.0000012	0.000032[b]
			MD	0.0031	0.0022	0.0022	0.0081	0.00054	0.00039
		DW + Organism[c]	EPA (2015)	0.00012	0.000018	0.000030	0.00031[b]	0.0000012	0.000032[b]
			MD	0.0031	0.0022	0.0022	0.008	0.00052	0.00039
		DW	MD	—	—	—	2	—	0.2

Notes:
Cell shading color indicates type of applicable criteria: Yellow = The most stringent applicable criteria for each Criteria Period; Medium blue = Applicable MD criteria that are less stringent than the downstream DC criteria.
[a] This criterion is based on carcinogenicity of 10^{-6} risk.

[b] EPA has issued an MCL for this chemical under the Safe Drinking Water Act. In some cases, the MCL may be more stringent.
[c] The long-term exposure component of applicable HH criteria is expressed as a 30-day average for DC and EPA criteria and as a mean of 10 samples collected over a representative temporal period and spatial extent for MD criteria.

Observations from the freshwater organochlorine pesticide WQC comparison include:

- Applicable DC aquatic life CCC and CMC WQC for all six pollutants are the most stringent currently applicable criteria for those use categories. Available Maryland criteria are equal to the DC aquatic life WQC for chlordane, dieldrin, and heptachlor epoxide, but are undefined for 4,4 DDD, 4,4 DDE, and 4,4 DDT. The DC criteria for 4,4 DDT and its degradants were applied to Maryland waters to meet the downstream DC WQC.
- The most stringent applicable HH organism WQC for organochlorine pesticides are the DC criteria, which align with EPA's 2015 HH criteria recommendations. The DC (2020) HH organism criteria for all organochlorine pesticides were also applied to Maryland waters to meet the downstream DC WQC.
- In an effort to align with the modeling platform and the previous TMDLs' assumptions, DDD, DDE, and DDT were grouped together, and the most stringent criterion was used as the TMDL endpoint for the group.

2.3.1.3 PAHs

Available PAHs WQC are listed in Table 2-5 and include aquatic life (CCC only) criteria and HH organism criteria. The most stringent *applicable* criteria are highlighted yellow for each Criteria Period, where DC criteria take precedence over Maryland criteria because there are currently no Maryland impairment listings for PAHs in the Anacostia River watershed. The only condition under which Maryland PAH criteria would be selected as an endpoint for DC impaired waters would be in the event that there are no applicable DC criteria, and that condition does not exist.

Current PAHs impairments are exclusive to waters in DC, but upstream contributions from Maryland will have to meet DC standards at the DC/MD state line. As a result, Maryland waters may need to meet the DC standards in cases where Maryland's standards are less protective. Applicable Maryland criteria for each Criteria Period that need to meet DC standards due to more stringent downstream criteria are highlighted blue. There are no Maryland criteria that are more protective than the downstream DC criteria.

Table 2-5. Applicable numeric PAHs WQC

		Aquatic life	Human health					
		4-day avg.	30-day average or 10-sample mean[a]					
		CCC	Organism			DW + organism		DW
PAH group	PAH pollutant	DC	DC	EPA (2015)	MD	EPA (2015)	MD	MD
PAH1 (2 + 3 ring) (µg/L)	Acenaphthene	50	90	90[b]	990	70[b]	670	—
	Acenapthylene	—	—	—	—	—	—	—
	Anthracene	—	400	400	40000	300	8300	—
	Fluorene	—	70	70	5300	50	1100	—
	Naphthalene	600	—	—	—	—	—	—
PAH2 (4 ring) (µg/L)	Benzo[a]anthracene	—	0.0013[c]	0.0013[c]	0.18[c]	0.0012[c]	0.038[c]	—
	Chrysene	—	0.13[c]	0.13[c,d]	0.18[c]	0.12[b,d]	0.038[c]	—
	Fluoranthene	400	20	20	140	20	130	—
	Pyrene	—	30	30	4000	20	830	—
PAH3 (5 + 6 ring) (µg/L)	Benzo[a]pyrene	—	0.00013[c]	0.00013[c,d]	0.18[c]	0.00012[c,d]	0.038[c]	0.2
	Benzo[b]fluoranthene	—	0.0013[c]	0.0013[c]	0.18[c]	0.0012[c]	0.038[c]	—
	Benzo[k]fluoranthene	—	0.013[c]	0.013[c]	0.18[c]	0.012[c]	0.038[c]	—
	Dibenzo[a,h]anthracene	—	0.00013[c]	0.00013[c]	0.18[c]	0.00012[c]	0.038[c]	—
	Indeno[1,2,3-c,d]pyrene	—	0.0013[c]	0.0013[c]	0.18[c]	0.0012[c]	0.038[c]	—

Notes:
Cell shading color indicates type of applicable criteria: Yellow = The most stringent applicable criteria for each Criteria Period; Medium blue = Applicable MD criteria that are less stringent than the downstream DC criteria.
[a] The long-term exposure component of applicable HH criteria is expressed as a 30-day average for DC and EPA criteria and as a mean of 10 samples collected over a representative temporal period and spatial extent for MD criteria.
[b] This chemical has a criterion for organoleptic (taste and order) effects. In some cases, the organoleptic criterion may be more stringent.
[c] This criterion is based on carcinogenicity of 10-6 risk.
[d] EPA has issued a Maximum Contaminant Level (MCL) for this chemical under the Safe Drinking Water Act. In some cases, the MCL may be more stringent.

Observations from the freshwater PAHs WQC comparison include:

- The *only* applicable aquatic life WQC for PAHs are DC criteria. Note that the selected TMDL endpoint was applied to Maryland waters to meet the downstream DC water quality requirements.
- The most stringent applicable HH WQC for PAHs are currently the DC criteria; these will be used as the TMDL endpoints. The HH organism WQC for all PAHs were applied to Maryland waters to meet the downstream DC water quality requirements.

- As illustrated in Table 2-5, PAHs were grouped into three groups based on ring structure. The 2003 TMDLs used a conservative assumption where the most stringent criterion within each PAH group was selected as the TMDL endpoint. This approach will be used again in these TMDLs to align with the modeling platform and the previous TMDLs' assumptions.

2.3.1.4 Sediment and Fish Tissue

Available fish tissue screening levels are presented in Table 2-6. Note that DC has adopted EPA fish tissue screening levels for determining fish tissue based HH impairments. In general, these numerical standards would be considered as TMDL endpoints in the absence of applicable WQC. However, current metals and toxic constituents impairments in the tidal Anacostia mainstem are based on fish tissue screening levels, which indicates a potential to consider those standards for use as TMDL endpoints. Whereas MDE has decided to convert Maryland's fish tissue thresholds into a TMDL endpoint to use in the Maryland tidal mainstem Anacostia River where fish tissue monitoring was used to originally list the water body as impaired, DOEE has chosen to solely use the applicable WQC as TMDL endpoints.[1]

For the Maryland portion of the tidal Anacostia mainstem, fish tissue screening levels were converted to corresponding water column and bed sediment concentrations using BAFs. This is the preferred approach of MDE when an impairment is based on a fish tissue listing. The calculation of BAFs (in L/kg) requires coincident fish tissue, sediment, and water column monitoring data; these are typically calculated at the fish species level to account for differences in trophic levels.

A baseline BAF is the ratio of the pollutant concentration in an organism's wet tissue to its concentration in water, normalized for lipid content of the fish tissue. Typically, a species that is most susceptible to accumulating and maintaining pollutant concentrations is selected as the target species for TMDL development. There is no guarantee that a BAF-based water column concentration endpoint would be more protective of existing applicable HH WQC, however. Because applicable water column criteria are available for individual DDT degradants and individual PAHs, the calculation of fish tissue-based endpoints using the below values for the grouped DDT degradants and PAHs may be ineffective. Because in these cases, we cannot compare fish tissue-based endpoints with existing WQC. Equations used for the calculation of baseline BAFs include:

$$totalBAF = \frac{[pollutant]_{tissue}}{[pollutant]_{water}}$$

Where $[pollutant]_{tissue}$ = pollutant concentration in wet fish tissue (µg/kg)

$[pollutant]_{water}$ = pollutant concentration in water (µg/liter)

$$baselineBAF = \left(\frac{totalBAF}{F_d} - 1\right) \times \frac{1}{\%lipid}$$

Where F_d = fraction of pollutant in water that is freely dissolved

[1] DOEE chose to apply only the applicable water quality column criteria as TMDL endpoints in an effort to be consistent across the jurisdiction and because those criteria are finalized in DC regulations and were appropriately calculated to address fish consumption human health risks. The fish tissue thresholds for many of the TMDL pollutants were not calculated according to the same pollutant groups as were the criteria (e.g., PAHs and DDT), so a comparison was impractical. Furthermore, some TMDL pollutants did not have an associated fish tissue listing threshold (e.g., copper and zinc). Please see tables 2-3 through 2-6.

Table 2-6. Available metals, toxic constituents, and total PAHs fish tissue screening levels

Media	Fish tissue (mg/kg)			
Jurisdiction	MD		EPA (2000)	
Type	Non-carcinogenic	Carcinogenic	Non-carcinogenic	Carcinogenic
Arsenic	—	—	1.2	0.026
Copper	—	—	—	—
Zinc	—	—	—	—
4,4 DDD	—	—	—	—
4,4 DDE	—	—	—	—
4,4 DDT	—	—	—	—
Total DDT[a]	—	—	2.0	0.117
Chlordane	—	—	2.0	0.114
Dieldrin	—	—	0.2	0.0025
Heptachlor epoxide	0.03315	0.00934	0.052	0.00439
Total PAHs	—	—	—	0.00547

Notes:
[a] sum of 4,4 and 2,4 – isomers of DDT, DDE, and DDD

2.4 ENDPOINTS

Recommended TMDL endpoints should be selected based on the review of the available and applicable water column and fish tissue WQC/threshold levels. The WQC for metals and toxic constituents impairments that are protective of both DC and Maryland designated uses are presented in Table 2-7. Fish tissue screening levels, which was the metric used to designate impairment for heptachlor epoxide in the Maryland tidal Anacostia mainstem, were also evaluated as converted WQC using BAFs calculated from available fish tissue, water column, and sediment monitoring data. Those calculation results showed that, while MDE's existing water column criteria are less stringent than the BAF-based water column concentrations (see detailed discussion in this section), the most downstream criteria are more stringent than the BAF-based water column concentrations; thus they were used as the endpoint.

The Anacostia Toxics TMDL model incorporates total DDT rather than the individual degradates. This is because there is little to no degradate data with which to configure and calibrate the model. To ensure that the TMDL will be protective of individual degradate criteria, the most stringent degradate criteria was used as the TMDL endpoint for DDT (Table 2-8).

Similar to DDT, the individual PAHs are not simulated in the model due to lack of configuration and calibration data. PAH was modeled in three groups (PAH1, PAH2, and PAH3), and the most stringent criteria within a group was used as the endpoint for that group. Table 2-8 shows how the individual PAH contaminants are categorized into the three PAH groups.

The most stringent *applicable* criteria are highlighted yellow; these drive TMDL reductions, as they are the most protective of water quality and human health.

Table 2-7. Recommended WQC TMDL endpoints

Pollutant group	Pollutant		CCC (4-day)	CMC (1-hr)	HH (30-day)[a]	Sediment (mg/kg)
Metals (µg/L)	Arsenic, dissolved		150	340	0.14	—
	Copper, dissolved		8.96	13.44	—	—
	Zinc, dissolved		118.14	117.18	26000	—
Organochlorine pesticides(µg/L)	DDT	4,4 DDD	0.001	1.1	0.00012	—
		4,4 DDE	0.001	1.1	0.000018	—
		4,4 DDT	0.001	1.1	0.00003	—
	Chlordane		0.0043	2.4	0.00032	—
	Dieldrin		0.056	0.24	0.0000012	—
	Heptachlor epoxide		0.0038	0.52	0.000032	0.000355
PAH1 (µg/L)	Acenaphthene		50	—	90	—
	Acenapthylene		—	—	—	—
	Anthracene		—	—	400	—
	Fluorene		—	—	70	—
	Naphthalene		600	—	—	—
PAH2 (µg/L)	Benzo[a]anthracene		—	—	0.0013	—
	Chrysene		—	—	0.13	—
	Fluoranthene		400	—	20	—
	Pyrene		—	—	30	—
PAH3 (µg/L)	Benzo[a]pyrene		—	—	0.00013	—
	Benzo[b]fluoranthene		—	—	0.0013	—
	Benzo[g,h,i]perylene		—	—	—	—
	Benzo[k]fluoranthene		—	—	0.013	—
	Dibenzo[a,h]anthracene		—	—	0.00013	—
	Indeno[1,2,3-c,d]pyrene		—	—	0.0013	—

Notes:
[a] The long-term exposure component of applicable HH criteria is expressed as a 30-day average for DC and EPA criteria and as a mean of 10 samples collected over a representative temporal period and spatial extent for MD criteria.
[b] MD WQC
[c] MD sediment screening value

2.4.1 Bioaccumulation Factors

It can be difficult to determine the occurrence and magnitude of hydrophobic pollutants in surface waters due to the tendency of those chemicals to adhere to sediments and organic material. Similarly, the pollutant concentrations resulting in biological impacts to aquatic species can also be difficult to determine where water column concentrations don't accurately reflect the contamination of species—particularly in benthic species that maintain continual contact with riverbed sediments.

BAFs or bio-sediment accumulation factors (BSAFs), when sediment is the media being evaluated) provide a means to assess the occurrence of hydrophobic pollutants, including the metals and toxic constituents relevant to these TMDLs, and their impact on aquatic life. They provide a method to determine ambient water quality thresholds that are protective of fish and other aquatic species by translating fish tissue listing thresholds, which are more easily measured in the environment, to associated water column concentrations.

MDE uses a Toxic Constituents Assessment Triad, where the determination of a water body's impaired status, also includes an assessment of fish tissue levels. As such, BAF and BSAF endpoints for heptachlor epoxide (HE) were determined using available fish tissue, sediment, and water column data. Those analyses were limited to HE because it is the only toxic constituents impairment identified for the Anacostia River by MDE.

2.4.1.1 BAF

Bioaccumulation factors are developed in a three-part calculation:

1. Total BAF: the ratio of pollutant contamination in the fish tissue to pollutant concentration in the water.
2. Baseline BAF: the Total BAF adjusted for fish lipid percentage and the pollutant dissolved fraction.
3. Adjusted Total BAF: Baseline BAF adjusted for median fish lipid percentage.

The Total BAF was calculated according to (EPA, 2003):

$$totalBAF = \frac{[HE]_{fish}}{[HE]_{water}}$$

Where: $[HE]_{fish}$ = is the HE concentration in wet fish tissue (nanogram [ng]/kg)

$[HE]_{water}$ = is the median water column HE concentration in the section of the river where the fish was caught

Baseline BAFs include lipid normalization for fish species to account for the feeding habits and related exposure of fish species to a contaminant. The calculation also normalizes for the freely dissolved HE in the water column. The Baseline BAF was also calculated according to EPA (2003) as:

$$Baseline\ BAF = \frac{[HE]_{fish}/\%Lipid}{[HE]_{water} \times \%fd}$$

Where: %fd = fraction of the HE concentration that is freely dissolved in water

%lipid = the fraction of fish tissue that is lipid

A freely dissolved contaminant is one that's not sediment-associated or adsorbed to dissolved organic carbon (DOC) or particulate organic carbon (POC). It can be estimated according to EPA (2003) as:

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

Where: K_{OW}: is the HE octanol-water partition coefficient ($10^{4.9055}$)

POC = particulate organic carbon estimated as 10% of total organic carbon calculated as the average concentration measured in the section of the river where a fish was caught

DOC = dissolved organic carbon estimated as 90% of total organic carbon calculated as the average concentration measured in the section of the river where a fish was caught

The Adjusted Total BAF can be thought of as being representative of the ecosystem, where fish lipid content and freely dissolved HE concentrations are not variable. Adjusted Total BAFs were calculated from the baseline BAFs by normalizing for fish species median lipid percentage and the median freely dissolved HE concentration:

$$Adj\ tBAF = (Baseline\ BAF \times Median\ \%Lipid + 1) \times Median\%fd$$

The HE fish tissue listing threshold of 9.34 µg/kg can then be divided by the median Adjusted Total BAF for each species to determine an associated HE water column threshold concentration. Those species-specific BAF endpoints are provided in Table 2-9; carp are the most susceptible species and thus have the most stringent water column concentration.

Table 2-8. Adjusted Total BAF fish species HE endpoints

Fish species	Adj-tBAF (L/kg)	HE water column endpoint (µg/L)
Blue catfish	10,209	0.000915
Carp	48,072	0.000194
Channel catfish	16,096	0.000580
Brown bullhead	20,929	0.000446
Northern snakehead	7,228	0.001292
Median	**16,096**	**0.000580**

2.4.1.2 BSAF

Bio-sediment accumulation factors are developed in a two-part calculation:

1. BSAF: the ratio of lipid adjusted fish tissue concentration to organic carbon adjusted sediment concentration.
2. Adjusted BSAF: BSAF adjusted for median fish lipid percentage and median sediment organic carbon percentage.

The BSAFs were calculated as:

$$BSAF = \frac{[HE]_{fish}/\%Lipid}{[HE]_{sediment}/\%Organic\ \ Carbon}$$

Where: $[HE]_{sediment}$ = is the HE concentration in the sediment (ng/kg)

% Organic Carbon = the percent organic carbon measured in the section of the river where a fish was caught

Sediment HE concentrations and percent organic carbon of stream bed sediments were taken from values developed for the Environmental Fluid Dynamics Code (EFDC) computational grid as described in Section 4.3.1. Similar to fish species Adjusted Total BAF, the Adjusted Sediment BAFs can be thought of as being representative of the ecosystem, where fish lipid content and percent organic carbon are not variable. Adjusted Sediment BAFs were calculated from the Baseline Sediment BAFs by normalizing for fish species median lipid percentage and the median organic carbon percentage:

$$Adj\text{-}SedBAF = BSAF \times \frac{Median\ \%Lipid}{Median\ \%Organic\ \ Carbon}$$

The HE fish tissue listing threshold of 9.34 µg/kg can then be divided by the median Adjusted Sediment BAF , for each species to determine an associated HE sediment target concentration. Those species-specific SedBAF endpoints are provided in Table 2-9, where, like for the BAF analysis, carp are the most susceptible species and thus have the most stringent sediment concentration target.

Table 2-9. Adjusted Sediment BAF fish species HE endpoints

Fish species	Adj-SedBAF (kg/kg)	HE Sed target (ug/kg)
Blue catfish	12.82	0.73
Carp	60.35	0.15
Channel catfish	20.21	0.46
Brown bullhead	26.27	0.36
Northern snakehead	9.07	1.03
Median	**20.21**	**0.46**

3.0 LSPC CONFIGURATION

A watershed model is a series of algorithms applied to watershed characteristics and meteorological data to simulate land-based processes over a selected period, including rainfall-runoff, interflow, groundwater flow, flow routing, water temperature, and pollutant loadings. Watershed models often use build-up and wash-off representations of pollutants on land surfaces and can accommodate other processes including pollutant-soil/sediment association, subsurface pollutant transport, and atmospheric deposition of pollutants. Many watershed models are also capable of simulating instream processes using land-based contributions as input. Watershed models can provide flow and pollutant loading (boundary conditions) to a receiving water model and can also simulate water quality processes within streams and lakes with relatively simple algorithms.

A calibrated watershed model can be used to characterize loadings from the Anacostia River watershed beginning at the headwaters in Maryland, ensuring that all major watershed sources and pathways are represented, including catchments adjacent to the tidal reaches of the Anacostia River. A watershed model can estimate the relative pollutant contributions from multiple sources and can connect these contributions to the spatial distribution of contamination over time. For TMDL development, the model applied should possess the following capabilities to be a scientifically sound representation of the watershed loading and transport system and an advantageous management tool:

- Simulate hydrologic variations due to time variable weather patterns and the related transient saturation or unsaturated condition of the land surface/subsurface.
- Simulate time variable chemical loadings from various sources in the watershed, including the sediment-associated pollutants (metals, organochlorine pesticides, and PAHs) that are the target of TMDL development.
- Simulate interactions within a stream channel.
- Provide model results with a broad range of spatial and temporal scales.
- Evaluate source loading abatement scenarios for water quality control/management design.

The Loading Simulation Program in C++ (LSPC) model version 5.0 ((U.S.EPA, 2009) is the platform selected for watershed simulation and toxic constituents TMDL development for the Anacostia River, its tributaries, and Kingman Lake because it meets these criteria. For additional discussion related to selection of the modeling framework for this TMDL, please see the Model Selection Memorandum prepared for this project (Tetra Tech, 2018a).

LSPC is a watershed modeling system that includes the most commonly used Hydrologic Simulation Program – FORTRAN (HSPF) algorithms for simulating watershed hydrology, erosion, water quality, and instream transport processes (Table 3-1). The algorithms of LSPC are identical to a subset of those in the HSPF model with selected additions, such as algorithms to dynamically address land use change over time. The EPA Office of Research and Development in Athens, Georgia, first made LSPC available as a component of EPA's National TMDL Toolbox (http://www.epa.gov/athens/wwqtsc/index.html).

Table 3-1. HSPF modules included in LSPC

Watershed modules (PERLND/IMPLND)	SNOW	Simulates snow fall, accumulation, and melting
	PWATER/IWATER	Simulates water budget for a pervious/impervious land segment
	SEDMNT/SOLIDS	Simulates production and removal of sediment for a pervious/impervious land segment
	PSTEMP	Simulates soil layer temperatures
	PWTGAS/IWTGAS	Estimates water temperature and dissolved gas concentrations in the outflows from pervious/impervious land segments
	PQUAL/IQUAL	Simulates water quality in the outflows from pervious/impervious land segments
Receiving water modules (RCHRES)	HYDR	Simulates instream hydraulic behavior
	ADCALC	Simulates instream advection of dissolved or entrained constituents
	HTRCH	Simulates instream heat exchange
	SEDTRN	Simulates instream behavior of inorganic sediment
	GQUAL	Simulates instream behavior of a generalized quality constituent
	RQUAL	Simulates instream behavior constituents involved in biochemical transformations
	NUTRX	Simulates the primary processes that determine the balance of inorganic nitrogen and phosphorus in natural waters
	PLANK	Simulates phytoplankton, zooplankton, and/or benthic algae

The LSPC watershed model is a dynamic hydrology/loading model that includes a one-dimensional fully mixed receiving water model component to simulate instream water quality of tributaries and nontidal portions of the Anacostia River. It includes hydrological and chemical/sediment loading simulation to predict chemical fate and transport at the subwatershed scale. The model can generate either hourly or daily intervals to predict and compare simulated conditions with the existing observed data and/or to further use the results for advanced management decision support. In addition, LSPC is tailored to interface with the EFDC, the selected receiving water model platform for the tidal portions of the Anacostia River. LSPC will be used to provide flow and loadings (boundary conditions) to the EFDC model and to support the determination of the required load reductions to meet TMDL endpoints.

LSPC requires considerable data for configuration and calibration, providing the ability to represent complex pollutant interactions in detail. The model provides a variety of hydrologic and pollutant loading outputs, which facilitate linkages to a receiving water model. The major components of the LSPC model that control the resolution at which simulations are run are the subwatershed delineation, hydrological response unit (HRU) land use categories, and weather data inputs. The TMDL model is based on the existing watershed model developed for the Anacostia River Remedial Investigation (Tetra Tech, 2019). Important characteristics of the Remedial Investigation LSPC model in the context of current TMDL development include:

- Relatively coarse watershed boundaries for the headwaters, but a more detailed segmentation for the urban mainstem drainages to capture municipal separate storm sewer system (MS4) and combined sewer overflow (CSO) outfalls in the combined sewer system (CSS) area, as well as known contaminated sites. The total model subwatershed count is 122 and the delineations are shown in Figure 3-1 and Figure 3-2. Limited adaptations have been made for the TMDL model to more accurately represent sources of the parameters of concern for the TMDL (e.g., National Pollution Discharge Elimination System [NPDES] facilities).
- Representation of NPDES dischargers in the Anacostia River watershed. The Remedial Investigation LSPC model originally included 50 individual facilities and 75 total outfalls discharging flow and total sediment; these were refined for the TMDL modeling so that there are now 8 facilities and 22 total outfalls.

- HRUs that combine land cover, hydrologic soil group, and slope into a composite model land use representation to properly capture upland pollutant loading and hydrology.
- Hourly meteorological data (precipitation, potential evapotranspiration, temperature, dew point temperature, wind speed, cloud cover, and solar radiation) from the Ronald Reagan Washington National Airport (01/1/2005–12/31/2015). For the TMDL model, these data have been extended through summer 2018.
- Simulation of sediment associated pollutant dynamics (adsorption/desorption), as well as contributions from bed sediments, which are critical for the simulation of metals, pesticides, and PAHs.

The remainder of this section describes how the LSPC watershed model was configured. It details the data used to represent key physical characteristics, driving force weather data, and representation of pollutant sources.

3.1 PHYSICAL REPRESENTATION

LSPC is a lumped model, where the watershed area is divided into numerous subbasins. Within each subbasin, processes are simulated for each type of land area on a per-acre basis, then multiplied by the relevant acreage to develop the total local load to the stream reach within the subbasin. Individual land areas are represented as HRUs, which combine land use/cover, soil, slope, and other characteristics. Each HRU is a generalized representation of a specific type of source area within the subbasin. For example, all parking lots within the subbasin would be represented by a single unit-area HRU with appropriate runoff and pollutant-generating characteristics, rather than simulating each parking lot individually. Where necessary, HRUs can be further divided—for instance, if one parking lot or type of parking lot generated higher pollutant loads than the typical parking lot it can be specified by a separate HRU. The HRU approach allows incorporation of a high degree of detail into the model while also allowing for efficient simulation and relatively short model run times.

3.1.1 Watershed Segmentation

Watershed segmentation refers to the subdivision of the entire model area into smaller, discrete subwatersheds and stream reaches for the modeling and analysis process. This subdivision was based primarily on existing hydrologic boundaries and engineered MS4 storm drain networks and secondarily on topography and the locations of flow and water quality monitoring stations.

Hydrologic boundaries for the Maryland portion of the Anacostia River watershed were obtained from the Metropolitan Washington Council of Governments (MWCOG), which developed watershed boundaries and hydrography flow lines for the watershed. Boundaries were developed using 30-meter resolution digital elevation models from the National Elevation Dataset (NED). Hydrologic and water quality monitoring locations were also used to inform the delineations since these data were used for model calibration. The hydrologic delineation for the Maryland portion of the watershed was then merged with MS4 sewershed boundaries for the Washington, DC, portion of the watershed to capture the urban drainage and CSOs that characterize the area. Maryland MS4 and non-MS4 areas and corresponding loads were accounted for outside of the model based on the most recent NPDES regulated stormwater and land use shapefiles provided by MDE. Finally, known contaminated sites were explicitly delineated from the merged watershed/sewershed boundaries so that they could be characterized for associated pollutant loads.

The final subwatershed count is 122, 35 of which are the result of delineating known contaminated sites. In general, subwatershed size tends to increase in less developed areas of the upper watershed, while smaller subwatershed sizes were used to characterize urban areas. The smaller urban drainages were used to better characterize the numerous MS4 and CSO outfalls that line the Anacostia River in the DC portion of the watershed. Final watershed segmentations are shown in Figure 3-1 and Figure 3-2. The DC and Maryland portions of the watershed are shown in separate figures to better show the many smaller urban drainage areas in the DC portion.

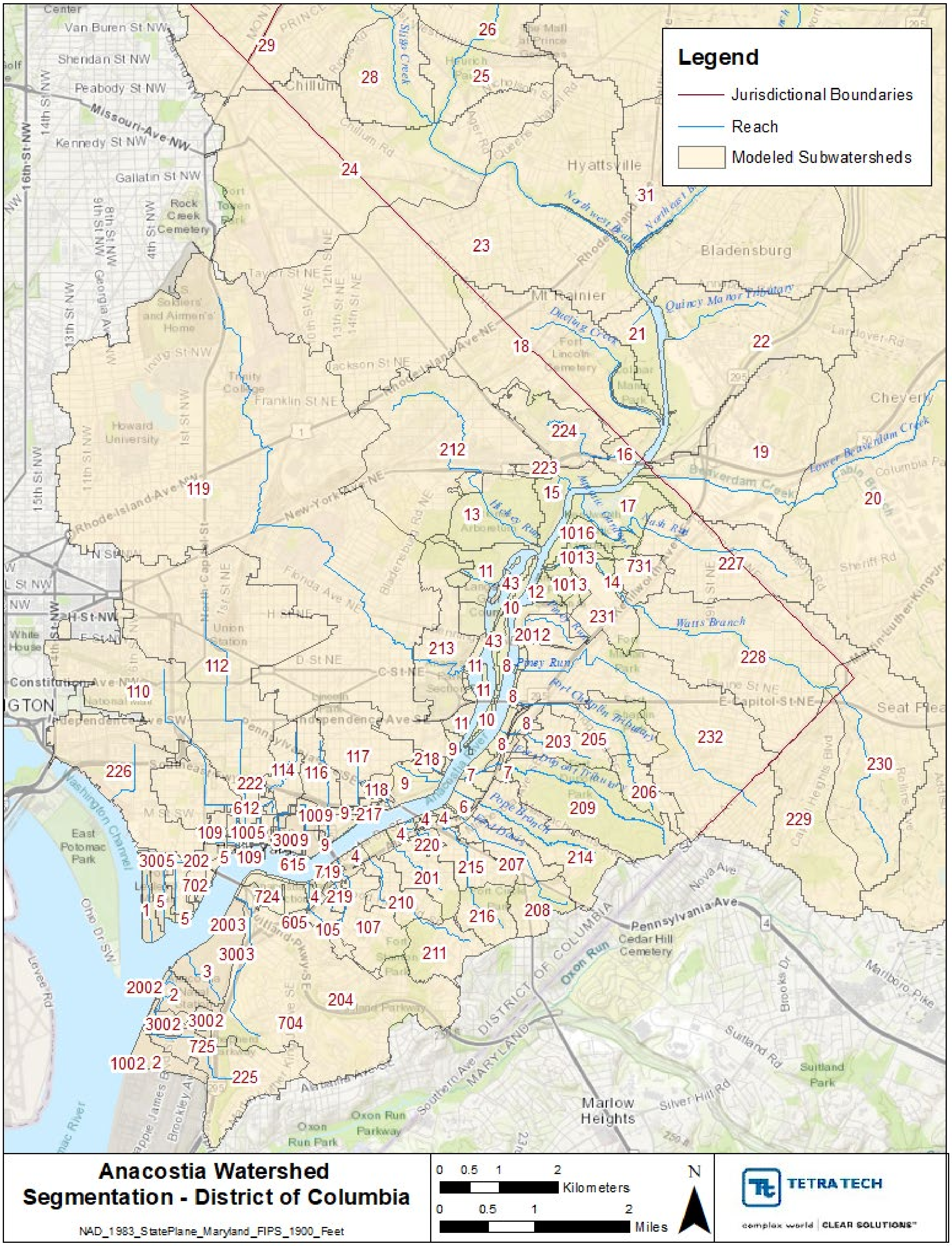


Figure 3-1. Anacostia River watershed segmentation focused on the District of Columbia.

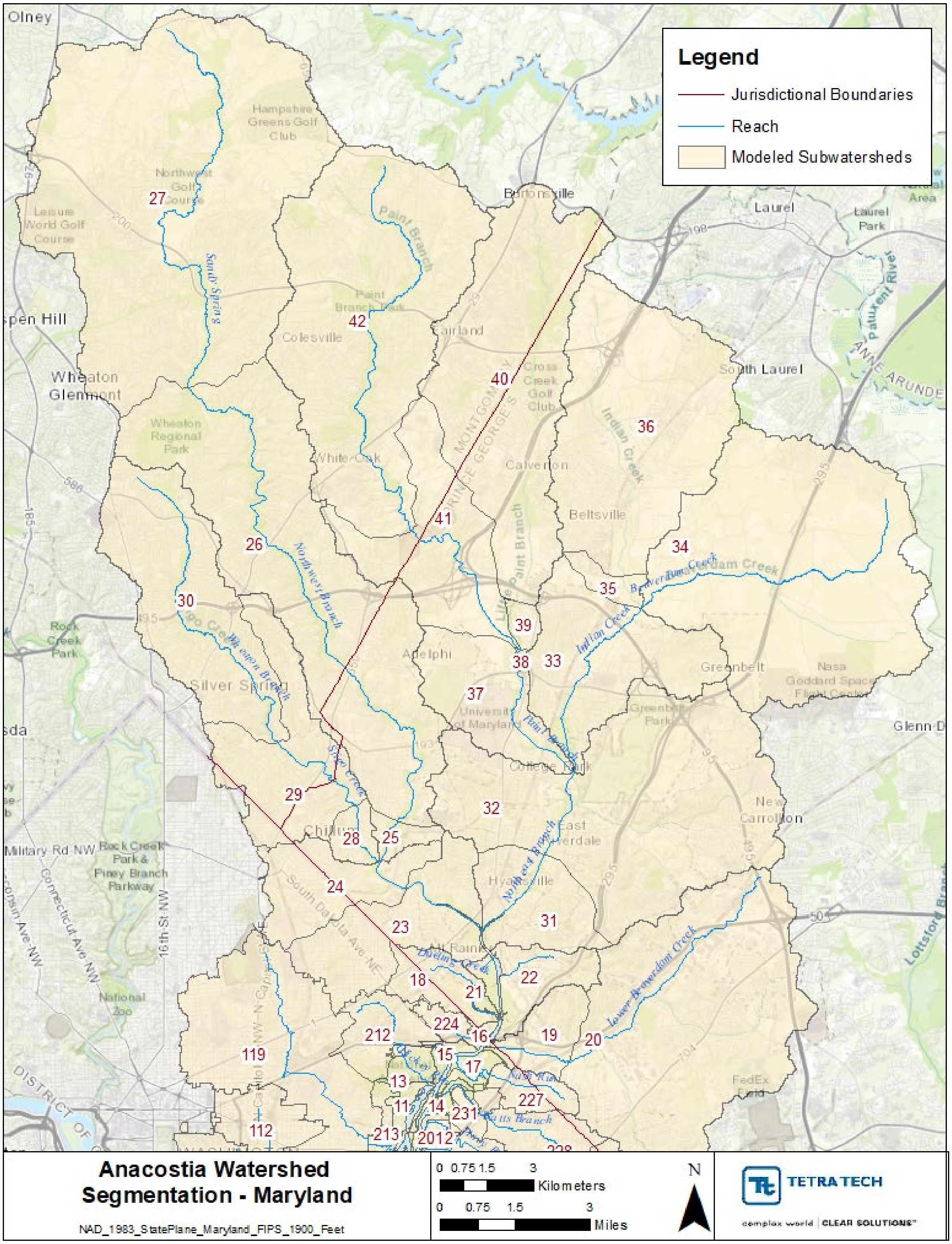


Figure 3-2. Anacostia River watershed segmentation focused on Maryland.

3.1.2 Reach Characteristics and Network Development

Model reaches are defined as the representative stream of each subwatershed and typically represent the main stream channel of a particular drainage. Each subwatershed was configured with a single associated stream reach, with reach connectivity from headwaters to outlets.

Similar to the data sources used to develop the watershed segmentation, model reaches relied on data made available from the MWCOG for the upper portion of the watershed, while MS4 sewer conveyance data available from the DC Geographic Information System (DC GIS) were used to characterize the DC portion of the watershed. In some cases, delineated subwatersheds in the DC portion of the watershed contained neither a digitized stream nor sewer line. Where this occurred, hypothetical drainage lines were developed using the ArcGIS spatial analyst hydrography tools that use Digital Elevation Model (DEM) elevation and slope data to determine likely flow paths. Length and slope data for natural reaches were estimated using the U.S. Geological Survey (USGS) National Elevation Dataset DEMs and digitized reach lengths.

Each representative reach in LSPC was assumed to be a completely mixed, one-dimensional segment with a trapezoidal cross section. Input parameters for the reaches include initial depth, length, depth, width, slope, Manning's roughness coefficient, and coefficients to describe the shape of the stream channel. The channel geometry is described by a bankfull width and depth (the main channel), a bottom width factor (r1), a flood plain width factor (w1) and slope of the flood plain (r2) derived from the contributing drainage area as described below (Figure 3-3).

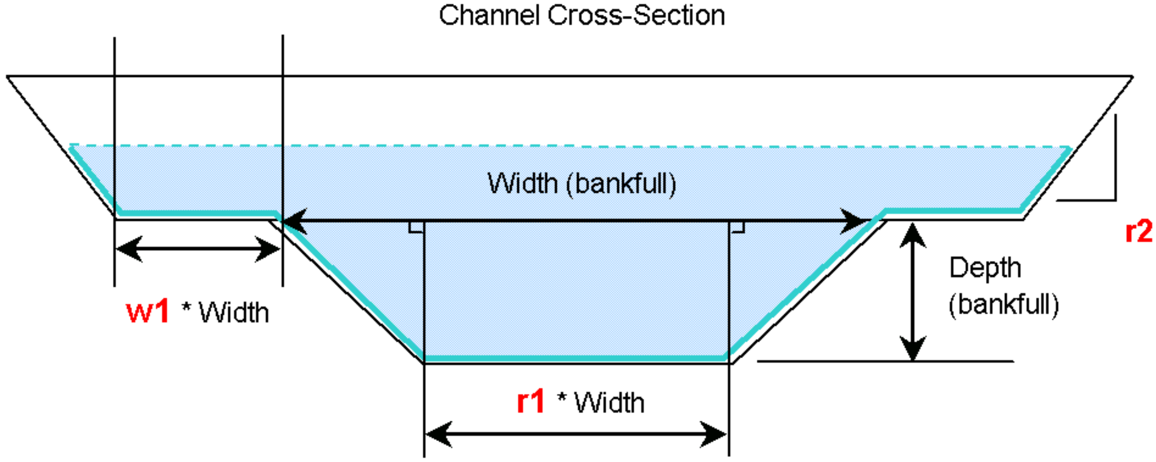


Figure 3-3. Stream channel representation in the LSPC model.

$$eq.1: BankfullDepth(ft) = 0.2838 \times (WatershedArea)^{0.4}$$

- WIDTH (Reach Bankfull Width) – Estimated using a hydraulic geometry equation using coefficients from literature values developed by (Leopold and Maddock, 1953) for rivers and streams of the eastern United States.

$$eq.2: BankfullWidth(ft) = 1.4995 \times (WatershedArea)^{14.49}$$

- R1 (Reach Ratio of Bottom Width to Bankfull Width) – Default value of 0.2.
- R2 (Reach Side Slope of Floodplain) – Default value of 0.5.
- W1 (Reach Floodplain Width Factor) – Default value of 1.5.

LSPC takes the attributes supplied for each reach and develops a function table (FTABLE). The FTABLE describes the hydrology of a river reach or reservoir segment by defining the functional relationship between water depth, surface area, water volume, and outflow in the segment. The assumption of a fixed depth, area, volume, outflow relationship does not account for cases where flow reverses direction or where one reach influences another upstream of it in a time-dependent way. The routing technique falls in the class known as "storage routing" or "kinematic wave" methods. In these methods, momentum is not considered.

In addition, custom FTABLES were developed for sewer lines that are part of the DC CSO system and for a reach representing a subsegment of Watts Branch. The CSO FTABLES define storage overflow relationships that replicate conditions where CSO reaches only discharge during significant rainfall events. The FTABLE for Watts Branch was developed to capture a more accurate hydrologic response for a stretch of the stream that is effectively partially impounded by a large box culvert providing pass-through for an overhead roadway.

3.1.3 HRU Development

In a watershed model land unit representation should be sensitive to features of the landscape that most affect hydrology and pollutant transport, including land use, related impervious assumptions, soils, and slope. In urban areas it is important to estimate the division of land use into pervious and impervious components, while in rural areas the type and extent of vegetative cover is a more important consideration. Depending on the goals of the model, if soil hydrologic groups are not homogenous in a watershed, it might be important to further divide pervious land cover by soil hydrologic group so that infiltration processes are better represented. Finally, slope might also be an important factor to properly capture land cover, especially if steep slopes are prevalent, as high slopes influence runoff and moisture-storage processes.

The combination of land use, soil hydrologic group, and slope were used to define the HRUs for the Anacostia River watershed model. The HRU approach provides certain advantages and efficiencies for model parameterization because it compartmentalizes the way process variables are assigned; also, it insulates that exercise from spatially variable influences like meteorology, which will naturally manifest itself differently for the same HRU located in different parts of a watershed. The main objectives for developing representative HRUs were:

- To support current source characterization objectives by representing hydrology and pollutant loading processes generated from land areas;
- To capture sufficient variability in hydrology and pollutant loading as related to different land uses and land covers;
- To balance the need for capturing landscape variability with a goal of reducing model complexity; and
- To support any potential future objectives of providing support to best management practice planning and implementation in the watershed.

The following summarizes the HRU development approach. A detailed discussion of each step follows.

1. Land cover within the watershed was represented with available polygon GIS data developed by the state of Maryland and Washington, DC.
2. Road areas in the Maryland portion of the watershed were augmented using Tiger Line Roads data converted to representative road areas.
3. The raw polygon land cover categories were simplified into broader model land use categories.
4. Unique percent impervious values were assigned to each urban area polygon using the 2011 National Land Cover Dataset Impervious Cover dataset.
5. Each pervious land cover category was classified by hydrologic soil group (HSG).
6. Each pervious urban land cover category was further distinguished as a low or high slope class (SC).

3.1.3.1 Land Use Coverage

The 2010 Maryland Land Use Land Cover (MDLU) and the 2004 Washington, DC, Existing Land Use (DCLU) datasets served as the base polygon GIS data used to develop HRUs for the Anacostia River watershed. The MDLU dataset was developed by the state of Maryland Geographic Information Office and obtained through the Maryland iMAP GIS data portal. The DCLU dataset was developed to support the Comprehensive Review Plan being conducted by the DC Office of Planning Long Range Planning Division; it represents a combination of 1999 planimetrics and DC Property Square Index boundaries and is available through the DC GIS Open Data catalog.

3.1.3.2 Maryland Road Areas Augmentation

The transportation parcels represented in the MDLU dataset are generally coarse, only representing major roads and thoroughfares. To augment these areas to be more consistent with the detailed representation of roads and highways in the DCLU dataset, Tiger Line Roads data were converted into representative areas for the Maryland portion of the watershed. The process of converting the road line features into representative areas included:

- Road descriptions of each feature line in the dataset were compiled as shown in Table 3-2**.**
- A random sampling of road line features was conducted using available Maryland Tax Map Grids to organize the sample.
- Sampled road lines were compared with aerial imagery, and road widths were measured and compiled for each road type.
- Road type widths were averaged to develop a representative width (buffer), which was then applied to the line features to create an analogue area coverage.
- Estimated road areas were spot checked against available aerial imagery and alignment with DCLU road areas.
- After confirming reasonable area and alignment representation, the estimated road areas were burned into the MDLU polygon dataset.

3.1.3.3 Assignment of Grouped Land Cover Classes to Model Land Uses

The MDLU and DCLU datasets define similar land use classifications, but they are not identical. A first step in the development of a cohesive land use dataset for the Anacostia River watershed was the merging of the two datasets. Table 3-2 lists the land use classificaitons for both datasets with like classifications matched. Once matched, a unified set of Grouped Land Cover Classes was developed with the goal of making those groupings generally represent land cover types that are expected to behave similarly from a hydrologic and pollutant loading standpoint. For instance, Commercial use is distinguished from Office/Institutional use by intensity of vehicle and foot traffic; a higher intensity of use tends to result in more residues on impervious surfaces.

Table 3-2. MDLU and DCLU matched land use classes

DCLU land cover classes	MDLU land cover classes	Grouped land cover class	Grouped ID
Water	Water	Water	1
—	Forest	Forest/Wetlands	2
—	Wetlands	Forest/Wetlands	2
—	Agriculture	Agriculture	3
—	Barren Land	Developed Open Space	4
—	Very Low Density Residential	Low Density Residential	5
Low Density Residential	Low Density Residential	Low Density Residential	5
Low-Medium Density Residential	—	Medium Density Residential	6
Medium Density Residential	Medium Density Residential	Medium Density Residential	6
High Density Residential	High Density Residential	High Density Residential	7
Parks and Open Spaces	—	Developed Open Space	4
Transportation Right of Way	—	Developed Open Space	4
—	Other Developed Lands	Developed Open Space	4
Commercial	Commercial	Commercial	8
Mixed Use	—	Commercial	8
Federal Public	—	Institutional	9
Institutional	Institutional	Institutional	9

DCLU land cover classes	MDLU land cover classes	Grouped land cover class	Grouped ID
Local Public	—	Institutional	9
Public, Quasi-Public, Institutional	—	Institutional	9
Industrial	Industrial	Industrial	10
Parking	—	Roads/Transportation/Utilities	11
Roads, Alleys, Median	Transportation	Roads/Transportation/Utilities	11
Traffic Circle	—	Roads/Transportation/Utilities	11
Transport, Communication, Utilities	—	Roads/Transportation/Utilities	11

3.1.3.4 Impervious Area

The National Land Cover Dataset is developed under a national program overseen by the Multi-Resolution Land Characteristics Consortium, a group of federal agencies that cooperate to create a consistent land cover GIS grid-based product for the entire United States. The 2011 data is based on interpretation of multi-seasonal Landsat satellite images into 30-meter grid cells and includes a grid with assignment of percent impervious cover. The combined polygon land cover dataset was overlain with the 2011 National Land Cover Dataset impervious dataset to assign the average percent impervious for each discrete polygon. Land cover categories were then split into pervious and impervious subcategories.

Table 3-3 summarizes the model land use categories and the associated impervious (IMPLND) and pervious (PERLND) components. Figure 3-4 shows the spatial coverage of percent impervious cover. It is assumed that impervious areas associated with pervious land uses are disconnected, meaning that runoff from these areas are captured by pervious lands. LSPC does not simulate the routing of runoff from different land areas; therefore, if a land area is classified as impervious, the runoff volume and timing is delivered to the stream without consideration of land uses that surround it.

Table 3-3. Aggregate land use categories and impervious/pervious components

Land cover	Impervious land cover code	Pervious land cover code	Total area (acres)	% Imp
Agriculture	DevOpen	Agri	5,535	4.4%
Commercial	Devperv	Comm	4,829	64.8%
Developed Open Space	DevOpen	Devperv	10,496	20.5%
Forest/Wetlands	DevOpen	ForestWet	20,138	3.8%
High Density Residential	ResHigh	Devperv	8,050	38.4%
Industrial	Ind	Devperv	4,030	61.8%
Institutional	Inst	Devperv	9,676	37.3%
Low Density Residential	ResLow	Devperv	9,604	10.7%
Medium Density Residential	ResMed	Devperv	25,902	27.5%
Roads/Transportation/Utilities	ToadTransUtil	Devperv	12,903	85.7%
Water	N/A	Water	1,002	7.9%
Total			112,166	31.0%

Note: % Imp = Percent impervious surface

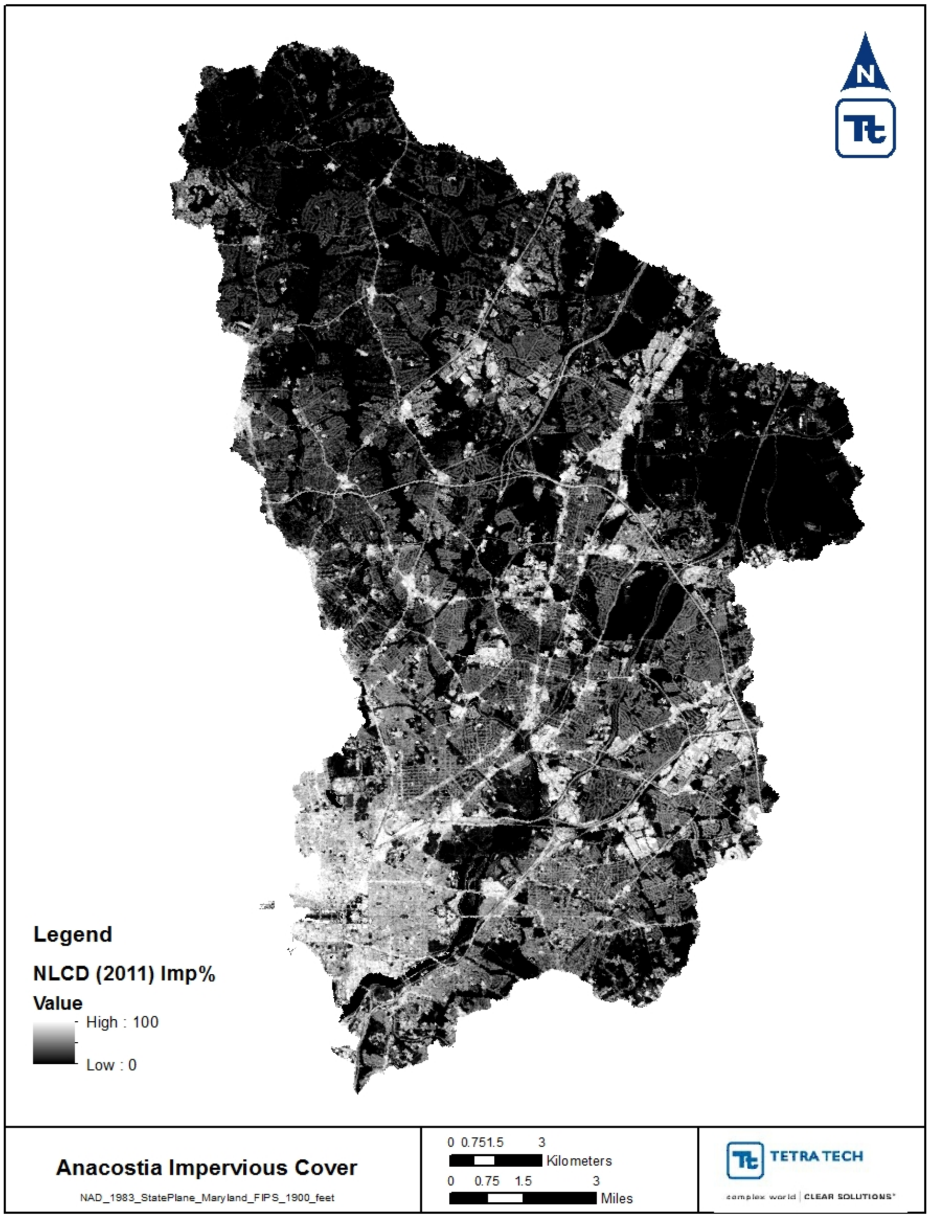


Figure 3-4. Percent impervious cover in the Anacostia River watershed.

3.1.3.5 Slope Class

Slope is also an important factor for HRU development, especially if steep slopes are prevalent; high slopes influence runoff and moisture storage processes. Percent slope was calculated from the 10-meter DEM from NED, and the slope values were classified as low (< 10%) and high (> 10%). Slope classes were dichotomized at 10% because past experience has shown that this threshold value strongly influences land use patterns (i.e., most urban development occurs on land with slopes less than 10%). The low/high slope grid was converted to a polygon coverage and spatially intersected with the land use/land cover coverage to allow for specification of slope class.

3.1.3.6 Model HRUs

To reduce model complexity, the pool of potential discrete HRU types was simplified using the following observations of tabular HRU area, balanced by project goals:

- Developed polygon areas were split into developed impervious and developed pervious model HRUs, based on the assigned percent impervious value.
- In urbanized areas, runoff response and pollutant loading is driven primarily by impervious surfaces; the urban land use designation was therefore retained and carried forward into the impervious HRU assignment.
- HSG and slope were considered more important for characterizing hydrology and pollutant loading for developed pervious land; therefore, HSG and slope class were retained, but the parent classification was not.
- HSG A soils comprise less than 3% of the watershed area; to reduce model complexity, HSG A soils were lumped with HSG B soils.
- The majority of Forest and Wetland land covers were classified as generally having slopes greater than 8% so the slope designation was removed, while the HSG classes were retained.
- Agriculture land was classified as generally having slopes less than 8% so the slope designation was removed, while the HSG classes were retained.
- Both slope class and HSG were retained for developed pervious land, resulting in six separate classes.

Final model HRUs are shown in Table 3-4, along with general groupings used for mapping and summary purposes.

Table 3-4. Model HRUs

HRU land cover	Hydrologic soil group	Slope	HRU ID	Total area (acres)	Data source(s)
Water	N/A	N/A	10	1,002.1	Directly from 2010 MD & DC Land Cover
Forest/ Wetlands	B	N/A	21	7,065.7	Directly from 2010 MD Land Cover (Merge Forest & Wetlands) + SSURGO HSG Overlay
	C		22	7,812.5	
	D		23	4,490.2	
Agriculture	B	N/A	31	1,912.1	Directly from 2010 MD Land Cover + SSURGO HSG Overlay
	C		32	2,886.9	
	D		33	494.4	
Developed Pervious	B	Low	41	21,019.2	Calculated as the pervious component [Impervious % assigned using 2011 USGS Impervious Gridded dataset (30 m)] of the 2010 MD & DC grouped developed land cover areas (Developed Open Space, Low/Med/High Density Residential, Commercial, Institutional, Industrial, Roads/Transportation/Utilities) + SSURO HSG Overlay + USGS NED (10m) Slope Classification (≥10% High, <10% Low)
		High	42	11,890.3	
	C	Low	43	8,658.4	
		High	44	5,517.2	
	D	Low	45	3,786.1	
		High	46	942.1	
Developed Open Space	Imp	N/A	50	3,167.3	Calculated as the impervious component [Impervious % assigned using 2011 USGS Impervious Gridded dataset (30m)] of the 2010 MD & DC grouped Developed Open Space areas
Low Density Residential	Imp	N/A	60	1,031.6	Calculated as the impervious component [Impervious % assigned using 2011 USGS Impervious Gridded

HRU land cover	Hydrologic soil group	Slope	HRU ID	Total area (acres)	Data source(s)
					dataset (30m)] of the 2010 MD & DC grouped Low Density Residential areas
Medium Density Residential	Imp	N/A	70	7,120.3	Calculated as the impervious component [Impervious % assigned using 2011 USGS Impervious Gridded dataset (30m)] of the 2010 MD & DC grouped Medium Density Residential areas
High Density Residential	Imp	N/A	80	3,088.8	Calculated as the impervious component [Impervious % assigned using 2011 USGS Impervious Gridded dataset (30m)] of the 2010 MD & DC High Density Residential areas
Commercial	Imp	N/A	90	3,127.2	Calculated as the impervious component [Impervious % assigned using 2011 USGS Impervious Gridded dataset (30m)] of the 2010 MD & DC grouped Commercial areas
Institutional	Imp	N/A	100	3,605.2	Calculated as the impervious component [Impervious % assigned using 2011 USGS Impervious Gridded dataset (30m)] of the 2010 MD & DC grouped Institutional areas
Industrial	Imp	N/A	110	2,489.3	Calculated as the impervious component [Impervious % assigned using 2011 USGS Impervious Gridded dataset (30m)] of the 2010 MD & DC Industrial areas
Roads/ Transportation/ Utilities	Imp	N/A	120	11,058.9	Calculated as the impervious component [Impervious % assigned using 2011 USGS Impervious Gridded dataset (30m)] of the 2010 MD & DC grouped Roads/Transportation/Utilities areas + 2015 Tiger Roads estimated road footprints for the MD portion of the watershed
Total				112,165.8	

3.2 METEOROLOGICAL DATA

Meteorological data are a critical component of the watershed model because they represent the forcing functions that drive both simulated hydrology and the water quality response. Models require appropriate representation of weather data constituents such as precipitation, potential evapotranspiration (ET), and temperature. In cases where an energy balance approach is used for snow simulation or for calculating ET, additional constituents, collectively referred to as climate data in LSPC applications, are needed. Those include dew point temperature, wind speed, cloud cover, and solar radiation.

Precipitation and other climate data required for the modeling application must be quality-controlled and continuous. Therefore, a major and crucial early effort for model development is assembly and processing of meteorological data.

3.2.1 Precipitation

In general, hourly precipitation data are recommended for nonpoint source modeling, because daily flows tend to average out high peaks during storm events. Daily data are also useful as they can be disaggregated and used directly or for patching missing data in an hourly time series.

The source of precipitation data for the watershed model was the National Climactic Data Center (NCDC) monitoring network. NCDC sources included the daily Global Historical Climate Network (GHCN) and hourly data from the Local Climatological Data (LCD) network. The LCD station also provided hourly meteorological data in addition to precipitation data which is discussed in the next section. An inventory of the stations and the period of record and the percent completeness of data is presented in Table 3-5. Percent complete refers to the completeness of data and was calculated using the data periods that were flagged as missing or deleted.

Table 3-5. Precipitation data station inventory

STAID	WBID	Station name	Elev. (feet)	Latitude	Longitude	Period of record	NCDC source	Percent complete	County
MD0700	180700	Beltsville	145	39.030	-76.931	01/2000 to 12/2015	GHCN (daily)	99.92%	Prince George's
MD5111	185111	Laurel 3 W	400	39.085	-76.900	01/2000 to 12/2017	GHCN (daily)	83.30%	Prince George's
VA8906	448906	Washington Reagan AP	10	38.865	-77.034	01/2000 to 12/2017	GHCN (daily) & LCD (hourly)	99.95%	Arlington

Hourly precipitation time series data were processed for the each of the monitoring stations. Daily precipitation data from each station were disaggregated to hourly using the hourly precipitation patterns from the Washington Regan Airport. To address gaps in the observed hourly precipitation time series, missing and incorrect data records were repaired (patched) based on the rainfall patterns at the other nearby stations with unimpaired data using the normal ratio method (Dunn & Leopold, 1978). This data patching method estimates a missing rainfall record with a weighted average from surrounding stations (assigned based on both proximity and similar elevation).

The Interstate Commission on the Potomac River Basin (ICPRB) HSPF model of the Anacostia River watershed used precipitation data from the Reagan National Airport exclusively for model simulation runs (Mandel et al 2007). Initial setup of the Anacostia River LSPC watershed model tested this configuration and assigned the three evaluated precipitation stations to the watershed using a Theissen Polygon framework. Testing showed that the single station setup used in the ICPRB model provided the best initial model results and, thus, was maintained in the current LSPC model setup. Figure 3-5 presents a summary of the annual rainfall totals at the Regan National Airport.

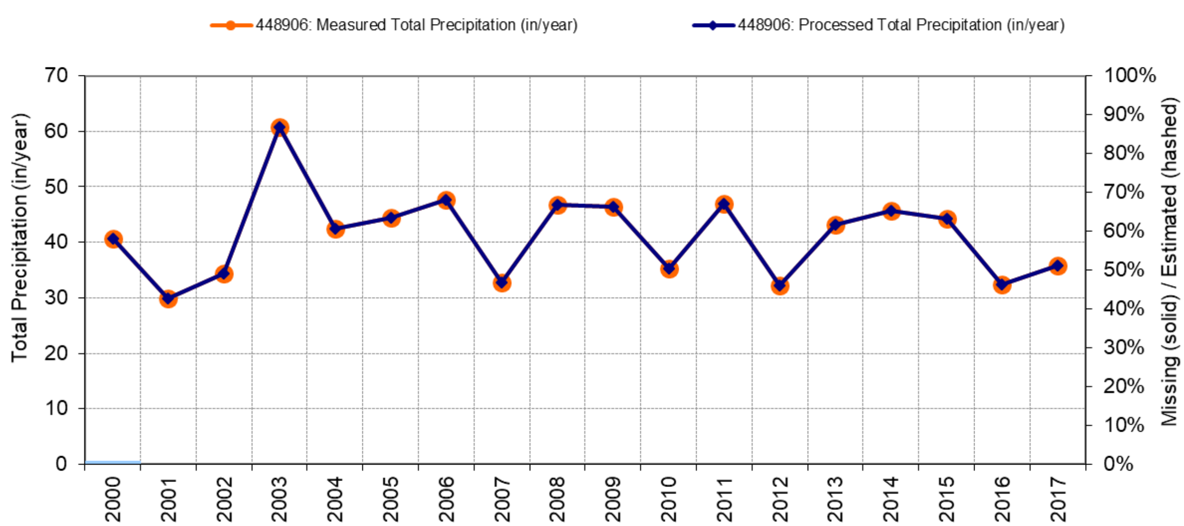


Figure 3-5. Total precipitation at Reagan National Airport monitoring station (ID: 448906), 2000–2017.

3.2.2 Potential Evapotranspiration and Climate Data

Climate data representing conditions in the Anacostia River watershed were obtained from the NCDC Reagan National Airport monitoring station (WASHINGTON REAGAN NTL AP: 448906). Those data were used to compute ET using the Penman energy-balance method to estimate pan evaporation followed by the application of season-specific pan coefficients to convert pan evaporation to potential evapotranspiration. The Penman energy-balance equations estimate pan evaporation as a function of air temperature, dew point temperature (or relative humidity), wind speed, and solar radiation. The NCDC dataset provided a good quality-controlled dataset for applying those equations. Table 3-6 is a summary of ET coefficients compiled from literature (Bedient & Huber, 1992), showing the range of variation among ET coefficients as a function of land cover and wind conditions. The calibrated pan evaporation coefficients for this modeling effort are presented below in Table 3-7 for reference purposes.

Table 3-6. Pan evaporation coefficients by land use from literature

Type of cover	Pan coefficient	Reference
St. Augustine grass	0.77	Weaver and Stephens (1983)
Bell peppers	0.85–1.04	
Grass and clover	0.08	Brutsaert (1982, p. 253)
Oak-pine flatwoods (East Texas)	1.2	Englund (1977)
Well-watered grass turf	—	Shih et al. (1983)
Light wind, high relative humidity	0.85	
Strong wind, low relative humidity	0.35	
Everglades agricultural areas (75% sugar cane, 25% truck crops and pasture)	0.65	
Irrigated grass pasture (central California)	0.76	Hargraeves and Simani (1982)

Source: Bedient & Huber 1992 (Table 1.2, p. 40)

Table 3-7. Monthly variable potential evapotranspiration coefficients and monthly mean PET

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
ET coefficient	0.25	0.3	0.4	0.5	0.55	0.55	0.55	0.55	0.55	0.5	0.3	0.25	—
Mean calculated (inches)	0.61	0.86	1.70	2.73	3.91	4.36	4.66	4.07	2.90	1.89	0.98	0.61	29.28
Estimated (inches)	0.69	0.93	1.86	2.97	3.85	4.38	4.66	4.07	3.02	1.96	0.93	0.64	29.97

Source: Northeast Regional Climate Center, 2017: Washington, DC (1980–2000); Estimated at Reagan National Airport

3.3 SOURCE REPRESENTATION

To represent the system using a linked modeling approach, sufficient data must be available to ensure that the model results are accurate. Source characterization is an important component of the dataset required to calibrate the model for contaminants, especially in the context of a TMDL. The sources of contaminants can be characterized using site-specific data, which are available for contaminated sites in the Anacostia River watershed. Figure 3-6 shows the locations of the contaminated sites. Contaminant levels in surface soils, interflow, groundwater, and dry and wet atmospheric deposition are directly applicable in the modeling environment. A variety of sources were used to characterize these media in the current ARSP model, as shown in Table 3-8. Other sources of data are available to estimate background concentrations as well, such as the Chesapeake Bay Program and the Centers for Disease Control and Prevention.

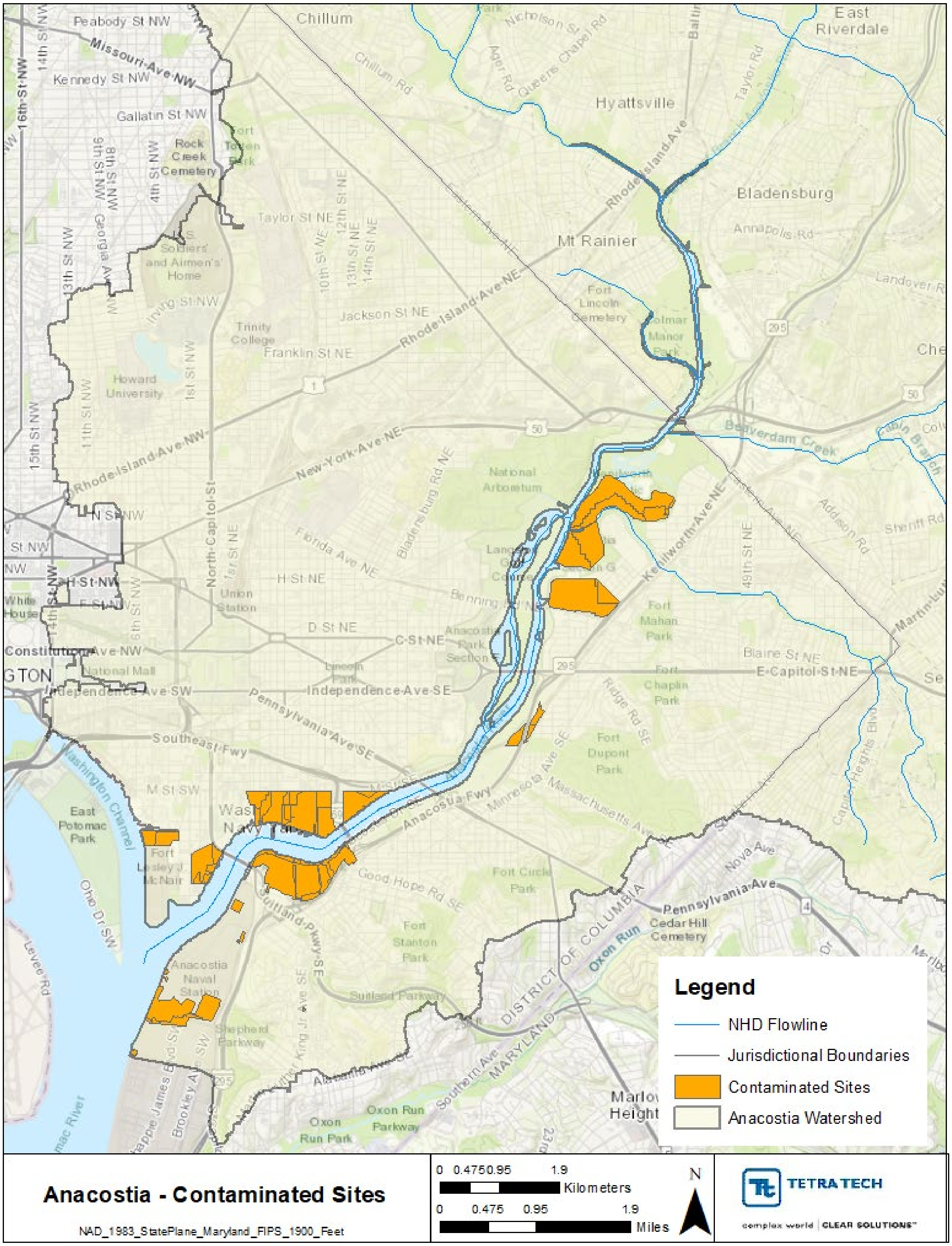


Figure 3-6. Location of contaminated sites in the Anacostia River watershed.

Table 3-8. Sources of literature used to estimate contaminant concentrations at contaminated sites in the Anacostia River watershed.

Report title	Report date	Prepared by
Kenilworth Park Landfill: Supplemental Groundwater Study Report	2016	The Johnson Company
Expanded Site Inspection Report for Anacostia River Park, Prince George's County, Maryland	2002	MDE
Revised Human Health Risk Assessment and Water Protection Level Evaluation Voluntary Cleanup Program, VCP Case No. VCP‐2015‐031 D.C. United Soccer Stadium Development Washington, DC	2016	Haley & Aldrich, Inc.
Preliminary Assessment/Site Investigation of Langston Golf Course, N.E. Washington, DC. Volume I of II	2001	Ecology and Environment, Inc.
Chemical Fingerprinting Assessment of The Potential Impact By CSX Transportation's Benning Yard On Fort Dupont Creek And Anacostia River Sediments	2013	NewFields
Site Characterization Report, Poplar Point, Washington DC	2003	Ridolfi, Inc.
FFA Draft, No Action Decision Document, Closure Document for Site 3- Athletic Fields, Joint Base Bolling, Washington, DC	2012	Naval Facilities Engineering Command
Remedial Investigation Report, Site 2—Metro Fill Area and Waterfront Fill Area, Joint Base Anacostia-Bolling, Washington, DC	2011	CH2MHill
Anacostia River Remedial Investigation Report, Phase I	2016	Tetra Tech, Inc.
Remedial Investigation Report (Draft), Benning Road Facility	2015	AECOM
Assessment of Health Risk to Utility and Landscape Workers on National Park Service Property South of East Station in Washington, DC	2002	Hydro-Terra, Inc.

A key function of the watershed model is to develop an estimate consistent with available monitoring data of sources of pollutant loads and their link to receiving streams loads. Watershed-based sources and pathways include:

- Urban runoff and associated loads (of solids and pollutants),
- Agricultural runoff and associated loads,
- Other runoff, such as from natural areas and associated loads,
- Atmospheric deposition, including spatial variation in deposition rates,
- Point source discharges (industrial, regulated stormwater outfalls, etc.),
- Spills and/or leaks (contaminated sites and industrial operations areas contributing high contaminant loads),
- Legacy contaminants of concern (COCs) in bed sediments of the Anacostia River, and
- Groundwater contributions to both watershed-based streams and to the Anacostia River directly.

Where available, monitoring data were used to characterize the various pollutant loading pathways to surface and groundwater water quality simulated in the watershed model. Major pathways represented in the LSPC model in order of increasing influence on toxic constituents water quality include:

1. Atmospheric deposition
2. Streambed sediment pollutant concentrations
3. Groundwater and interflow pollutant loading
4. Stormwater/surface runoff pollutant loading

Toxicological profiles of the TMDL pollutants were developed by the Agency of Toxic Substances and Disease Registry (ATSDR), which include a variety of literature sources detailing a compilation of loading rates across the four major source pathways. Other sources used to parameterize the LSPC model include USGS well monitoring data that were used to characterize groundwater concentrations, contaminated site monitoring data collected throughout the Anacostia River watershed, and stream bed sediment data collected in the Anacostia River tributaries. A summary of those data sources and a comparison to the final model values are detailed in the following subsections. These final modeled source parameter values were determined by applying literature values and adjusting these values during the calibration process. For source groups with multiple datasets, average values were typically used as starting values. Contaminated site representation is also discussed in Section 3.1.1, and loading parameters are discussed in Sections 3.3.2 and 3.3.3, below.

3.3.1 Atmospheric Deposition

Atmospheric deposition in LSPC includes the specification of two loading rates, one for dry deposition and one for wet deposition. The sole source for the characterization of those loadings were values given in the ATSDR toxicological profiles. Literature values for wet deposition, characterizing pollutant concentrations in rainfall, were available for metals and organochlorine pesticides. Rainfall concentrations of PAHs are assumed to be negligible due to their hydrophobic nature. Dry-weather deposition rates were only available for metals. All other pollutants are assumed to have a negligible presence in atmospheric particulates in comparison to other loading pathways. Comparisons of modeled and literature atmospheric deposition rates are provided in Figure 3-7 through Figure 3-9.

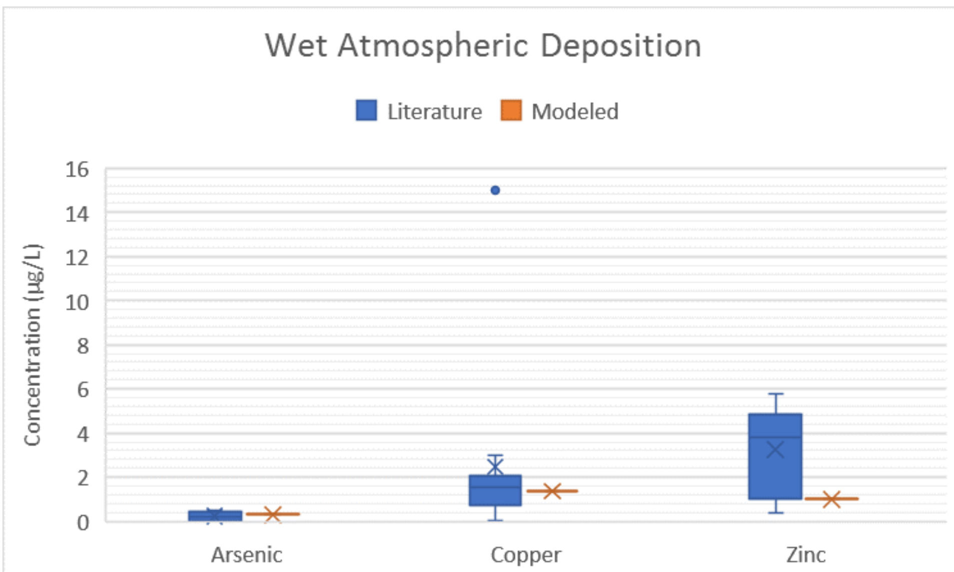


Figure 3-7. Modeled versus literature-based wet atmospheric deposition rates for arsenic, copper, and zinc.

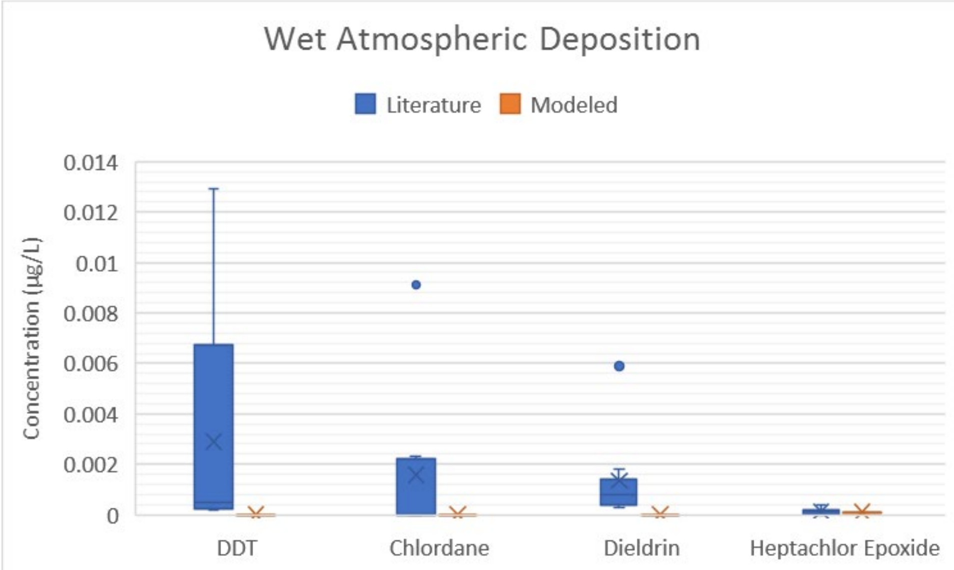


Figure 3-8. Modeled versus literature-based atmospheric deposition rates for DDT, chlordane, dieldrin, and heptachlor epoxide.

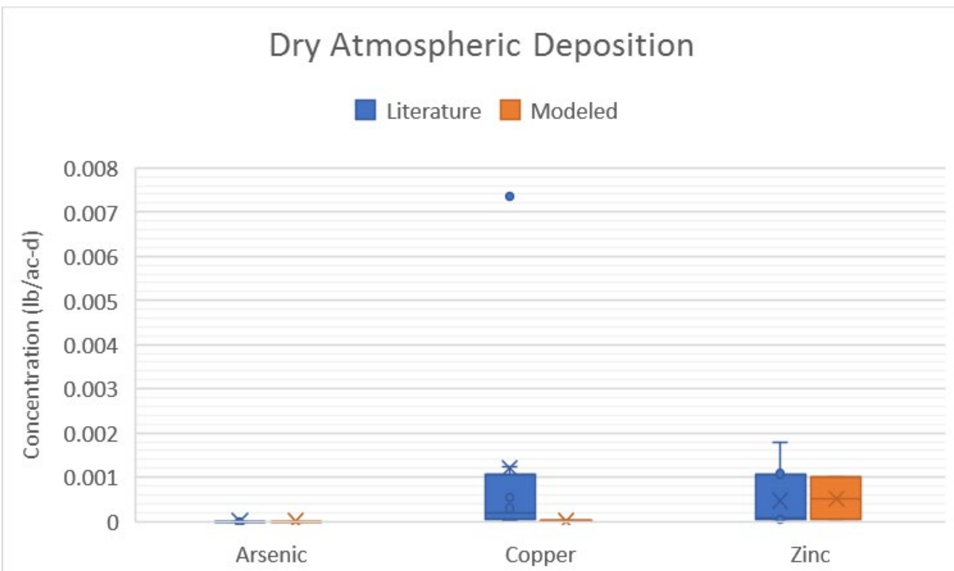


Figure 3-9. Modeled versus literature-based dry atmospheric deposition rates for arsenic, copper, and zinc.

3.3.2 Streambed Sediments

Pollutant concentrations associated with streambed sediments have the potential to release into the water column. Those releases happen through two mechanisms: (1) direct diffusion of dissolved fractions in pore spaces into the overlying surface water and (2) the resuspension of contaminated streambed sediments, whereby adsorbed pollutants are then desorbed due to the different equilibrium concentrations of dissolved and adsorbed fractions in the water column as compared to the bed.

The LSPC watershed model allows for the assignment of streambed sediment pollutant concentrations to properly simulate those contributions. Table 3-9 provides a comparison of modeled streambed sediment concentrations to those collected at locations throughout the watershed in two recent studies.

Table 3-9. Comparison of modeled and literature streambed sediment pollutant concentrations

Pollutant	Modeled (µg/kg)	2019 NPS Tributary Study[a] (µg/kg)		2019 USGS Tributary Study[d] (µg/kg)	
		Min median	Max median	Min	Max
Arsenic	100	NS	NS	0.46	1.9
Copper	500	NS	NS	14	83
Zinc	1000	NS	NS	2.9	37
DDT	0.05	ND	2.1[b]	ND	20
Chlordane	0.5	0.85	6.9	ND	23
Dieldrin	0.1	ND	1.02	ND	0.89
Heptachlor epoxide	0.05	ND	0.2	ND	0.9
PAH1	50	NS	NS	NS	NS
PAH2	50	NS	NS	NS	NS
PAH3	50	76.83[c]	336.79[c]	NS	NS
Alkylated PAH	—	NS	NS	71	7500
Non-alkylated PAH	—	NS	NS	210	4700
Total PAH	—	NS	NS	280	52000

Notes:
ND = Not detected in sample; NS = Not sampled
[a] Source: (Johnson Company, 2019); Table 9
[b] Sample was DDE
[c] PAH3 value corresponds to benzo(a)pyrene.
[d] Source: (Wilson, 2019); tables 10, 12 and 14

3.3.3 Subsurface Outflows

The LSPC model includes two subsurface pollutant loading pathways groundwater outflows and interflows. Groundwater outflows represent discharge from the active shallow aquifer, or active groundwater. Groundwater contributions affect water quality most during dry-weather conditions when no rainfall-driven runoff is occurring. Interflow, on the other hand, is driven by precipitation events and can be thought of as shallow lateral flows occurring in the top inch or two of surface soils. Depending on model parameterization, interflow can be equally important to surface runoff in determining the shape and intensity of a storm hydrograph.

The Anacostia River watershed model incudes pollutant contributions through both groundwater and interflow. Pollutant loading through those pathways was characterized using a mix of sediment associated and dissolved fractions. Both pathways were assumed to have the same loading characteristics, where the assigned soil potencies and dissolved concentrations were identical.

Subsurface dissolved concentrations were developed using available literature sources and monitoring data. Literature sources included those provided in the ATSDR, and monitoring data included sampling results from USGS well locations and contaminated sites throughout the watershed. A comparison of the distribution of the dissolved concentrations generated by the final calibrated model and those available from the various data sources are provided in the box-and-whisker plots in Figure 3-10 through Figure 3-12.

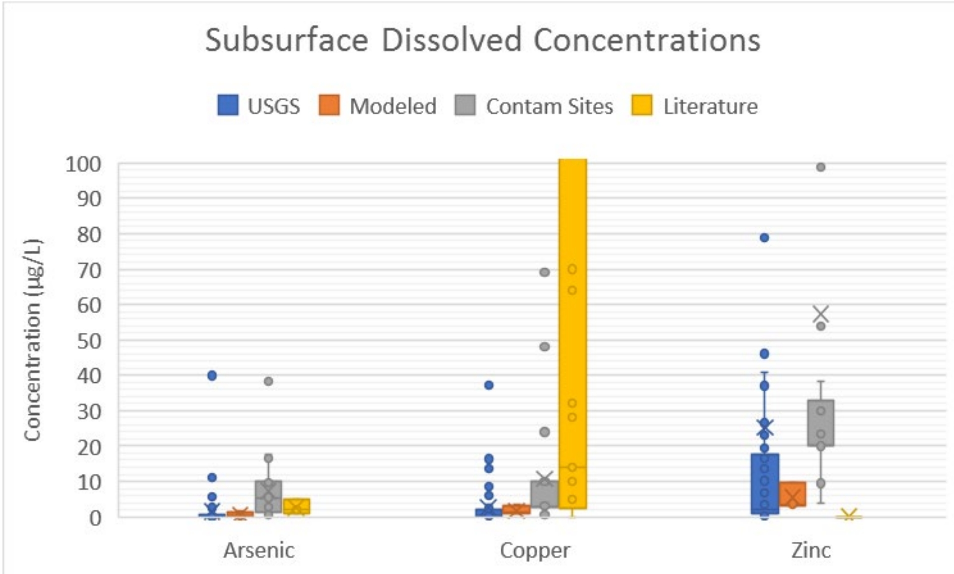


Figure 3-10. Range of modeled and literature-based subsurface dissolved concentrations of arsenic, copper, and zinc

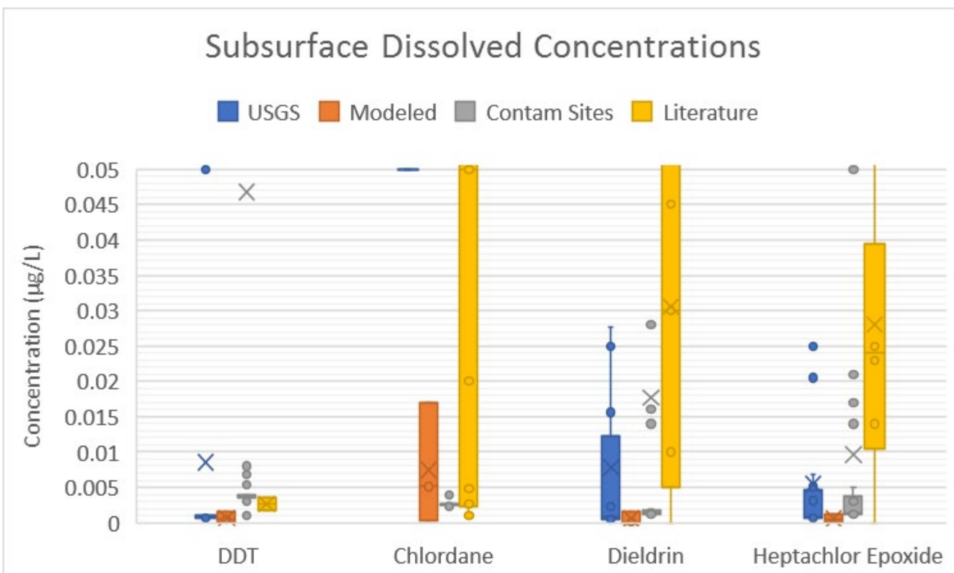


Figure 3-11. Range of modeled and literature-based subsurface dissolved concentrations of DDT, chlordane, dieldrin, and heptachlor epoxide.

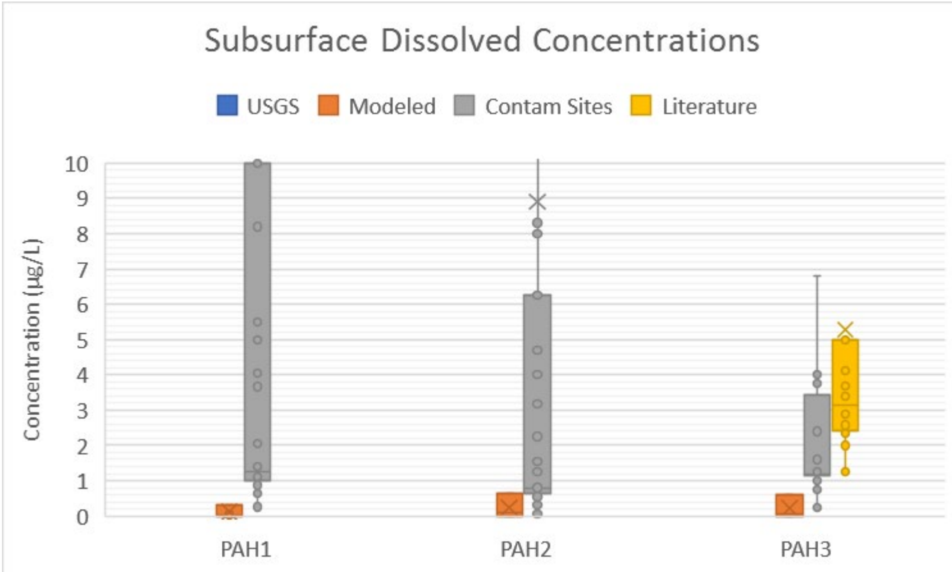


Figure 3-12. Range of modeled and literature-based subsurface dissolved concentrations of PAH1, PAH2, and PAH3.

Similar to dissolved concentrations, subsurface soil potencies were developed using available literature sources and monitoring data. Literature sources included those provided in the ATSDR, and monitoring data included sampling results from USGS well locations and contaminated sites throughout the watershed. A comparison of the distribution of the dissolved concentrations generated by the final calibrated model and those available from the various data sources are provided in the box-and-whisker plots in Figure 3-13, Figure 3-14, and Figure 3-15.

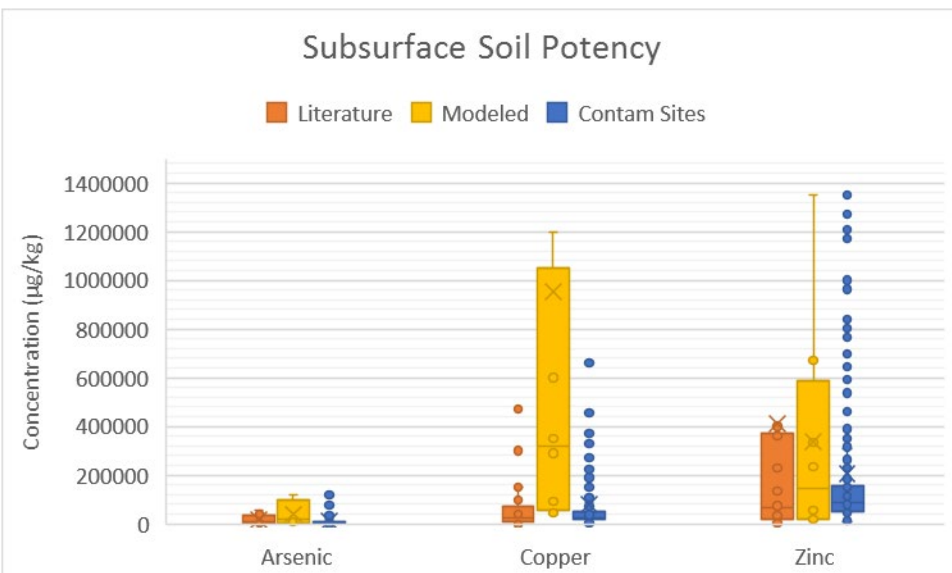


Figure 3-13. Range of modeled and literature-based subsurface soil potencies of arsenic, copper, and zinc.

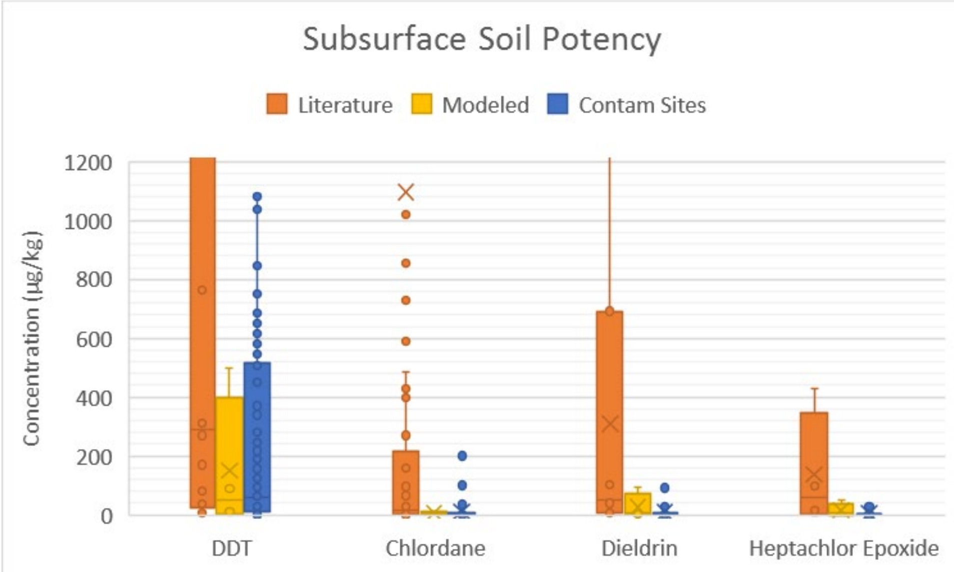


Figure 3-14. Range of modeled and literature-based subsurface soil potencies of DDT, chlordane, dieldrin, and heptachlor epoxide.

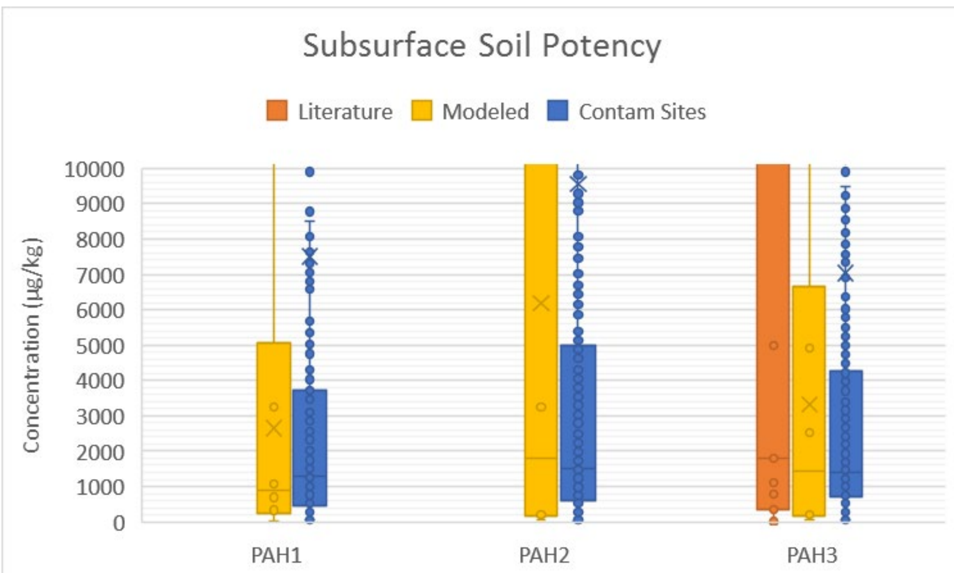


Figure 3-15. Range of modeled and literature-based subsurface soil potencies of PAH1, PAH2, and PAH3.

3.3.4 Surface Runoff

Pollutant loading from surface runoff in the LSPC model includes constituents transported in surface flows (dissolved) and carried with sediment (sediment associated). Source representation (i.e., model parameterization) for the pathway includes the assignment of both dissolved concentrations and sediment-associated potency factors similar to what was done for the subsurface pathways. Characterizing runoff volume and water quality of surface flows from the watershed are dependent on the underlying model HRU. For example, more runoff will be generated if the HRU is impervious versus pervious or if it is a pervious area with a lower infiltration rate. Similarly, the loading characteristics assigned to the HRU will determine the quantity of toxic constituents associated with a runoff event.

Surface dissolved concentrations were developed primarily by using literature sources available for groundwater as a guide because locally available data for surface runoff were not available. The concentrations assigned to subsurface flows were generally increased for characterization of surface runoff to account for the greater ratio of water volume to sediment/soil in surface flows. Similarly, sediment potency factors were reduced from subsurface concentrations to account for the same condition. The dissolved concentrations generated by the final calibrated model and soil potency factors for surface runoff are provided in the box-and-whisker plots in Figure 3-16 through Figure 3-18, respectively.

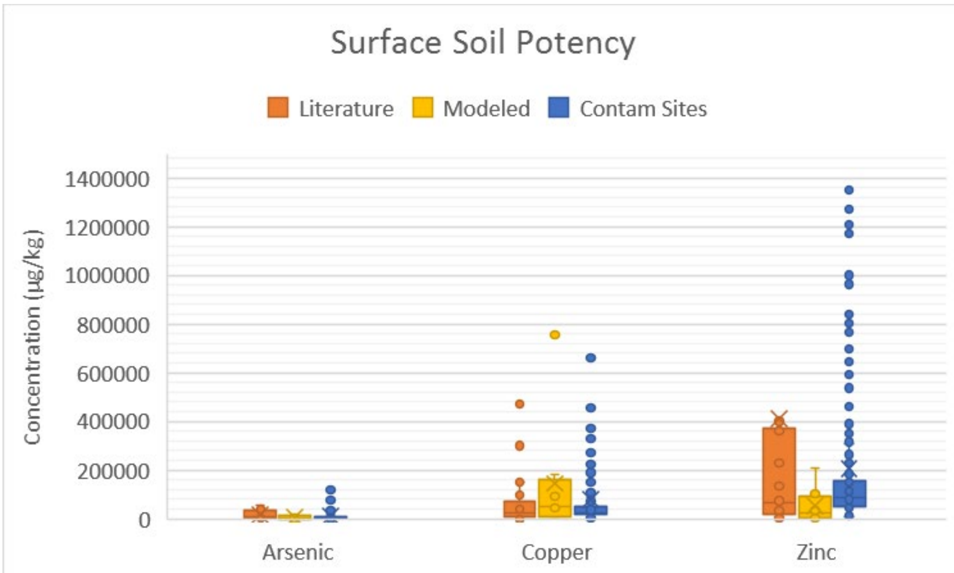


Figure 3-16. Range of modeled and literature-based surface soil potencies for arsenic, copper, and zinc.

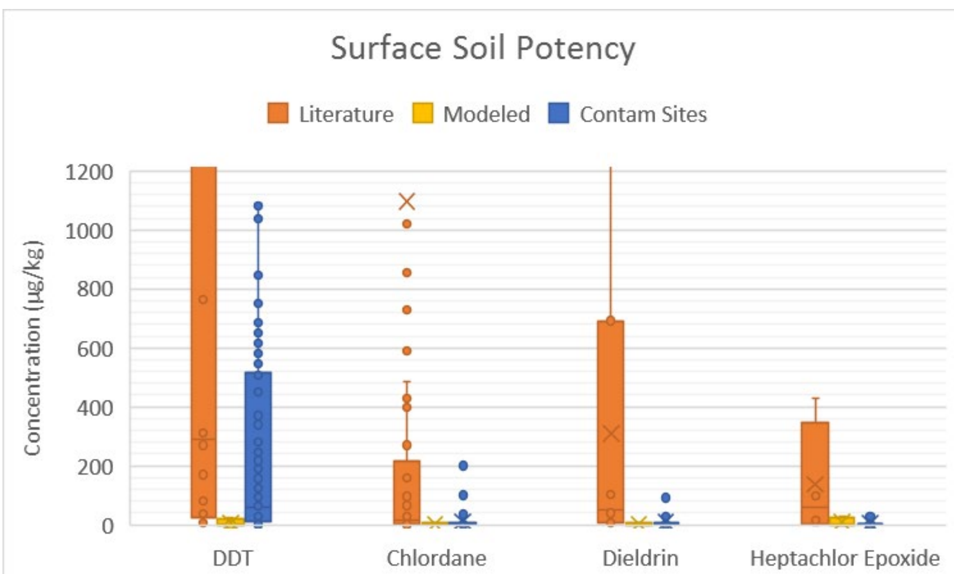


Figure 3-17. Range of modeled and literature-based surface soil potencies for DDT, chlordane, dieldrin, and heptachlor epoxide.

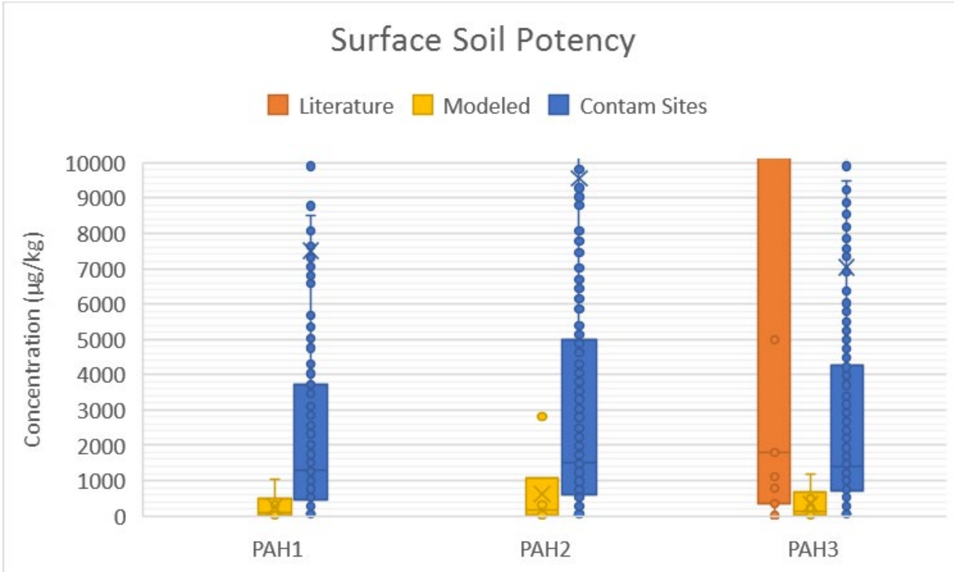


Figure 3-18. Range of modeled and literature-based surface soil potencies for PAH1, PAH2, and PAH3.

3.3.5 Point Sources

Point sources in the Anacostia River watershed include individually permitted wastewater facilities, as well as stormwater dischargers. The point source categories in the watershed include:

- Individually permitted wastewater NPDES dischargers
- Multi-sector general permits (MSGPs)
- Municipal separate storm sewer system (MS4) dischargers
- Combined sewer overflows (CSOs)

Representation of the outflows and toxic constituents loads attributed to the point source categories used available monitoring data and the simulated rainfall-runoff and pollutant-loading relationships for the watershed land areas. Monitoring data were used to characterize wastewater dischargers and CSOs, while watershed simulations were used for MS4s and MSGPs. Additional details related to the facilities are provided in Appendix A.

3.3.5.1 Individual NPDES Permits

Individual permitted facilities incorporated into the model are shown in Figure 3-19, and Table 3-10 summarizes basic details. Note that DC0000141 (Washington Navy Yard), as a known contaminated site, was delineated into the model as a subbasin and is simulated based on associated runoff and loading characteristics (See Section 3.3 for discussion. Its load is treated as a wasteload allocation (WLA) in the TMDL.

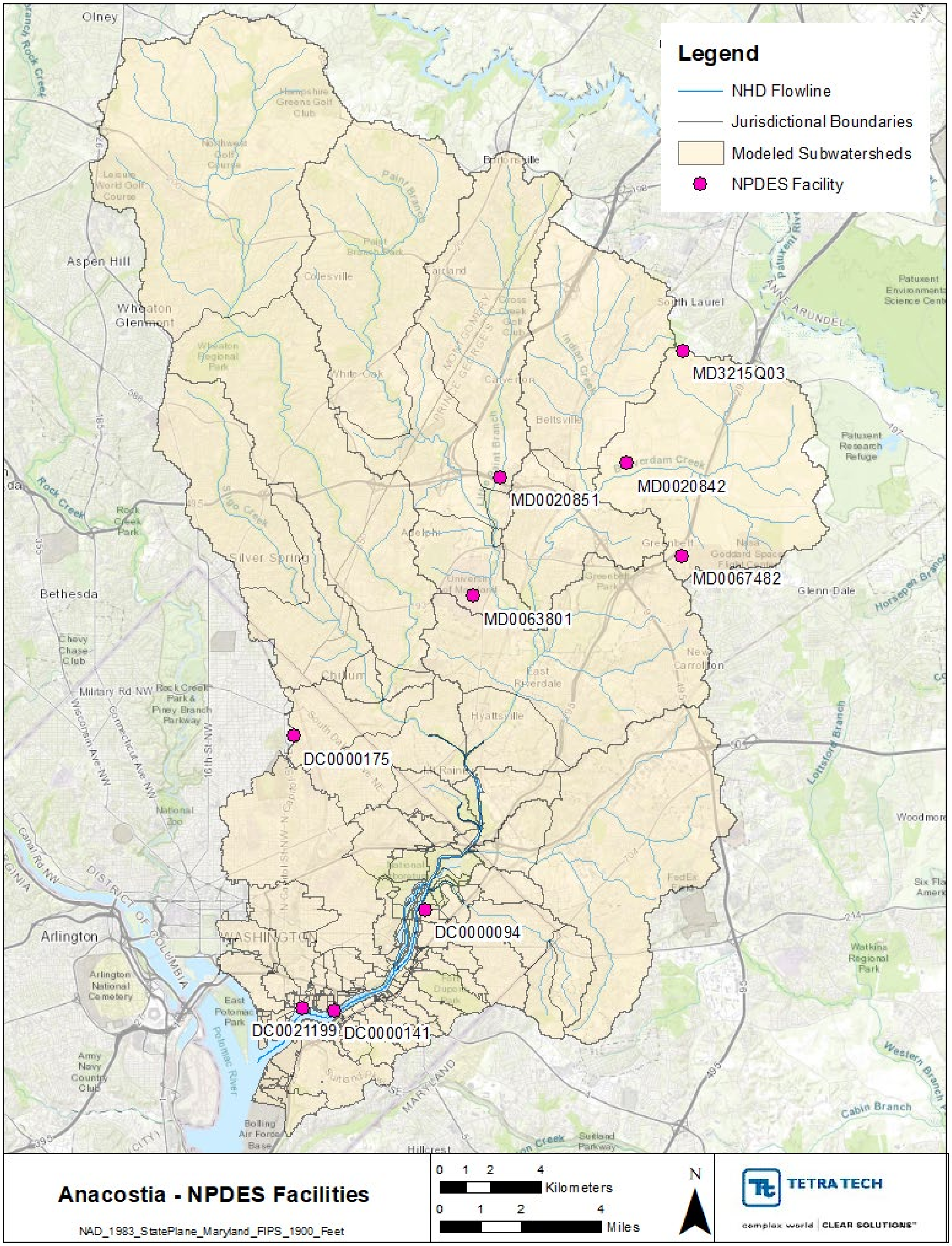


Figure 3-19. Individual NPDES facilities in the Anacostia River watershed.

Table 3-10. Individual NPDES permits represented in the Anacostia Toxic Constituents Model

NPDES ID	Facility name	Type	Outfalls	Latitude	Longitude
DC0000094	PEPCO Environment Management Services	Industrial	13	38.9000	-76.9583
DC0000141[a]	Washington Navy Yard	Industrial	1,5, 6, 7, 8, 9, 13, 14, CSO14F, CSO15G, CSO15H, MS401E	38.87194	-76.991389
DC0000175	SUPER CONCRETE CORPORATION	Industrial	4	38.9486	-77.0058
DC0021199	D.C. Water (BLUE PLAINS)	Publicly owned treatment works	19	38.8725	-77.0025
MD0063801	University of Maryland, College Park	Industrial	1, 2, 3, 4, 5, 7, 10, 12, 14, 16, 18, 19	38.9892	-76.9461
MD0020842	USDA East Side WWTP	Municipal	2	39.0247	-76.8861
MD0020851	USDA West Side WWTP	Municipal	2	39.0215	-76.9322
MD0067482	NASA Goddard Flight Center	Industrial	1, 2, 3, 4	38.998888	-76.866000
MD3215Q03[b]	FDA – Center for Veterinary Medicine	Industrial	1	39.056007	-76.865892

Notes:
WWTP = wastewater treatment plant; USDA = U.S. Department of Agriculture; NASA = National Aeronautics and Space Administration; FDA = Food and Drug Administration
[a] Included in the allocation tables as a WLA for the Washington Navy Yard; representative latitude/longitude is for outfall 001
[b] Estimated latitude/longitude is from GIS

For existing conditions, Discharge Monitoring Reports (DMRs) available from MDE and DOEE were used to characterize the flows and toxic constituents pollutant concentrations of discharges from facilities regulated under NPDES in the Anacostia River watershed. DMR data typically consists of measured outfall flows and associated pollutant concentrations reported on a monthly or quarterly basis. Eight facilities, representing 22 outfalls to the Anacostia River and its tributaries were identified and incorporated into the LSPC model. Those facilities, their outfalls, average flow rate, and average concentration for existing conditions are shown in Table 3-11.

Table 3-11. Anacostia River watershed NPDES facilities existing condition configuration.

NPDES permit	Outfall	Avg. Flow (cfs)	As (µg/L)	Cu (µg/L)	Zn (µg/L)	DDT (µg/L)	Chlordane (µg/L)	Dieldrin (µg/L)	Heptachlor epoxide (µg/L)	PAH1 (µg/L)	PAH2 (µg/L)	PAH3 (µg/L)
DC0000094	13	0.103	*0.14*	41.608	233.844	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
DC0000175	4	0.271	*0.14*	*8.96*	*117.18*	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
DC0021199	19	1.374	*0.14*	*8.96*	*117.18*	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
MD0020842	2	0.331	3	28.992	18.434	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
MD0020851	2	0.106	5.846	28.421	14.174	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
MD0063801	1	0.002	5.846	29.881	14.174	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
	2	0.027	**1**	45.049	**24**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	3	0.093	**1**	45.2	**40.1**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	4	0.107	**1**	37.162	**23.2**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	5	0.137	**1**	37.384	**17.1**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	7	0.042	**1**	37.355	**35.9**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	10	0.004	**1**	39.03	**54.6**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	12	0.029	**1**	36.414	**90.8**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	14	0.015	**1**	36.729	**82.3**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	16	0.046	**1**	36.421	**36.3**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	18	0	**1**	29.814	**7.5**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
	19	0.049	**1**	42.699	**7.5**	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	**2.5**	**2.5**	**2.5**
MD0067482	1	0.549	5.846	7.464	14.174	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
	2	0.02	5	2.889	14.174	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
	3	0.016	6.696	6.687	14.174	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
	4	0.08	5.846	8.121	14.174	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*
MD3215Q03	1	0.048	5.846	27.483	14.174	*0.000018*	*0.00032*	*0.0000012*	*0.000032*	*0.065*	*0.0013*	*0.00013*

Notes:
DC0000141 was modeled as a contaminated site with associated loading characteristics.

Plain Text	Average of DMR reported concentrations by month
Underlined Text	Average of DMR reported concentrations for the entire period of record for all facilities evaluated
Bolded Text	Concentrations reported as part of the NPDES permit application
Italicized Text	Water quality criteria concentrations (*italicized text*)
Underlined / Italicized Text	Maximum detection limits concentrations for acenaphthene and acenaphthylene

Often DMR data included a record of facility flows but did not include toxic concentrations. Where coincidently reported data on toxic constituents concentrations were available, these concentrations were assigned to monitored flows. If those data were not available, alternative methods were used to estimate the concentrations. The methods used in descending order of preference were as follows:

1. Average of DMR reported concentrations by month.
2. Average of available DMR-reported concentrations for the entire period of record for all facilities evaluated.
3. Concentrations reported as part of the NPDES permit application.
5. Water quality criteria concentrations. (For PAH1, facilities with no data and no corresponding permit information were set to the maximum detection limit reported for the lab Quality Assurance Project Plan (QAPP) that was submitted as part of the ARSP.)

The impact of setting up the point source discharges based on these assumptions is conservative in that there is not an assumption of zero discharge in the event of nondetect or no data available in the DMRs. When existing discharges are assigned at criteria, then no reductions are necessary to the facility under the TMDL scenario.

3.3.5.2 Multi-Sector General Permits and Municipal Separate Storm Sewer System Discharges

The determination of runoff volume and pollutant loads was handled in a similar way for both MSGPs and MS4s. In both cases the watershed simulations for the contributing upland areas within the defined boundaries of the permitted areas were used to estimate the respective contributions. The major difference between the two was that the boundaries of MS4s were included explicitly in the watershed segmentation for DC as described in Section 3.1.1. The contributing area of MSGPs, on the other hand, was determined outside of the model using a GIS overlay of the permitted site boundaries and model HRU land cover data. The HRU distribution for each permitted area was then used in conjunction with unit area runoff and loading rates to determine those contributions. Similar to the MSGP contributing areas, MS4 contributing areas for Maryland were also determined outside of the model by using a GIS overlay of regulated stormwater and land uses coverages (MDE_AR_Regulated_Stormwater&LU) data and calculating the loading based on loading rates. Figure 3-20 shows the locations of MS4 subwatersheds in DC; MSGPs represent a small proportion of the area and are not depicted. A spatial layer of MS4 areas for the Maryland portion is not available.

3.3.5.3 Combined Sewer System

Similar to MS4s, CSS boundaries were incorporated directly into the watershed model segmentation. To achieve discharges that replicated the storm-driven overflows that characterize CSOs, FTABLES were used as described in Section 3.1.1. For combined sewer lines that are part of the DC CSS, overflow relationships were developed that replicate conditions where CSS reaches discharge only during significant rainfall events. To do this, two outlets were assigned to CSS segments, where the first outlet removes flow and loads from the simulation, representing conveyance to DC Water's Blue Plains Treatment Facility. Note the Anacostia River Tunnel Project began providing overflow storage capacity in March 2018, which is after the end of the simulation period of 2014–2017 and not applicable for this work. Therefore, the second outlet discharges directly to the Anacostia River during high flow events once the first outlet exceeds the critical volume. Toxic constituents concentrations were then assigned to overflows based on simulated instream concentrations. Figure 3-20 highlights locations of MS4s, CSS and contaminated sites in DC.

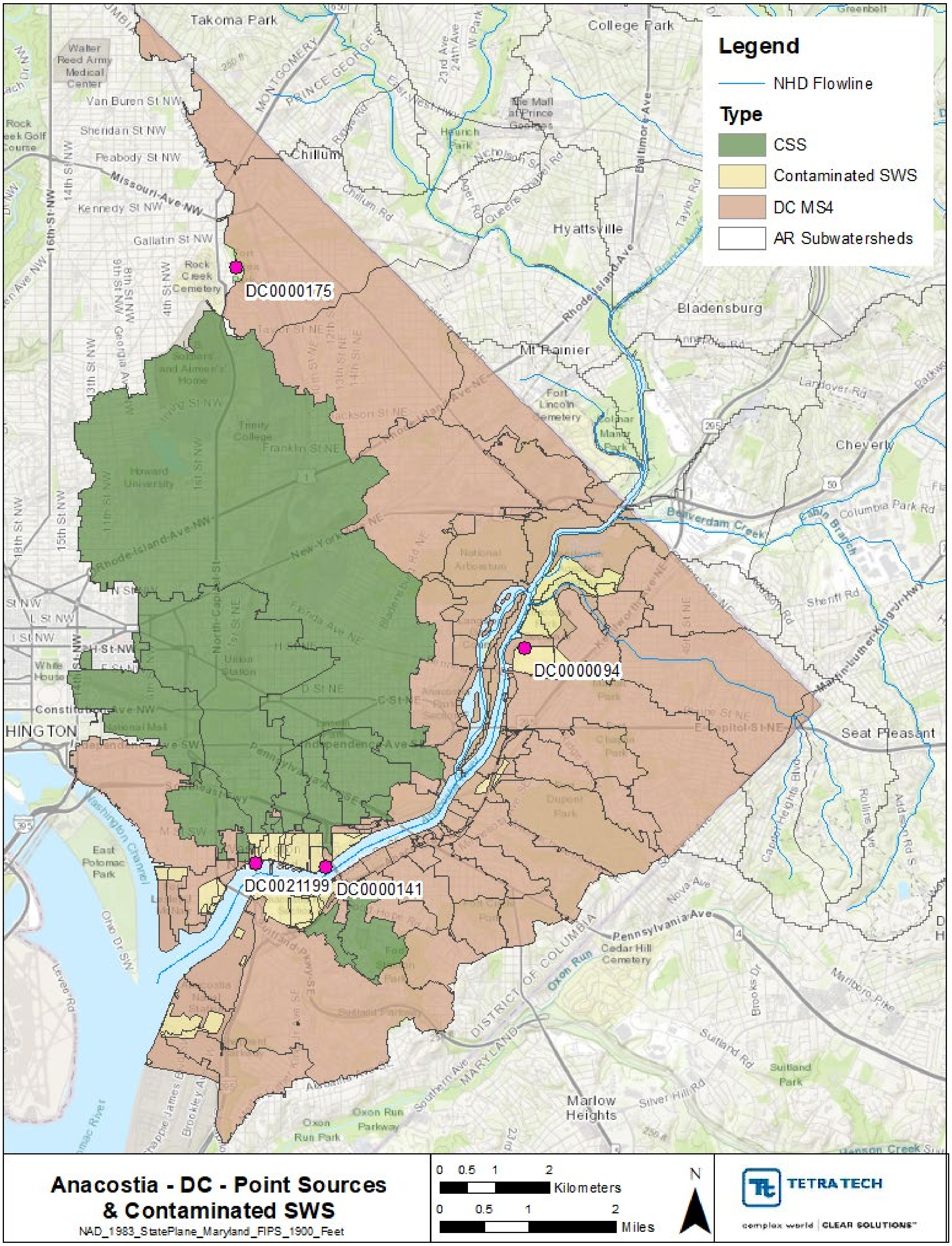


Figure 3-20. Locations of MS4, CSS, and contaminated site subwatersheds in the District of Columbia.

4.0 ENVIRONMENTAL FLUID DYNAMICS CODE CONFIGURATION

A receiving water model was used as a part of the evaluation given the complex flow dynamics in the tidal Anacostia River, coupled with the variable hydrologic inputs from the surrounding watershed. EFDC[2] was selected as the receiving water model for this project (Tetra Tech, 2018a). Previous receiving water studies completed in the Anacostia River provide a strong basis for using an EFDC framework for the tidal Anacostia River (Tetra Tech, 2019). The EFDC model has been applied worldwide for both hydrodynamic and water quality applications and can be easily linked to the watershed models that have been evaluated for representation of watershed source loadings.

EFDC is a general-purpose modeling package for simulating one- or multi-dimensional flow, transport, and bio-geochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model (Hamrick, 1992) was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. This model is EPA-supported and is used extensively to support receiving water modeling studies and TMDLs throughout the world.

Modeling the Anacostia River to support the ARSP as well as this TMDL requires evaluating source-response linkages and estimating existing loadings. As part of the linked modeling system, the EFDC model provides a dynamic representation of hydrodynamic conditions, conventional water quality conditions, sediment transport, and toxic pollutant concentrations in the tidal Anacostia River. Flows, suspended sediment, and pollutant loads from the catchments adjacent to the tidal Anacostia River are described using the LSPC model.

In tidal systems, such as the tidal Anacostia River, the transport of particulate and dissolved materials is a process governed by the interaction between freshwater inflows, ocean tidal oscillations, and windshear over the water surface. During periods of high tributary inflows, estuary processes are mostly driven by advective transport and have a higher flushing capacity. During periods of low tributary inflows, conversely, the estuary processes are more influenced by dispersive transport largely driven by tidal dynamics.

4.1 PHYSICAL REPRESENTATION

The EFDC model requires inputs specified as being continuous through time (continuous time series), and the LSPC model provides continuous estimates of flow, water temperature, suspended sediment, and the load of toxic parameters of interest in dissolved and particulate form. Most water quality measurements, including measured toxic constituents concentrations are grab samples. The LSPC model therefore provides a continuous estimate of concentration loading with time.

Establishing an appropriate model domain and grid for the receiving water body (tidal Anacostia River) is essential for meeting the objectives of the modeling effort. The location of model boundaries determines what data can be used as boundary conditions for the final model configuration. As detailed below, the EFDC modeling domain includes the tidal Anacostia River and the Potomac River in Virginia, Maryland, and DC.

A curvilinear-orthogonal model grid system was established to represent the EFDC modeling domain and provide linkage to the LSPC watershed model. The horizontal boundaries of the Anacostia River grid were based on digital orthophotography basemaps obtained in the ArcGIS environment. The grid was developed for areas between riverbanks to simulate open water portions of the system.

The tidal Anacostia River portion of the grid extends from the confluence of the Anacostia and Potomac rivers upstream to the USGS gages on Northeast Branch and Northwest Branch, which represent the head of tide locations on the Anacostia River. On the Potomac River, the grid extends upstream to the Little Falls USGS gage, and downstream to the National Oceanic and Atmospheric Administration (NOAA) tide estimation station in

[2] www.epa.gov/ceam/environmental-fluid-dynamics-code-efdc

Alexandria, Virginia. Higher horizontal grid resolution was developed for the tidal Anacostia study area, while a coarser resolution was applied to the Potomac River.

The horizontal grid cells were segmented vertically into five vertical layers. Bathymetry data from DOEE's Remedial Investigation (Tetra Tech, 2019b), U.S. Army Corps of Engineers (USACE) data (circa 2012), and NOAA data (circa 1974–1977) were used to estimate bottom elevations within the horizontal grid. The spatial distribution of data from each dataset are shown in Figure 4-1. The bed elevations for each grid cell were then interpolated based on the composite dataset that includes the DOEE, USACE, and NOAA data. Estimated points indicate areas where bathymetric data were interpolated based on adjacent soundings. The final horizontal grid and corresponding bed elevations are shown in Figure 4-2.

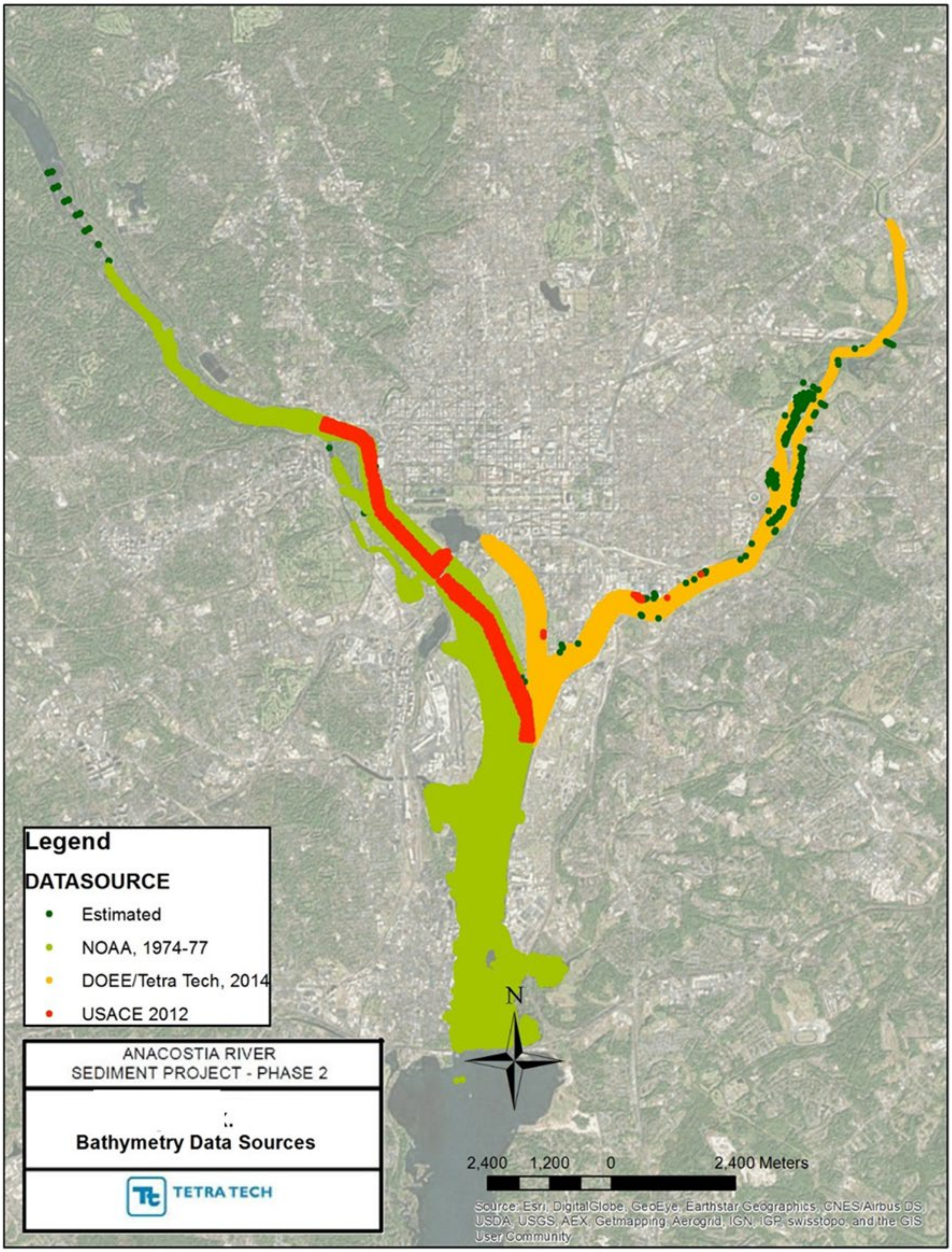


Figure 4-1. Bathymetry data sources.

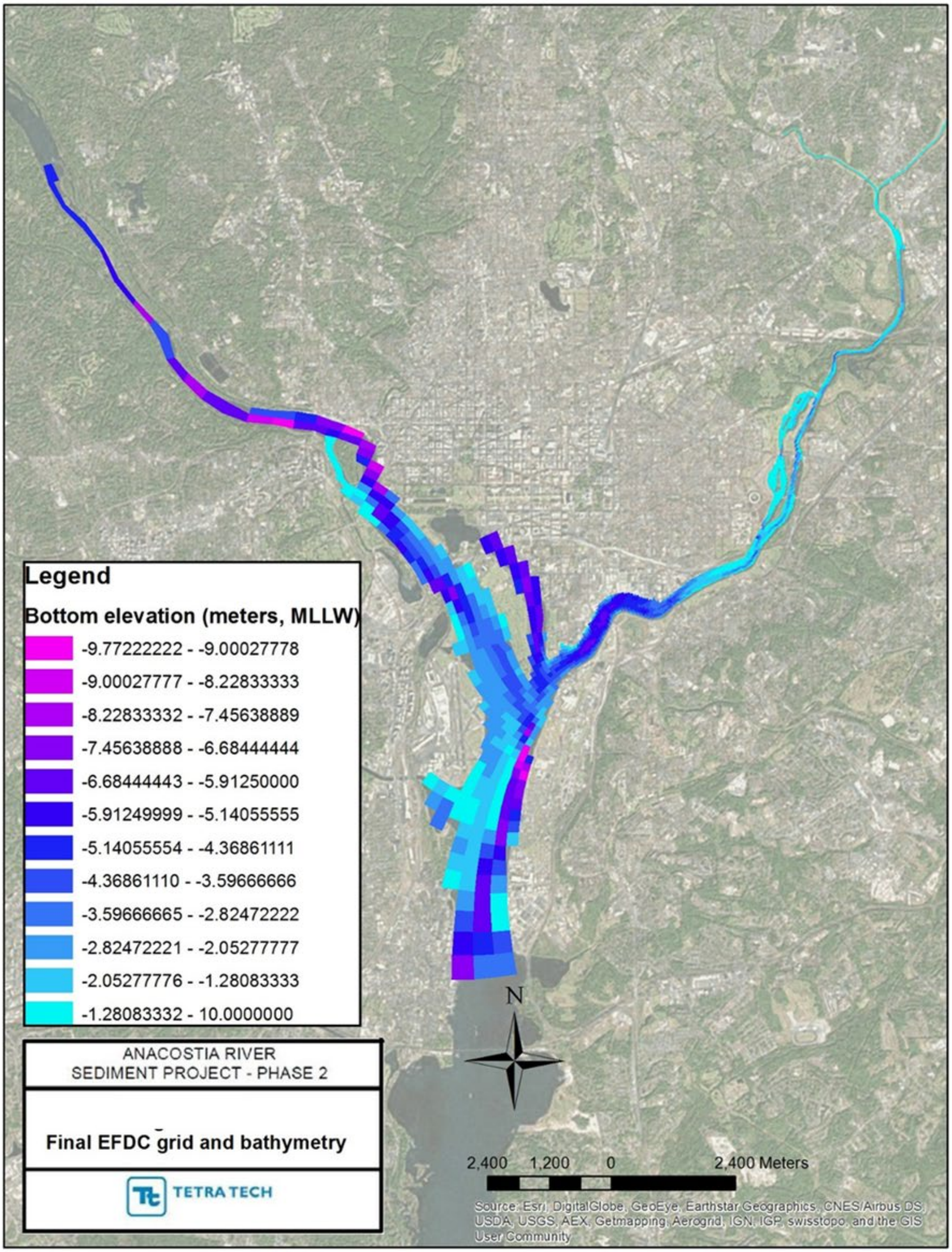


Figure 4-2. Final EFDC grid and bottom elevations (MLLW, 2010 Tidal Epoch).

4.1.1 Boundary Conditions

Hydrodynamics, sediment transport, and toxicant transport in the tidal Anacostia River are influenced mainly by three types of boundary conditions, including (1) upstream boundary conditions, (2) lateral boundary conditions, and (3) downstream open water tidal boundary conditions along with air/water surface boundary conditions. Sediment and toxicant transport are also influenced by the available mass in the sediment bed, or river bottom.

Tidal influence can reach as far upstream as the confluence of Northeast Branch and Northwest Branch under low flow conditions. Given this, the upstream extent of the grid was extended beyond those locations, as described in the previous section. While it is likely that there is little upstream advective transport at this point, the tidal influence will affect the hydrodynamics (velocity and depth), particularly at a subdaily scale. Other tributaries adjacent to the main stem of the tidal Anacostia River are largely nontidal until they reach the main stem. As discussed previously, the nontidal portions of the Anacostia River watershed are represented by the LSPC model, which provides tributary loads as boundary conditions for the EFDC model.

For the downstream Potomac River open boundary, tidal predictions at NOAA's Alexandria, VA, station (ID: 8634214) and USGS' Potomac River near Washington, DC, station (ID: USGS 01646500), were used for water levels and tidal forcing. Monitoring data collected at the USGS Chain Bridge station (USGS 01646580) were used to provide the sediment concentrations at the Potomac River boundaries. Observations at ARSP surface sediment sampling station RI-R1-09 were used to assign the pollutant concentrations because no relevant contaminant concentration data are available from the Chain Bridge station.

The tidal Anacostia River boundary flows were based on calibrated LSPC model results. The lateral boundary conditions include dynamic flow, sediment, and toxicant loads from (1) tributaries and direct drainage areas and (2) MS4 and CSS outfalls from the surrounding upstream, nontidal areas bordering the river. Similar to the upstream boundary conditions, the watershed model provides the lateral boundary conditions for direct stormwater inflows. Modeled estimates of CSS overflows between 2013 and 2015 developed by DC Water were used to calibrate CSS contributions (DC Water, 2014), (DC Water, 2015), (DC Water, 2016).

In addition to the loadings from inflowing water, air deposition can contribute toxic constituents via direct deposition to the water surface. The total mass of air deposition depends on the surface area of the water body. Outside of the tidal river and associated water body surfaces, the air deposition contribution to loading is through rainfall-runoff processes and was included in the watershed model. Existing studies provide some air deposition data over the tidal Anacostia (Table 4-1).

Table 4-1. Sources of literature used to estimate contaminant concentrations

Report title	Report date	Prepared by
Kenilworth Park Landfill: Supplemental Groundwater Study Report	2016	The Johnson Company
Expanded Site Inspection Report for Anacostia River Park, Prince Georges County, Maryland	2002	MDE
Revised Human Health Risk Assessment and Water Protection Level Evaluation Voluntary Cleanup Program, VCP Case No. VCP‐2015‐031 D.C. United Soccer Stadium Development Washington, DC	2016	Haley & Aldrich, Inc.
Preliminary Assessment/Site Investigation of Langston Golf Course, N.E. Washington, DC. Volume I of II	2001	Ecology and Environment, Inc.
Chemical Fingerprinting Assessment of The Potential Impact by CSX Transportation's Benning Yard On Fort Dupont Creek And Anacostia River Sediments	2013	NewFields
Site Characterization Report, Poplar Point, Washington DC	2003	Ridolfi, Inc.
FFA Draft, No Action Decision Document, Closure Document for Site 3-Athletic Fields, Joint Base Bolling, Washington, DC	2012	Naval Facilities Engineering Command

Report title	Report date	Prepared by
Remedial Investigation Report, Site 2—Metro Fill Area and Waterfront Fill Area, Joint Base Anacostia-Bolling, Washington, DC	2011	CH2MHill
Anacostia River Remedial Investigation Report, Phase I	2016	Tetra Tech, Inc.
Remedial Investigation Report (Draft), Benning Road Facility	2015	AECOM
Assessment of Health Risk to Utility and Landscape Workers on National Park Service Property South of East Station in Washington, DC	2002	Hydro-Terra, Inc.

4.1.2 Processes

The EFDC model is a dynamic model that requires initial conditions to start the simulation. Initial conditions can also be considered as the net result of historical processes before the beginning time of the simulation. The initial conditions are required for the simulated toxic constituents and sediment in both water column and bed sediment layers of the model. The toxic constituents and sediment concentrations in the water column are highly variable in time due to variable freshwater flow and loading, as well as tidal influences in the river; however, the initial conditions are not persistent. A spin-up period (2–3 months up to a few years of initial simulation time is needed to stabilize model results) is necessary to ensure that initial condition effects are eliminated. In practice, therefore, the actual calibration period of the ARSP model begins 5 months into the simulation (June 1, 2014, for the January 1, 2014, start date). The spin-up period allows for the establishment of model boundary and initial conditions consistent with observed data.

The sediment and toxic constituents levels in the bed sediment layers change over a much longer time scale than those in the water column in the tidal river. As a result, the initial condition “memory” in the bed sediments is much longer than the initial conditions “memory” in the water column. The specification of the initial conditions (concentrations) in the sediment layer relied on surface sediment sampling results obtained during the Remedial Investigation.

4.2 METEOROLOGICAL DATA

The EFDC model applied observed data from Reagan National Airport (DCA) to align with the LSPC watershed model. The model parameters used in the EFDC simulation include:

- Dry bulb atmospheric temperature
- Wet bulb atmospheric temperature
- Precipitation
- Evaporation
- Solar radiation
- Cloud cover

See Section 3.2 for additional information regarding development of the meteorological dataset.

4.3 SOURCE REPRESENTATION

As mentioned in Section 3.3, representation of the system using a linked modeling approach requires sufficient data to ensure that the model results are accurate. Source characterization is an important component of the dataset required to calibrate the model for contaminants.

The major sources and discharge pathways for contaminants to migrate into the tidal Anacostia River and degrade surface water, bed sediment, and biota quality to the tidal Anacostia River include:

- Urban runoff and associated loads of contaminants (nonpoint stormwater discharges)
- Watershed (nonurban) contaminant loading simulated by LSPC

- Point source discharges (e.g., CSS outfalls, MS4 outfalls, etc.)
- Spills and/or leaks to proximate soil, into linked surface water, or directly into the Anacostia River
- Legacy contamination in bed sediments and exchange of this contamination with the water column
- Atmospheric deposition, including spatial variation in deposition rates
- Vessel discharges
- Migration and discharge of contaminated groundwater into the river
- Tributary inflows to the Anacostia River
- Deposition of sediments
- Transport of resuspended contaminated sediments
- Release of contaminated sediment porewater
- Volatilization
- Dispersion across downstream boundaries

4.3.1 Sediment Representation

Sediment transport components include, for both the tidal river and the upstream watershed, internal and point source sediment and solids loads and their distribution into modeled classes, effective particle diameters, or settling velocities for sediment and solids classes. Other key parameters are erosion parameters, defining critical stress and mass erosion rates for cohesive sediment. Open boundary suspended sediment concentrations were determined based on measured data. Upstream sediment loads along the tidal Anacostia River were based on the calibrated LSPC model's delivery of the sediment to the river.

4.3.1.1 Sediment and Solids Size and Settling Classes

Sediment loads were introduced to the EFDC model as two groups: cohesive and noncohesive sediments. The EFDC model allows the simulation of multiple size classes of cohesive and noncohesive instream sediment. A sediment-processes-function library within EFDC allows the model user to choose from a wide range of currently accepted parameterizations for settling, deposition, resuspension, and bed load transport. Noncohesive sediment, or sand, was simulated separately from cohesive sediment, which was subdivided further into two additional groups: silt and clay. Deposition and erosion parameterizations were initially selected to be consistent with literature values and previous studies. To evaluate settling velocities and load distributions, cesium isotope data collected within the study area (and documented in the ARSP Remedial Investigation Report) were used to evaluate model performance spatially.

4.3.1.2 Sediment Bed Initial Conditions

The sediment bed is represented by multiple layers; it includes a number of armoring representations for noncohesive sediment and a finite strain consolidation formulation for dynamic prediction of bed layer thickness, void ratio, and pore water advection. The sediment transport component can operate in a morphological mode with full coupling with the hydrodynamic component to represent dynamic evolution of bed topography.

Initial conditions provide a starting point from which the model generates future predictions through time. For a dynamic model such as EFDC, initial conditions of water surface elevation, water temperature, salinity, and water column sediment and toxicant concentrations must be specified. Initial conditions were set to reasonable values based on observed data and modeling judgment.

The initial distribution of sediment classes within the model domain is 20% clay, 20% silt, and 60% sand, which is based on data obtained during the ARSP Remedial Investigation. Given the abundance of silt and clay, significant capacity exists in the bed layers for toxicant partitioning.

4.3.1.3 External and Internal Sediment and Solids Sources

As discussed previously, sediment transport in the tidal Anacostia River is influenced primarily by upstream tributary inflows, lateral tributary inflows, and boundary conditions along the tidal Potomac River. Upstream sediment contributions from the LSPC model were calibrated by sediment size class based on observed data collected at the five USGS stations shown in Table 4-2. The simulated sediment fractions predicted by the LSPC watershed model are input to the EFDC model.

Nonsimulated boundary conditions include Rock Creek, the Upper Potomac River at Little Falls, Four Mile Creek, Pimmit Run, Oxon Run, and the open boundary on the Potomac River at Alexandria, Virginia. Observations of flow and total suspended solids (TSS) were obtained from the Rock Creek USGS gage at Joyce Road (USGS 01648010), and a regression was developed to produce a time series of TSS at that location. The Little Falls USGS gage did not have sufficient TSS data to develop a regression with flow, so sediment data from the Chain Bridge (USGS 01646580) gage was used and the regression applied to Little Falls flow observations. The open boundary at Alexandria, Virginia, was assigned a constant sediment concentration of 21 mg/L, distributed as 1 mg/L sand, 10 mg/L silt, and 10 mg/L clay.

Table 4-2. Anacostia River watershed sediment size class data locations

Station ID	Station location	Drainage area (mi^2)	Begin date	End date
USGS-01649500	Northeast Branch Anacostia River at Riverdale, MD	72.8	Aug-38	Present
USGS-01651000	Northwest Branch Anacostia River near Hyattsville, MD	49.4	Jul-38	Present
USGS-01649190	Paint Branch near College Park, MD	13.1	Oct-07	Present
USGS-01650800	Sligo Creek near Takoma Park, MD	6.45	Oct-08	Present
USGS-01651770	Hickey Run at National Arboretum at Washington, DC	0.99	Oct-12	Present
USGS-01651800	Watts Branch at Washington, DC	3.28	Jun-92	Present

Notes: mi^2 = square miles

4.3.2 Toxic Pollutant Representation

The original EFDC model that was adapted for this effort was configured to model the fate and transport of total polychlorinated biphenyl (PCB) congeners, a key COC for the ARSP. For this TMDL, the 10 pollutants for which the Anacostia River is impaired were also configured. In a tidal system such as the tidal Anacostia River, the transport of particulate and dissolved materials is a process governed by the interaction between freshwater inflows, ocean tidal oscillations, and wind shear over the water surface. Transport in these systems is highly influenced by hydrologic conditions. For instance, during periods of high freshwater inflows, estuary processes are mostly driven by advective transport and have a higher flushing capacity. During periods of low freshwater inflows, however, the estuary processes are more influenced by dispersive transport and have an increasing mixing capacity as a result of the tide dynamics. Transport during average flow conditions is substantially more complex given that tidal systems may be partially mixed as a result of the vertical gradients of density generated by the confluence of freshwater and saltwater. However, the Anacostia River is essentially a tidal freshwater system and is characterized by water surface elevation changes due to tidal fluctuations with no salinity impacts.

4.3.2.1 Sediment Bed Initial Conditions

Toxicant concentration levels in the bed sediment layers change over a much longer time scale than the levels in the water column in water bodies such as the tidal Anacostia River, Kingman Lake, and Washington Channel. Contaminant concentrations in the bed sediments thus change much more slowly or have a much longer “memory” relative to the water column. The initial conditions in the sediment, as defined in the model, are based on the data collected or otherwise amassed to support the ARSP Remedial Investigation.

Initial contaminant concentrations in the bed sediment were applied at the beginning of the simulation to provide initial run conditions and are essential for a representative simulation of toxicants. ARSP data collected during the Remedial Investigation were used directly to assign these initial concentrations, except for the PAH1, PAH2, and PAH3 groups, where nondetection results were more common. In the case of the PAH groups, nondetection results were translated into values equal to half the detection limit for that sample. Figure 4-3 shows the initial surface sediment heptachlor epoxide concentrations in the EFDC TMDL model. Initial condition concentrations for the other nine contaminants are provided in Appendix C.

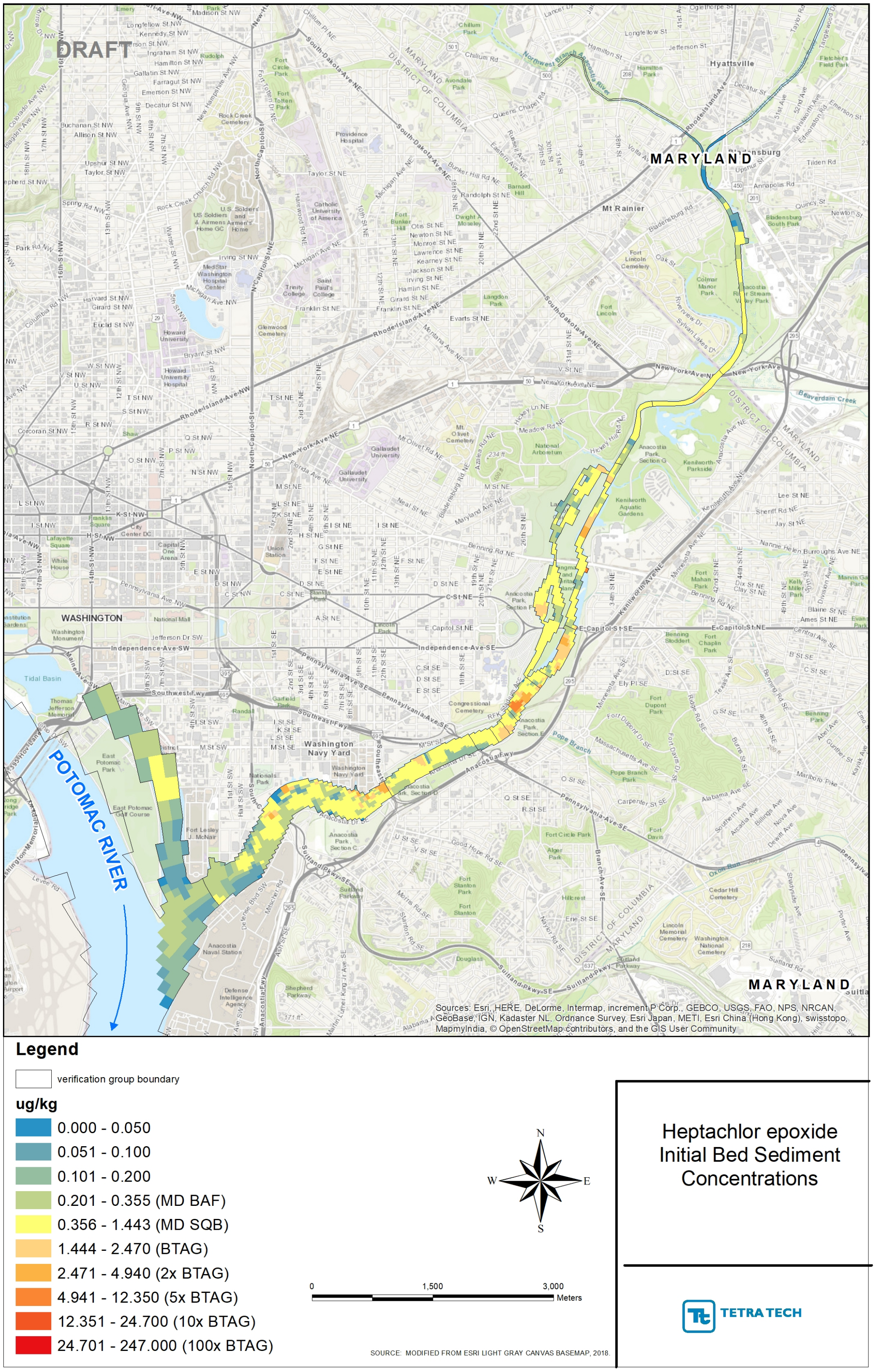


Figure 4-3. Initial heptachlor epoxide concentrations in EFDC surface bed sediments (µg/kg).

4.3.2.2 Partitioning Formulation

The partitioning of contaminants between the dissolved and solids phases is an important and complex process influencing pollutant transport and bioavailability in the water column, exchanges with the sediment bed, and fractionation between solids and pore water within the sediment bed. Given the limited amount of available data to characterize contaminant partitioning between the various media, a three-phase equilibrium partitioning approach was implemented.

Nonpolar organics can be distributed in various phases in aquatic ecosystems. One representation of this distribution is that the chemicals are partitioned among particulate organic matter (POM), dissolved organic matter (DOM), and also the freely dissolved form (U.S.EPA, 1998). The degree of partitioning, as characterized by the dissolved (free plus DOC-complexed) and particulate fractions, *fd* and *fp*, respectively, is an important parameter that controls the fate of chemicals. The transport of both the dissolved and particulate chemical phases is related to this phase distribution (U.S.EPA, 1998).

In the EFDC model, it is assumed that contaminants are distributed among the three phases mentioned previously—freely dissolved, DOC-complexed, and sorbed or POC-bound—and that contaminants are in equilibrium across these phases. It is often assumed that equilibrium between the dissolved and particulate phases occurs over a time scale of only a few hours to a day. This is the basis of the equilibrium partitioning assumption that is commonly used in the field of contaminant transport and fate modeling.

The transport of a sorptive contaminant (a contaminant that readily partitions between the dissolved and particulate phases) in the water column is governed by transport equations for the contaminant dissolved in the water phase, for the contaminant sorbed to material effectively dissolved in the water phase, and for the contaminant sorbed to suspended particles. The sorption kinetics represented in the model are based on the Langmuir isotherm ((Chapra, 1997). As shown by the equation below, the mass fractions sum up to 1: water fraction (f_w), suspended sediments fractions (f_s) and dissolved organic fraction (f_d):

$$\boldsymbol{f_w + \sum_i f_s^i + \sum_j f_d^j = 1} \qquad \text{Equation 1}$$

The influence of third-phase partitioning to nonsettling or dissolved colloidal organic material is evaluated through interpretation of monitoring data; it is not directly represented in the model. In the bed sediment, the nature of the carbon present, especially the role of black carbon, is used to empirically adjust effective partition coefficients and resulting porewater concentrations. These adjustments are based on work by (Gschwend et al 2015)for the USACE, and they do not involve the explicit simulation of black carbon as a variable.

Metals also sorb to particulate matter, but through processes that differ from those that control the partitioning of nonpolar organics. Full representation of metals partitioning requires a complete analysis of competing ions in a geochemical model, which is beyond the scope of this project. The EFDC simulation uses a simplified representation of ionic metal sorption as a function of simulated suspended sediment concentrations using the approach documented by EPA (1996). In this approach, an approximate partition coefficient to particulate matter (K_P, liters per kilogram [L/kg]) is represented in the following form:

$$\boldsymbol{K_P = K_{PO} \cdot TSS^{\alpha}} \qquad \text{Equation 2}$$

where total suspended solids ([TSS], milligrams per liter [mg/L]) and KPO and α are metals-specific coefficients.

The EFDC model simulation includes chemical transformations of hydrolysis, photolysis, biodegradation, and oxidation. For some contaminants, these degradation processes are extremely slow and could be ignored; however, for other COCs, such as some PAHs, degradation can be rapid and is a significant part of the mass balance. Exchange of contaminants across the air-water and sediment-water interfaces can be included in the calculations. Implementation of these processes in EFDC is described in detail in (Westin Solutions, 2006). Transfer of particle-bound contaminants across the sediment-water interface and between bed sediment layers is influenced by bioturbation, diffusion, and other mixing forces such as prop wash. The sediment bed is modeled as a series of vertical layers in a computationally active zone and an archive layer. The archive layer provides a record of buried mass that could become uncovered by a substantial erosion event.

5.0 LSPC CALIBRATION

Besides configuration data, the other type of dataset that is required by a linked modeling system is a calibration dataset. Streamflow and sediment data are available from a number of stations in the watershed and provide a good calibration dataset for a dynamic modeling system. As is common throughout the country, contaminant monitoring data are sparser. While calibration data are available for metals listed in Table 2-3, relatively fewer are available for pesticides and PAHs. However, several studies have been conducted in recent years to help fill this gap. The ARSP has conducted a Remedial Investigation of the tidal Anacostia River (Tetra Tech, 2018b). To support that effort, a large monitoring dataset was developed to characterize surface waters, bed sediment, pore water, and manhole sediment quality for contaminants listed in Table 2-4; they are included in the appendices of the Remedial Investigation report. All these data have been collected since 2014; they offer a current snapshot of ongoing and legacy sources of contamination and the impacts on water quality, and they provide good information for the source characterization effort. The data are discussed and summarized in sections 4 and 6 of the Remedial Investigation report, which is available online.

The Anacostia TMDL modeling approach consists of a linked watershed/receiving water modeling system describing hydrology, hydrodynamics, and pollutant loading in the Anacostia River watershed. Additional data (in situ water quality monitoring and synoptic and episodic surveys of water chemistry) were collected in 2018 and 2019 to further build upon existing data to characterize the water conditions and levels of contaminants. The 2018–2019 monitoring effort was conducted to support the comparison of data to both WQC and to model predicted concentrations of TMDL parameters.

5.1 HYDROLOGY

Watershed hydrology plays an important role in determining nonpoint and stormwater source flow and ultimately identifying nonpoint and stormwater source loadings to a water body. The watershed model must appropriately represent the spatial and temporal variability of hydrological characteristics within a watershed. Key hydrological characteristics include interception storage capacities, infiltration properties, evaporation and transpiration rates, and watershed slope and roughness.

LSPC's algorithms for simulating hydrology are identical to those in HSPF. The LSPC/HSPF modules used to represent watershed hydrology include PWATER (water budget simulation for pervious land units) and IWATER (water budget simulation for impervious land units). The HSPF Version 12 User's Manual presents a detailed description of relevant hydrological algorithms (Bicknell et al 2014).

Multiple hydrologic components are contained within LSPC including precipitation, interception (CEPSC), evapotranspiration, overland flow, infiltration, interflow (IRC), subsurface storage (upper zone storage is UZSN and lower zone storage is LZSN), groundwater flow (AGWRC), and groundwater loss (DEEPFR). Figure 5-1 provides a graphical representation of these processes (note: capitalized acronyms are computer code routine names). Rain falls and lands on constructed landscapes, vegetation, and soil. Varying soil types allow the water to infiltrate (INFILT) at different rates (using the Philip infiltration algorithm) or enter shallow interflow pathways (INTFW), while evaporation and plant matter exert a demand on available water from the lower zone (LZETP), active groundwater (AGWETP), and baseflow (BASETP). Water flows overland based on a specified slope (SLSUR), surface roughness (NSUR), and distance (LSUR) and through the soil matrix.

The land representation in the LSPC model contains three major flow pathways: surface, interflow, and groundwater outflow. The model simulates total actual ET by trying to fulfill potential ET (PET) by first removing water from baseflow outflow, then interception storage, then upper zone storage, then groundwater storage, and, finally, lower zone storage. Some of the parameter values for the hydrology model are considered constant and others are allowed to vary by month, but no parameters are allowed to vary by year. All parameters were allowed to vary by HRU category.

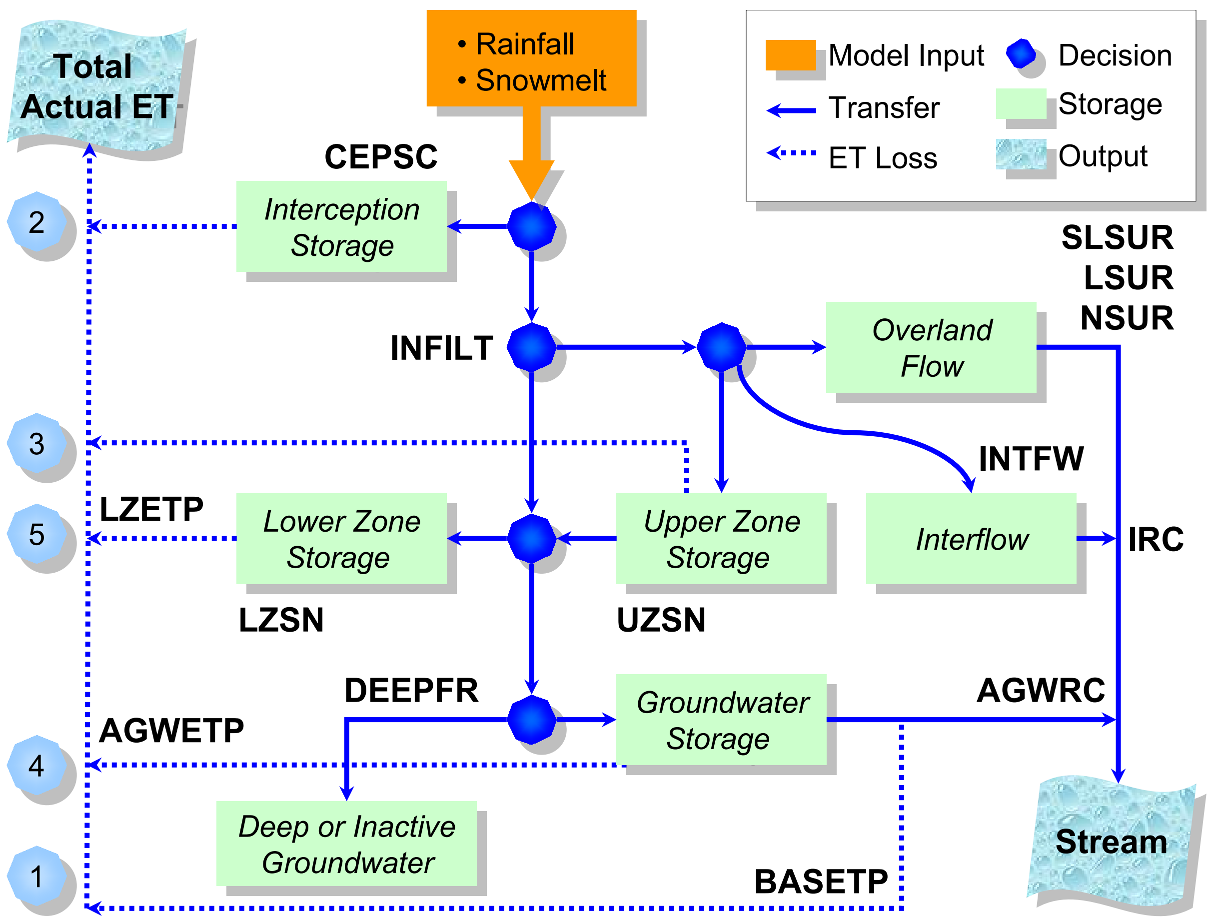


Figure 5-1. LSPC hydrologic simulation fluxes, pathways, and storages.

5.1.1 Observed Flow Data

As part of the ARSP, available hydrologic data were reviewed for use in calibrating and evaluating the predictive ability of the Anacostia River watershed model. Hydrology monitoring stations were first georeferenced with both the subwatershed boundaries and reach layers to identify the associated model outflow points for comparison. Upstream drainage area characteristics, such as contributing land use distribution, were also summarized for each flow gage as presented in the following section.

Table 5-1 provides a summary of the monitoring stations along with the period of record drainage area and whether and how the station was used for calibration. Long-term continuous stream monitoring conducted by USGS is available for six locations in the watershed. Figure 5-2 shows the location of the flow calibration stations.

Table 5-1. Anacostia River watershed hydrology calibration locations

Station ID	Station location	Drainage area (mi^2)	Begin date	End date	Calibration use
USGS-01649500	Northeast Branch Anacostia River at Riverdale, MD	72.8	Aug-38	Present	Flow and WQ
USGS-01651000	Northwest Branch Anacostia River near Hyattsville, MD	49.4	Jul-38	Present	Flow and WQ
USGS-01649190	Paint Branch near College Park, MD	13.1	Oct-07	Present	Flow only
USGS-01650800	Sligo Creek near Takoma Park, MD	6.45	Oct-08	Present	Flow only
USGS-01651770	Hickey Run at National Arboretum at Washington, DC	0.99	Oct-12	Present	Flow and WQ
USGS-01651800	Watts Branch at Washington, DC	3.28	Jun-92	Present	Flow and WQ

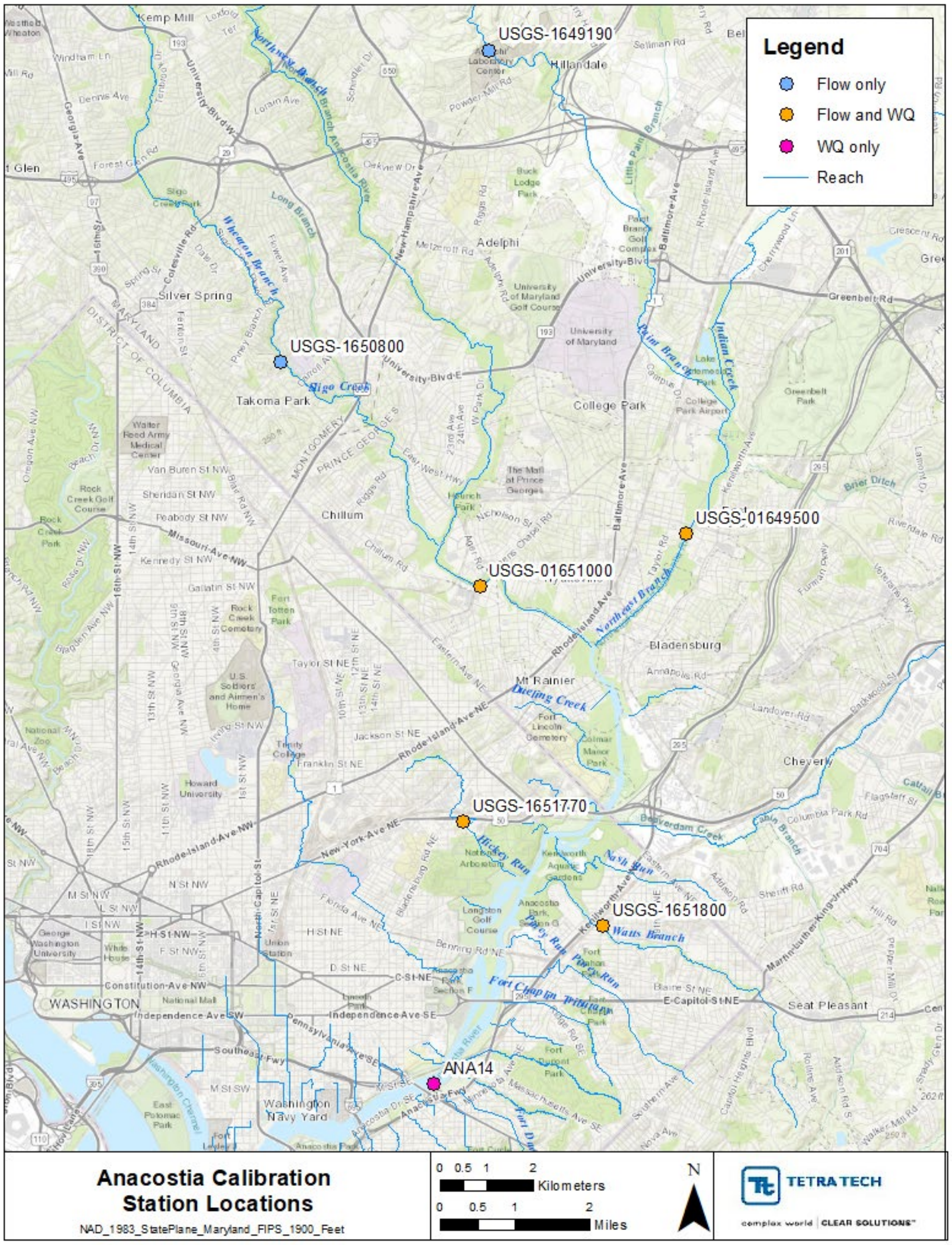


Figure 5-2. Anacostia LSPC calibration station locations.

5.1.2 Calibration Results

The hydrologic calibration developed for the ARSP watershed model was used directly for the TMDL toxic constituents effort. That hydrologic calibration followed the standard operating procedures for the model described in (U.S. EPA, 2000), (Donigian et al 1984), and (Lumb et al 1994). Daily, monthly, seasonal, and total modeled flow volumes were compared to observed data, and error statistics were calculated for the percent difference, along with the Nash-Sutcliffe coefficient of model fit efficiency (NSE) for daily average flows. Unlike relative error on volumes, NSE (Nash & Sutcliffe, 1970) is a measure of the ability of the model to explain the variance in the observed data. Values may vary from -∞ to 1.0. A value of NSE = 1.0 indicates a perfect fit between modeled and observed data, while values equal to or less than 0 indicate the model's predictions of temporal variability in observed flows are no better than using the average of observed data. The accuracy of a model increases as the value approaches 1.0 and an NSE of 0.75 or greater on monthly flows constitutes a good modeling fit (i.e., usefulness of the model) for watershed applications. The baseline adjustment coefficient (Cunnane, Garrick, & Nash, 1978), which is also presented, is a modified version of the NSE, but can be interpreted similarly.

The percent volume errors were then compared to recommended tolerance targets from (Donigian et al 1984) and (Lumb et al 1994). Targets are shown in Table 5-2 and represent long-term averages for relative error. In general, meeting these targets indicates that a model calibration is reliable and can be used effectively for decision making. In contrast, failure to achieve these targets does not indicate that the model is unusable, but rather indicates a need to consider the impacts of model uncertainty on decisions. Values for hydrologic parameters were set in accordance with the ranges recommended in U.S. EPA (2000) and adjusted during calibration.

Model results were also visually compared to observed data using time series plots, and additional graphical and tabular monthly comparisons were performed. Less credence was placed in the seasonal summer and storm event summer statistics because runoff volumes are low (or nonexistent) during the dry seasons, and storms are rare.

Table 5-2. Criteria for the hydrology calibration

Category	Recommended criteria (%)
Error in total volume	±10
Error in 50% lowest flows	±10
Error in 10% highest flows	±15
Seasonal volume error - summer	±30
Seasonal volume error - fall	±30
Seasonal volume error - winter	±30
Seasonal volume error - spring	±30
Error in storm volumes	±20
Error in summer storm volumes	±50
Nash-Sutcliffe efficiency statistic (NSE)	>0.75

Source: Modified from Lumb et al. 1994 and Donigian et al. 1984

The initial evaluation focused on the period from 01/01/2008 through 12/31/2017, as this period was the most recent 10 years during model development, and it captured the first two years of the Remedial Investigation sampling effort. Figure 5-3 through Figure 5-5 present modeled versus observed comparisons at the Northeast Branch USGS streamflow gage.

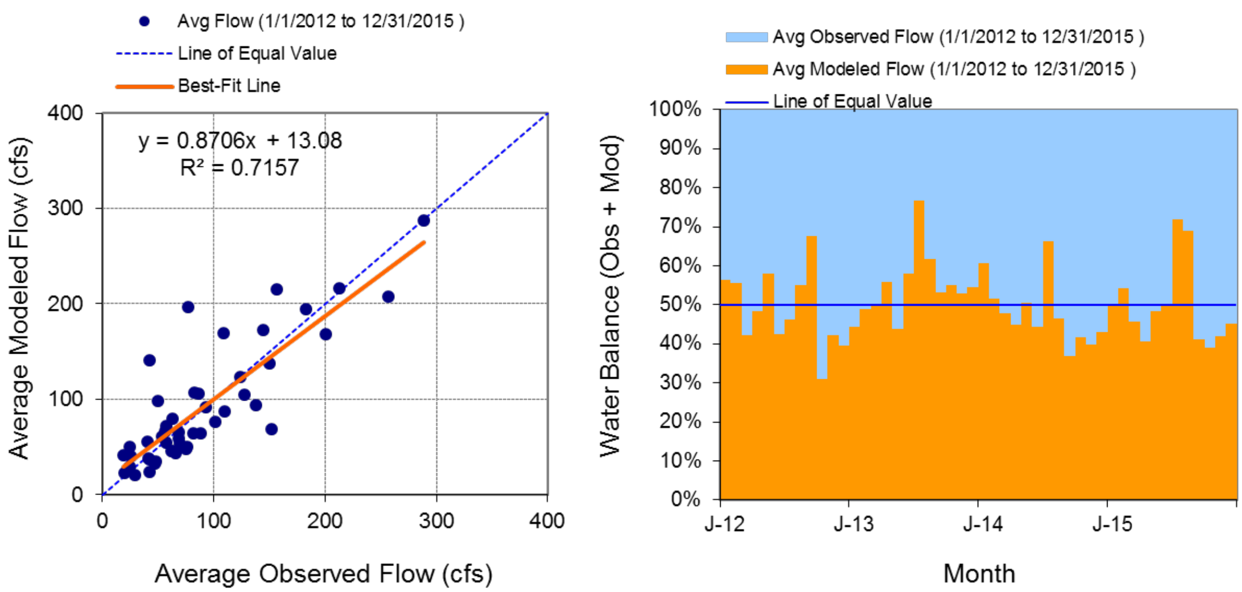


Figure 5-3. Monthly modeled versus observed flow regression (left) and equal value plot (right) at USGS 01649500 NORTHEAST BRANCH ANACOSTIA RIVER AT RIVERDALE, MD, station.

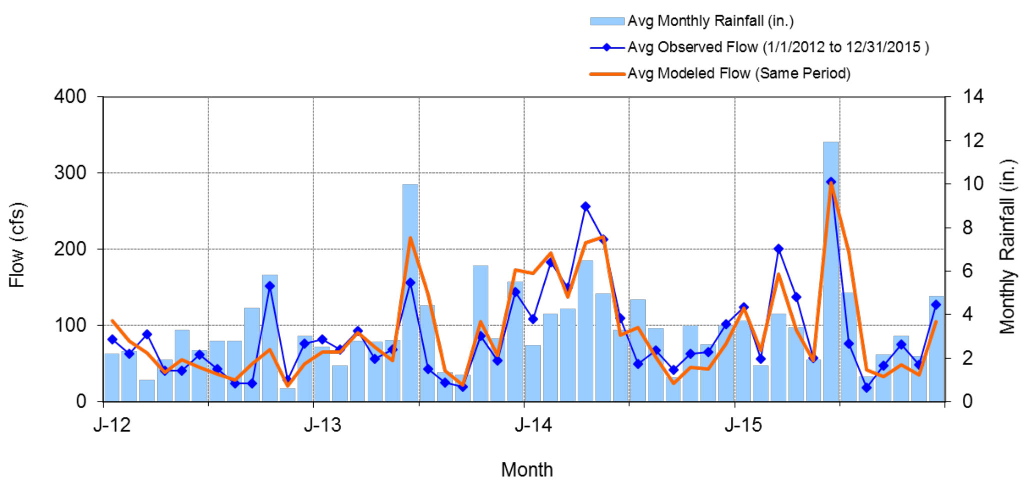


Figure 5-4. Monthly modeled versus observed flow time series comparison at USGS 01649500 NORTHEAST BRANCH ANACOSTIA RIVER AT RIVERDALE, MD, station.

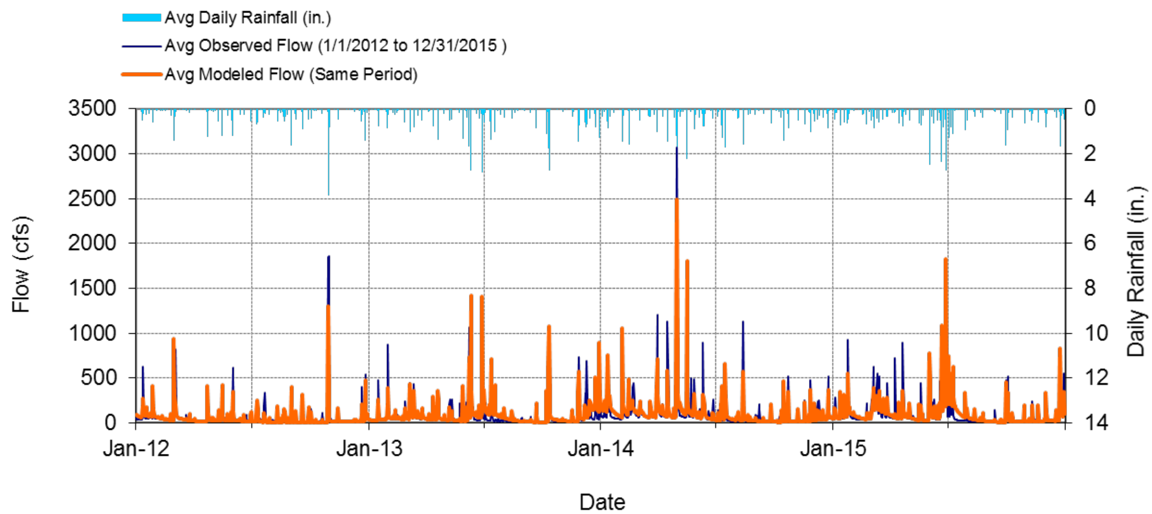


Figure 5-5. Daily modeled versus observed flow time series comparison at USGS 01649500 NORTHEAST BRANCH ANACOSTIA RIVER AT RIVERDALE, MD, station.

Table 5-3 provides error statistics for the six USGS gages for the period of record within the calibration timeframe, and it shows good alignment with the suggested targets shown in Table 5-2.

Table 5-3. Summary flow statistics for all LSPC calibration stations

Watershed	NE Branch	NW Branch	Paint Branch	Sligo Creek	Watts Branch	Hickey Run
Time Period	1/1/2005-12/31/2015	1/1/2005-12/31/2015	1/1/2008-12/31/2015	1/1/2009-12/31/2015	1/1/2005-12/31/2015	1/1/2013-12/31/2015
Errors (Simulated-Observed)	**Error Statistics**					
Error in total volume:	2.81	7.18	9.04	3.46	7.73	**20.56**
Error in 50% lowest flows:	3.70	6.94	-9.77	-3.05	-9.93	3.06
Error in 10% highest flows:	-13.86	-12.50	-2.17	-7.71	1.82	12.17
Seasonal volume error - Summer:	15.59	23.99	22.69	-6.53	9.92	**55.12**
Seasonal volume error - Fall:	-6.01	-3.20	1.72	2.32	-0.07	16.44
Seasonal volume error - Winter:	0.87	13.36	8.66	15.46	6.75	27.61
Seasonal volume error - Spring:	5.45	2.81	8.26	2.62	13.73	7.37
Error in storm volumes:	-16.79	-16.95	-10.97	-10.98	0.26	15.69
Error in summer storm volumes:	-4.69	-0.25	3.30	-14.06	8.37	**58.32**
Nash-Sutcliffe Coefficient of Efficiency, E:	0.663	0.694	0.565	0.603	0.755	0.687
Baseline adjusted coefficient (Garrick), E':	0.477	0.469	0.333	0.469	0.542	0.531

5.2 WATER QUALITY

5.2.1 Sediment

The simulation of sediment loading from the watershed is important due to the hydrophobic nature of the TMDL toxic constituents. The delivery of those toxic constituents to surface water is at least partially driven by sediment erosion, transport, and fate when those pollutants are sediment associated.

HSPF simulates sediment yield to streams in two stages. First, HSPF calculates the detachment rate of sediment by rainfall (in tons/acre) as:

$$DET = (1\text{-}COVER) \cdot SMPF \cdot KRER \cdot P^{JRER}$$

where DET is the detachment rate (tons/acre), COVER is the dimensionless factor accounting for the effects of cover on the detachment of soil particles, SMPF is the dimensionless management practice factor, KRER is the coefficient in the soil detachment equation, JRER is the exponent in the soil detachment equation, which is recommended to be set to 1.81, and P is precipitation depth in inches over the simulation time interval. Direct addition of sediment (e.g., from wind deposition) is also added via the parameter NVSI. Actual detached sediment storage available for transport (DETS) is a function of accumulation over time and the reincorporation rate, AFFIX.

The transport capacity for detached sediment from the land surface (STCAP) is represented as a function of overland flow:

$$STCAP = KSER \cdot SURS{+}SURO^{JSER}$$

where KSER is the coefficient for transport of detached sediment, SURS is surface water storage (inches), SURO is surface outflow of water (inches/hour), and JSER is the exponent for transport of detached sediment.

HSPF/LSPC representation of instream sediment transport is described in Bicknell et al. (2014). The model includes simulation of the transport, deposition, and scour of streambed sediment. The model uses a single sediment bed layer with a defined initial bed composition and depth. As a one-dimensional reach model, HSPF does not directly distinguish between channel bed and bank erosion. As a result, all scour and deposition are represented as a nominal change in sediment bed depth and the simulation continuously updates the bed composition in each reach based on relative amounts of scour or deposition of the three defined size classes: sand, silt, and clay.

Sediment parameter values were assigned to the TMDL model directly from the ARSP modeling system. The sediment parameters were adjusted during the calibration process to represent current conditions in the watershed and compared with observed datasets. These datasets included grab samples of TSS instream, as well as several annual loading study estimates. The final calibrated parameter set is presented in Table 5-4 through Table 5-7. Parameter definitions and ranges can be found in EPA's Technical Note #8 (https://www.epa.gov/sites/production/files/2015-08/documents/2006_02_02_basins_tecnote8.pdf) .

Table 5-4. Sediment parameter group 1

defid	deluid	smpf	krer	jrer	affix	cover	nvsi	kser	jser	kger	jger	accsdp	remsdp
1	Water	1	0	1.81	0.05	0.78	0	0	2	0	2.5	0	0
1	ForestWet_B	1	0.29	1.81	0.05	0.78	0	1	2	0	2.5	0	0
1	ForestWet_C	1	0.3	1.81	0.05	0.78	0	1	2	0	2.5	0	0
1	ForestWet_D	1	0.32	1.81	0.05	0.78	0	1	2	0	2.5	0	0
1	Agri_B	1	0.48	1.81	0.05	0.78	0.002	2.5	2	0	2.5	0	0
1	Agri_C	1	0.52	1.81	0.05	0.78	0.002	2.5	2	0	2.5	0	0
1	Agri_D	1	0.55	1.81	0.05	0.78	0.002	2.5	2	0	2.5	0	0
1	Devperv_B_Low	1	0.38	1.81	0.05	0.78	0.003	1.4	2	0	2.5	0	0
1	Devperv_B_High	1	0.38	1.81	0.05	0.78	0.003	1.4	2	0	2.5	0	0
1	Devperv_C_Low	1	0.41	1.81	0.05	0.78	0.003	1.4	2	0	2.5	0	0
1	Devperv_C_High	1	0.41	1.81	0.05	0.78	0.003	1.4	2	0	2.5	0	0
1	Devperv_D_Low	1	0.45	1.81	0.05	0.78	0.003	1.4	2	0	2.5	0	0
1	Devperv_D_High	1	0.45	1.81	0.05	0.78	0.003	1.4	2	0	2.5	0	0
1	DevOpen_Imp	1	0.45	1.81	0.05	0.78	0.003	1.4	2	0	2.5	0	0
1	ResLow_Imp	1	0	0	0	0.78	0	0.7	2	0	2.5	0.0002	0.02
1	ResMed_Imp	1	0	0	0	0.78	0	0.85	2	0	2.5	0.0004	0.02
1	ResHigh_Imp	1	0	0	0	0.78	0	0.9	2	0	2.5	0.0006	0.02
1	Comm_Imp	1	0	0	0	0.78	0	1	2	0	2.5	0.0006	0.015
1	Inst_Imp	1	0	0	0	0.78	0	0.8	2	0	2.5	0.0002	0.04
1	Ind_Imp	1	0	0	0	0.78	0	1	2	0	2.5	0.0004	0.01
1	RoadTransUtil_Imp	1	0	0	0	0.78	0	1	2	0	2.5	0.0006	0.01

Table 5-5. Sediment parameter group 2

defid	deluid	sed_suro	sed_ifwo	sed_agwo	sed_1	sed_2	sed_3
1	Water	0	0	0	0.02	0.5	0.48
1	ForestWet_B	3000	20	1	0.02	0.5	0.48
1	ForestWet_C	1000	20	1	0.02	0.5	0.48
1	ForestWet_D	500	20	1	0.02	0.5	0.48
1	Agri_B	3000	50	3	0.02	0.5	0.48
1	Agri_C	1000	50	3	0.02	0.5	0.48
1	Agri_D	500	50	3	0.02	0.5	0.48
1	Devperv_B_Low	3000	80	4	0.02	0.5	0.48
1	Devperv_B_High	3000	80	10	0.02	0.5	0.48
1	Devperv_C_Low	1000	80	4	0.02	0.5	0.48
1	Devperv_C_High	1000	80	10	0.02	0.5	0.48
1	Devperv_D_Low	500	80	4	0.02	0.5	0.48
1	Devperv_D_High	500	80	10	0.02	0.5	0.48
1	DevOpen_Imp	1000	80	7	0.02	0.5	0.48
1	ResLow_Imp	20	0	0	0.02	0.5	0.48
1	ResMed_Imp	40	0	0	0.02	0.5	0.48
1	ResHigh_Imp	40	0	0	0.02	0.5	0.48
1	Comm_Imp	40	0	0	0.02	0.5	0.48
1	Inst_Imp	20	0	0	0.02	0.5	0.48
1	Ind_Imp	40	0	0	0.02	0.5	0.48
1	RoadTransUtil_Imp	40	0	0	0.02	0.5	0.48

Table 5-6. Sediment parameter group 3

rgid	bedwid	beddep	por	burial
1	16	5	0.5	0

Table 5-7. Sediment parameter group 4

rgid	sed_id	sedflg	sedo	sedfrac	db50/d	w	rho	ksand/taucd	expsnd/taucs	m	burial
1	1	1	8	0.38	0.005	0.2	2.5	0.2	2	0.001	0
1	2	1	8	0.46	0.0002	0.001	2.2	0.001	0.15	0.002	0
1	3	1	8	0.16	0.00001	0	2	0.00001	0.15	0.003	0

Sediment calibration of the LSPC model was performed at the six locations in the watershed where hydrology was assessed (see Table 5-1). Ambient water quality data and annual load study results were used to calibrate the LSPC sediment simulation. Figure 5-6. through Figure 5-11 show the calibration to ambient TSS data. Figure 5-12 through Figure 5-16 show annual loading estimates from the LSPC sediment simulation compared with other sediment studies. Figure 5-17 through Figure 5-20 show the annual sediment load estimates for each study normalized by rainfall.

5.2.1.1 Time Series Comparison

A comparison of modeled time series versus observed data was made at six locations, representing the majority of the contributing area in the Anacostia River watershed. The LSPC model provided a good match with observed values at all six locations. The range of observed values was represented at all locations except Paint Branch, which had a single observation above the maximum LSPC value (3,070 mg/L; maximum LSPC concentration was 1,993 mg/L at the Paint Branch location).

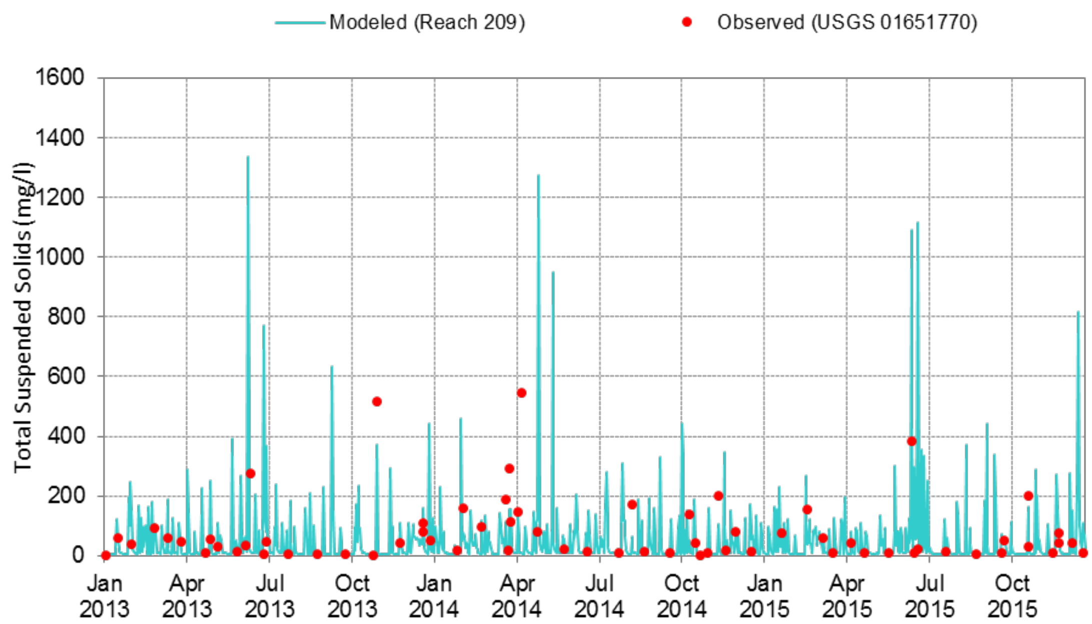


Figure 5-6. TSS calibration at Hickey Run USGS gage (USGS 01651770).

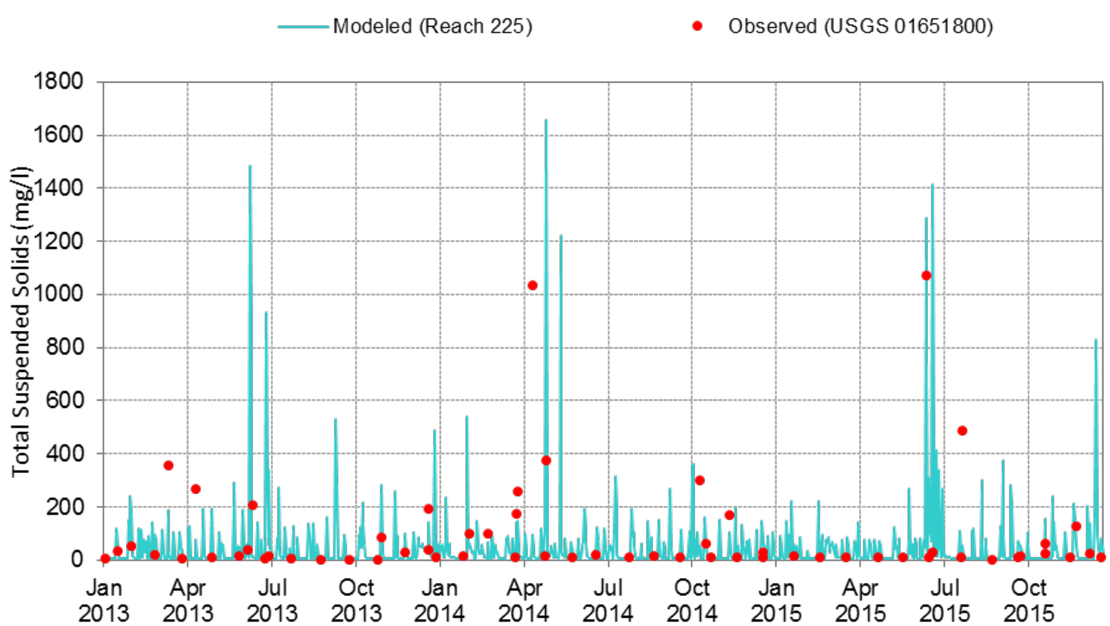


Figure 5-7. TSS calibration at Watts Branch USGS gage (USGS 01651800).

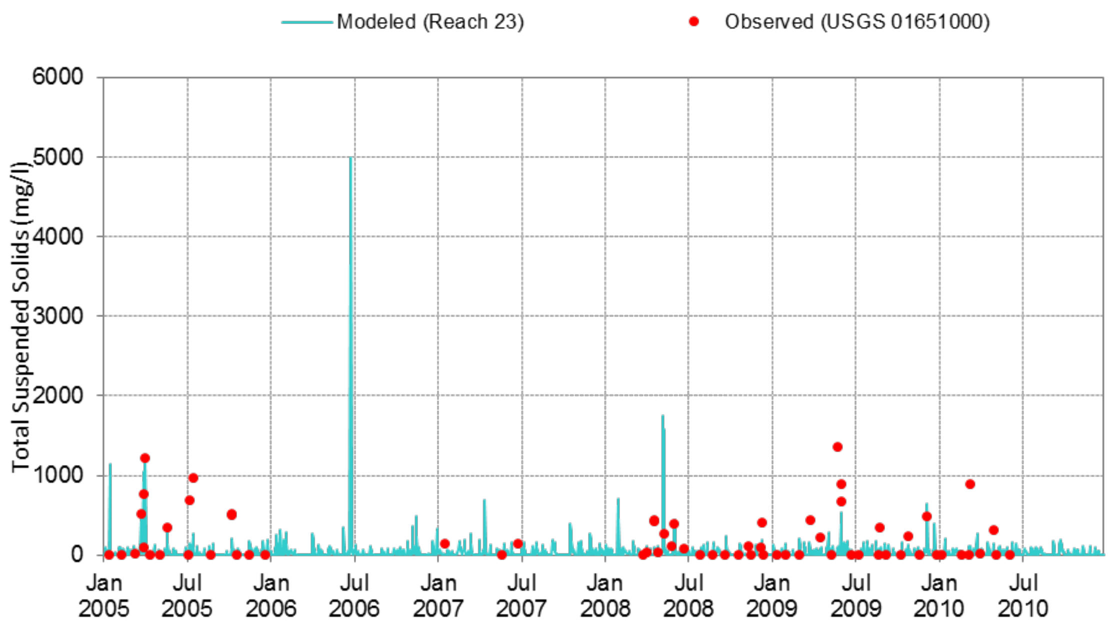


Figure 5-8. TSS calibration at Northwest Branch USGS gage (USGS 01651000).

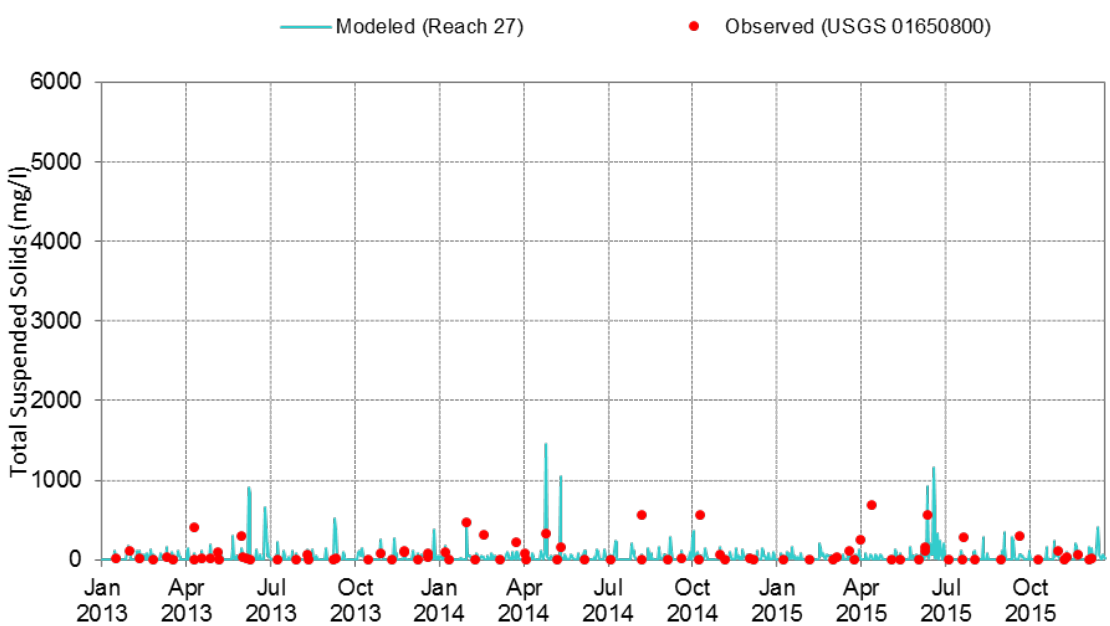


Figure 5-9. TSS calibration at Sligo Creek near Takoma Park USGS gage (USGS 01650800).

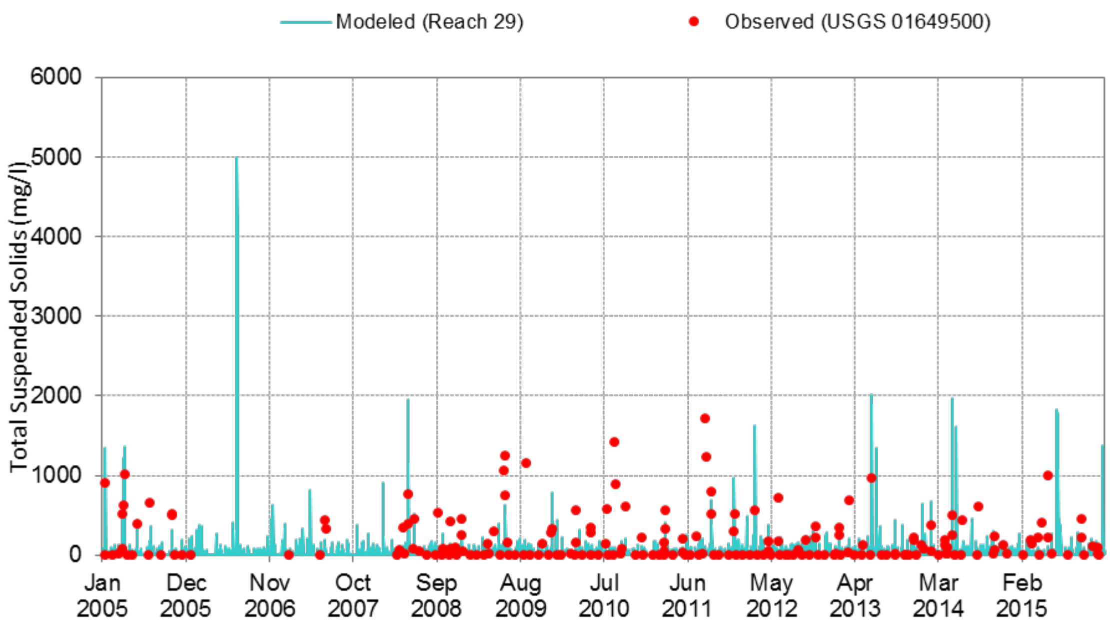


Figure 5-10. TSS calibration at Northeast Branch USGS gage (USGS 01649500).

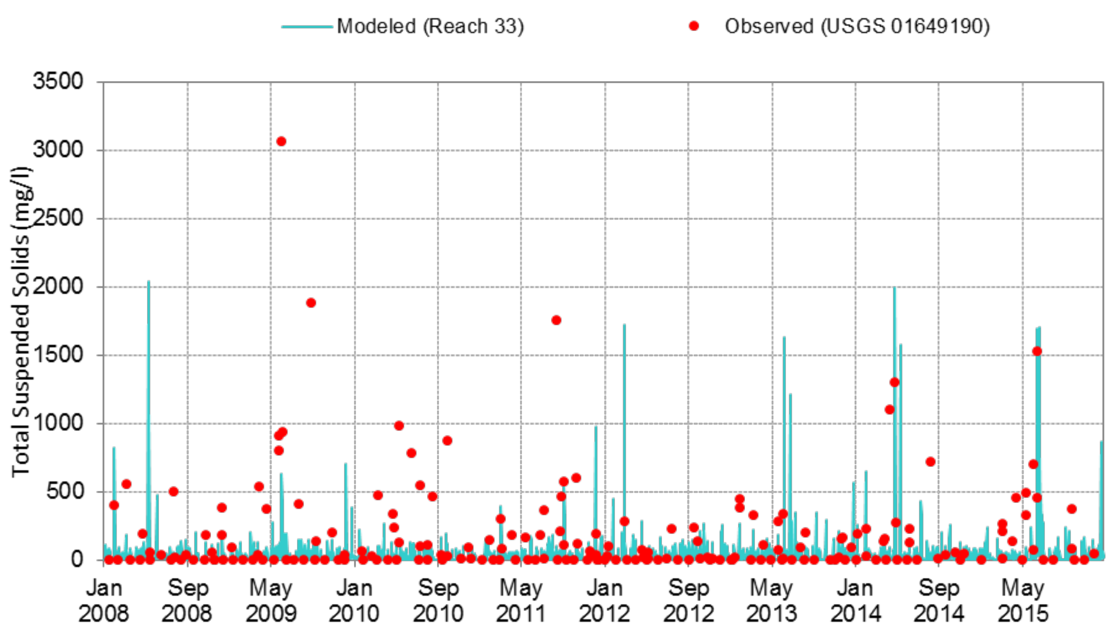


Figure 5-11. TSS calibration at Paint Branch near College Park USGS gage (USGS 01649190).

5.2.1.2 Annual Sediment Loading Comparison

The sediment loading studies listed in Table 5-8 are summarized here and represent different time periods characterized by a range of dry and wet years. To account for rainfall on loading estimates, loading rates (tons/acre/year) were then plotted with annual rainfall totals and summarized in Section 5.2.1.3. A comparison of annual loading estimates from previous studies to LSPC results was made at four locations, representing most of the contributing area in the Anacostia River watershed. The LSPC model provided a good match, with observed values at Northwest (Figure 5-12) and Northeast (Figure 5-13) branches of the Anacostia River. The summed load from these two locations falls within the range of other studies that estimate sediment contributions from those locations (Figure 5-14). The LSPC model overestimates sediment contributions from two smaller watersheds, likely due to site scale features that are not explicitly represented in the LSPC model. These locations are Beaverdam Creek (Figure 5-15) and Watts Branch (Figure 5-16).

Table 5-8. Sediment loading studies used in LSPC sediment calibration

Model	Reference	Time period	Annual average rainfall (inches)
LSPC Model	—	2014–2017	42.39
TAM/WASP v2	Schultz (2003)	1988–1990	43.13
TAM/WASP v3	Schultz et al. (2007)	1995-1997	44.93
USGS Estimator Loads	Miller et al. (2007)	2004–2005	41.74
USGS LOADEST Loads	Miller et al. (2007)	2004–2005	41.74
ICPRB ESTIMATOR Loads (by water year)	Schultz et al. (2007)	1995–2005	43.04
USGS LOADEST Loads	Miller et al. (2007)	2004	39.10
USGS LOADEST Loads	Miller et al. (2007)	2005	44.38
USGS Estimator Loads	Miller et al. (2007)	2004	39.10
USGS Estimator Loads	Miller et al. (2007)	2005	44.38

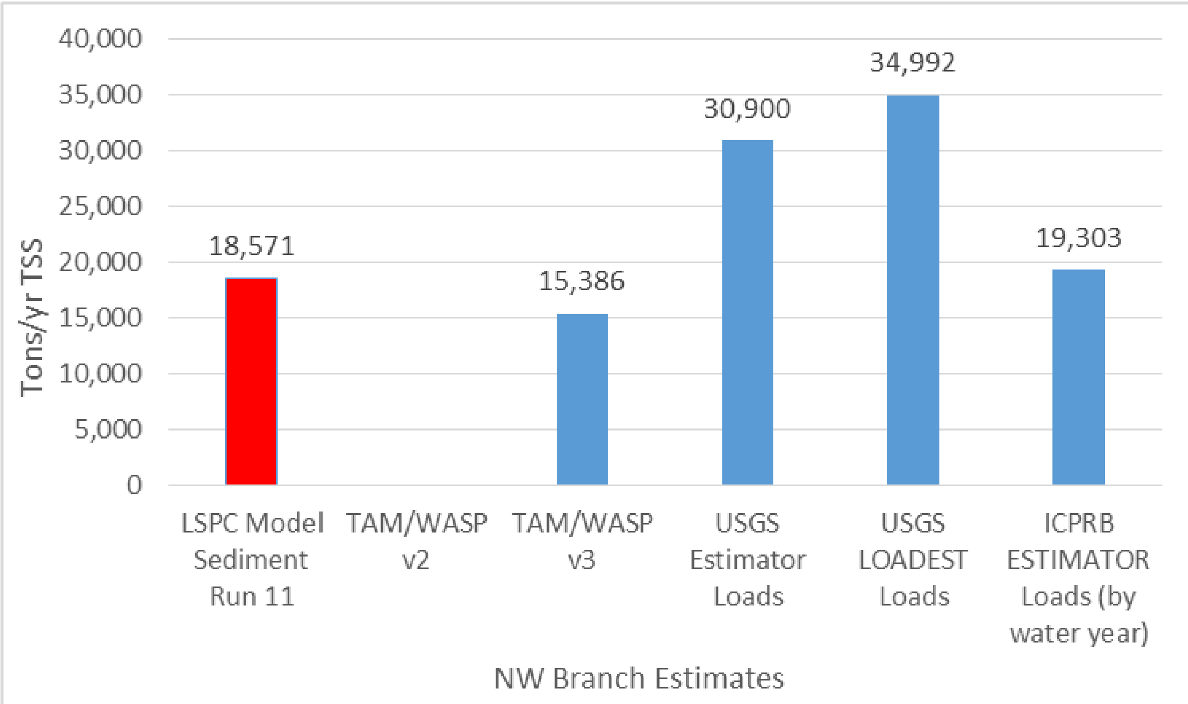


Figure 5-12. Annual TSS load estimates from studies at the NW Branch USGS Gage (USGS 01651000).

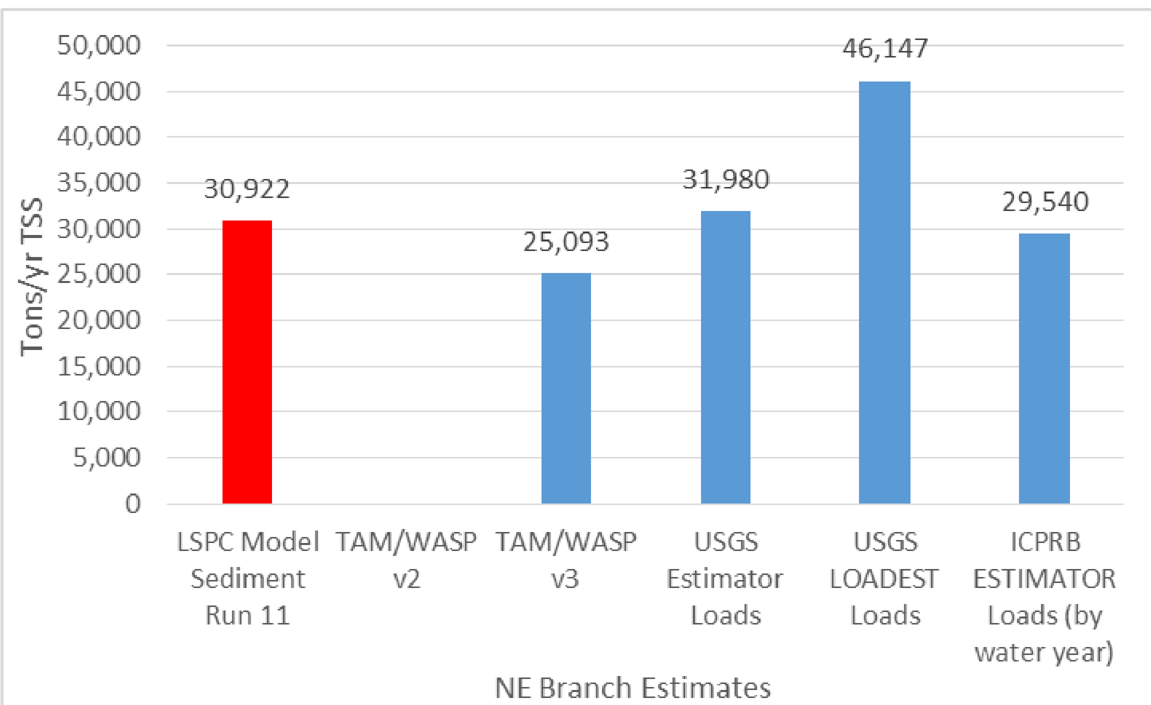


Figure 5-13. Annual TSS load estimates from studies at the NE Branch USGS gage (USGS 01649500).

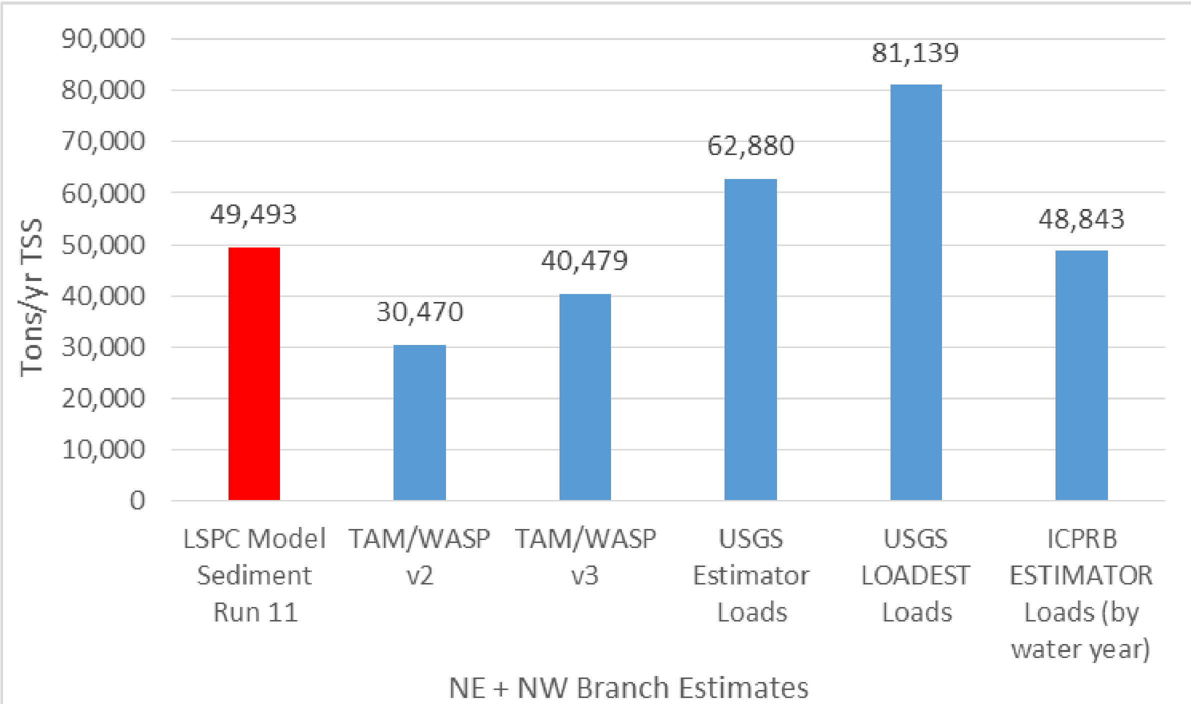


Figure 5-14. Annual TSS load estimates from studies at the NE Branch + NW Branch USGS gage (USGS 01649500 + USGS 01651000).

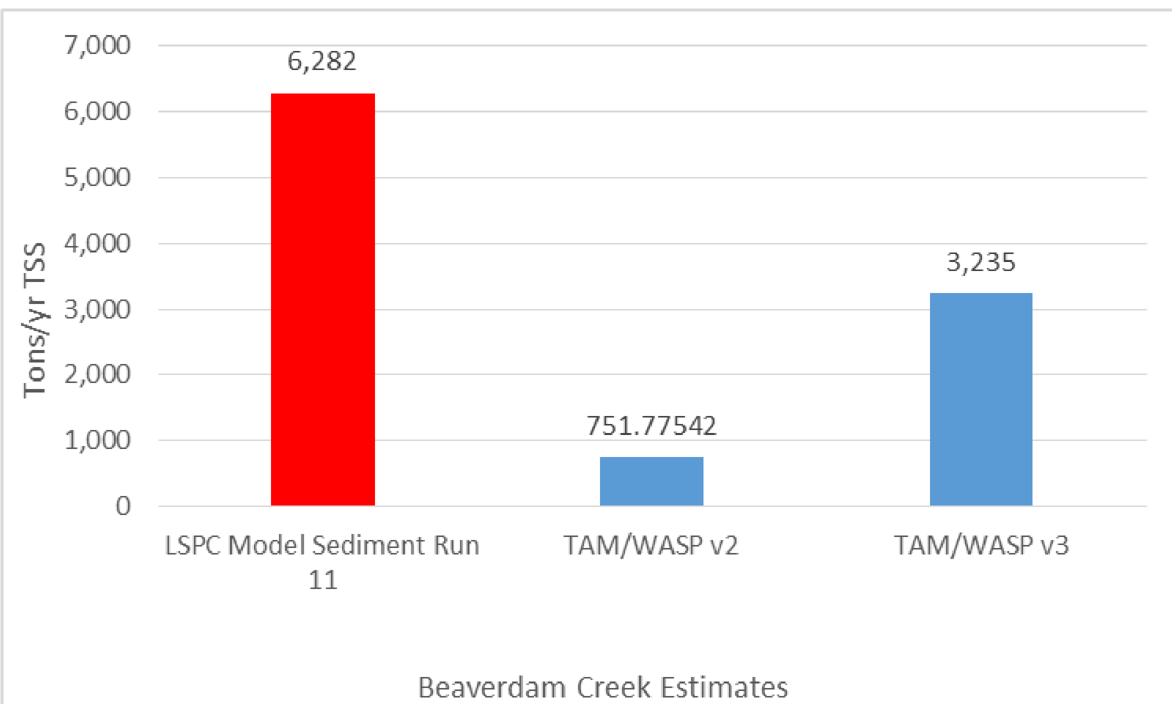


Figure 5-15. Annual TSS load estimates from studies at the Beaverdam Creek USGS gage.

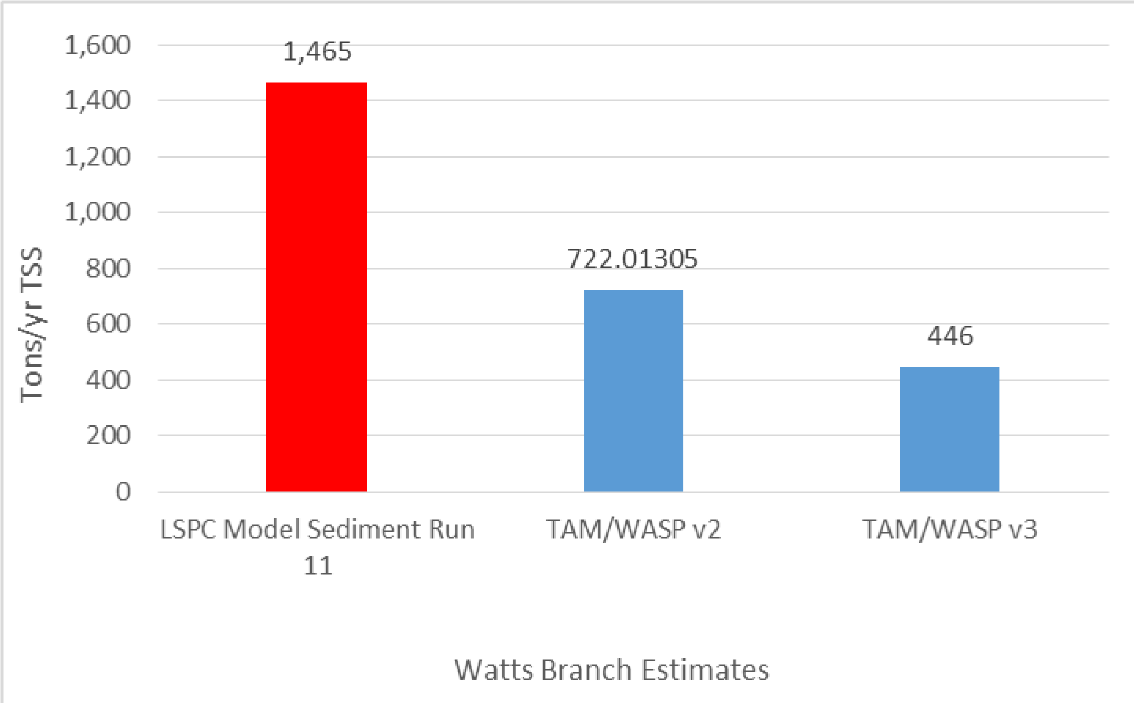


Figure 5-16. Annual TSS load estimates from studies at the Watts Branch USGS gage (USGS 01651800).

5.2.1.3 Rainfall-normalized Sediment Loading Comparison

The sediment loading studies shown in Figure 5-12 through Figure 5-16 represented different time periods characterized by a range of dry and wet years. To account for rainfall on loading estimates, loading rates (tons/acre/year) were plotted with annual rainfall totals in Figure 5-17 through Figure 5-20. Loading rates from the LSPC model fall very close to the trendline for Northwest (Figure 5-17) and Northeast **(**Figure 5-18) branches based on previous studies and rainfall experienced during that study. As expected, sediment loading rates from Beaverdam Creek (Figure 5-19) and Watts Branch (Figure 5-20) are overestimated in LSPC relative to previous studies.

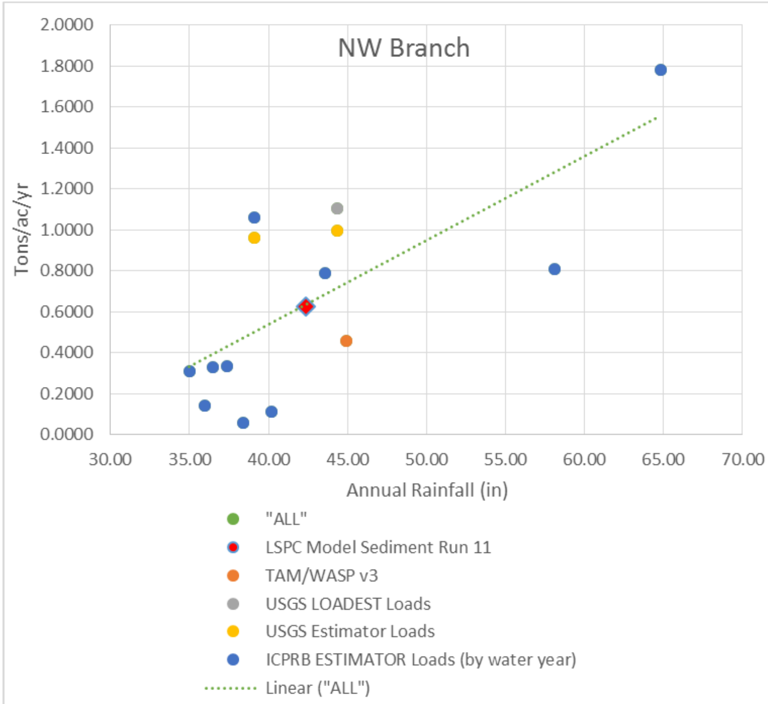


Figure 5-17. Annual TSS load estimates normalized by rainfall at the Northwest Branch USGS gage (USGS 01651000).

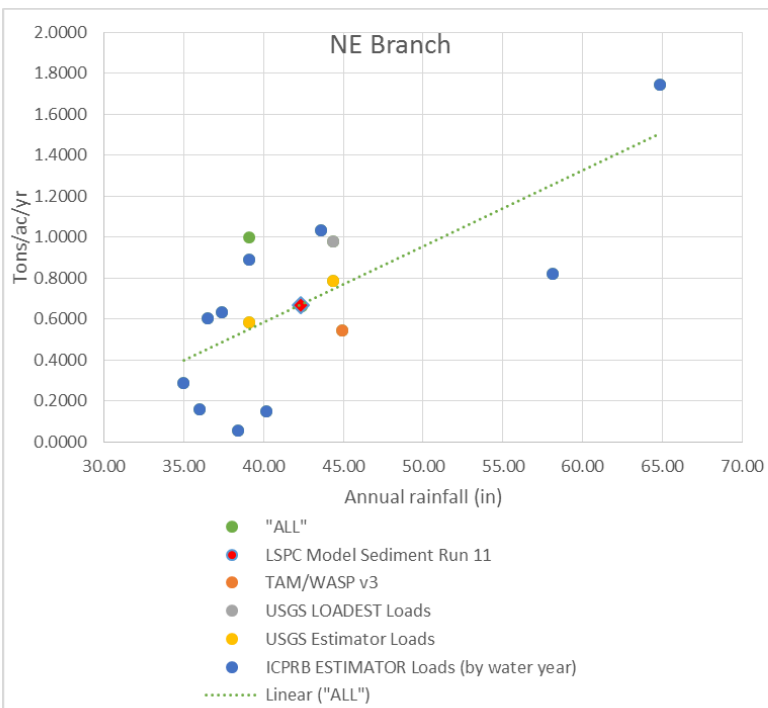


Figure 5-18. Annual TSS load estimates normalized by rainfall at the Northeast Branch USGS gage (USGS 01649500).

Figure 5-19. Annual TSS load estimates normalized by rainfall at the Beaverdam Creek USGS gage.

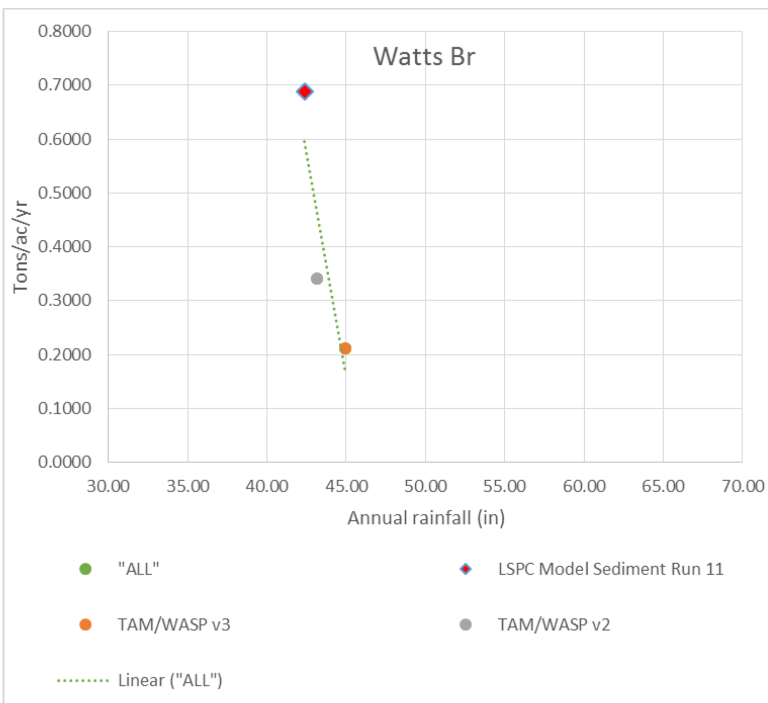


Figure 5-20. Annual TSS load estimates normalized by rainfall at the Watts Branch USGS gage (USGS 01651800).

5.2.2 Toxic Constituents

The LSPC model provides a general and flexible framework for simulating pollutants, including hydrophobic organic toxic constituents. As with the simulation of sediment, there are three major components to simulating toxic constituents derived from the land surface: availability of contaminant mass on the land surface, washoff of contaminants to stream, and fate and transport within receiving water bodies. Toxic constituents are tracked in the model as dissolved and particulate mass in surface flow pathways and dissolved mass in subsurface pathways.

5.2.2.1 Surface Loading

Loading processes for pollutants in LSPC are represented for each land unit (i.e., HRU) using the PQUAL modules (simulation of pollutants for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules. These modules allow for the simulation of pollutant loading as solids/sediment-associated, as a buildup-washoff relationship, as a concentration in land segment surface and subsurface outflow, or as a combination of the three.

Watershed areas that were identified as contaminated sites, such as specific urban industrial areas, were separated into specific HRU categories that inherit the hydrologic parameters of their parent HRU, but have different pollutant loading characteristics. This was informed, in part, by source area investigations conducted in the Anacostia River watershed.

For the Anacostia River watershed, given the hydrophobic nature of the pollutants covered in this TMDL modeling report, a combination approach of sediment potency (e.g., pounds of arsenic per ton of sediment eroded) plus dissolved concentrations were used to characterize pollutant generation from both pervious and imperious land segments. For pervious land, an additional specification of pollutant concentrations in subsurface flow pathways was also developed.

During calibration for chemical parameters, the first step is to assign groundwater concentrations to pervious land segments based on available data and literature. The next step is to assign initial dissolved concentrations and soil potency based on similar data sources. After the initial assignments are made, those values are modified iteratively to calibrate to instream observations.

The LSPC watershed model water quality simulation was calibrated for the shared EFDC modeling time period, 2014–2017. Calibration metrics focused on ensuring that the model showed reasonable agreement between observed and simulated pollutant concentrations in both the Anacostia River mainstem and its tributaries. Reasonable agreement was defined in consultation with EPA Region 3, DOEE, and MDE as average simulated and observed concentrations being the same order of magnitude. This calibration metric was selected in consideration of the generally very low environmental concentrations associated with the toxic pollutants of concern and the general paucity of monitoring data, where much of the data that is available consists of nondetects.

To calibrate water quality in the river mainstem, pollutant concentrations were first simulated in LSPC, before those results were passed to the EFDC receiving water model. Because the watershed model is only capable of 1-D unidirectional flow, the simulation of water quality in the mainstem assumed fully mixed conditions and was used to determine the approximate expected quality of the EFDC tidal simulation results. Testing showed that the LSPC representation of the mainstem showed good agreement with the EFDC simulation of the middle portion of the tidal Anacostia.

To simulate water quality in the mainstem Anacostia in LSPC, a reach was added to the model that was configured with the basic dimensions of the tidal mainstem segment. The outlets of the upstream tributaries were then routed to the mainstem segment, where the aggregate outflows and pollutant loads are fully mixed.

To achieve a reasonable calibration for the watershed model, water quality simulation of major pollutant source pathways were configured based on the data analysis detailed in the Source Representation section of this report including:

- Wet and dry atmospheric deposition rates
- Bed sediment pollutant concentrations

- Surface and subsurface (background) soil pollutant potency factors
- Surface runoff, interflow, and groundwater pollutant concentrations

All pollutant source pathways were initialized based on the initial watershed source characterization and then were refined during the calibration process.

LSPC simulated water quality was calibrated at four watershed locations coinciding with the USGS gages. Two locations are on the major tributaries draining the upper portion of the watershed—the Northeast Branch (USGS 0164950) and Northwest Branch (USGS 01651000). The other two locations are on tributaries draining more urban portions of the watershed—Watts Branch (USGS 01651800) and Hickey Run (USGS 01651770). The locations of those calibration locations are shown in Figure 5-2. In addition, water quality simulated in the mainstem was compared to water quality observations recorded at the tidal Anacostia station ANA14/R3-08 located below Kingman Lake. The number of monitoring observations available for LSPC calibration are shown in Table 5-9.

Table 5-9. The number of pollutant monitoring observations at LSPC calibration locations

Number of pollutant monitoring observations	USGS 01651000 (NW Branch)	USGS 01649500 (NE Branch)	USGS 01651800 (Watts Branch)	USGS 1651770 (Hickey Run)	ANA14/R3-08 Anacostia Mainstem
As (dissolved)	—	—	—	1	4
Cu (dissolved)	—	—	28	31	4
Zn (dissolved)	—	—	28	31	4
DDT	2	2	—	2	4
Chlordane	2	2	—	2	4
Dieldrin	2	2	—	2	4
Heptachlor epoxide	2	2	—	2	5
PAH 1	6	6	—	5	4
PAH 2	6	6	—	5	4
PAH 3	6	6	—	5	4

Calibration results are summarized in Table 5-10 as a meet/does not meet calibration criteria where filled dots identify where calibration criteria were met and unfilled ones did not meet criteria. Calibration results presented as average simulated and observed concentration and percent difference between the two are presented in Table 5-10. Important things to note regarding the calibration include:

- For samples where a toxicant was not detected, half the detection limit for the toxicant was used as a calibration target.
- Calibration metrics were met for all pollutants in the Anacostia mainstem except zinc.
- Zinc met calibration criteria in the tributaries, even though it is underpredicted, whereas it is overpredicted in the mainstem.
- Copper met calibration metrics in all locations with monitoring data.
- Arsenic met calibration metrics in the mainstem but not in the Hickey Run tributary site where only one observation was available.
- Organochlorine toxicants generally met the calibration criteria for tributary and mainstem locations, except DDT, where there was a large discrepancy between concentrations observed in the tributaries and the mainstem. It should be noted that only two data points were available for each organochlorine constituent at each tributary location.

- DDT was underpredicted for the tributary calibration locations but showed good agreement in the mainstem.
- PAH calibration metrics were met at all locations.

Table 5-10. LSPC water quality calibration assessment

Pollutant calibration assessment	USGS 01651000 (NW Branch)	USGS 01649500 (NE Branch)	USGS 01651800 (Watts Branch)	USGS 1651770 (Hickey Run)	ANA14/R3-08 Anacostia Mainstem
As (dissolved)				○	●
Cu (dissolved)			●	●	●
Zn (dissolved)			●	●	○
DDT	○	○		○	●
Chlordane	●	●		●	●
Dieldrin	●	●		●	●
Heptachlor epoxide	●	○		○	●
PAH 1	●	●		●	●
PAH 2	●	●		●	●
PAH 3	●	●		●	●

Notes:
●: meets calibration criteria

○: does not meet calibration criteria

Table 5-11. LSPC water quality calibration simulated and observed concentrations and percent difference

Pollutant average concentration (µg/L)	USGS 01651000 (NW Branch)			USGS 01649500 (NE Branch)			USGS 01651800 (Watts Branch)			USGS 1651770 (Hickey Run)			ANA14/R3-08 Anacostia Mainstem		
	Obs	Mod	% Diff	Obs	Mod	% Diff	Obs	Mod	% Diff	Obs	Mod	% Diff	Obs	Mod	% Diff
As (dissolved)	—	0.50	—	—	0.61	—	—	0.32		1.05	0.40	-62%	0.88	0.74	-16%
Cu (dissolved)	—	2.84	—	—	4.11	—	4.40	2.05	-53%	3.21	2.42	-25%	3.32	4.95	49%
Zn (dissolved)	—	9.99	—	—	6.90	—	9.65	5.12	-47%	9.52	5.84	-39%	7.72	12.16	58%
DDT	0.0020	0.0004	-78%	0.0025	0.0003	-87%	—	0.0004	—	0.0053	0.0005	-90%	0.0005	0.0005	-4%
Chlordane	0.0041	0.0055	35%	0.0070	0.0044	-38%	—	0.0051	—	0.0112	0.0068	-39%	0.0039	0.0060	54%
Dieldrin	0.0003	0.0006	94%	0.0004	0.0005	41%	—	0.0005	—	0.0008	0.0007	-10%	0.0007	0.0009	28%
Heptachlor epoxide	0.0008	0.0007	-11%	0.0010	0.0006	-43%	—	0.0007	—	0.0021	0.0008	-61%	0.0008	0.0009	10%
PAH 1	0.05	0.06	8%	0.04	0.12	173%	—	0.05	—	0.10	0.07	-28%	0.10	0.10	5%
PAH 2	0.21	0.13	-39%	0.21	0.18	-15%	—	0.12	—	0.34	0.16	-52%	—	0.20	—
PAH 3	0.19	0.11	-42%	0.21	0.16	-22%	—	0.10	—	0.34	0.14	-59%	—	0.17	—

6.0 EFDC CALIBRATION

6.1 HYDRODYNAMICS

Adjustable parameters and forcing functions for the hydrodynamic model include open boundary water surface elevations, atmospheric conditions, bottom roughness, and downstream freshwater flows (note: upstream flows were accounted for by the watershed model).

The primary hydrodynamic calibration datasets for the model are water surface elevation and temperature. Salinity and current velocity data were not available for the calibration effort. Acoustic Doppler Current Profiler (ADCP) data typically used for velocity calibrations were also not available.

Given the complexity of transport in estuaries, one of the most important objectives during the development of water quality models is to calibrate the transport model to ensure that it has the ability to reasonably reproduce the mixing regimes and seasonal variations of temperature and salinity, extent of salinity intrusion (if applicable), dynamics of water surface elevations, currents during ebb and flood periods, and freshwater flow distribution through the system. Hydrodynamic calibration was not performed for this effort. Please refer to the ARSP Surface Water Model report for details on hydrodynamic calibration.

6.2 WATER QUALITY

EFDC water quality was calibrated first for sediment and then for toxic parameters. Calibration of these components is described below.

6.2.1 Sediment

The calibration of the EFDC receiving water body model is the process by which sediment model parameters and other inputs are varied in order to obtain the best possible match between model-predicted and observed suspended sediment concentrations, bed morphology changes, and net sediment flux at selected locations. Sediment transport calibration parameters include, for both the tidal river and the upstream watershed, internal and point source sediment and solids loads and their distribution into modeled classes (e.g., effective particle diameters, or settling velocities for sediment and solids classes). Other key parameters include erosion parameters, including critical stress and mass erosion rates for cohesive sediment. The calibration of sediment was not performed for this effort. Please reference the ARSP Surface Water Model report for details on sediment calibration. Parameters regarding sediment settling velocities, critical shear stresses, and other mechanical attributes were kept unchanged as no site-specific data were available. Primary EFDC sediment calibration parameters for the ARSP effort included distribution of tributary flows and iterative adjustment to the LSPC model. Model results were most sensitive to the magnitude of sediment loading from tributaries, which vary significantly across watersheds.

6.2.2 Toxic Constituents

Toxic contaminants for the tidal EFDC portion of the modeling system were calibrated at six locations coinciding with historical sampling locations. These stations were selected to characterize the tidal Anacostia system from its upstream to downstream extent. All impaired tidal water bodies are represented by these stations except for the Maryland Tidal Northwest Branch Anacostia segment. However, as described in the LSPC calibration section above, LSPC was calibrated at the Northwest Branch USGS gage (the upstream extent of the EFDC model), which provides a comparison of water quality at that location. The number of monitoring observations available for EFDC calibration are shown in Table 6-1, and EFDC pollutant calibration locations are shown in Figure 6-1.

Table 6-1. The number of pollutant monitoring observations at EFDC calibration locations

Number of observations (2014–2017)	AR01/R7-20 Bladensburg	ANA-01/R7-19 DC Line	ANA-11/R4-09 Near RFK	ANA-14/R3-08 PA Ave. bridge	ANA-24/R1-15 Ft. McNair	KNG-01/KL-19 Kingman Lake
As (dissolved)	7	10	10	7	4	10
Cu (dissolved)	7	10	10	7	4	10
Zn (dissolved)	7	10	10	7	4	10
DDT	7	12	10	7	11	10
Chlordane	7	10	10	7	11	10
Dieldrin	7	12	10	7	11	10
Heptachlor epoxide	7	12	10	7	11	10
PAH 1	7	12	10	7	4	10
PAH 2	7	12	10	7	4	10
PAH 3	7	12	10	7	4	10

Calibration results are summarized in Table 6-2 as a meet/does not meet calibration criteria, where unfilled dots identify where calibration criteria were met and X's identify where criteria were not met. Table 6-3 includes calibration results presented as average simulated and observed concentration and percent difference between the two. Important things to note regarding the calibration include:

- For samples where a toxicant was not detected, half the detection limit for that sample was used as a calibration point.
- Because the calibration exercise compares point data to a time variable model, differences in timing can affect apparent agreement.
- Overall seasonality and processes are well represented
- Calibration metrics were met for all pollutants in the Anacostia mainstem except for zinc.
- Zinc met calibration criteria in the tributaries—even though it was underpredicted—but zinc was overpredicted in the mainstem.
- Copper met calibration metrics in all locations with monitoring data.
- Arsenic met calibration metrics in the mainstem, but not in the Hickey Run tributary site where only one observation was available .
- Organochlorine toxicants generally met the calibration criteria for tributary and mainstem locations, except DDT, where there was a large discrepancy between concentrations observed in the tributaries and the mainstem. It should be noted that only two data points were available for each organochlorine constituent at each tributary location.
- DDT was underpredicted for the tributary calibration locations but showed good agreement in the mainstem.
- PAH calibration metrics were met at all locations.

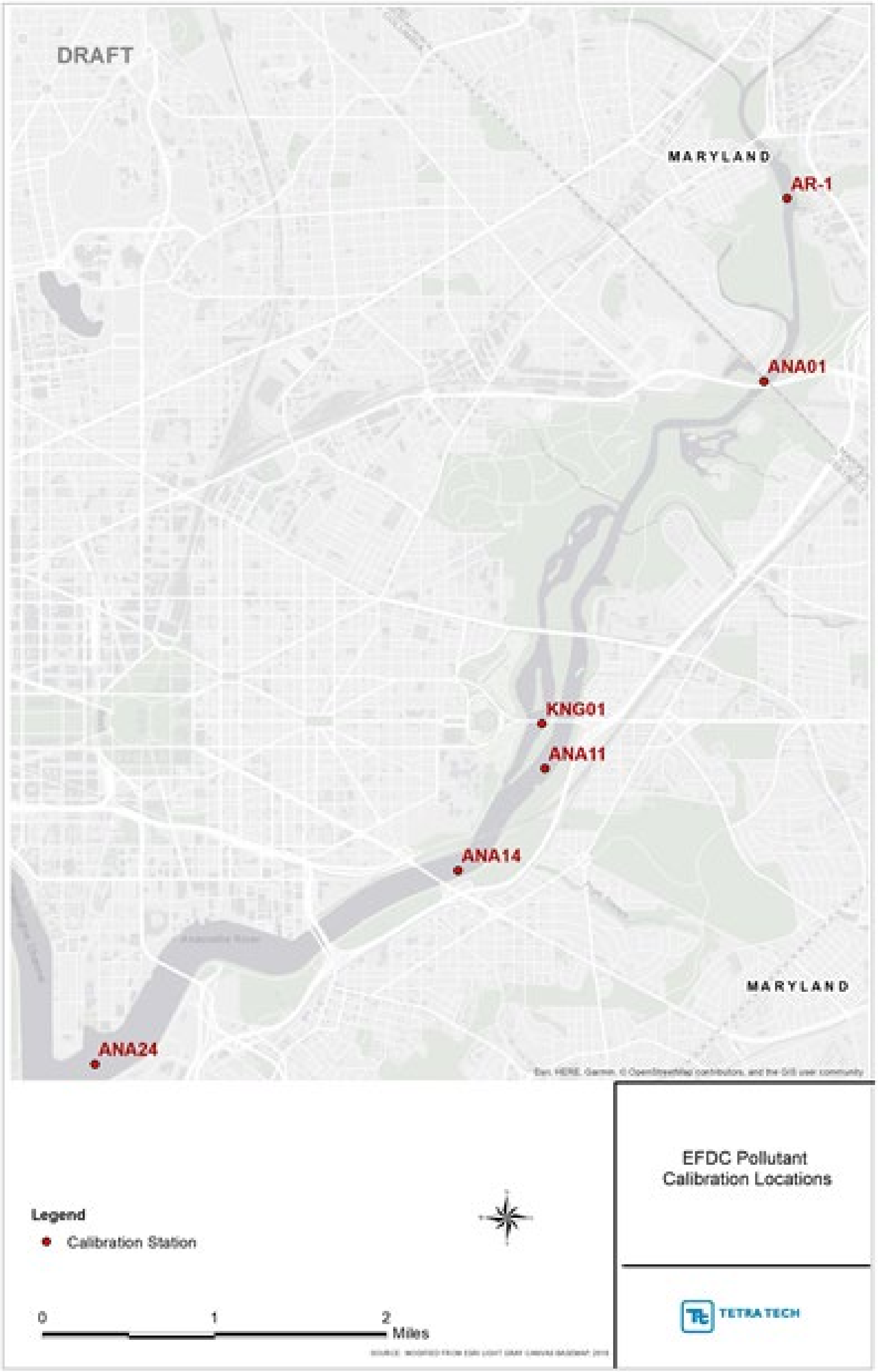


Figure 6-1. EFDC calibration locations

Table 6-2. EFDC water quality calibration assessment

Pollutant calibration assessment	AR01 / R7-20	ANA-01 / R7-19	ANA-11/ R4-09	ANA-14/ R3-08	ANA-24/ R1-15	KNG-01/ KL-19
	Bladensburg	DC line	Near RFK	PA Ave. bridge	Ft. McNair	Kingman Lake
As (dissolved)	●	●	●	●	●	●
Cu (dissolved)	●	●	●	●	●	●
Zn (dissolved)	●	●	●	●	●	●
DDT	●	●	●	●	●	●
Chlordane	●	●	●	●	●	●
Dieldrin	●	●	●	●	●	●
Heptachlor epoxide	●	●	●	●	●	●
PAH 1	●	●	○	●	●	●
PAH 2	●	●	○	●	●	●
PAH 3	○	●	○	●	●	●

● - meets

○ - does not meet

Table 6-3. EFDC water quality calibration simulated and observed concentrations and percent difference

Pollutant average concentration (µg/L)	AR01/R7-20			ANA-01/R7-19			ANA-11/R4-09		
	Bladensburg			DC Line			Near RFK		
	Obs	Mod	% Diff	Obs	Mod	% Diff	Obs	Mod	% Diff
As (dissolved)	0.70	0.76	8.57%	0.78	0.81	3.44%	0.75	1.22	63.19%
Cu (dissolved)	4.73	5.18	9.57%	4.19	5.73	36.86%	3.67	9.95	170.99%
Zn (dissolved)	6.93	10.68	54.26%	3.93	12.08	207.38%	7.15	26.74	274.20%
DDT	3.15E-04	3.79E-04	20.04%	5.81E-04	4.00E-04	-31.03%	2.96E-03	4.91E-04	-83.41%
Chlordane	2.79E-03	4.96E-03	78.02%	2.43E-03	5.39E-03	121.78%	1.95E-03	6.84E-03	251.41%
Dieldrin	8.59E-04	5.98E-04	-30.40%	4.07E-04	7.03E-04	72.65%	3.90E-03	9.71E-04	-75.09%
Heptachlor epoxide	6.53E-04	6.61E-04	1.12%	3.99E-04	7.37E-04	84.66%	3.85E-03	9.62E-04	-74.98%
PAH 1	1.08E-01	1.00E-01	-7.50%	8.59E-02	1.10E-01	27.44%	9.64E+00	1.79E-01	-98.15%
PAH 2	1.61E+00	1.64E-01	-89.84%	1.06E-01	1.78E-01	66.81%	9.07E+00	2.44E-01	-97.32%
PAH 3	4.27E+00	1.44E-01	-96.62%	1.33E-01	1.52E-01	13.67%	1.31E+01	1.80E-01	-98.62%
	ANA-14/R3-08			ANA-24/R1-15			KNG-01/KL-19		
	PA Ave. bridge			Ft. McNair			Kingman Lake		
	Obs	Mod	% Diff	Obs	Mod	% Diff	Obs	Mod	% Diff
As (dissolved)	0.74	1.41	90.04%	0.76	0.87	13.73%	0.66	1.37	107.51%
Cu (dissolved)	3.39	11.85	249.60%	3.34	5.32	59.07%	3.55	11.71	229.77%
Zn (dissolved)	5.39	34.12	533.07%	3.84	13.65	255.32%	26.13	34.18	30.80%
DDT	5.14E-04	4.99E-04	-2.89%	6.36E-04	4.03E-04	-36.63%	6.22E-04	4.89E-04	-21.37%
Chlordane	1.94E-03	6.97E-03	259.36%	2.42E-03	2.21E-03	-8.86%	1.94E-03	6.92E-03	256.81%
Dieldrin	2.92E-04	9.70E-04	232.29%	2.48E-04	4.94E-04	99.18%	3.61E-04	9.61E-04	166.56%
Heptachlor Epoxide	3.23E-04	9.85E-04	204.91%	2.18E-04	6.09E-04	179.72%	2.93E-04	9.67E-04	230.74%
PAH 1	1.21E-01	2.16E-01	79.12%	1.01E-01	1.10E-01	8.81%	7.58E-02	2.03E-01	168.64%
PAH 2	2.06E-01	2.58E-01	25.37%	7.94E-02	6.50E-02	-18.20%	1.26E-01	2.55E-01	102.45%
PAH 3	1.49E-01	1.82E-01	22.56%	1.32E-01	4.49E-02	-66.08%	1.19E-01	1.82E-01	53.15%

Notes: Observed values calculated based on 0.5*Detection Limit for nondetect results

The water quality interaction calculations in the model are, by necessity, simplified representations of extremely complex aquatic ecosystem dynamics. In addition, as with all models, the model is limited by the quality and completeness of the available input data. The Anacostia model is able to represent the complex characteristics of the Anacostia River. It is able to simulate the detailed hydrodynamics in the system, while taking into account the dynamic watershed loading from the watershed and tidal exchange with the Potomac River. The model includes mechanisms for toxicant release from the contaminated streambed sediment due to diffusion and resuspension. Point data only permits comparison during a snapshot in time, and this snapshot is representative of only a single condition. The precise timing of all physical, chemical, and biological phenomenon are likely not perfect in any model. As long as the trends, relationships, and magnitudes are well-represented, and thus the underlying physics and kinetics are also being represented, a model can be confidently applied in scenario analyses. Overall, the calibration of the modeling framework was deemed acceptable, especially considering the linkage of two models and the complexity of modeling 10 different pollutants using a sparse toxicant dataset.

6.3 CALIBRATION PARAMETERS

The primary parameters or factors controlling toxicant calibration across the 10 pollutants include inflows and loads generated by the LSPC watershed model and Potomac River inflow characteristics.

7.0 ALLOCATION SCENARIO

The development of a TMDL allocation is the process of reducing pollutant loads to achieve the applicable water quality targets. The allocation scenario was developed through an iterative process of first implementing watershed reductions until the endpoints were met in the tributaries and then evaluating whether those reductions were sufficient to meet the endpoints in the tidal portions. Evaluation of the results of the initial watershed reductions in EFDC showed water quality meeting the endpoints in the tidal portions of the Anacostia River for two of the 10 parameters: zinc and PAH1. All other parameters were exceeding the endpoints in almost all the tidal portions of the Anacostia.

Further analysis of flow and rainfall conditions with model results showed the tidal portions were not meeting the endpoints under both wet and dry conditions, that the watershed loads were driving noncompliance during wet periods, and the pollutant fluxes from the bed sediments were driving noncompliance during dry conditions. Therefore, a further reduction methodology was developed and implemented to achieve additional watershed reductions aimed at ensuring the endpoints are met during wet periods and that tidal portion bed sediment reductions geared at ensuring the endpoints are met during dry periods.

Once the watershed and bed sediment reductions were sufficient to achieve the endpoints in the entire system, an additional analysis was completed to estimate the time needed for the watershed load reductions to result in bed sediment concentration conditions identified in the reduction analysis via natural attenuation. See Section 7.5 for additional discussion and rationale.

The following sections provide additional details related to how the allocation scenario was developed.

7.1 INITIAL WATERSHED REDUCTIONS

Model reaches within a subwatershed are fully mixed 1-D segments with a defined pour point. The simulated water quality at a reach pour point lends itself to the assessment of applicable endpoint verification because that pour point can be associated with the downstream end of an impaired segment. Initial LSPC watershed load reductions were done using the following systematic methodology.

1. Point source discharges were set to criteria concentrations.
2. Watershed loading was reduced using a top-down approach where the farthest upstream subwatersheds (see Figure 3-2) were targeted first. Once instream water quality targets were met in those watersheds

(see Figure 2-1), the subwatersheds directly downstream were then reduced until targets were met in all subwatersheds.

3. Instream water quality concentrations were compared against the endpoints at the model reach pour point.
4. Watershed loadings were reduced on a land use basis. In each subbasin, all urban land uses were assigned equal percent load reductions up to a threshold of 99.9% reduction. If this was not sufficient to meet the endpoint, then all agricultural land uses in the subbasin were reduced equally until the water quality target was met.
5. After the above subbasin reductions were implemented in the model, if there were still areas not meeting the endpoints, then bed sediment toxic constituents concentrations were reduced universally for the entire watershed.

Initial watershed loading reductions (ranging from 50%–99.9% of current loads depending on parameter, land use and subbasin) were sufficient to achieve instream water quality targets for the majority of the pollutants in the tributaries. Three pollutants, dieldrin, PAH2, and PAH3, also required 90%, 80% and 98% bed sediment reductions, respectively, across the watershed to meet endpoints. This is likely due to the very low endpoint concentrations for each of those toxic constituents where any bed sediment contribution would likely lead to an endpoint exceedance. The US Fish and Wildlife Service (Ghosh et al 2019) identified a net positive diffusive flux of PAHs from streambed sediments at all monitoring locations in the Anacostia River watershed and at two locations for dieldrin. No reductions were required to meet the PAH1 endpoint (50 µg/L 4-day average). This is due to the relatively high concentration for the endpoint where the watershed loading does not result in instream water quality conditions that exceed water quality targets.

7.2 SENSITIVITY ANALYSIS

The results of the initial watershed reductions were evaluated in the EFDC model. It was determined that the first round of watershed reductions were sufficient to meet the endpoints in the tidal portions for zinc and PAH1 only. Before revisiting the LSPC allocations, a source sensitivity analysis was performed to investigate the relative influence of contaminant sources. The analysis provided information to help identify sources driving the remaining exceedances. For each contaminant requiring additional reductions to reach attainment in tidal verification units, pollutant source groups (i.e., watershed contributions, Potomac River contributions, and bed sediment contributions) were removed individually to quantify the effect on water column concentrations.

Note that boundary conditions for the allocation scenarios were set differently depending on the pollutant. The endpoints were used for all parameters except for copper, zinc, and PAH1, which had high WQC (e.g., PAH1 = 50 µg/L). For these three parameters, the observed boundary condition data were used.

First, watershed contributions of the contaminant were eliminated as a source group, while riverbed and Potomac River contributions were kept in place to determine if reductions to sources other than the watershed are required (see Figure 7-1). The elimination of watershed sources revealed that for some contaminants, additional reductions from the sediment bed would be needed due to exceedances that persisted during low-flow conditions in the system.

Similarly, riverbed sediment contamination was eliminated in a separate sensitivity scenario, while watershed and Potomac River contributions were kept in place to assess attainment in the water column (see Figure 7-2). This scenario helped isolate exceedances caused by wet-weather conditions.

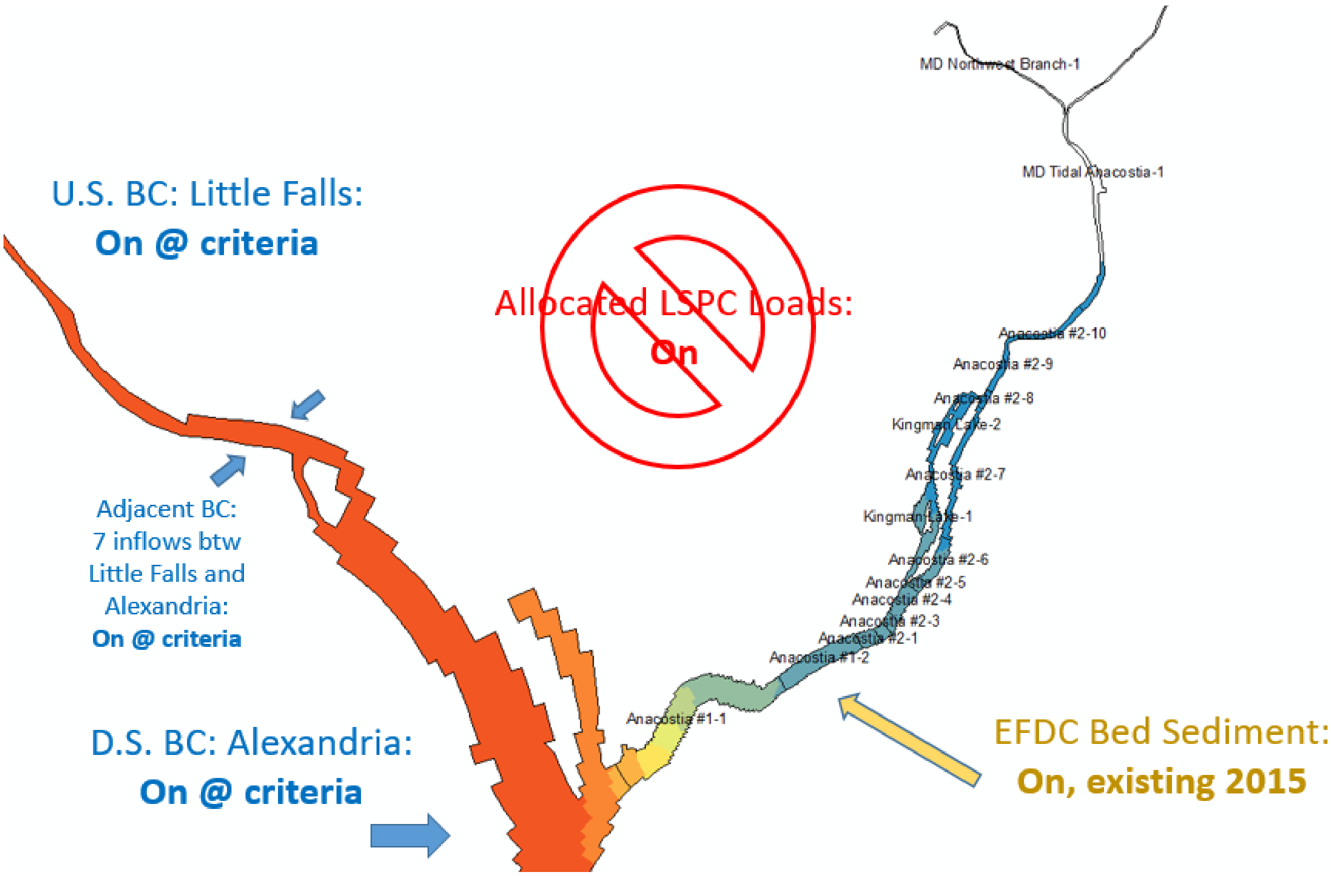


Figure 7-1. Source sensitivity run; relative heptachlor epoxide concentrations in the water column with tributary contributions eliminated

An additional scenario to isolate the impact of just the Potomac River boundary inputs to the Anacostia River was also evaluated. For this, the upstream Potomac Little Falls and downstream boundary at Alexandria, Virginia. were turned off and the Anacostia bed sediment and LSPC allocation loads were kept in place (see Figure 7-3). The scenario showed some improvement in the nearby lower Anacostia #1 verification unit but exceedances still persisted throughout the Anacostia River. Therefore, it was determined that the influence of boundary conditions at the Anacostia/Potomac confluence were not significantly driving the exceedances.

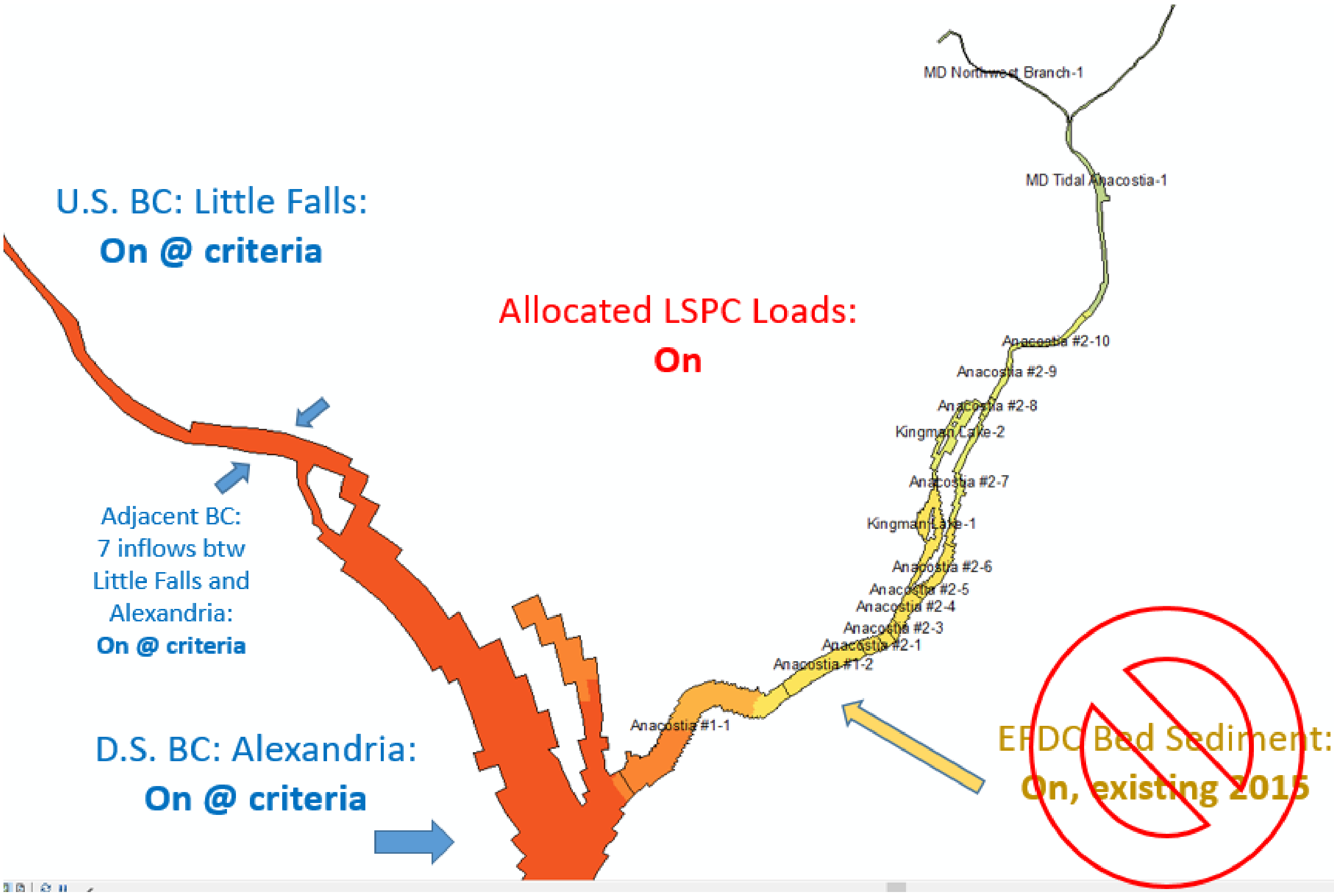


Figure 7-2. Source sensitivity run; relative heptachlor epoxide concentrations in the water column with tidal bed sediment contributions eliminated.

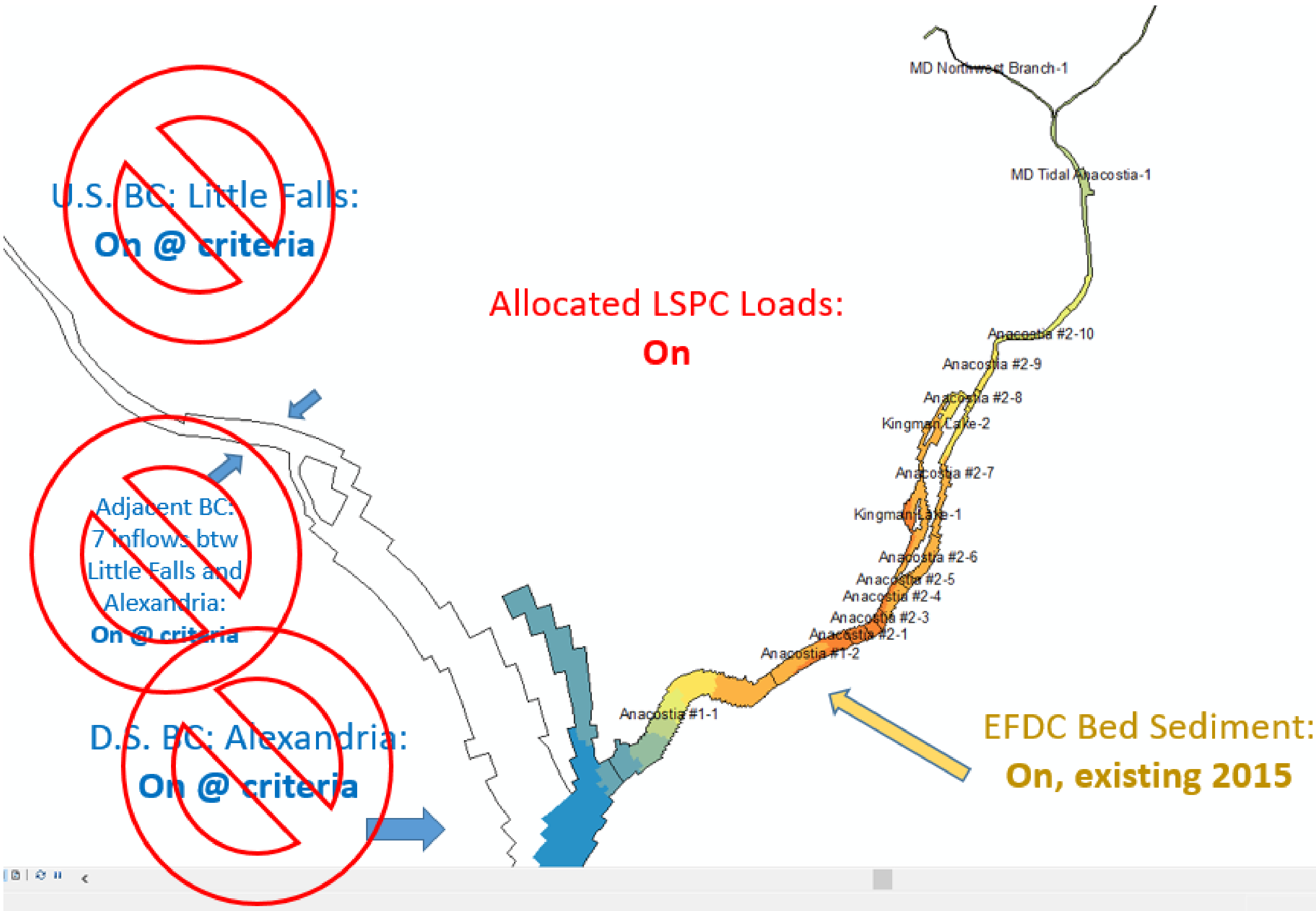


Figure 7-3. Source sensitivity run; relative heptachlor epoxide concentrations in the water column with Potomac River contributions eliminated.

Figure 7-5 shows the water column concentration time series for heptachlor epoxide for the allocation period, based on the initial allocations in LSPC. It illustrates two exceedances of the TMDL target for heptachlor epoxide—one occurring during a high-flow condition and one occurring during a low-flow condition. It is important to distinguish the flow conditions coinciding with an exceedance because low flow conditions exhibit exceedances due to increased contaminant desorption from bed sediments and decreased flushing, while high flow conditions exhibit exceedances due to increased contaminant loading from upland sources.

The Anacostia 1-2 verification unit (farthest downstream, as shown in Figure 7-4) was used to investigate source sensitivity impacts on the tidal Anacostia River because, based on model results, it is least sensitive to source reductions due to the bathymetry of the area and the tendency for flows and pollutants to persist in this area relative to other verification units.

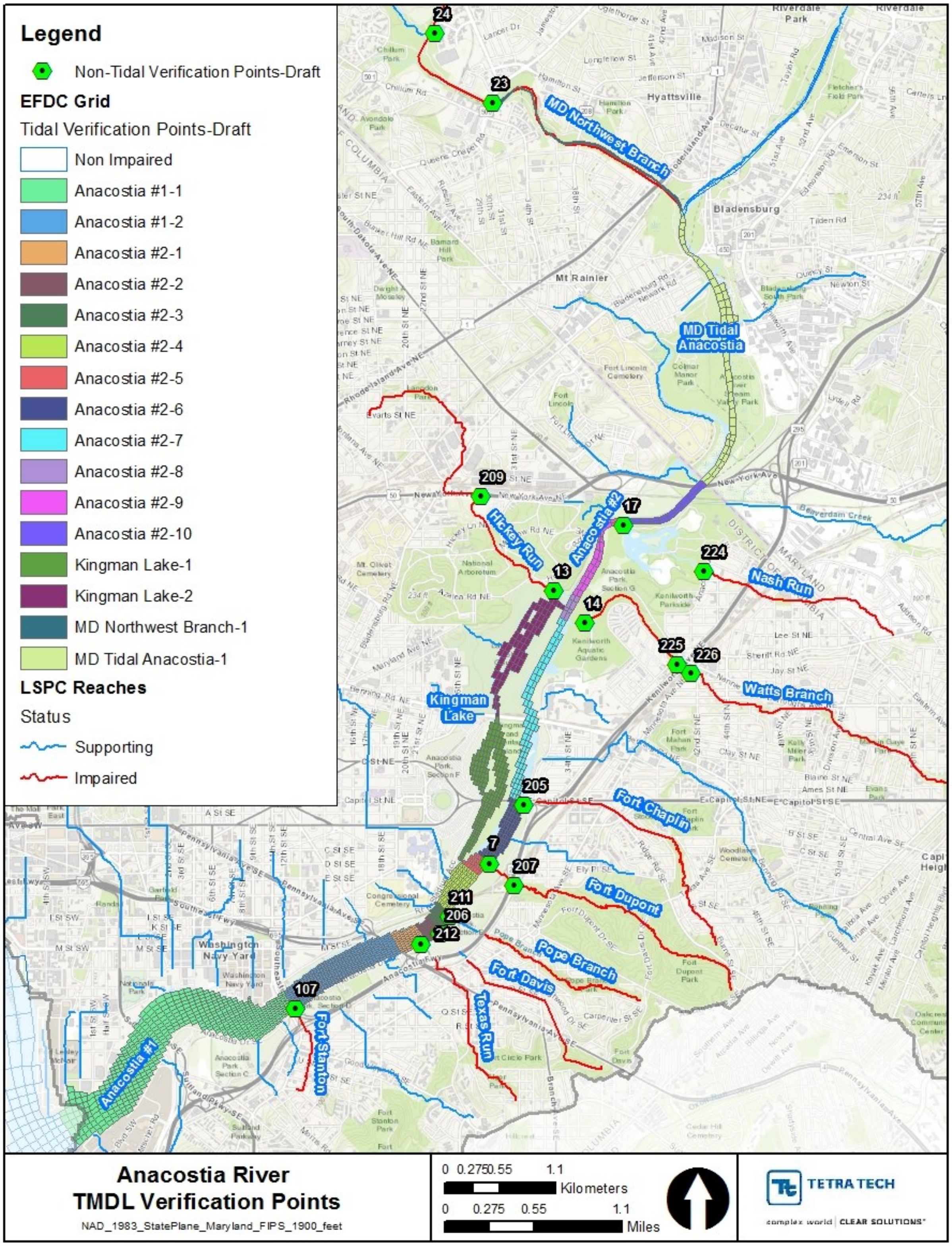


Figure 7-4. EFDC verification units.

From the results of the sensitivity analysis, more targeted reduction strategies (to the watershed and/or the bed sediments) were identified to achieve the endpoints in all portions of the system. Reductions to bed sediments were simulated to evaluate the level of bed sediment concentrations associated with meeting endpoints in the tidal portion but were not explicitly representative of any specific dredging or remediation activities.

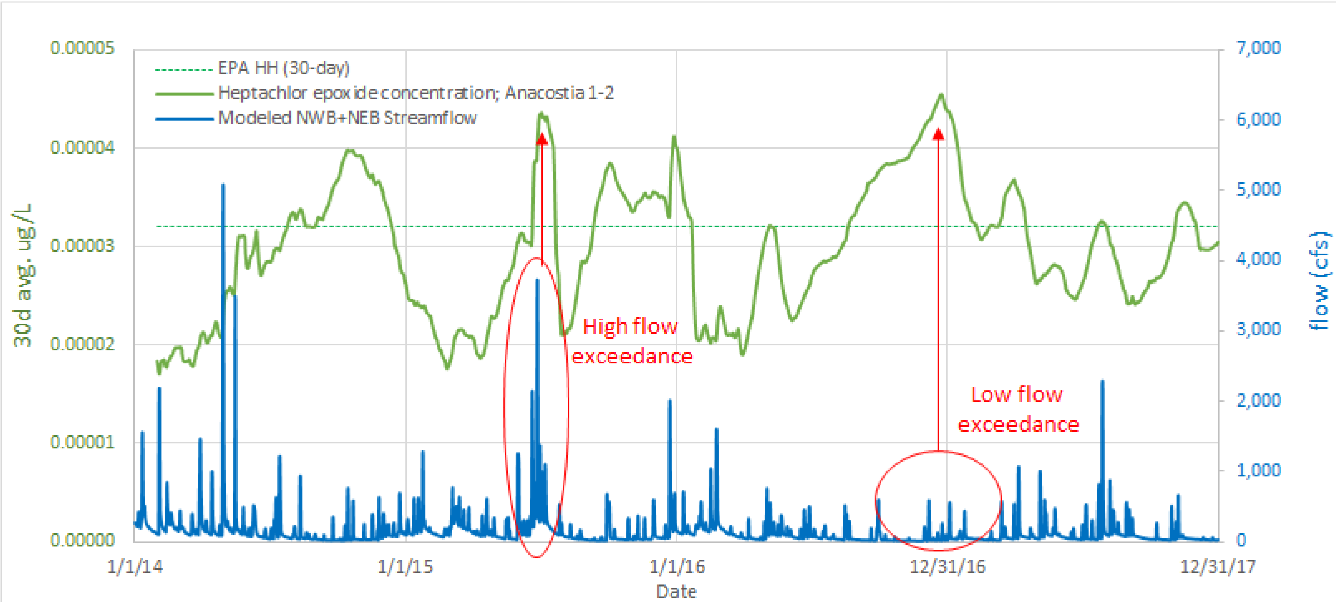


Figure 7-5. Example time series showing exceedance during a low-flow and a high-flow event.

7.3 ADDITIONAL WATERSHED REDUCTIONS

Based on the sensitivity analysis and the evaluation of flow conditions during which exceedances were still predicted to occur, additional watershed reductions were conducted. Because the first round of watershed reductions were sufficient to meet the TMDL endpoints in the tidal portions for zinc and PAH1, no further reductions were necessary for these two parameters. For all other parameters, additional reductions were implemented in the watershed model until the TMDL endpoints in the tidal portions of the Anacostia River met water quality *during wet conditions*. An exception to this was copper, for which additional reductions from the watershed were not required to meet in the tidal portions during wet weather and only bed sediment reductions were required in the EFDC model to meet the dry weather exceedances.

Additional reductions were implemented as follows:

1. Point source reductions were kept at the same level as previously determined in the initial round of reductions (i.e., no further reductions to point sources).
2. The same land uses reduced during round one were then targeted for additional reductions. Additional reductions were applied based on available capacity remaining after the first round of reductions. For example, if the reduction to a land use was 85% in the first round and an additional 50% reduction was required to meet the water quality in the tidal portion of the Anacostia, then the new reduction applied would be 92.5% (0.85 + (1-0.85) * 0.50 = 0.925).
3. First, the urban land use reductions were maximized by applying the additional reductions equally to all the urban land uses targeted in the first round.
4. If maximizing urban land use reductions was not sufficient, agricultural land uses targeted for reduction in the first round were further reduced. Dieldrin, PAH2, and PAH3 required further agricultural land use reductions. Dieldrin also required targeting agricultural areas that were not targeted in the previous round.

5. The reduced LSPC loads were evaluated in the EFDC model to ensure endpoint attainment during wet conditions.

Table 7-1 lists the ranges of reductions applied to urban and agricultural land uses.

Table 7-1. Ranges of percent reductions required for each parameter

Contaminant	Range of urban land use reductions required	Range of agricultural land use reductions required	Universal[1] bed sediment reductions
Arsenic	0 – 99.98%	0%	—
Chlordane	81.07 – 99.77%	0%	—
Copper	0 – 99%	0%	—
DDT	87.69 – 99.85%	0%	—
Dieldrin	100%	0 – 100%	90%
Heptachlor epoxide	85 – 99.9%	0%	—
PAH1	0%	0%	—
PAH2	0 – 100%	0 – 99.25%	80%
PAH3	100%	0 – 87%	98%
Zinc	0 – 84%	0%	—

Notes:
[1] Bed sediment reductions applied equally across all land uses in all subbasins

Figure 7-3 through Figure 7-11 present maps color coded by the overall percentage reductions required for each parameter by subwatershed. Note that reductions were applied to multiple land uses in each subwatershed to achieve the target; the maps show the overall reduction in each subwatershed.

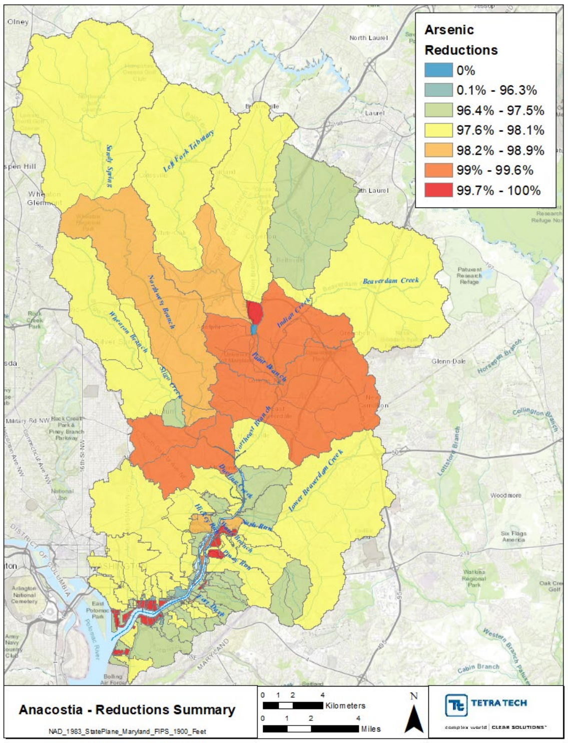


Figure 7-6. Required percent reductions by subwatershed (arsenic).

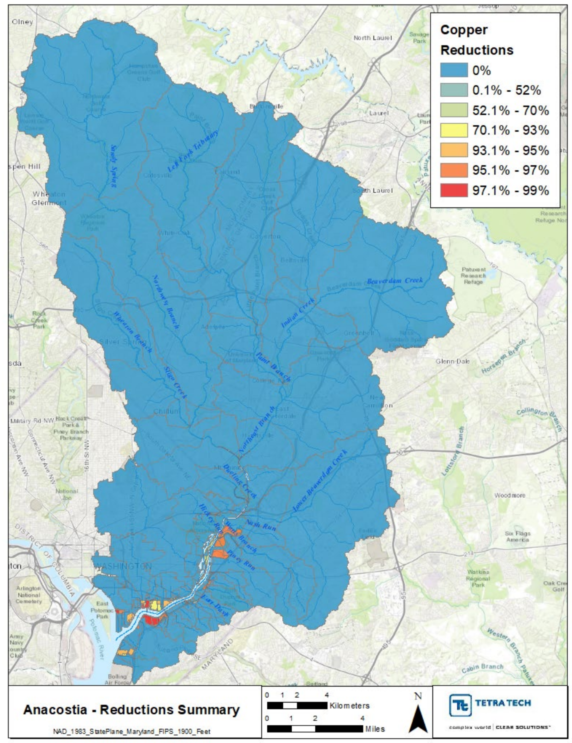


Figure 7-7. Required percent reductions by subwatershed (copper).

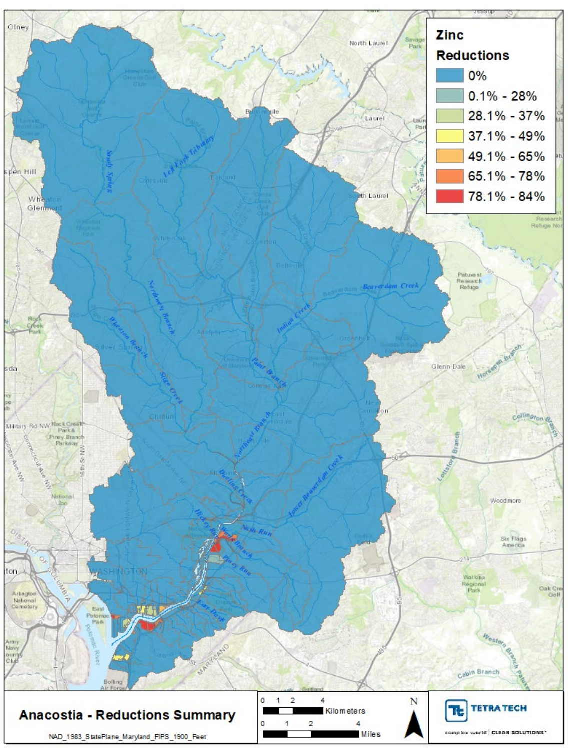


Figure 7-8. Required percent reductions by watershed (zinc).

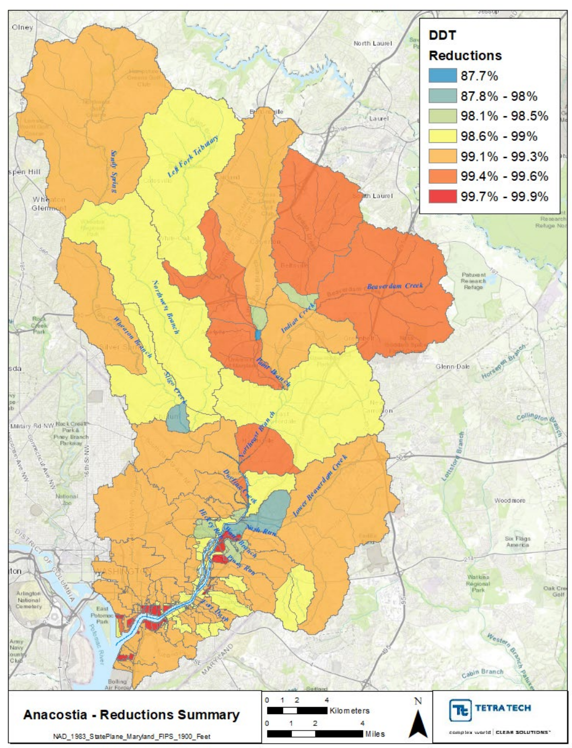


Figure 7-9. Required percent reductions by subwatershed (DDT).

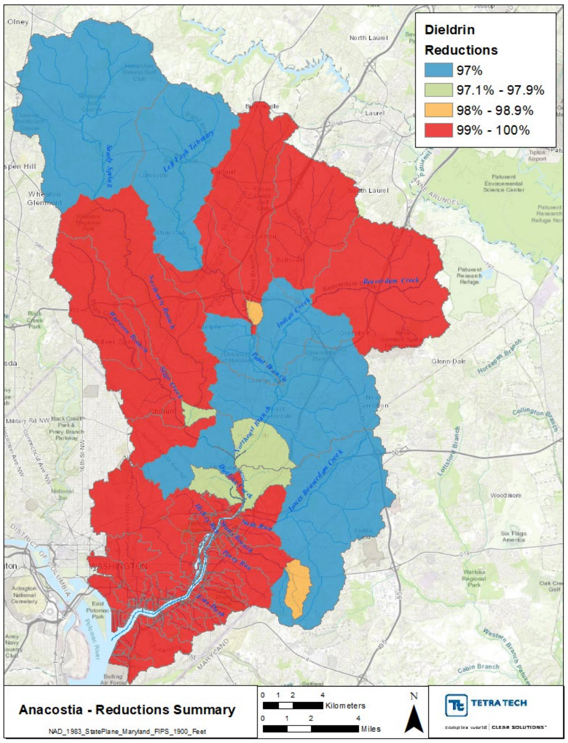


Figure 7-10. Required percent reductions by subwatershed (dieldrin).

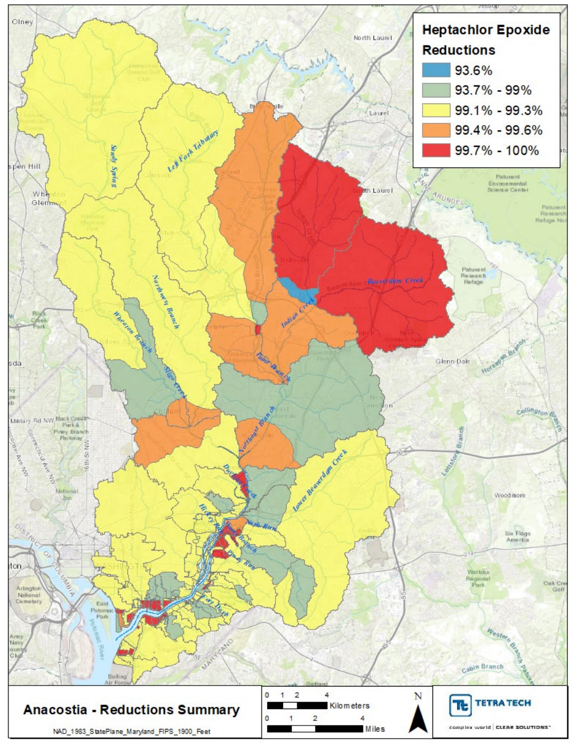


Figure 7-11. Required percent reductions by subwatershed (heptachlor epoxide).

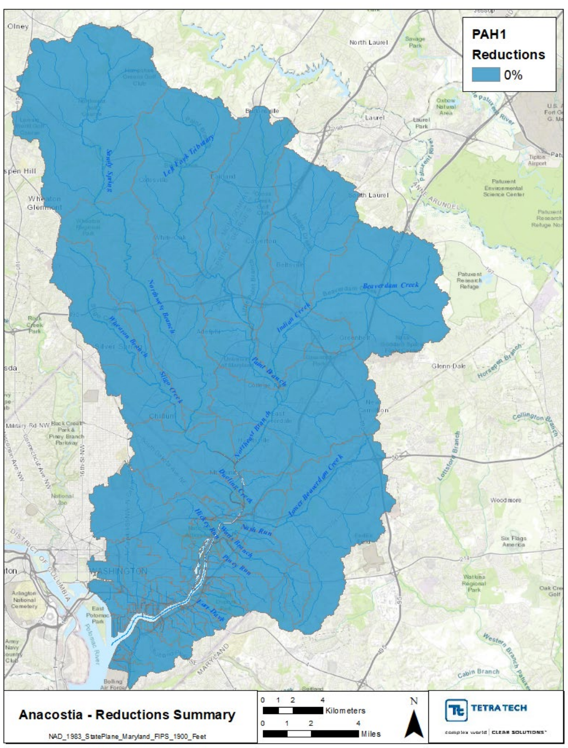


Figure 7-12. Required percent reductions by subwatershed (PAH1).

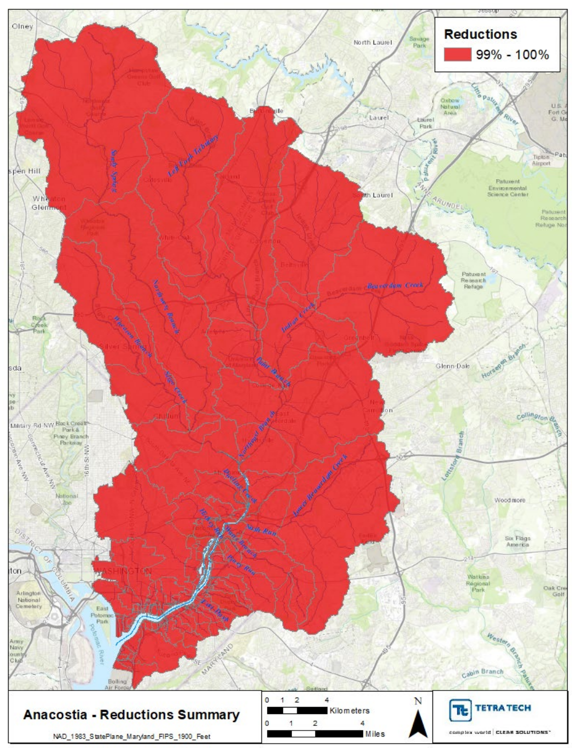


Figure 7-13. Required percent reductions by subwatershed (PAH2).

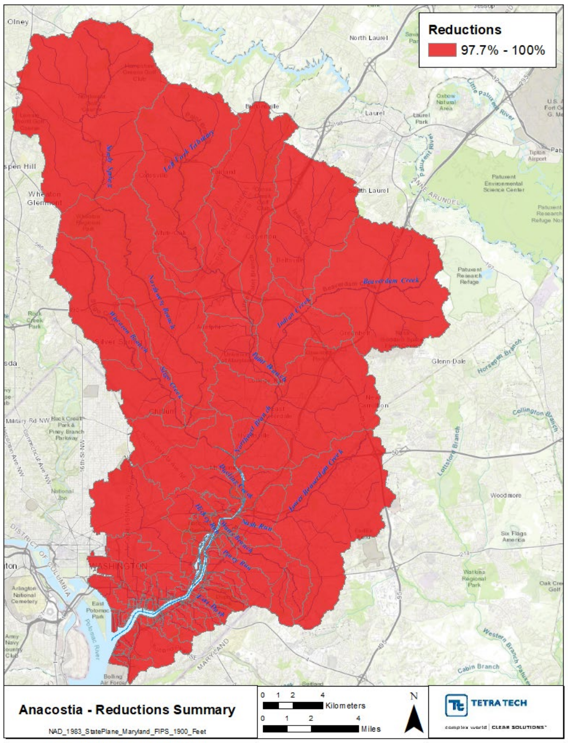


Figure 7-14. Required percent reductions by subwatershed (PAH3).

7.4 TIDAL ANACOSTIA BED SEDIMENT REDUCTIONS

Once watershed reductions were verified in EFDC to be sufficient to meet the TMDL endpoints during wet weather conditions, the next step was to identify the bed sediment reductions sufficient to ensure the tidal portions meet the endpoints during dry conditions as well. Bed sediments, or sediments that comprise the river bottom, have been shown to contain elevated concentrations of all toxicants addressed in this TMDL, and they act as a source to the overlying water column. Reductions were made to bed sediment contaminants concentrations that do not meet the TMDL targets with watershed reductions alone. Table 7-2 provides bed sediment reductions by contaminant that allow for attainment of the TMDL target.

Table 7-2 presents the required bed sediment reductions to each parameter under the TMDL allocation scenario along with the associated TMDL endpoint and the BAF-based bed target for heptachlor epoxide. Figure 7-2 shows the time series of heptachlor epoxide modeled water quality concentrations in all the verification units after bed sediment reductions.

Table 7-2. Attainment status under allocation scenario

Pollutant	Water column target (µg/L)	BAF bed target (µg/kg)	Bed sediment reduction
Heptachlor epoxide	3.20E-05	3.55E-01	55%
Chlordane	3.20E-04	—	98%
Dieldrin	1.20E-06	—	93%
DDT	1.80E-05	—	99%
Arsenic	0.14	—	98%
Copper	8.96	—	76%
Zinc	117.18	—	0%
PAH1	50	—	0%
PAH2	1.30E-03	—	99.5%
PAH3	1.30E-04	—	99.50%

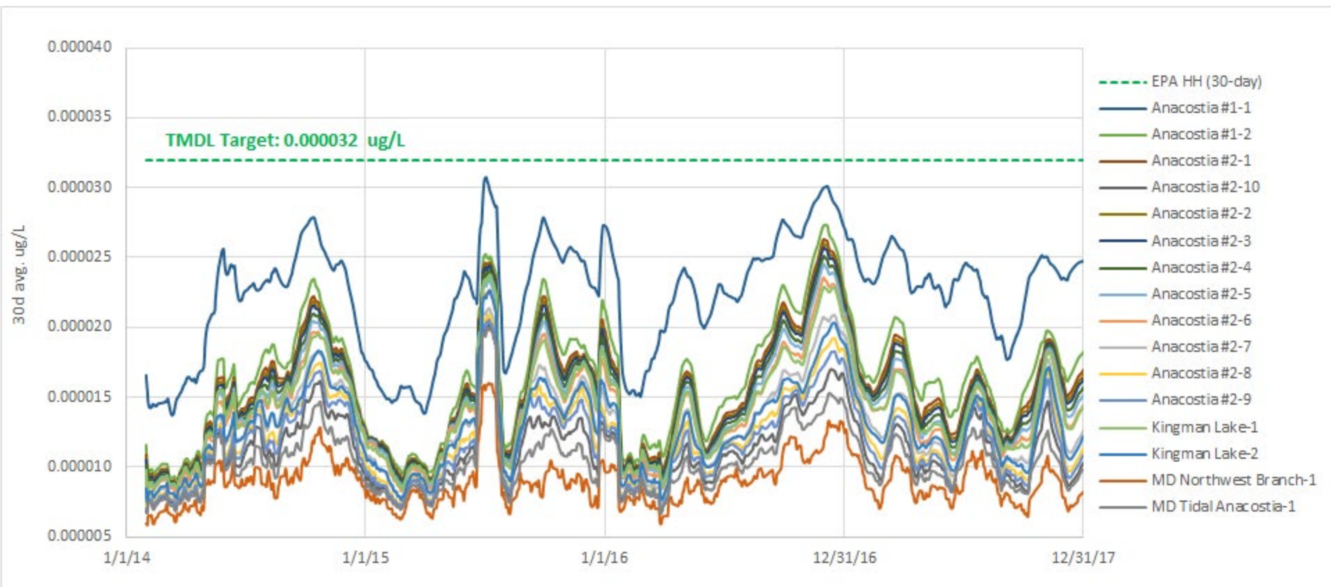


Figure 7-15. Time series showing the TMDL endpoint is met for all verification units (heptachlor epoxide).

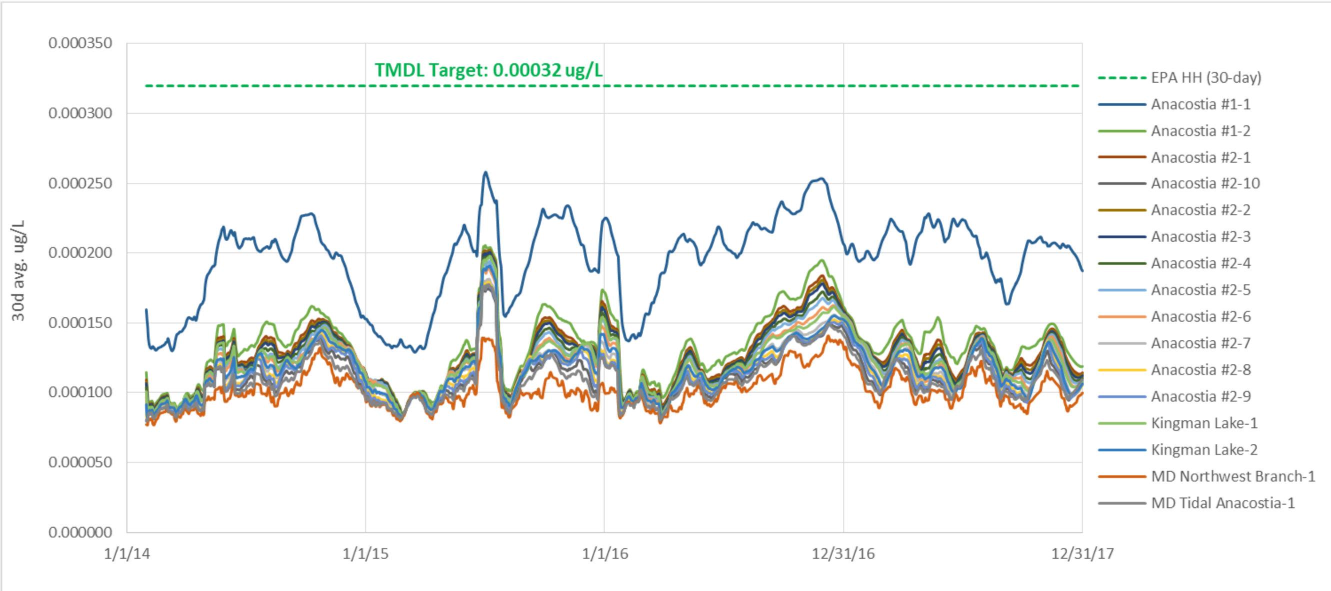


Figure 7-16. Time series showing the TMDL endpoint is met for all verification units (chlordane).

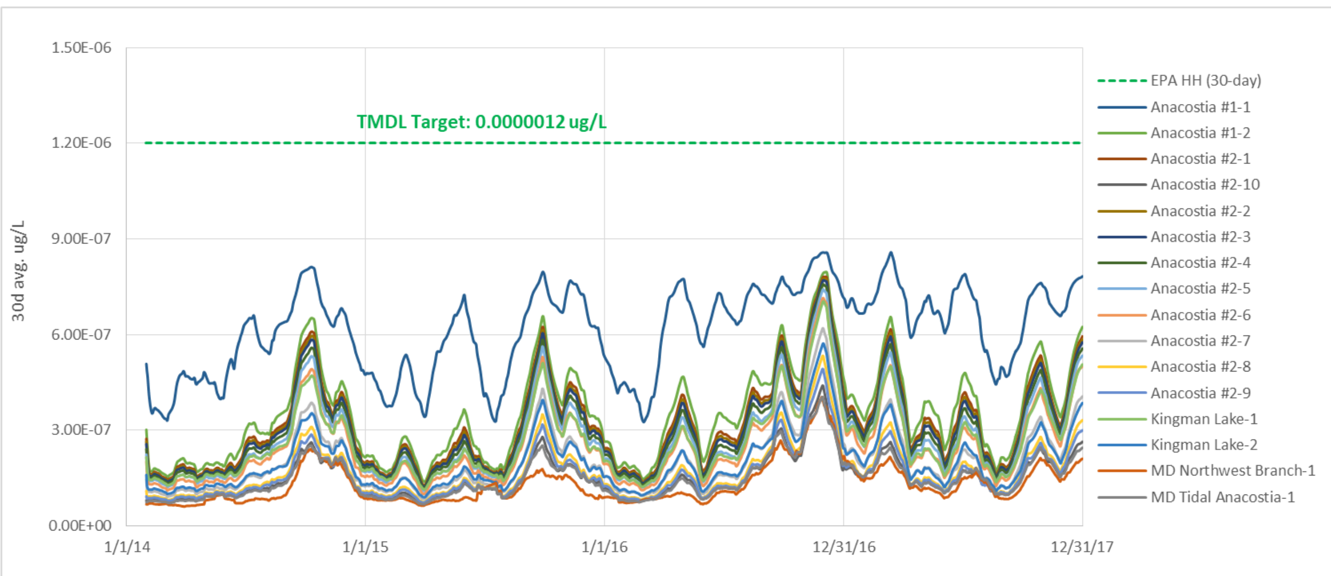


Figure 7-17. Time series showing the TMDL endpoint is met for all verification units (dieldrin).

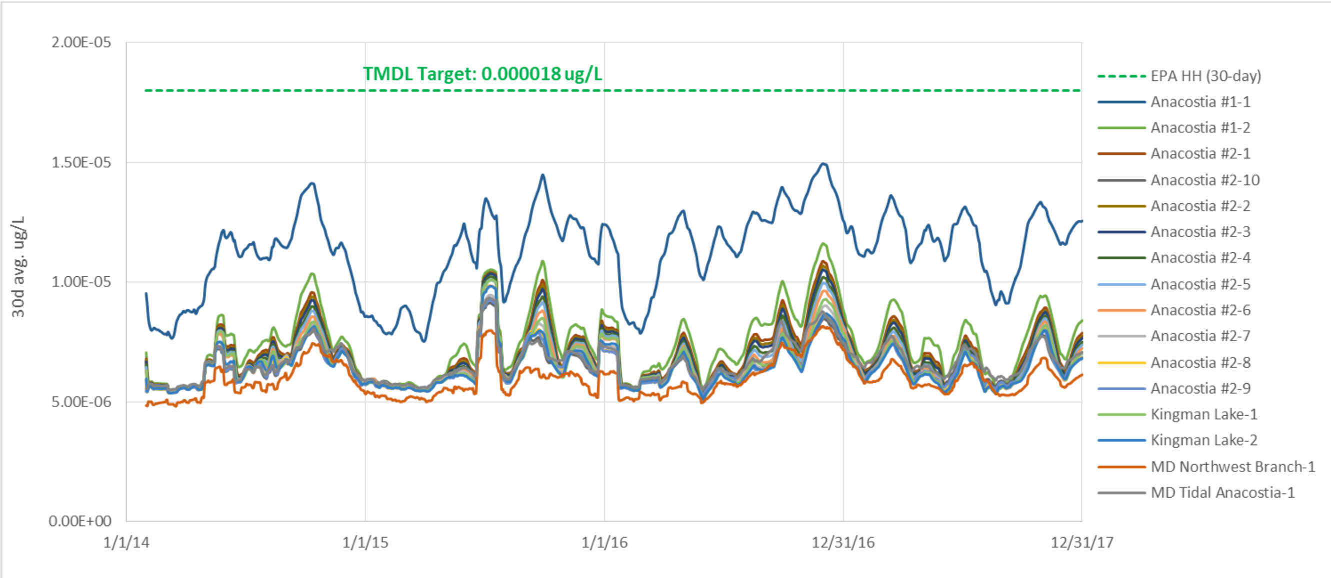


Figure 7-18. Time series showing the TMDL endpoint is met for all verification units (DDT).

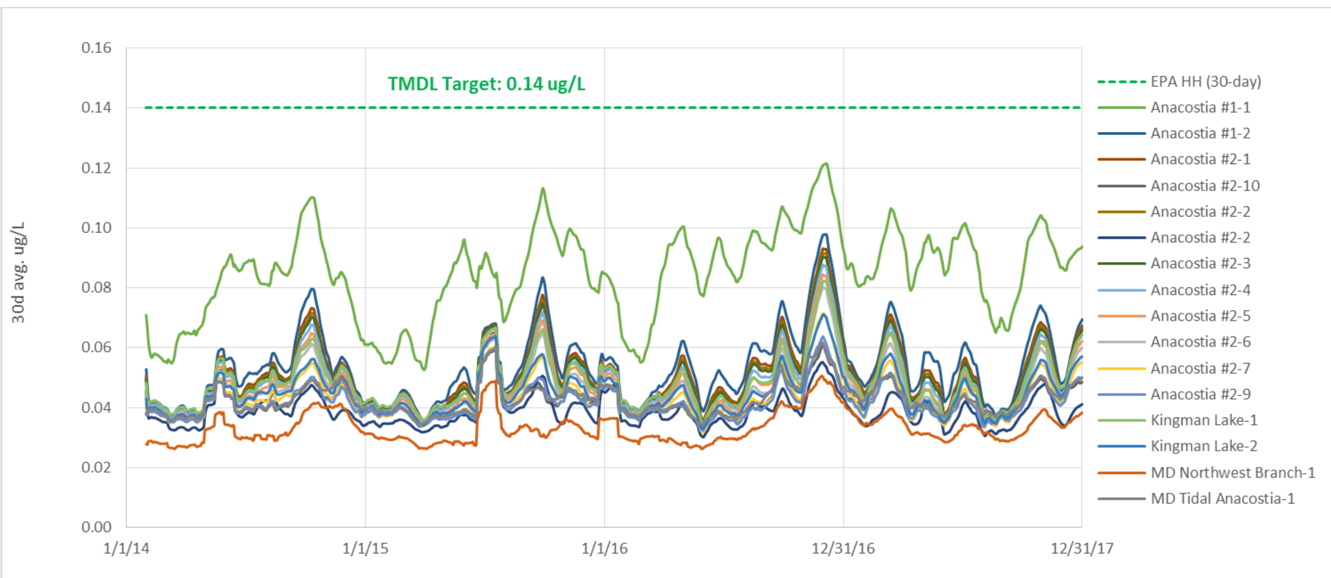


Figure 7-19. Time series showing the TMDL endpoint is met for all verification units (arsenic).

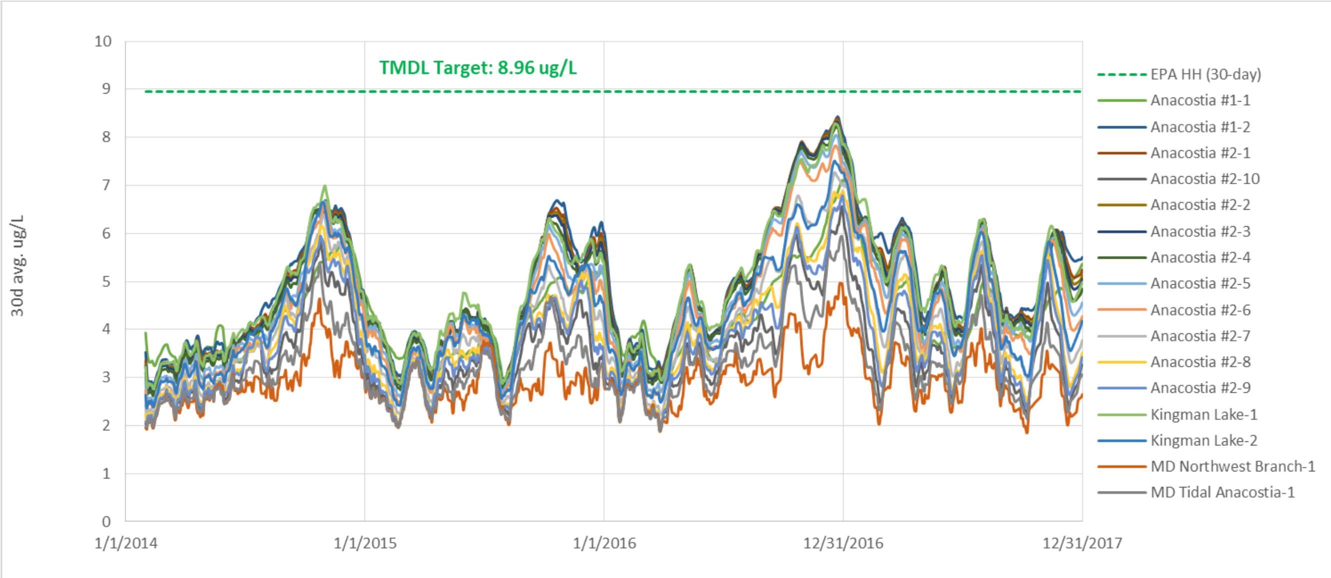


Figure 7-20. Time series showing the TMDL endpoint is met for all verification units (copper).

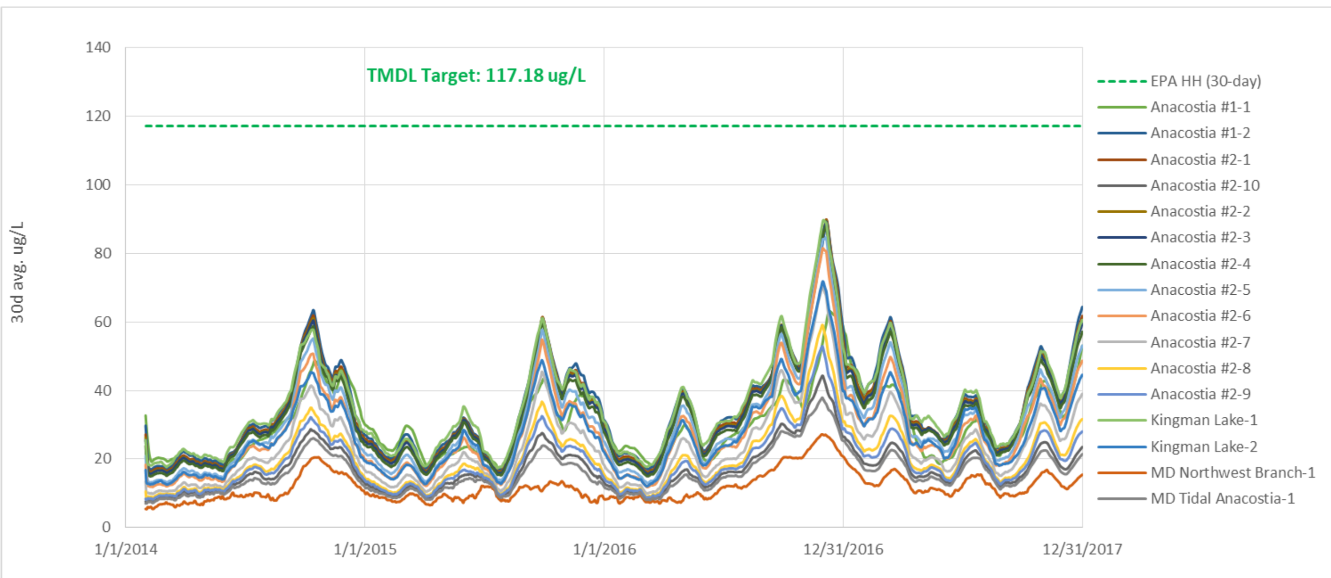


Figure 7-21. Time series showing the TMDL endpoint is met for all verification units (zinc).

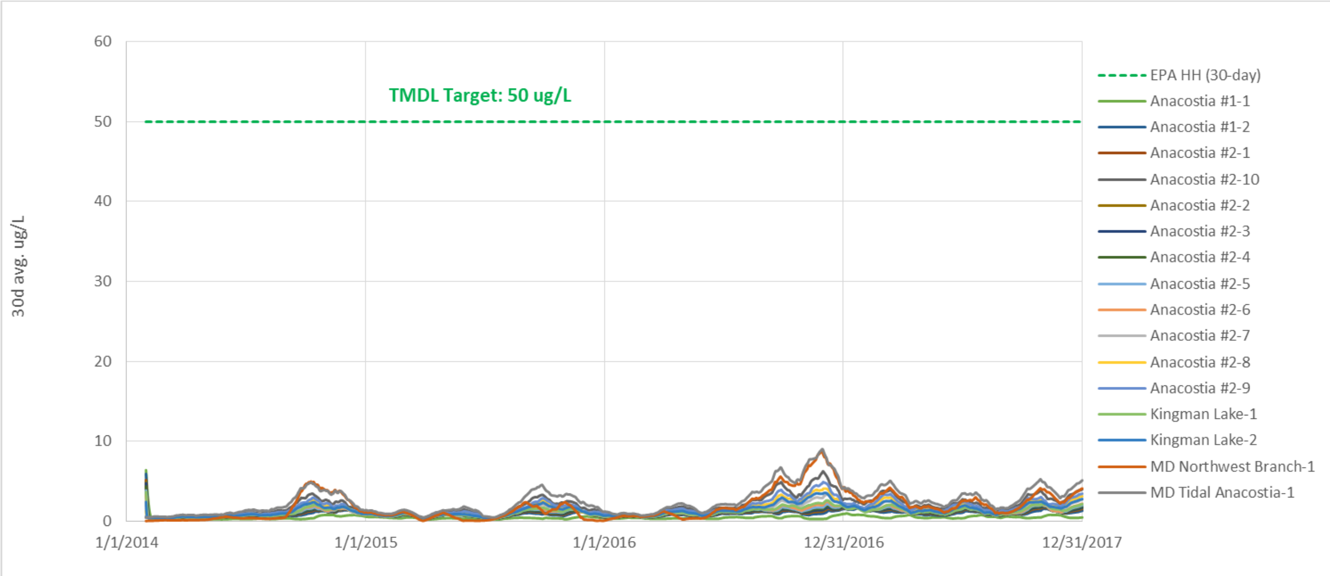


Figure 7-22. Time series showing the TMDL endpoint is met for all verification units (PAH-1).

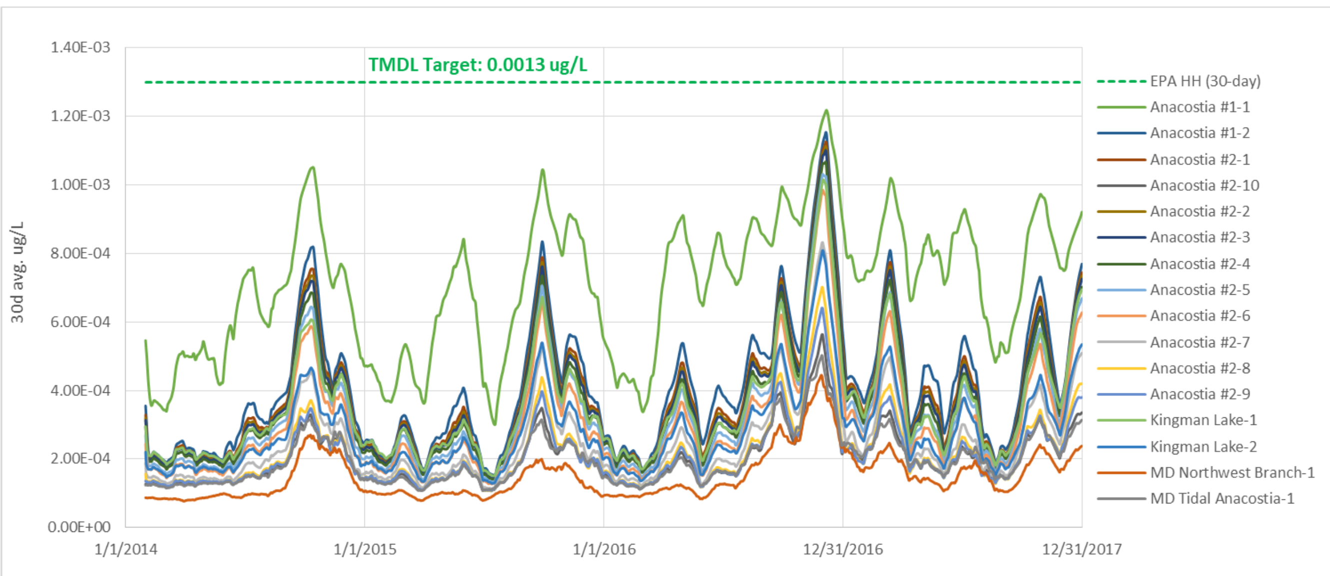


Figure 7-23. Time series showing the TMDL endpoint is met for all verification units (PAH-2).

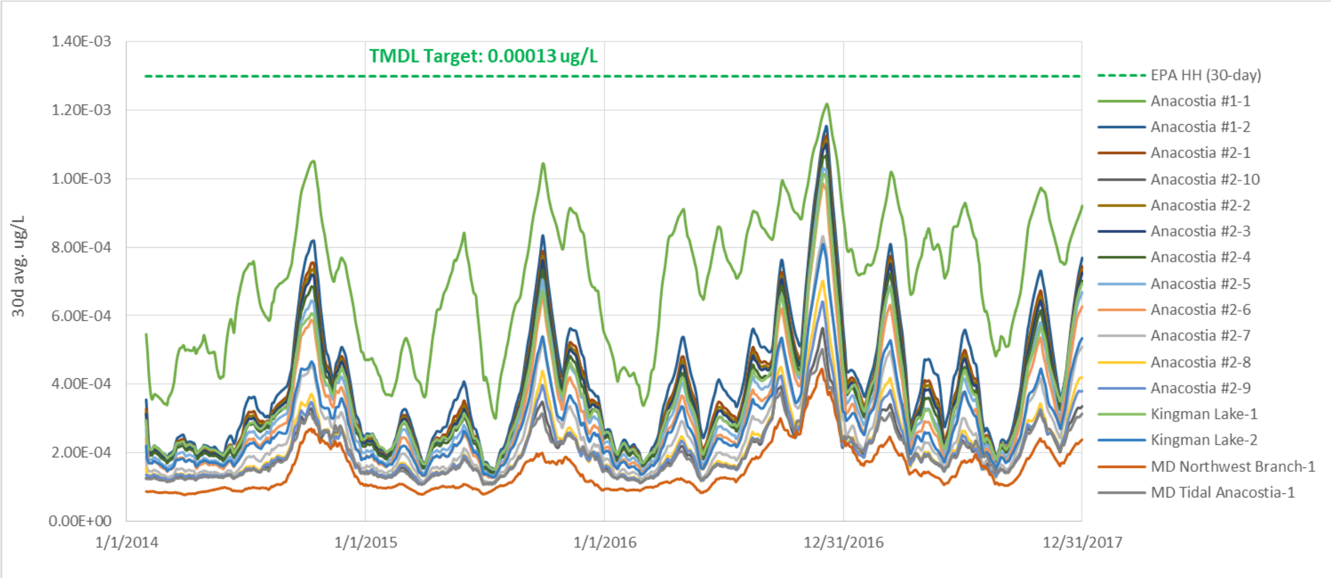


Figure 7-24. Time series showing the TMDL endpoint is met for all verification units (PAH-3).

7.5 ATTENUATION TIMELINE ANALYSIS

Due to the effects of contaminant flux from bed sediments to water column under the watershed allocation scenario, there is an expectation that, over time, clean sediments from the watershed will result in elimination of the contaminant flux and, therefore, attainment of TMDL endpoints in the water column. A methodology was developed to use the changes in bed sediment concentrations during the 4-year model period, and extrapolation of the predicted bed sediment concentration to identify the length of time at which the water column concentration/bed sediment concentration gradient no longer contributes to contaminant fluxes to cause the violation of the TMDL target. For each of the 10 contaminants, the stepwise process below was followed.

Step 1: Identify Bed Sediment Targets for each Verification Unit

- The bed sediment target is based on the required percent bed sediment reduction identified during the allocation analysis (i.e., if required reduction is 55%, then the target is 55% lower than the existing bed sediment concentration).
- Calculate area-weighted average bed sediment concentration by verification unit for the allocation scenario using bed sediment concentrations from the beginning of the model period.

Step 2: Run Trend Analysis Scenario

- Apply existing bed sediment concentrations to the allocation scenario and run.

Step 3: Extrapolate Future Bed Sediment Concentrations

- Using the 4-year trend analysis scenario results, conduct a trend analysis on the change in bed sediment concentrations for all verification units (i.e., identify how predicted bed sediment concentrations change from the beginning of the 4-year simulation to the end).
- Based on the temporal change trends, extend the relationship of bed sediment concentration and time. Using linear regression, extrapolate future bed sediment concentrations forward in time.

Step 4: Calculate Attenuation to Bed Sediment Targets

- For each verification unit, calculate the time needed for existing bed sediment pollutant concentrations to decrease to concentrations that support meeting TMDL targets for the water column. This step identifies the future year at which natural attenuation may be expected to result in meeting the TMDL endpoints, and therefore the water column criteria.

The goal of this analysis was to estimate the time it will take for natural attenuation of contaminants in the bed sediments to be replaced by clean bed surface sediments, resulting in no contaminant flux to the water column.

As a result, this analysis demonstrates that load allocations (LAs) to bed sediment are not required because natural attenuation is the mechanism that will result in attainment of the TMDL endpoints.

Figure 7-25 shows allocation scenario modeled heptachlor epoxide concentrations in bed sediments for each verification unit between 2014 and 2017 (graphics for other parameters are shown in Appendix B). The average concentration in bed sediment decreases over the modeled time period in all verification units under the allocation scenario. However, with the exception of the Maryland Northwest Branch verification unit, none of the verification units show a 55% decrease over the 4-year allocation period, which is estimated to be required to meet the water column TMDL target (see Table 7-2). A trend analysis using a linear regression of each time series was developed to extrapolate concentrations forward in time to the target concentrations in each verification unit. This approach of capturing and representing attenuation was used because performing simulations longer than 50 years with the model framework was considered infeasible due to computing limitations and the number of contaminants.

Table 7-3 provides the results of the attenuation analysis for heptachlor epoxide as an example. The linear regression equation, initial and target bed sediment concentration, and estimated time for natural attenuation to be sufficient for meeting the endpoints for each verification unit are provided. The attenuation analysis suggests that bed sediment concentrations decrease by 55% between 2017 and 2125. Average bed sediment concentrations in the Maryland Northwest Branch verification unit decrease by 55% by 2017, while the analysis shows that the lower segment of Kingman Lake (Kingman Lake 1) is the slowest to attenuate to target conditions. Table 7-4 summarizes the attenuation estimates for all pollutants.

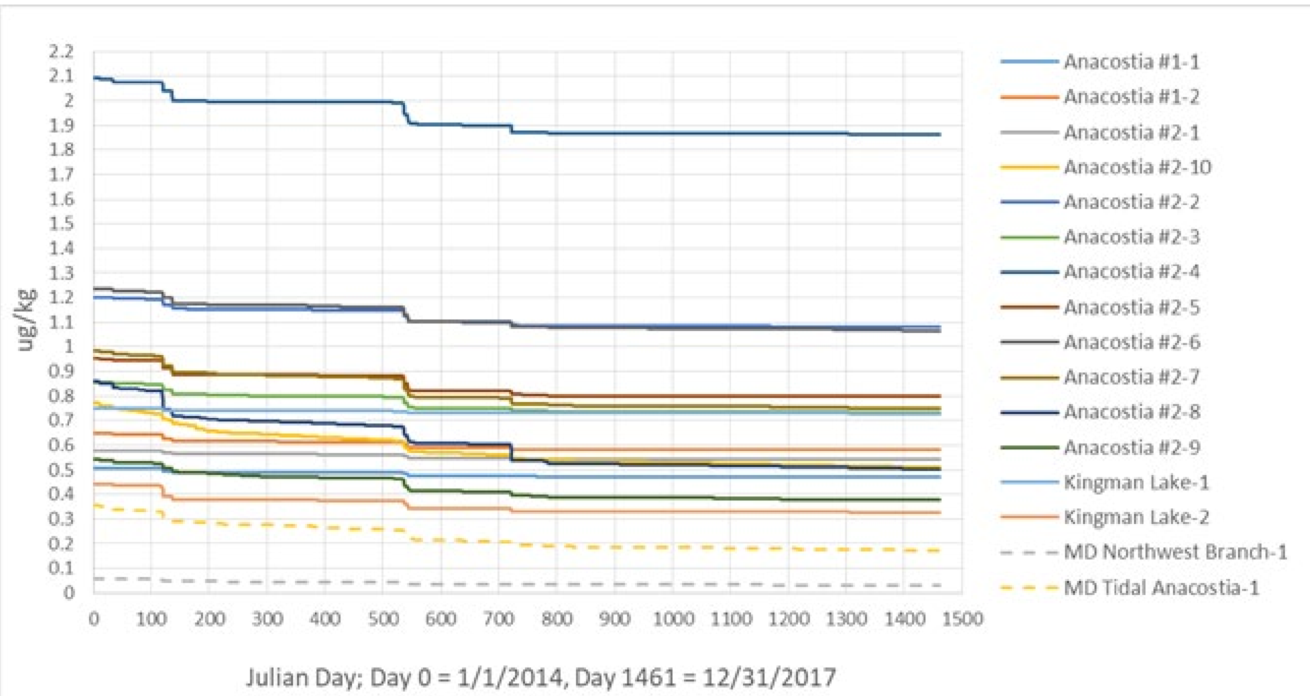


Figure 7-25 Modeled heptachlor epoxide bed sediment concentrations for each verification unit (2014 – 2017).

Table 7-3. Results of the attenuation analysis for heptachlor epoxide

Verification unit	Linear regression equation (x = days, y = µg/kg)	1/1/2014 bed concentration (µg/kg)	Bed conc target (55% reduction) (µg/kg)	Date achieved	Achievement (years)
Anacostia #1-1	y = -2E-05x + 0.4964	0.51	0.23	8/11/2050	37
Anacostia #1-2	y = -4E-05x + 0.6288	0.65	0.29	2/11/2037	23
Anacostia #2-1	y = -2E-05x + 0.5695	0.58	0.26	5/5/2056	42
Anacostia #2-10	y = -0.0002x + 0.6981	0.77	0.35	10/18/2018	5
Anacostia #2-2	y = -8E-05x + 1.1739	1.20	0.54	8/30/2035	22
Anacostia #2-3	y = -8E-05x + 0.8247	0.86	0.39	1/16/2029	15
Anacostia #2-4	y = -0.0002x + 2.0395	2.09	0.94	1/10/2029	15
Anacostia #2-5	y = -0.0001x + 0.9149	0.95	0.43	4/24/2027	13
Anacostia #2-6	y = -0.0001x + 1.2008	1.24	0.56	8/26/2031	18
Anacostia #2-7	y = -0.0002x + 0.9306	0.99	0.44	9/2/2020	7
Anacostia #2-8	y = -0.0002x + 0.7727	0.86	0.39	4/14/2019	5
Anacostia #2-9	y = -0.0001x + 0.5081	0.54	0.24	3/27/2021	7
Kingman Lake-1	y = -1E-05x + 0.7437	0.75	0.34	3/7/2125	111
Kingman Lake-2	y = -7E-05x + 0.4023	0.44	0.20	12/24/2021	8
MD Northwest Branch-1	y = -2E-05x + 0.0494	0.06	0.03	4/23/2017	3
MD Tidal Anacostia-1	y = -0.0001x + 0.3099	0.36	0.16	1/29/2018	4

Table 7-4. Attenuation timeline estimates for all pollutants

	Attenuation year									
Verification unit	Heptachlor epoxide	Chlordane	Dieldrin	DDT	Arsenic	Copper	Zinc	PAH1	PAH2	PAH3
Anacostia #1-1	2050	2063	2087	2091	2096	2075	n/a	n/a	2092	2088
Anacostia #1-2	2037	2048	2052	2071	2060	2050	n/a	n/a	2063	2064
Anacostia #2-1	2056	2076	2073	2081	2080	2064	n/a	n/a	2082	2083
Anacostia #2-10	2018	2024	2025	2031	2026	2021	n/a	n/a	2026	2026
Anacostia #2-2	2035	2039	2059	2054	2067	2062	n/a	n/a	2060	2058
Anacostia #2-3	2029	2035	2034	2039	2045	2037	n/a	n/a	2046	2046
Anacostia #2-4	2029	2042	2055	2051	2048	2046	n/a	n/a	2048	2046
Anacostia #2-5	2027	2039	2043	2039	2041	2036	n/a	n/a	2045	2044
Anacostia #2-6	2031	2036	2034	2043	2048	2035	n/a	n/a	2040	2041

	Attenuation year									
Verification unit	**Heptachlor epoxide**	**Chlordane**	**Dieldrin**	**DDT**	**Arsenic**	**Copper**	**Zinc**	**PAH1**	**PAH2**	**PAH3**
Anacostia #2-7	2020	2029	2026	2031	2030	2029	n/a	n/a	2031	2031
Anacostia #2-8	2019	2023	2024	2022	2023	2022	n/a	n/a	2023	2023
Anacostia #2-9	2021	2027	2023	2028	2026	2013	n/a	n/a	2028	2029
Kingman Lake-1	2125	2131	2165	2189	2220	2198	n/a	n/a	2213	2224
Kingman Lake-2	2021	2031	2033	2031	2039	2039	n/a	n/a	2037	2038
MD Northwest Branch-1	2017	2020	2020	2026	2027	2023	n/a	n/a	2024	2024
MD Tidal Anacostia-1	2018	2021	2020	2020	2021	2021	n/a	n/a	2021	2021

7.6 ALLOCATION TABLES/RESULTS

Total annual baseline and TMDL loads were tabulated for each assessment unit, jurisdiction, and source. Maximum daily loads were proportioned between the WLA and LA based on the proportions in the annual load allocations. Due to the complexity of the watershed and allocations, they are presented in Appendix C in Microsoft Excel spreadsheet format. Loads are presented in multiple ways:

- Cumulative loads (upstream to downstream) for the Maryland Tidal Anacostia, Anacostia #2, and Anacostia #1.
- Loads for individual assessment units.

7.7 DAILY LOADS

Daily loads were calculated using the LSPC model's reach output. The methodology uses the model reach output time-series for each of the watersheds that are feeding into the impaired segments. Specifically, daily flow and concentration (for each of the 10 pollutants) time series data from the most downstream pour point model output files for each of the impaired segments were extracted. The daily output time series for each of the impaired segments was used to calculate the maximum of the daily loads. Ratios of the WLA and LA loadings from the annual average loadings calculated for each impaired segment were used to parse out the maximum daily load to the WLA and LA values. The WLA and LA are aggregated for each segment (i.e., individual sources are not assigned daily loads).

There are two important things to note about the daily loads. The daily loads are based on loading in the reach and not from the land segment source areas. The loading of the toxicant from the reach is subject to various transformation processes after it reaches the stream from the land. It should be noted that the TMDL endpoint for evaluation in most cases is a 30-day average.

8.0 TMDL ELEMENTS

This section provides discussion of key TMDL elements and the modeling that supports the TMDL, including critical conditions, seasonal variability, margin of safety, and conservative assumptions.

8.1 SEASONALITY AND CRITICAL CONDITIONS

Federal regulations (40 CFR 130.7(c)(1)) require TMDLs to consider critical conditions for streamflow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality and designated uses of the water bodies are protected during periods when they are most vulnerable. Critical conditions include combinations of environmental factors that result in attaining and maintaining the endpoints and have an acceptably low frequency of occurrence (U.S. EPA, 2001).

Toxic TMDLs for the Anacostia River watershed adequately address critical conditions for flow through the use of a dynamic model and analysis of all flow conditions in the basin. Available water quality and flow data show that critical conditions for toxic parameters in the watershed occur under all conditions (i.e., under both low-flow and high-flow scenarios). Therefore, the use of a dynamic modeling application capable of representing conditions resulting from both low- and high-flow regimes is appropriate. The linkage of the tidal Anacostia River to a dynamic watershed loading model ensures that nonpoint and stormwater source loads from the watershed delivered at times other than the critical period were also considered in the analysis. The TMDLs are based on the entire modeled period of 2014–2017.

Critical conditions for toxic parameter loads were also considered by determining WLAs based on maximum flows from dischargers set by design flows specified in NPDES permits for each facility. Use of design flows in TMDL determination provides additional assurance that when design flows are reached, the water quality in the stream will meet the TMDL endpoints.

Model simulation of multiple complete years accounted for seasonal variations. Continuous simulation (modeling over a period of several years that captured precipitation extremes) inherently considers seasonal hydrologic and source loading variability. The constituent concentrations were simulated on a subdaily time step, capturing seasonal variation and allowing for evaluation of critical conditions.

8.2 MARGIN OF SAFETY

The margin of safety (MOS) is the portion of the pollutant loading reserved to account for any uncertainty in the data. There are two ways to incorporate the MOS (U.S. EPA, 1991): (1) implicitly by using conservative model assumptions to develop allocations or (2) explicitly by specifying a portion of the TMDL as the MOS and using the remainder for allocations. The modeling framework applied to develop these TMDLs was calibrated against monitoring data collected throughout the watershed and impaired water bodies. Although these monitoring data represented actual conditions, they were not of a continuous time series and might not have captured the full range of instream conditions that occurred during the simulation period. The implicit MOS also accounts for those cases where monitoring might not have captured the full range of instream conditions.

There is an implicit margin of safety achieved through the adoption of conservative analyses and modeling assumptions. Conservative assumptions include the following:

- Permitted WWTPs were represented at the maximum allowable permitted concentration as opposed to actual discharges from the WWTP.
- Because there was very limited data to characterize and calibrate the model for the degradates, total DDT was modeled and the most stringent of the degradate criteria was used as the TMDL endpoint (DDE) for allocations. By using the most stringent of the degradate criteria as the endpoint, the TMDL ensures that those criteria can be met under the allocation scenario even though only DDT was simulated.
- Grouped the PAHs in three groups and used the most stringent criterion of the individual PAH in each group as the TMDL endpoint for allocations.
- Developed the TMDLs based on the entire simulated period of 2014–2017 to incorporate the widest range in environmental conditions, rather than a shorter period of time that may not include relatively wet or dry periods.
- Calculated BAF-based water column concentrations and compared to WQC for heptachlor epoxide and used the most stringent as the TMDL endpoint.

- For NPDES facilities that had no DMR monitoring data for use in setting existing conditions, represented all at criteria except for PAH1[3]
- When monitoring data recorded a nondetect, concentrations were applied at half the detection limit during model setup and calibration. This potentially overestimates baseline concentrations if toxicant values were below the detection limit or zero .

[3] Criteria for PAH1 is sufficiently high (five orders of magnitude higher than other parameters) that setting PAH1 discharges equal to criteria had a disproportional effect on the model results. Facilities with no PAH1 monitoring data were set to the maximum detection limit of 0.065 µg/L.

9.0 REFERENCES

AWRP. (2010). *Anacostia Rivver Watershed Restoration Plan and Report.* Anacostia River Watershed Partnership.

Bedient, P., & Huber, W. (1992). *Hydrology and Floodplain Analysis, 2nd Edition.* Reading, MA: Addison-Wesley.

Bicknell, B. R., Imhoff, J. C., Kittle, Jr, J. L., Jobes, T. H., & Duda, P. B. (2014). *HSPF Version 12.4 User's Manual.* Athens, GA: National Exposure Research Laboratory, Office of Research and Development, United States Environmental Protection Agency.

Chapra, S. C. (1997). *Surface Water Quality Modeling.* New York, NY.: McGraw HIll.

Cunnane, C., Garrick, M., & Nash, J. E. (1978). A criterion of efficiency for rainfall-runoff models. *Journal of Hydrology, 36*(3-4), 375-381.

DC Health. (2005). *Anacostia River Watershed Implementation Plan.* DC Department of Health.

DC Water. (2014). *Year 2013 Nine Minimum Control Annual Report for Combined Sewer System.* Disctrict of Columbia, Water and Sewer Authority. Washington, D.C.: DC Water. Retrieved from https://dcwater.com/sites/default/files/documents/2013NMC_FINAL.pdf

DC Water. (2015). *Year 2014 Nine Minimum Controls Annual Report for Combined Sewer System.* Distric of Columbia, Water and Sewer Authority. Washington, D.C.: DC Water. Retrieved from https://dcwater.com/sites/default/files/documents/2014NMC_FINAL.pdf

DC Water. (2016). *Year 2015 Nine Minimum Controls Annual Report for Combined Sewer System.* Washington, D.C.: DC Water. Retrieved from https://dcwater.com/sites/default/files/documents/2015NMC_FINAL.pdf

DDOE. (2014). *2014 Integrated Report to the US Environmental Protection Agency and Congress Pursuant to Sections 305(b) and 303(d) Clean Water Act (P.L. 97-117).* Washington, D.C.: District Department of the Environment.

Donigian, A. S., Imhoff, J. C., Bicknell, B. R., & Kittle, J. L. (1984). *Application Guide for the Hydrologic Simulation Program - FORTRAN.* Athens, GA: U.S. Environmental Protection Agency.

Dunn, T., & Leopold, L. (1978). *Water in Environmental Planning.* San Francisco, California: W.H. Freeman and Company.

Ghosh, U., Lombard, N., Bokare, M., Pinkney, A., Yonkos, L., & Harrison, R. (2019). *Passive samplers and mussel deployment, monitoring, and sampling for organic constituents in Anacostia River tributaries: 2016-2018 Year I Interim Report.* Annapolis, MD: U.S. Fish and Wildlife Service, Chesapeake Bay Field Office.

Gschwend, P., Apell, J., & MacFarlane, J. K. (2015). *Obtaining Measures of Freely-Dissolved Polychlorinated Biphenyls (PCBs) in Pore Water of the Lower Duwamish Waterway (LDW) Sediments Using Passive Polyethylene Samplers for Comparison with Calculations Based on Sediiment Concentrations and Partitioning to.* Submitted to USACE, Seattle District.

Hamrick, J. (1992). Estuarine environmental impact assessment using a three-dimensional circulation and transport model. In M. S. al (Ed.), *Estuarine and Coastal Modeling: Proceedings of the 2nd International Conference* (pp. 292-303). American Society of Civil Engineers.

Johnson Company. (2019). *Draft NPS Tributary Sediment Sampling Study Report, Anacostia River Sediment Project Site, National Capital Region.* Prepared for the National Park Service.

Leopold and Maddock. (1953). *Hydraulic Geometry of Stream Channels and Some Physiographic Implicatoins, USGS Professional Paper 252.* U.S. Geological Survey.

Lumb, A. M., McCammon, R. B., & Kittle, J. L. (1994). *User's Manual for an Expert system (HSPEXP) for Calibration of the Hydrologic Simulation Program - FORTRAN.* Reston, VA: U.S. Geological Survey.

Mandel, R., Kim, S., Nagel, A., & Schultz, C. L. (2007). *Anacostia sediment models: Phase 3 Anacostia HSPF watershed model and Version 3 TAM/WASP water clarity model.* Rockville, MD: Interstate Commission on the Potomac River Basin.

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models: Part 1:A discussion of principles. *Journal of Hydrology, 10*(3), 282-290.

Tetra Tech. (2018a). *Anacostia River Toxics TMDL Model Selection Recommendation Final Technical Memorandum.* Fairfax, VA.

Tetra Tech. (2018b). *Draft Remedial Investigation Report: Anacostia River Sediment Project.* Sterling, VA: Prepared for the Department of Energy and the Environment.

Tetra Tech. (2019). *Anacostia River Sediment Remediation Investigation Modeling Report.* Fairfax, VA: Prepared by Tetra Tech for DOEE.

Tetra Tech. (2019b). *Remedial Investigation Report, Anacostia River Sediment Project.* Washington, D.C.: Prepared for DC Department of Energy and Environment. April 2019.

U.S. EPA. (1991). *Technical Support Document for Water Quality based Toxics Control. EPA/505/2-90-001.* Washington, DC.: U.S. Environmental Protection Agency, Office of Water.

U.S. EPA. (2000). *BASINS Technical Note 6 on Estimating Hydrology and Hydraulic Parameters for HSPF.* Washington, D.C.: United States Environmental Protection Agency, Office of Water.

U.S. EPA. (2001). *Protocol for Developing Pathogen TMDLs* (Vol. Volume). (Editor, Ed.) Washington, D.C.: USEPA.

U.S. EPA. (2003). *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000), Technical Support Document. Vol. 2, Development of National Bioaccumulation Factors.* Washington, D.C.: U.S. Environmental Protection Agency, Offic of Water, Office of Science and Technology.

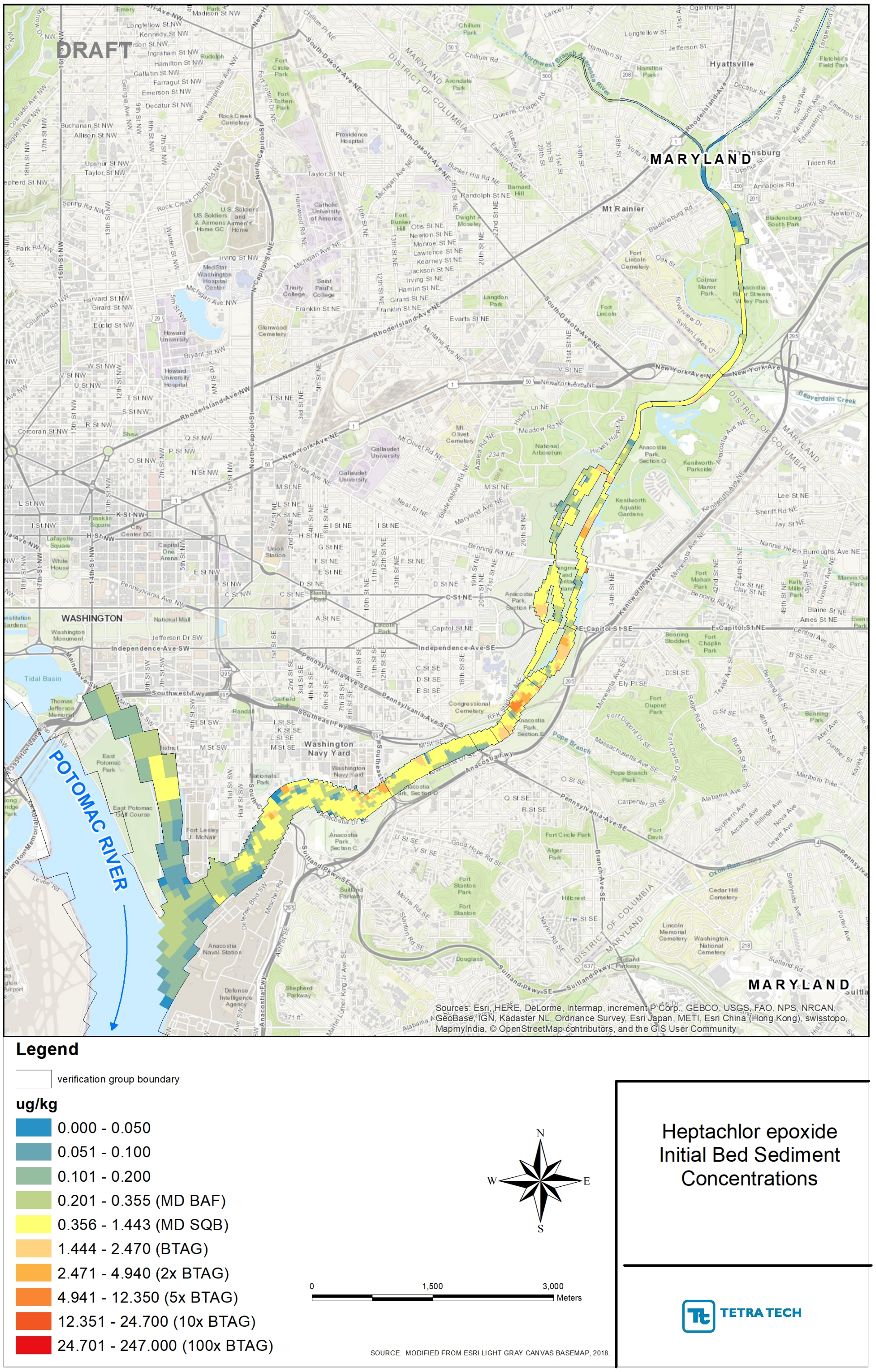
U.S. EPA. (1998). *Ambient Water Quality Criteria Derivation Methodology Human Health: Technical Support Document. Final Draft.* Washington, D.C.: United States Environmental Protection Agency.

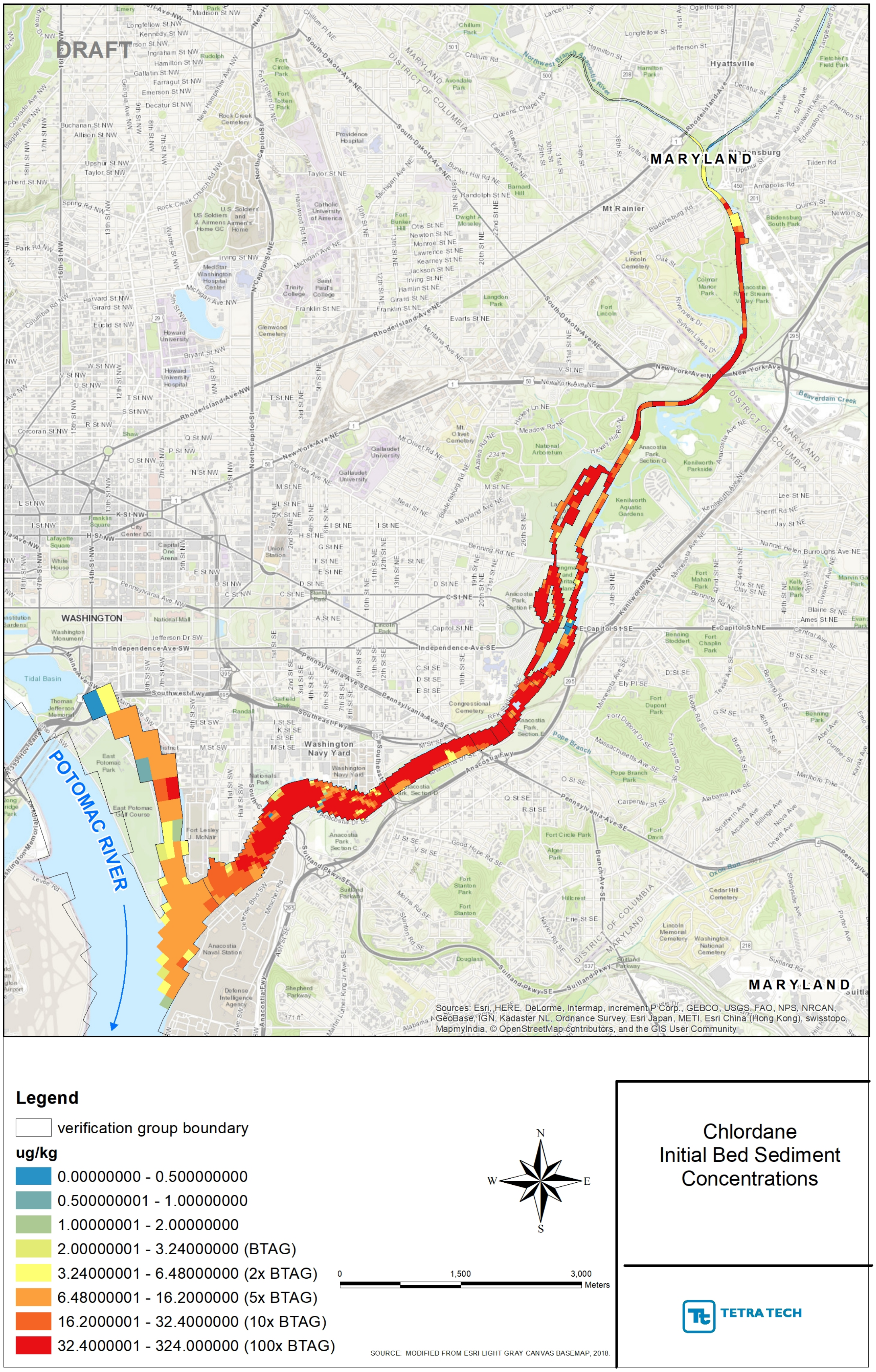
U.S. EPA. (2009). *Loading Simulation Program in C++ (LSPC) Version 3.1, EPA Region 3 and 4 User's Manual.* United States Environmental Protection Agency.

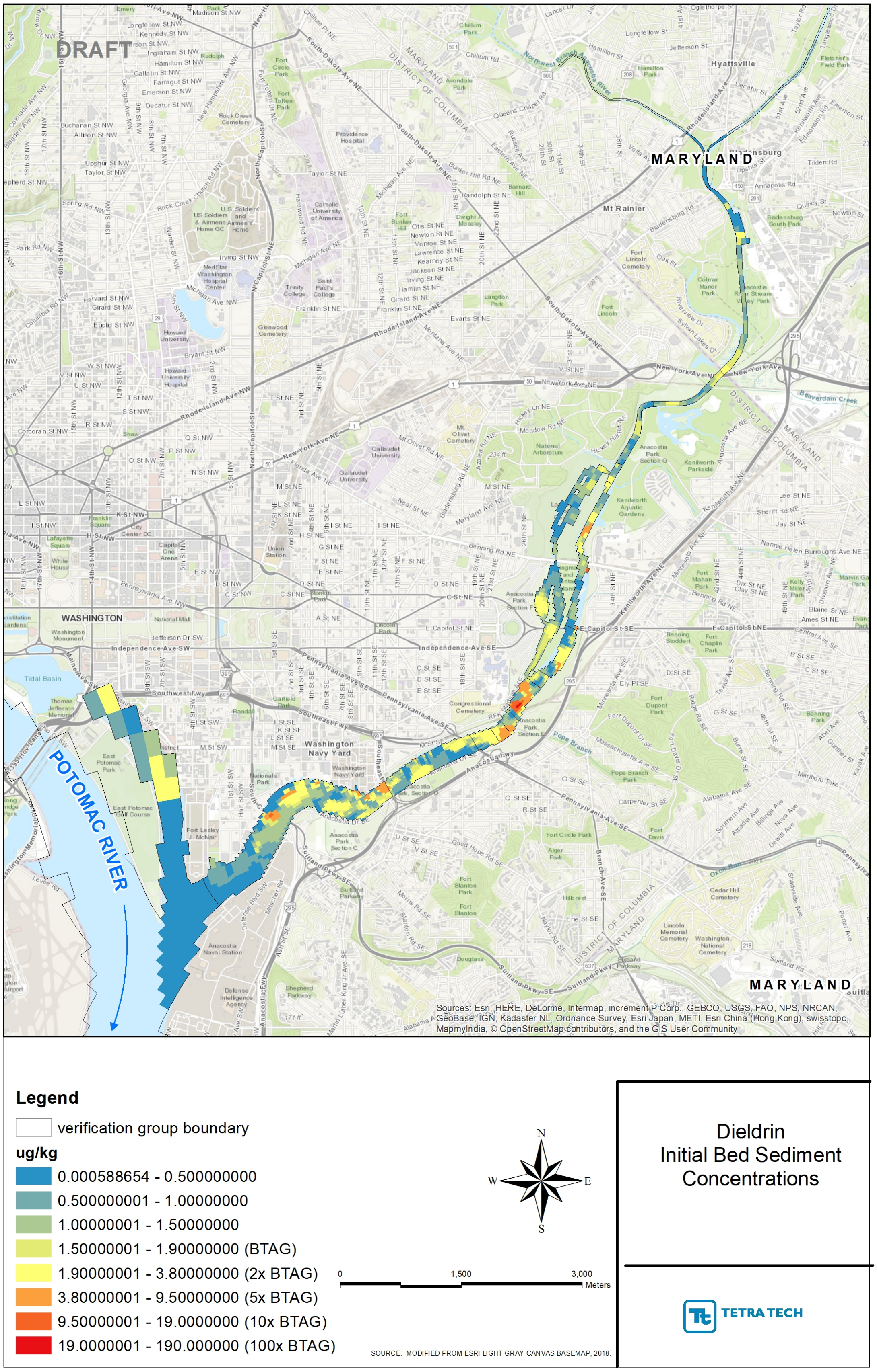
Westin Solutions. (2006). *Final Model Documentation Report: Modeling Study of PCB Contamination in the Housatonic River, Volume 1.* Retrieved from https://semspub.epa.gov/src/document/01/258097

Wilson, T. P. (2019). *Sediment and Chemical Contaminant Loads in Tributaries to the Anacostia River, Washington, District of Columbia, 2016-17.* Washington, D.C.: USGS. Retrieved from https://doi.org/10.3133/sir20195092

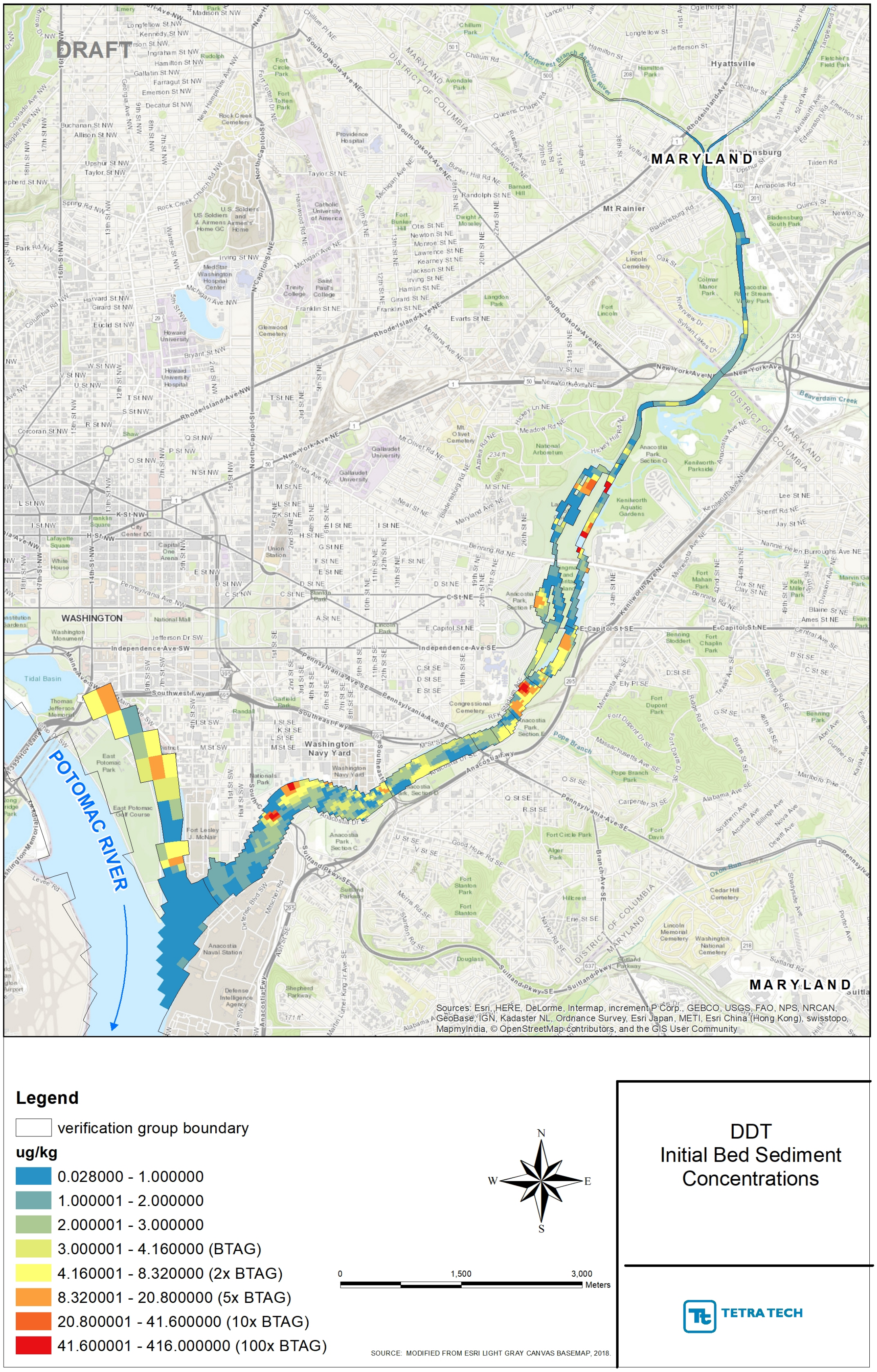
APPENDIX A – INITIAL EFDC BED SEDIMENT POLLUTANT CONCENTRATIONS




DRAFT
MARYLAND
WASHINGTON
POTOMAC RIVER
MARYLAND
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Legend
verification group boundary
ug/kg
0.00000000 - 0.500000000
0.500000001 - 1.00000000
1.00000001 - 2.00000000
2.00000001 - 3.24000000 (BTAG)
3.24000001 - 6.48000000 (2x BTAG)
6.48000001 - 16.2000000 (5x BTAG)
16.2000001 - 32.4000000 (10x BTAG)
32.4000001 - 324.000000 (100x BTAG)
N
W
E
S
0
1,500
3,000
Meters
SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2018.
Chlordane
Initial Bed Sediment
Concentrations
TETRA TECH

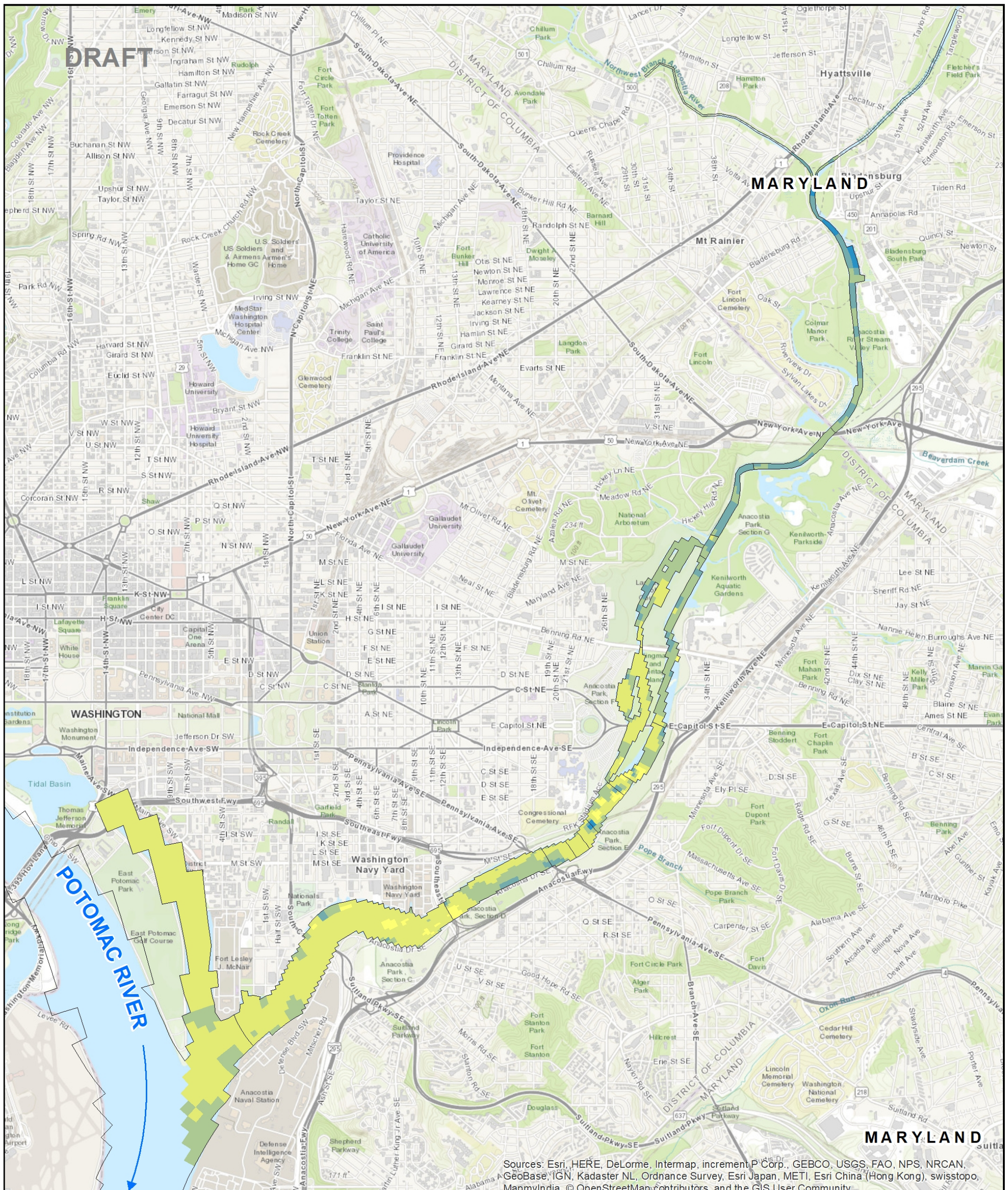


Dieldrin
Initial Bed Sediment Concentrations



DDT
Initial Bed Sediment Concentrations

TETRA TECH



Legend

verification group boundary

mg/kg

- 0.340000000 - 1.00000000
- 1.00000001 - 2.50000000
- 2.50000001 - 5.00000000
- 5.00000001 - 9.80000000 (BTAG)
- 9.80000001 - 19.6000000 (2x BTAG)
- 19.6000001 - 49.0000000 (5x BTAG)
- 49.0000001 - 98.0000000 (10x BTAG)
- 98.0000001 - 980.000000 (100x BTAG)

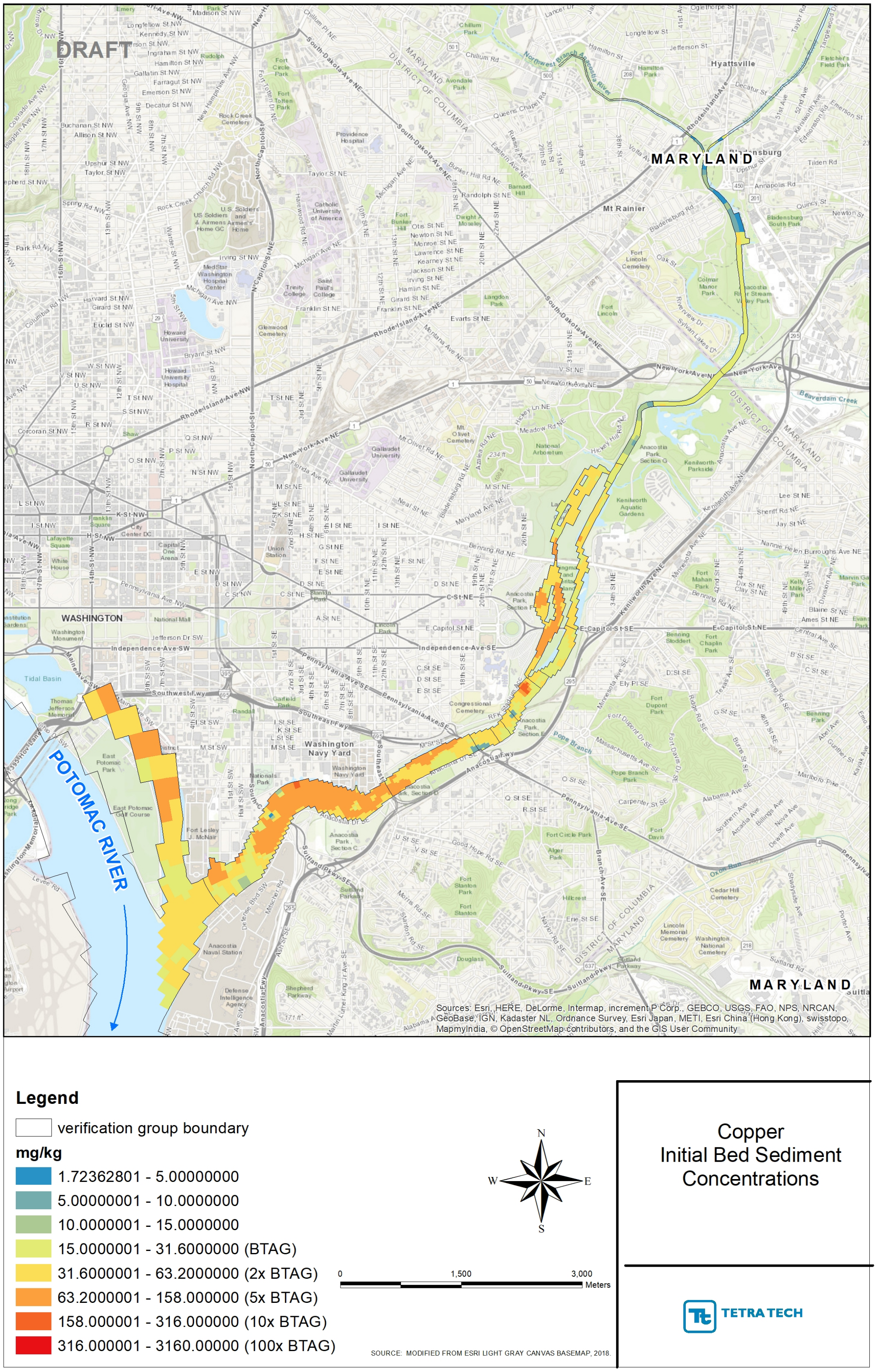
N E S W

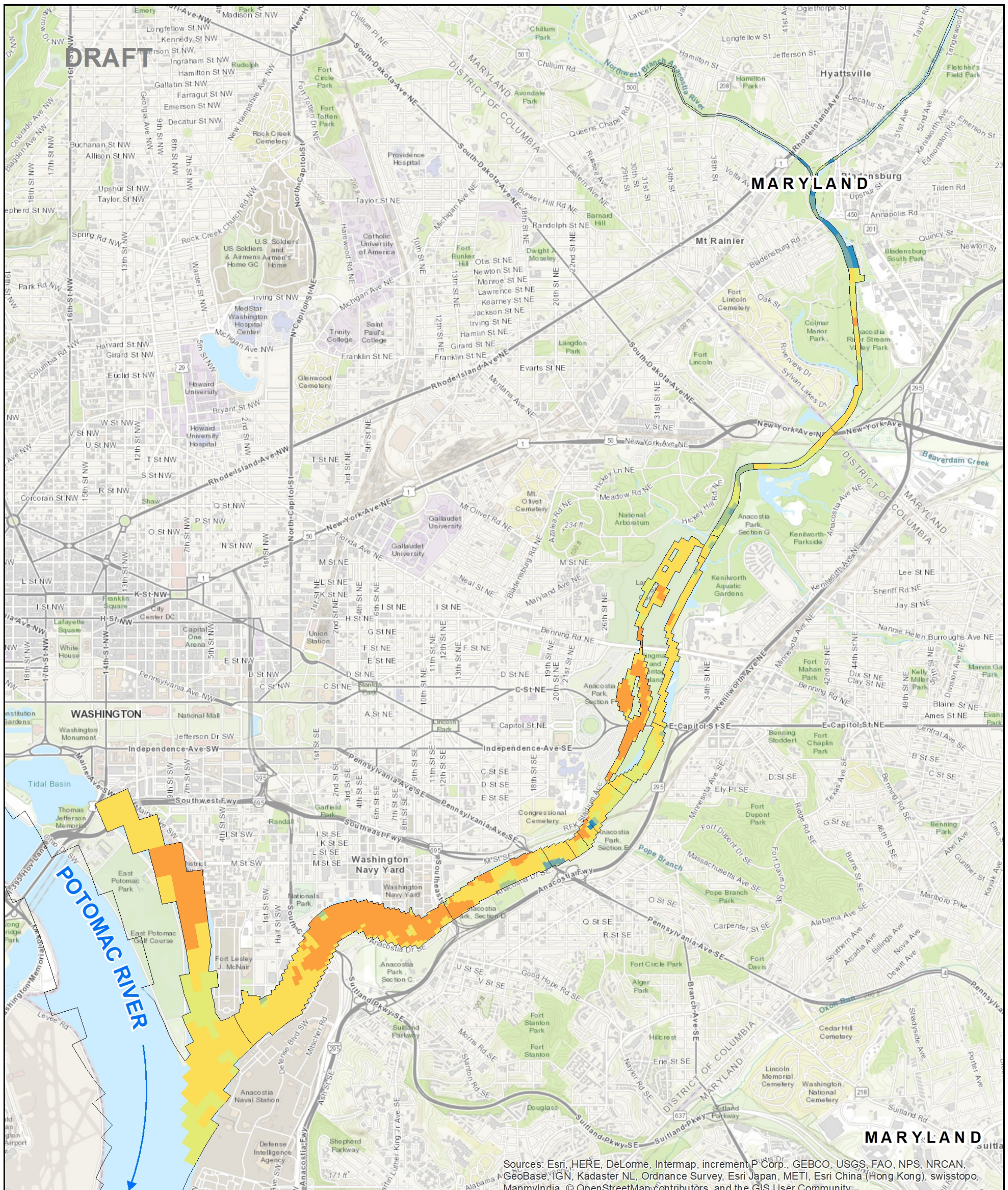
0 1,500 3,000 Meters

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2018.

Arsenic
Initial Bed Sediment
Concentrations

TETRA TECH


DRAFT
MARYLAND
WASHINGTON
POTOMAC RIVER
Washington Navy Yard
Anacostia Naval Station
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Legend
verification group boundary
mg/kg
1.72362801 - 5.00000000
5.00000001 - 10.0000000
10.0000001 - 15.0000000
15.0000001 - 31.6000000 (BTAG)
31.6000001 - 63.2000000 (2x BTAG)
63.2000001 - 158.000000 (5x BTAG)
158.000001 - 316.000000 (10x BTAG)
316.000001 - 3160.00000 (100x BTAG)
N
W
E
S
0
1,500
3,000
Meters
SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2018.
Copper
Initial Bed Sediment
Concentrations
TETRA TECH



Legend

verification group boundary

mg/kg

- 12.4473852 - 25.0000000
- 25.0000001 - 50.0000000
- 50.0000001 - 75.0000000
- 75.0000001 - 121.000000 (BTAG)
- 121.000001 - 242.000000 (2x BTAG)
- 242.000001 - 605.000000 (5x BTAG)
- 605.000001 - 1210.00000 (10x BTAG)
- 1210.00001 - 12100.0000 (100x BTAG)

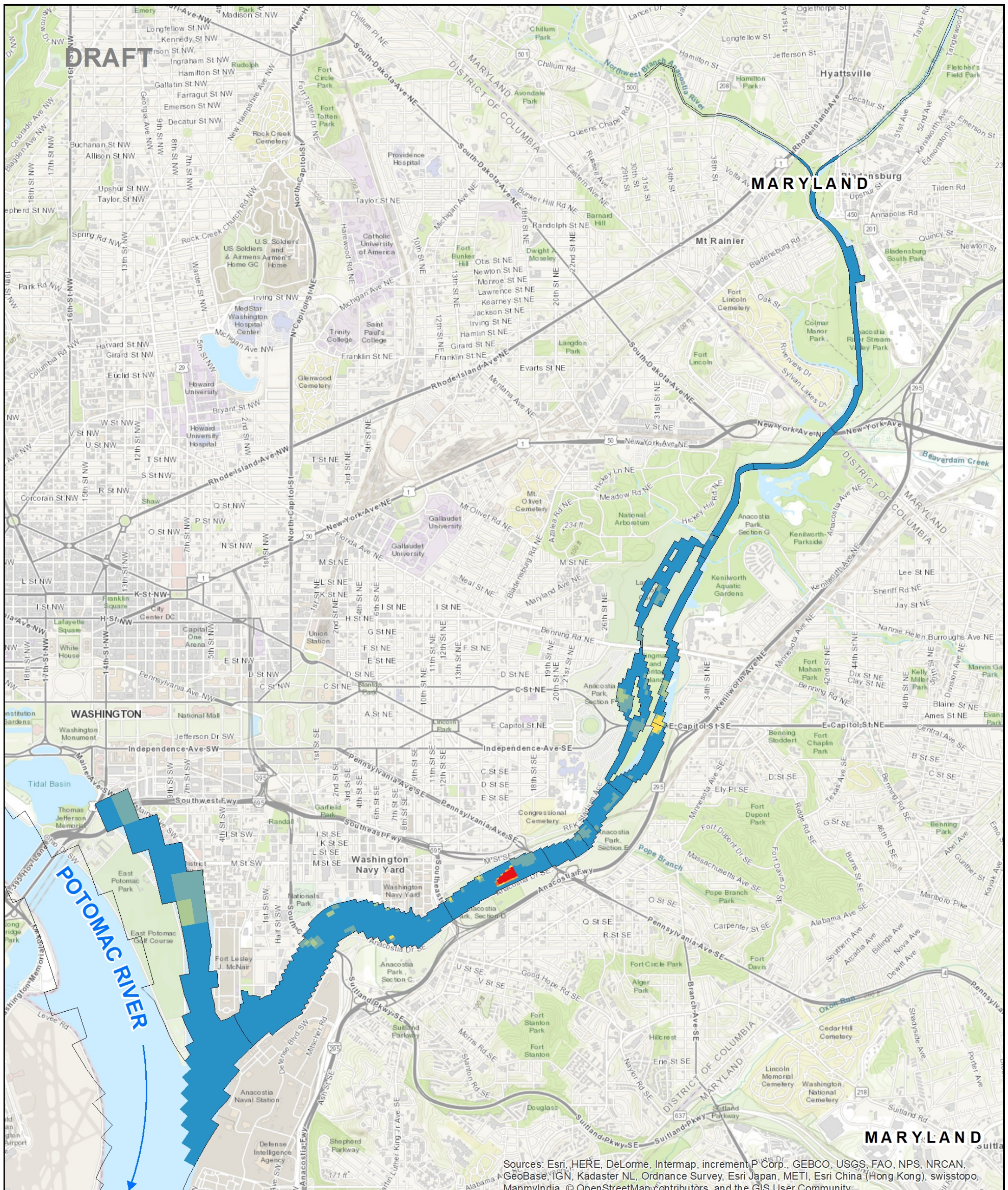
N W E S

0 1,500 3,000 Meters

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2018.

Zinc
Initial Bed Sediment
Concentrations

TETRA TECH



Legend

verification group boundary

ug/kg

- 7 - 500
- 501 - 1000
- 1001 - 1500
- 1501 - 1610 (BTAG; TPAH)
- 1611 - 3220 (2x BTAG; TPAH)
- 3221 - 8050 (5x BTAG; TPAH)
- 8051 - 16100 (10x BTAG; TPAH)
- 16101 - 161000 (100x BTAG; TPAH)

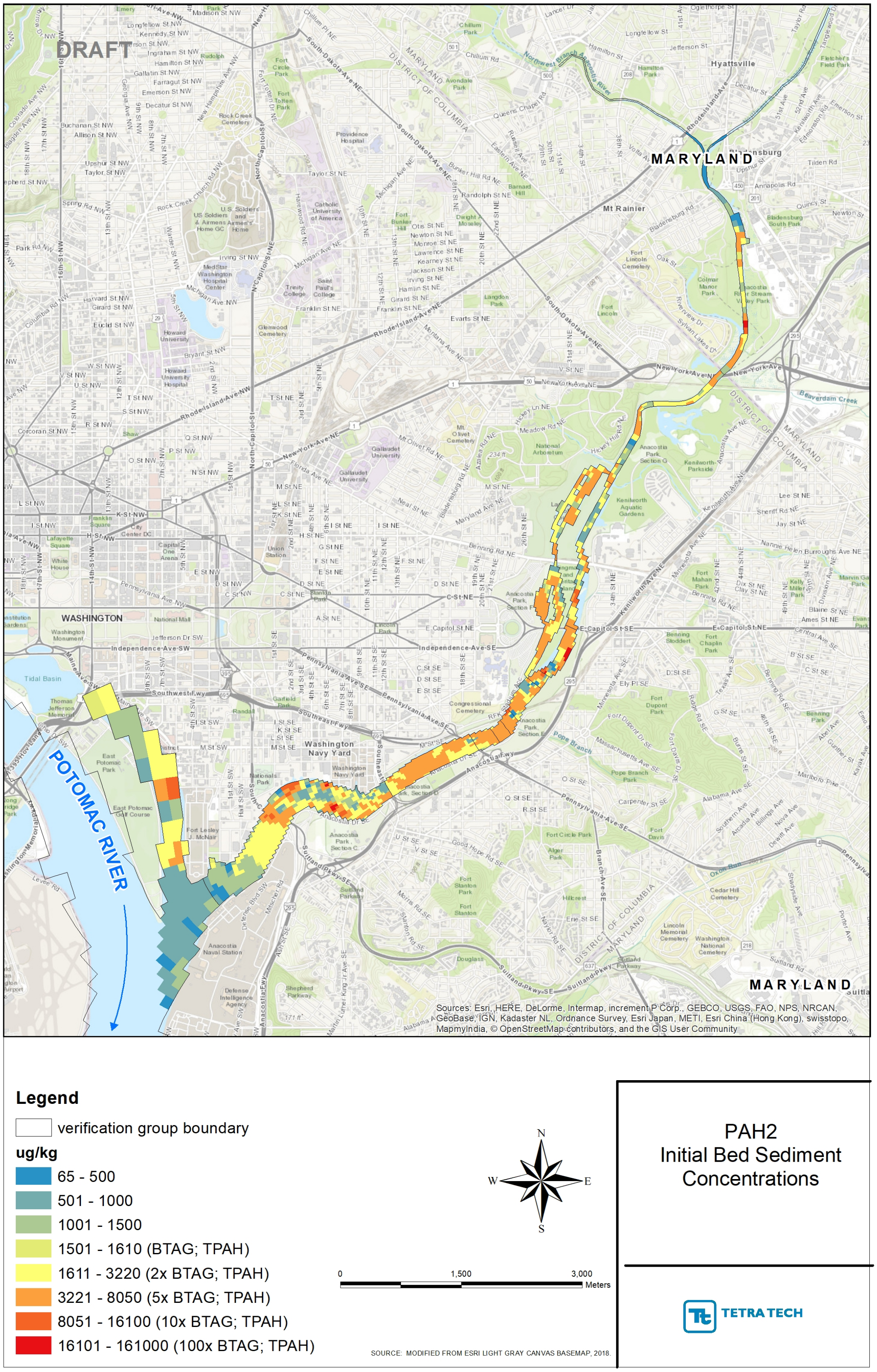
N W E S

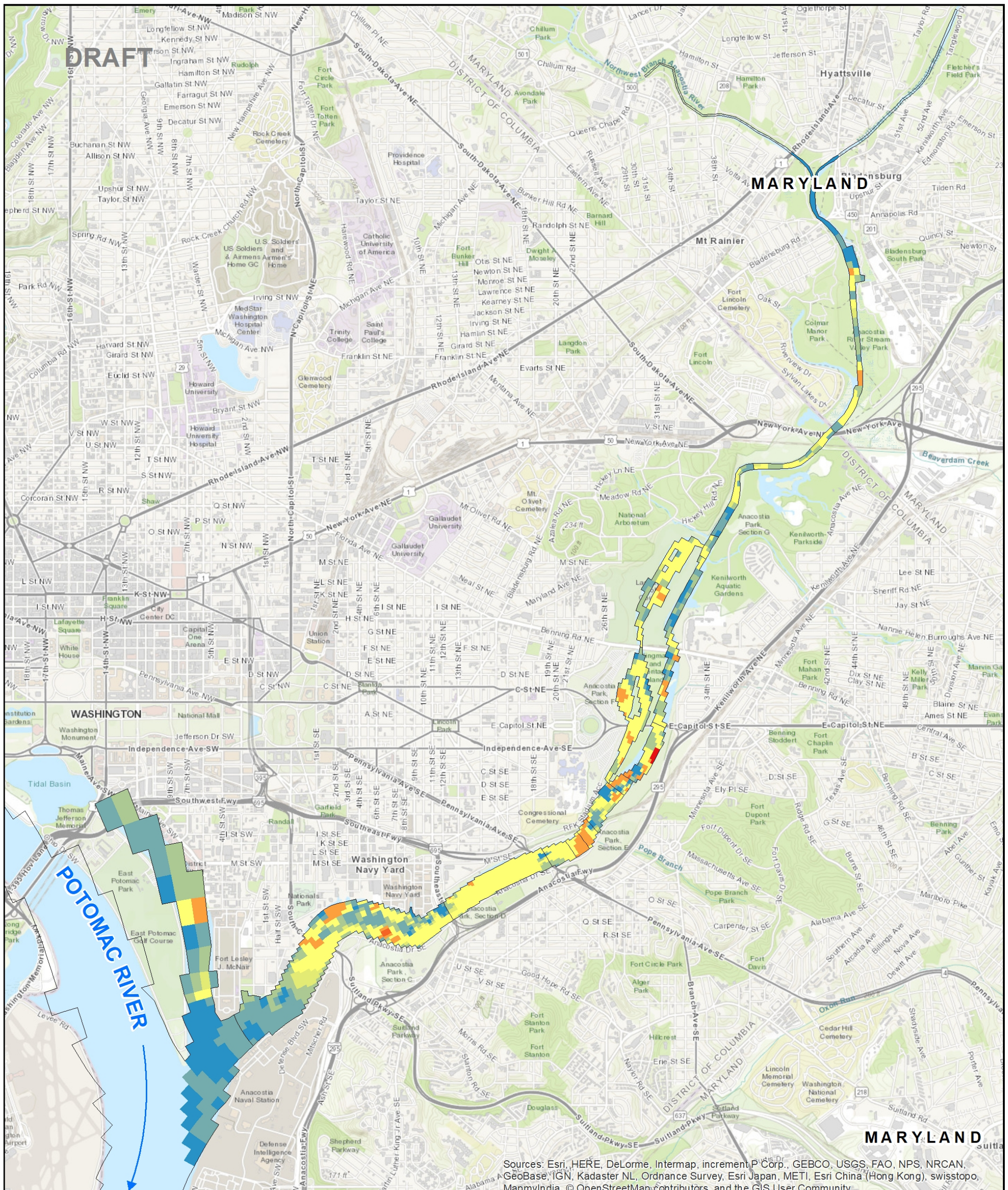
0 1,500 3,000 Meters

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2018.

PAH1
Initial Bed Sediment Concentrations

TETRA TECH


DRAFT
MARYLAND
WASHINGTON
POTOMAC RIVER
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Legend
verification group boundary
ug/kg
65 - 500
501 - 1000
1001 - 1500
1501 - 1610 (BTAG; TPAH)
1611 - 3220 (2x BTAG; TPAH)
3221 - 8050 (5x BTAG; TPAH)
8051 - 16100 (10x BTAG; TPAH)
16101 - 161000 (100x BTAG; TPAH)
N
W
E
S
0
1,500
3,000
Meters
SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2018.
PAH2
Initial Bed Sediment
Concentrations
TETRA TECH



Legend

verification group boundary

ug/kg

- 71 - 500
- 501 - 1000
- 1001 - 1500
- 1501 - 1610 (BTAG; TPAH)
- 1611 - 3220 (2x BTAG; TPAH)
- 3221 - 8050 (5x BTAG; TPAH)
- 8051 - 16100 (10x BTAG; TPAH)
- 16101 - 161000 (100x BTAG; TPAH)

N E S W

0 1,500 3,000 Meters

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2018.

PAH3
Initial Bed Sediment Concentrations

TETRA TECH

APPENDIX B – TIMELINE ANALYSIS RESULTS

Allocation scenario modeled parameter concentrations in bed sediments for each verification unit in 2014–2017.

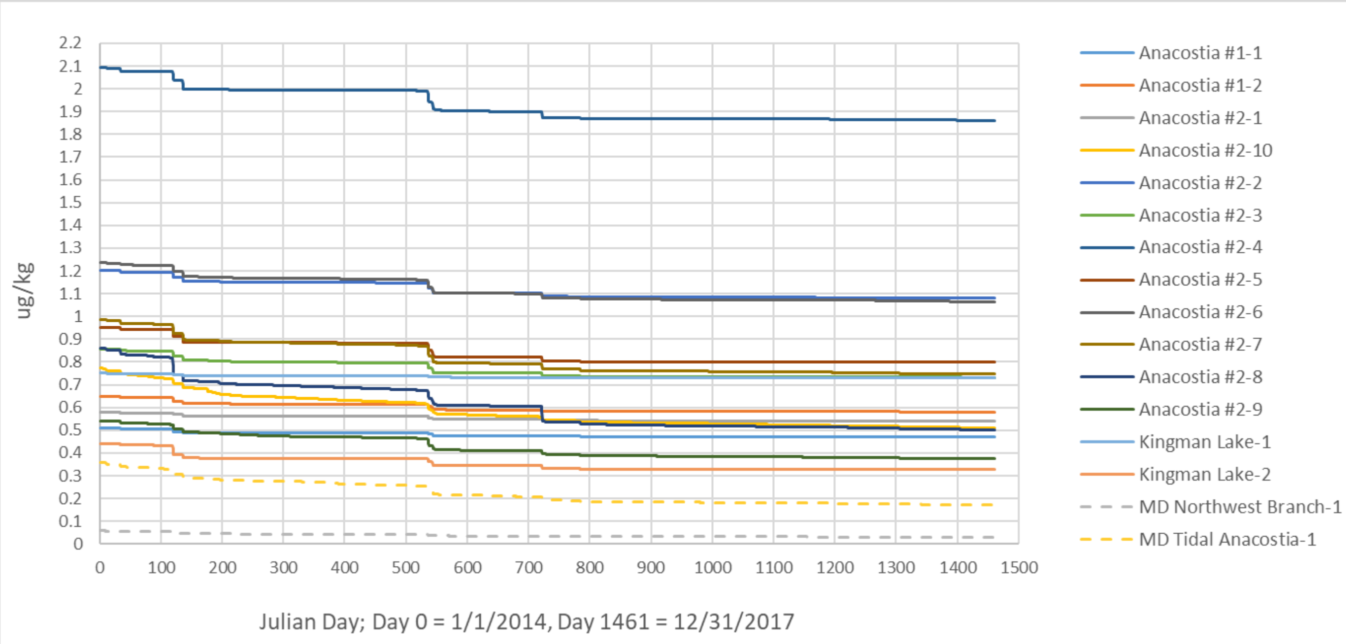


Figure B-1. Heptachlor epoxide

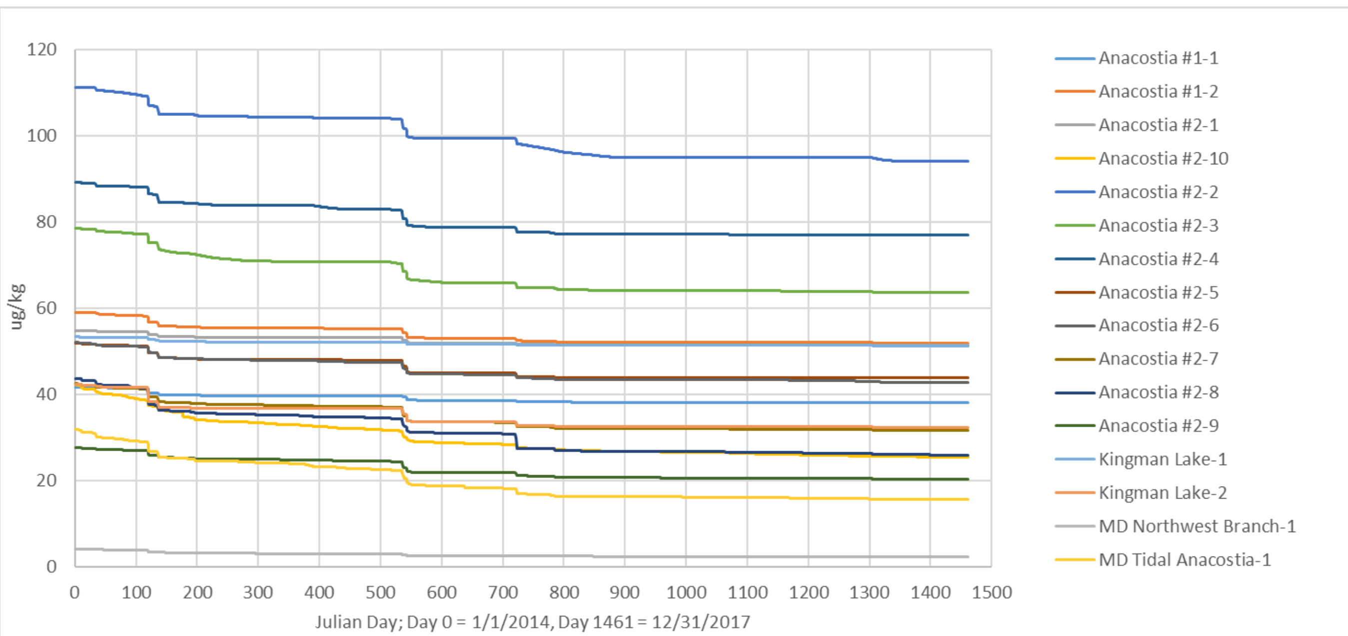


Figure B-2. Chlordane

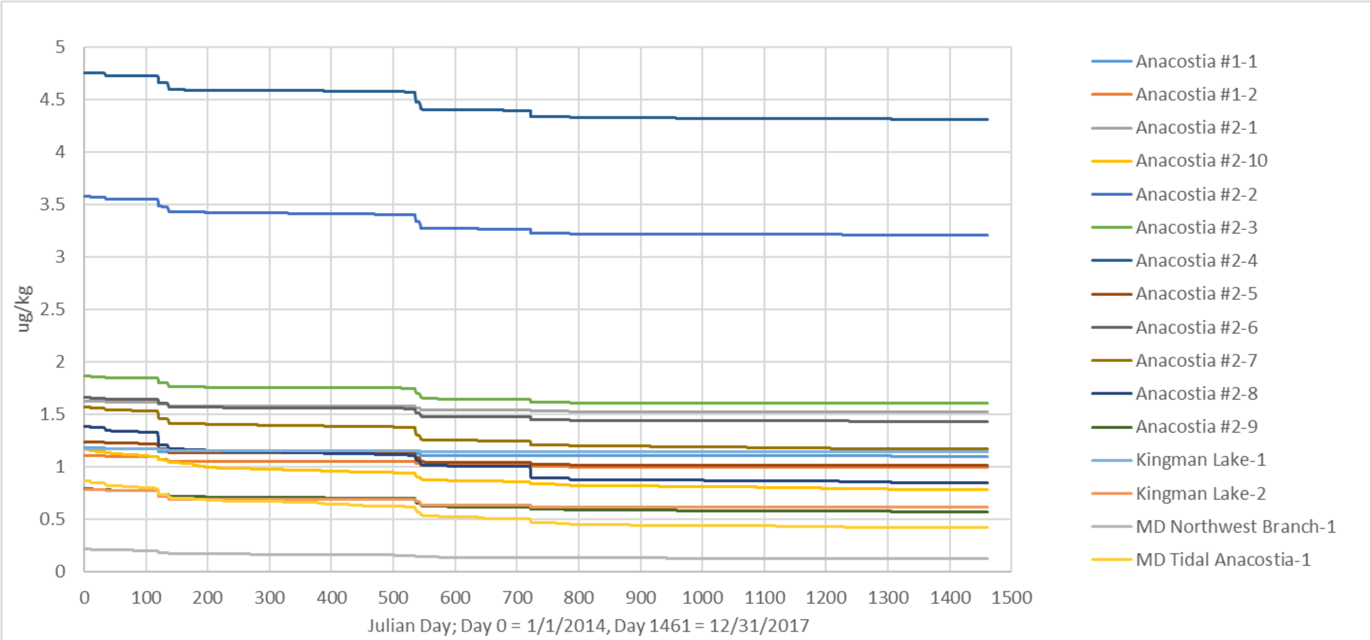


Figure B-3. Dieldrin

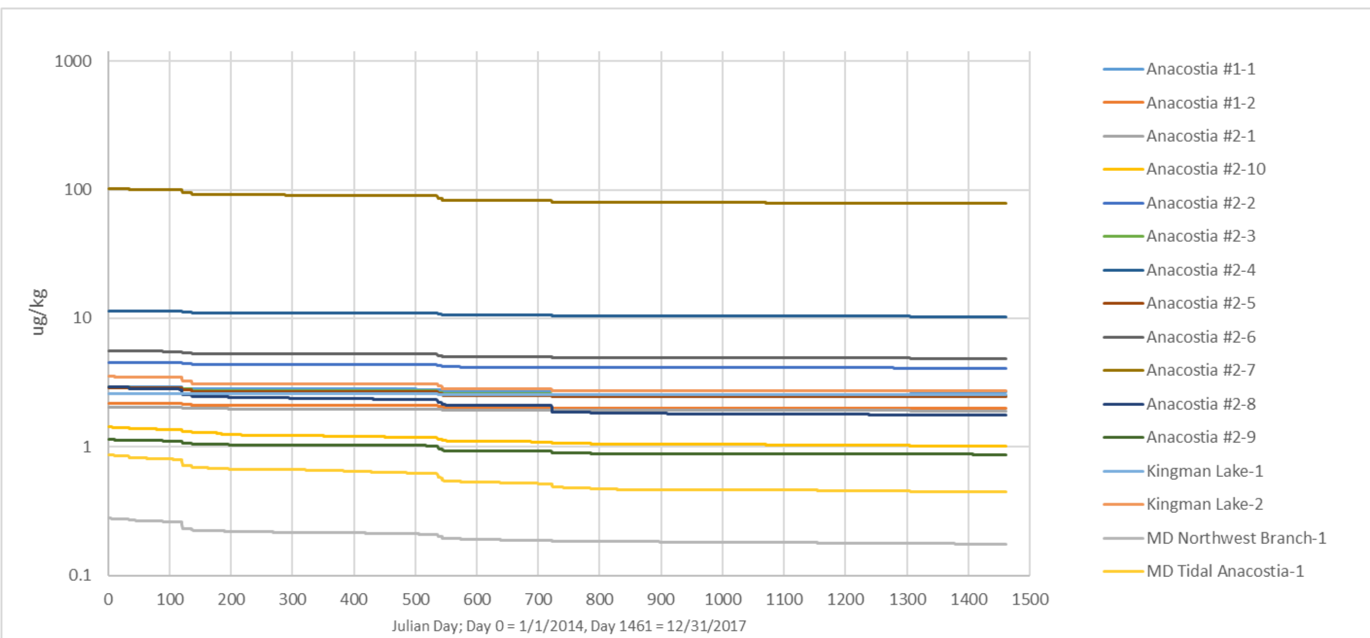


Figure B-4. DDT

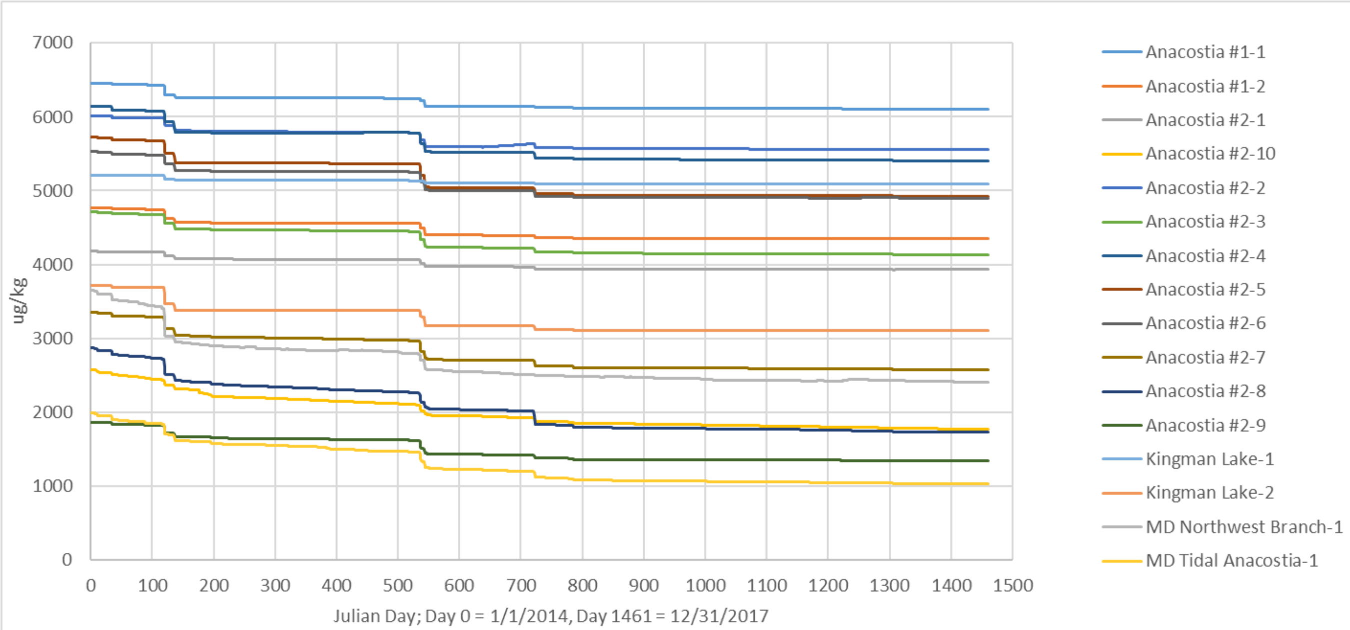


Figure B-5. Arsenic

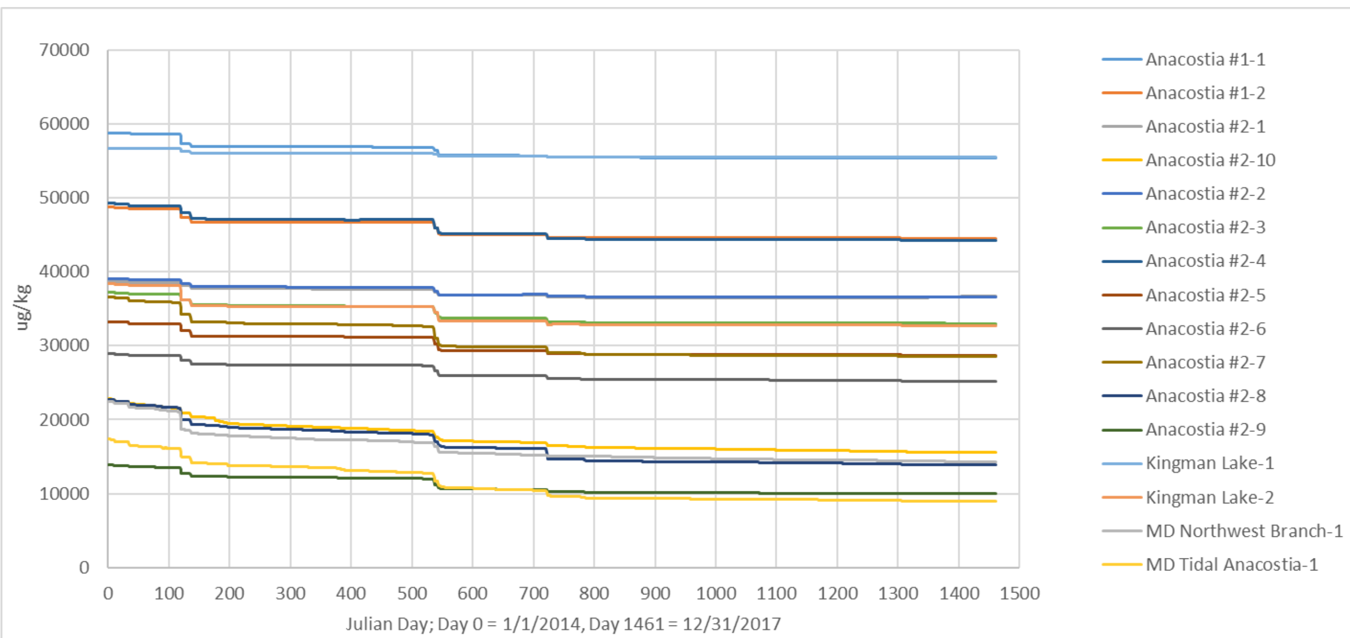


Figure B-6. Copper

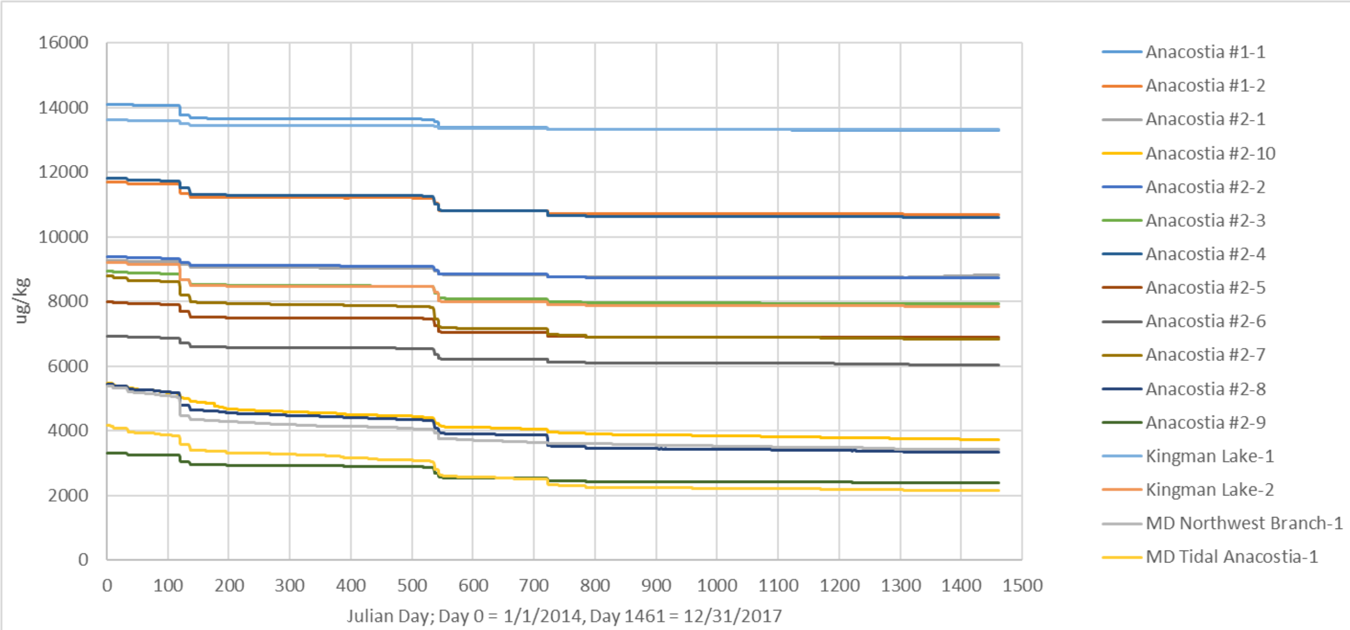


Figure B-7. Zinc

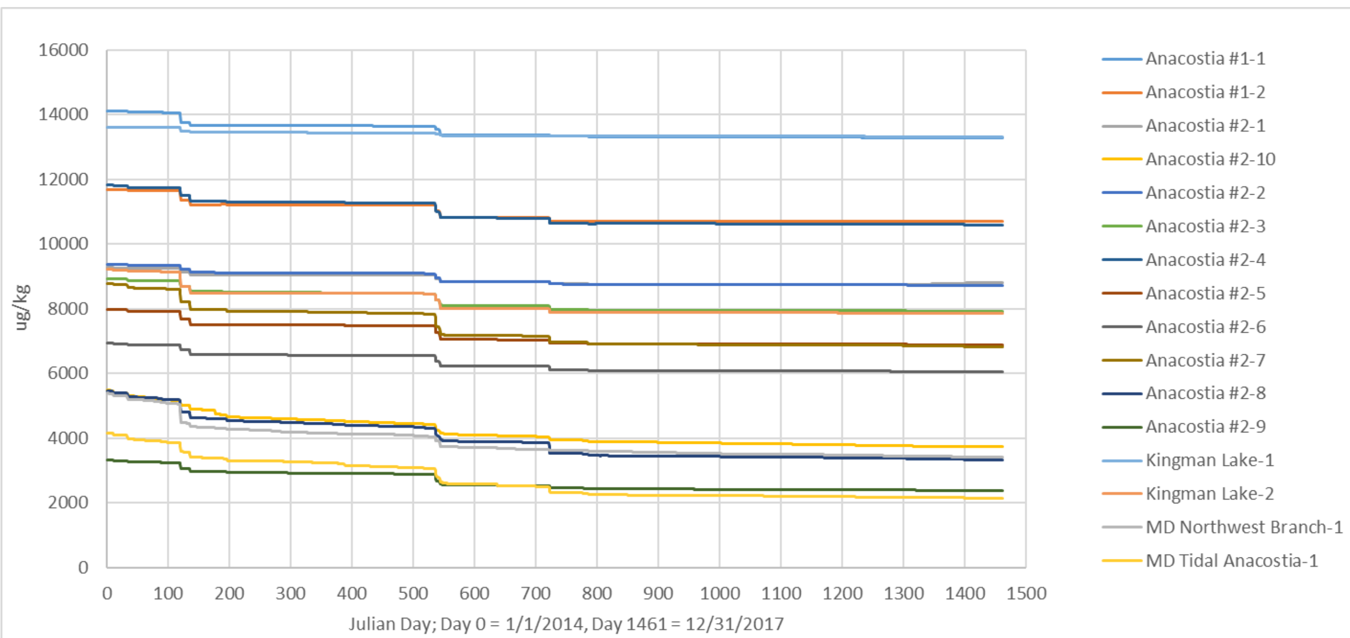


Figure B-8. PAH1

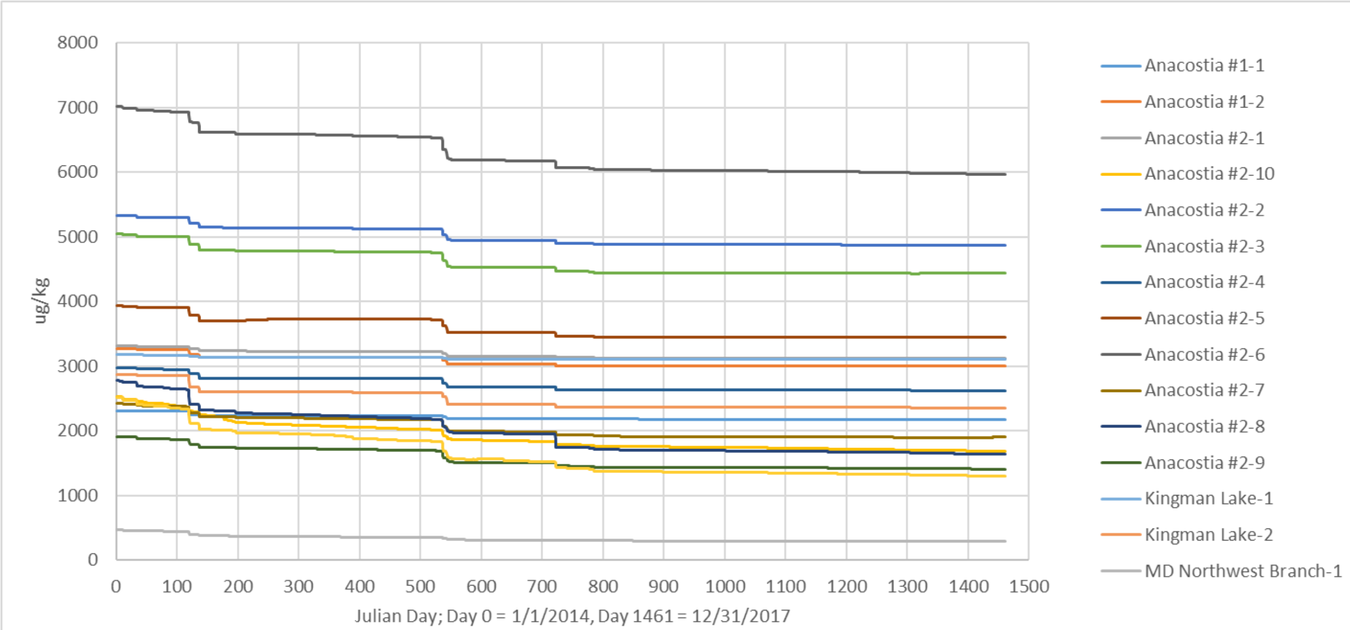


Figure B-9. PAH2

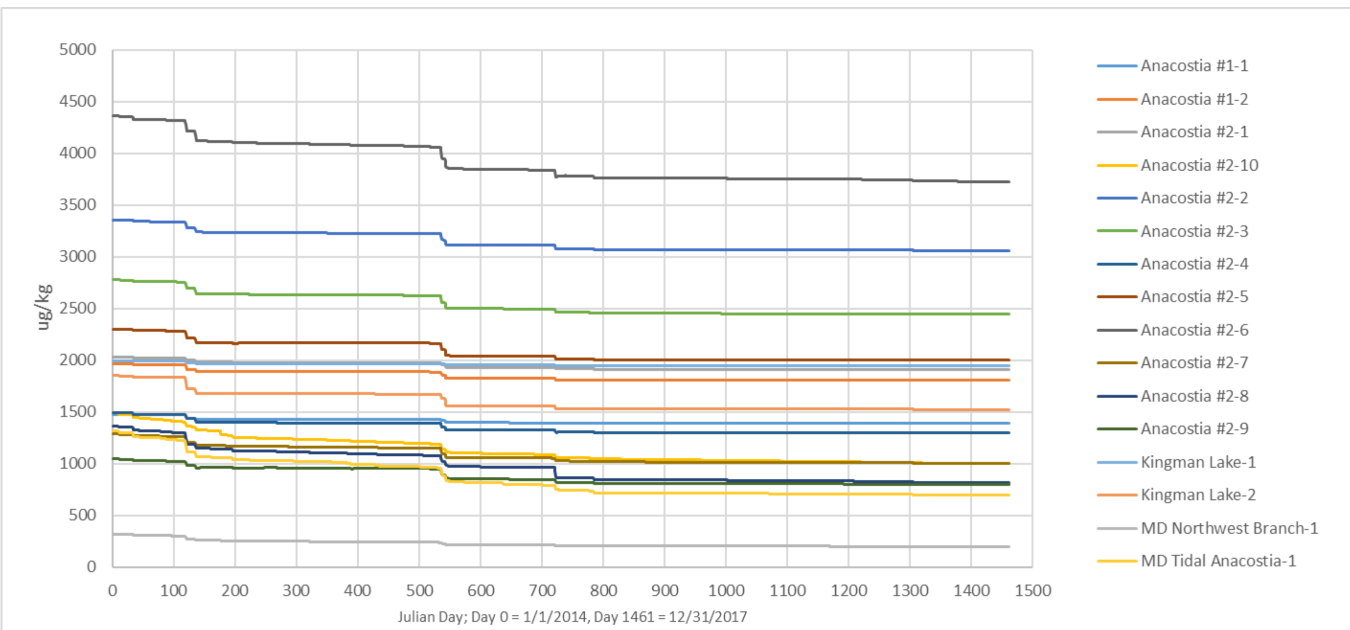


Figure B-10. PAH3

APPENDIX C – ALLOCATIONS

See accompanying spreadsheet: Anacostia Toxics TMDL Appendix C Allocations.xlsx