BASELINE/PERFORMANCE MONITORING PLAN

For the Main Stem, Kingman Lake, and Washington Channel

Anacostia River Sediment Project, Washington, DC

Prepared for

DEPARTMENT OF ENERGY & ENVIRONMENT

Department of Energy and Environment
Government of the District of Columbia

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Abbreviations and Acronyms

µg/kg	microgram per kilogram
ARAR	applicable or relevant and appropriate requirement
ARSP	Anacostia River Sediment Project
ASTM	American Society for Testing and Materials
B/P	Baseline/Performance
BaPE	benzo(a)pyrene
BERA	baseline ecological risk assessment
BSAF	biota sediment accumulation factor
BTV	background threshold value
BU	beneficial use
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	constituent of concern
CSM	conceptual site model
CSS	combined sewer system
CSX	CSX Transportation Corporation
CWG	Consultative Work Group
DC (or District)	District of Columbia
DCBRA	District of Columbia Brownfields Revitalization Act
DDE	dichlorodiphenyldichloroethylene
DOEE	District of Columbia Department of Energy and Environment
DOEE Fisheries	DOEE's Fisheries and Wildlife Division, Fisheries Management Branch
DQO	data quality objective
EAA	early action area
EDD	electronic data deliverables
EPA	U.S. Environmental Protection Agency
EqP	equilibrium partitioning
ESD	Explanation of Significant Differences
ESTCP	Environmental Security Technology Certification Program
EU	exposure unit
FFS	focused feasibility study
FS	feasibility study
g	gram
GIS	geographic information system
HHRA	human health risk assessment

HMW	high molecular weight
IR	infra-red
IROD	Interim Record of Decision
ISM	incremental sampling methodology
ITRC	Interstate Technology & Regulatory Council
LCCAR	Leadership Council for a Cleaner Anacostia River
LDPE	low-density polyethylene
LMW	low molecular weight
m	meter
MDE	Maryland Department of the Environment
MGP	manufactured gas plant
MNR	monitored natural recovery
mm	millimeter
MS4	municipal separate storm sewer system
MWCOG	Metropolitan Washington Council of Governments
n	number of individual fish of a given species
ng/kg	nanogram per kilogram
NELAP	National Environmental Laboratory Accreditation Program
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRA	Natural Resources Administration
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCB	polychlorinated biphenyl
PDI	pre-design investigation
Pepco	Potomac Electric Power Company
PECS	potential environmental cleanup site (plural: PECSes)
PRG	preliminary remediation goal
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RAL	remedial action level
RAL_{RW}	remedial action level (river-wide)

RAL_{EAA}	remedial action level (early action areas)
RAO	remedial action objective
RBC	risk-based concentration
RI	remedial investigation
RME	reasonable maximum exposure
RSL	regional screening level
ROD	Record of Decision
SDG	sample delivery group
SMART	specific, measurable, attainable, relevant, and time-bound
SOP	standard operating procedure
SWAC	surface weighted average concentration
TBC	to be considered
TEF	toxic equivalency factor
TEQ	toxic equivalent
TOC	total organic carbon
95UCL	95 percent upper confidence limit on the mean
UMBC	University of Maryland Baltimore County
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife
USGS	U.S. Geological Survey
WQC	water quality criterion

GLOSSARY OF KEY TERMS

Adaptive Management. Adaptive management practices, often described as "learning by doing," acknowledge that long-term project goals may be achieved more efficiently when managers use a flexible evidence-based approach or follow the science when making decisions. Within an adaptive management framework, data are reviewed and evaluated to test hypotheses, clarify relationships, and revise initial assumptions so that the project can be optimized.

Cleanup timeframe. Time required to achieve the remedial action objectives (RAOs).

***Ex-situ* porewater.** Porewater monitored in the laboratory by inserting passive samplers into sediment samples previously collected from the river.

Forage Fish. Species of small fish that are consumed by game fish and other predatory fishes. Targeted forage fish in this B/P Monitoring Plan may include banded killifish, mummichog (also called Atlantic killifish), eastern silvery minnow, and young pumpkinseed.

Game fish. Large fish typically caught by recreational or subsistence anglers for consumption. Targeted game fish in the B/P Monitoring Plan may include largemouth bass, brown bullhead, and carp.

***In-situ* porewater.** Porewater monitored by inserting passive samplers in the sediment in the river.

Indicator. A medium or process (for example, concentration of polychlorinated biphenyl [PCB] in surface sediment or growth in amphipods exposed to surface sediment) selected for its link to a RAO. Change in one or more indicators over time is used to measure progress toward attainment of the RAOs.

Metrics. Measurable, quantifiable values by which the effectiveness of remediation is evaluated (for example, sediment preliminary remediation goals [PRGs], concentrations of constituents of concern [COCs] in game fish).

Percent reduction. The percent difference between a value measured at a starting time (for example, Time 0) and at a later time (for example, Time 1).

Power analysis. Statistical power analysis is the evaluation of the ability to detect statistically significant results when real differences exist in the variable being considered. Use of power analysis evaluates the statistical implications of alternative sampling strategies (that is, the number of sample locations).

Reference Areas. A reference area is typically used to define background (or ambient) conditions during an investigation to determine whether a site-specific release has occurred in the past. The important feature of the reference area is that it is unaffected by the action. The reference area in the Northwest and Northeast Branches is expected to undergo changes over time that are independent of remediation in the EAAs and source control measures in District of Columbia (DC). Therefore, concentrations of COCs in sediment, surface water, and tissues in the reference area can be compared with the same indicators in the remediated EAAs over time to provide unbiased evaluation of the effect of remedial actions.

Stratified Sampling. A stratified sampling design supports evaluation of a population of samples in terms of smaller sub-groups known as strata. In stratified sampling, the sub-groups (that is, strata) share attributes or characteristics (for example, sediment samples collected within EAA versus samples collected outside of EAAs).

Trigger criterion. A benchmark value of an indicator used to determine subsequent action.

EXECUTIVE SUMMARY

This Baseline/Performance Monitoring Plan (B/P Monitoring Plan) presents the rationale and sampling that the District of Columbia Department of Energy and Environment (DOEE) will use to document and evaluate baseline conditions and performance of the interim remedial actions defined for the Anacostia River Sediment Project (ARSP) study area. DOEE's Interim Record of Decision (IROD) for the ARSP study area identified early action areas (EAAs) in three operable units (OUs) for remediation of sediment with the highest concentrations of total polychlorinated biphenyl (PCB) congeners in the river (DOEE 2020). The IROD is currently being updated with an Explanation of Significant Differences (ESD) (DOEE 2023).

The interim remedy targets four constituents of concern (COCs) in sediment that pose a risk to human health[1] at or above 1E-05 (one-in-one hundred thousand) risk level or to ecological receptors: total PCB congeners (human health), dioxin toxic equivalent (TEQ) (ecological), chlordane (ecological), and dioxin-like PCB TEQ (human health and ecological). The B/P Monitoring Plan addresses these COCs as well as polycyclic aromatic hydrocarbons (PAHs). As stated in the IROD, PAHs may be monitored in sediment to the extent necessary to support evaluation and interpretation of observed toxicity to ecological receptors. For example, tumors in resident fish have been linked with exposure to PAHs in river sediments (Pinkney et al. 2018), although recent studies report that the incidence of tumors in brown bullhead (*Ameiurus nebulosu*) in the Anacostia River has declined (Pinkney et al. 2019).

The IROD was designed to make substantial progress toward cleanup of sediments in the ARSP study area to achieve overall remedial action objectives (RAOs), but it marks only the beginning of a comprehensive cleanup process for the river, which includes source control efforts and remediation at potential environmental cleanup sites (PECSes, plural of potential environmental cleanup site [PECS]) in the ARSP study area.

The B/P Monitoring Plan was developed in accordance with guidance and recommendations from Interstate Technology & Regulatory Council (ITRC), U.S. Environmental Protection Agency (EPA), and best practices to establish protocols and approaches that DOEE will use to evaluate the success of the interim remedial actions. The plan includes explicit provisions for assessing data and adjusting monitoring protocols within an adaptive management framework.

The remedies to address COCs in the EAAs are described in the IROD (DOEE 2020). The B/P Monitoring Plan establishes protocols for collecting and analyzing data on seven key indicators that will be used to evaluate progress toward the achievement of the RAOs. The relationship of B/P monitoring indicators with RAOs is shown in **Table ES.1-1.** DOEE will use the results of the monitoring described in this plan to evaluate the effectiveness of the interim remedial actions in the EAAs, source controls, and other

[1] The Proposed Plan noted that benzo(a)pyrene (BaPE) was identified as a COC in the ARSP HHRA at the 1E-06 target risk level. However, BaPE does not pose risk to human health at or above the 1E-05 risk level selected for the interim remedial action. Although BaPE is not a COC, concentrations of BaPE within the EAAs will be incidentally reduced by the interim remedial actions. BaPE may be addressed by future remedial action in the ARSP study area.

actions in achieving the RAOs and develop a final Record of Decision (ROD). **Table ES.1.1** Relationship of B/P Monitoring Indicators to Remedial Action Objectives

Indicator	**Remedial Action Objective[1]**			
	RAO 1	**RAO 2[2]**	**RAO 3**	**RAO 4**
Surface sediment • Concentrations of COCs and PAHs in composited sediment samples	✓		✓	✓
Sediment porewater • Concentrations of COCs in *ex-situ* porewater passive samplers in composite sediment samples (*in-situ* porewater passive samplers may be used in EAAs depending on the remedial design)	✓		✓	✓
Surface water • Concentrations of COCs in *in-situ* surface water passive samplers	✓		✓	✓
Benthic invertebrate toxicity assessment • Laboratory toxicity test using benthic invertebrates exposed to surface sediment	✓		✓	✓
Benthic invertebrate bioaccumulation assessment • Laboratory bioaccumulation test using *Lumbriculus* exposed to surface sediment	✓		✓	✓
Forage fish • Concentrations of COCs in whole-body forage fish tissue samples	✓		--	✓
Game fish • Concentrations of COCs in edible tissues of resident game fish	✓		--	✓

1. Remedial Action Objectives

RAO 1: Reduce risks associated with the consumption of COCs in fish from the tidal Anacostia River by people with the highest potential exposure.

RAO 2: Reduce risks associated with direct exposure of people to surface sediment in shallow water (fringe sediment) in the tidal Anacostia River.

RAO 3: Reduce risks associated with COCs in sediment to levels protective of benthic and aquatic invertebrates based on direct chronic exposure to surface sediment and surface water.

RAO 4: Reduce risks associated with COCs in surface sediment to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey

2. At the 1E-05 risk level, RAO 2 is satisfied and thus not considered further in the B/P Monitoring Plan.

For each of the seven key indicators, the B/P Monitoring Plan specifies (1) reasons for monitoring; (2) sampling locations; (3) monitoring protocols and metrics; and (4) adaptive management decision points for each of these indicators.

The ultimate purpose of the B/P Monitoring Plan is to support the development of a final ROD for all OUs in the ARSP. The plan optimizes DOEE's ability to detect changes over time in key indicators and attribute those changes to the appropriate causal agents (for example, interim remedial actions, targeted source control efforts, other regional events) to the extent feasible. The B/P Monitoring Plan will provide unbiased, transparent, independently validated results suitable for documenting the success of the interim remedies in meeting RAOs and reducing risk. The seven key indicators support a weight-of-evidence approach to monitoring changes over various time scales, and the concurrent monitoring in the Reference Area provides the spatial resolution necessary to interpret trends that may or may not be related to the interim remedial actions. Evaluating interactions of indicators from the same location and across locations improves statistical robustness and minimizes the incidence of faulty conclusions based on limited monitoring data.

Results of each B/P monitoring event will be used within an adaptive management framework to adjust and refine subsequent monitoring events. The overarching goal of such intentional learning is to continually refine monitoring protocols to acquire the most robust data possible within the schedule and budgetary confines of the project. Methods and results that yield insight into processes that will support the final ROD may be refined and enhanced to increase their effectiveness while methods or indicators that are deemed redundant may be eliminated. DOEE will evaluate monitoring data within an adaptive management framework. If one or more indicators are found to vary together over several sampling events, DOEE may consider eliminating a redundant indicator. DOEE will share any changes in the B/P Monitoring Plan with key stakeholders, including EPA and the National Park Service (NPS), along with supporting data and rationale, as discussed in **Section 6.9**. Key data gaps identified during B/P monitoring will be addressed as warranted by the data.

By its nature, performance monitoring is an iterative process. Within the adaptive management framework, numerous decision points are built into the B/P Monitoring Plan so that DOEE can make the best use of all monitoring data. Intended uses of the results of each indicator and the expected monitoring interval and duration are summarized in **Table ES.1.2.** When the sediment-based surface weighted average concentration (SWAC) and other indicators shows downward trends, then the interim remedial actions will be considered effective, and DOEE may consider transitioning from the IROD to a final ROD. Recovery of the ARSP will be dependent on the interim remedial action and the natural deposition of cleaner sediments in the river, allowing monitored natural recovery (MNR) to play an important role in downward contamination trends and overall reduction of monitoring indicators. At that time, DOEE will evaluate the extent to which RAOs have been achieved and determine the next course of action.

Table ES.1.2 Summary of B/P Monitoring Indicator Data Use

Indicator	Monitoring Parameter	Intended Use of Data	Expected Monitoring Interval and Duration[3]
Surface Sediment	Concentrations of COCs and PAHs	Calculate OU-specific SWACs for comparison with preliminary remediation goals (PRGs); correlation with forage fish and game fish; trend analyses; input to bioaccumulation model[1]	Every two to three years until downward trends are observed in sediment
Porewater	Concentrations of COCs	Correlation with sediment, forage fish, and game fish; trend analyses; input to bioaccumulation model[1]	Every two to three years until downward trends are observed in porewater
Surface Water	Concentrations of COCs	Correlation with sediment, forage fish, and game fish; trend analyses; input to bioaccumulation model[1]	Every two to three years until downward trends are observed in surface water
Benthic Invertebrate Toxicity Tests	Survival and growth (midge and amphipod); reproduction (amphipod only)	Correlate with sediment and porewater analytical results; trend analyses; measure progress toward RAO 3	Every two to three years until downward trends are observed in toxicity
***Lumbriculus* Bioaccumulation Test**	Concentration of COCs in whole-body tissue	Correlate with sediment, porewater, forage fish, and game fish; refine sediment Regional Screening Level (RSL) for game fish ingestion; input to bioaccumulation model[1]; trend analyses; measure progress toward RAO 3 and RAO 4	Every two to three years until downward trends are observed in invertebrate tissue
Forage Fish Tissue	Concentrations of COCs in whole-body fish tissue	Estimate cleanup timeframe; correlate with game fish; refine sediment RSL for game fish ingestion[2]; input to bioaccumulation model[1]; trend analyses; measure progress toward RAO 4	Every two to three years until downward trends are observed in forage fish tissue
Game Fish Tissue	Concentrations of COCs in edible tissue	Estimate cleanup timeframe; correlate with forage fish; refine sediment RSL for game fish ingestion; ground truth bioaccumulation model[1]; trend analyses; measure progress toward RAO 1	Every two to three years (or when DOEE's Fisheries and Wildlife Division, Fisheries Management Branch [DOEE Fisheries] conducts sampling) until downward trends are observed in game fish tissue

1: Bokare et al. 2021, Ghosh et al. 2022

2: Under an adaptive management framework, the process used to calculate sediment cleanup goal (which is based on game fish ingestion) may be adjusted as new information becomes available or our understanding of the link between fish and

sediment is refined. Refer to Appendix A of the River-wide Feasibility Study (FS) Report for more information on the RSLs calculated to support sediment cleanup goal (Tetra Tech 2019c).
3: Monitoring intervals are not pre-set. Intervals will be adaptively established for the indicators based on the changes observed over time to make decisions for next sampling round and revisited during the 5-year review.

1. Introduction

This Baseline/Performance (B/P) Monitoring Plan presents the rationale and sampling that the District of Columbia Department of Energy and Environment (DOEE) will use to document and evaluate baseline conditions and performance of the interim remedial actions defined for the Anacostia River Sediment Project (ARSP) study area. DOEE selected an interim remedy for addressing contaminated sediments within three operable units (OU) of the tidal portion of the Anacostia River in Washington, District of Columbia (DC or District) in an Interim Record of Decision (IROD) issued September 30, 2020; the IROD is currently being updated with an Explanation of Significant Differences (ESD)[2] (DOEE 2020, 2023). The ARSP study area includes approximately 9 miles of tidal portion of the Anacostia River that begins at the confluence of the Northwest Branch and Northeast Branch near Bladensburg in Prince George's County, Maryland and extends downstream to its confluence with the Potomac River (**Figure 1.1**). The study area is divided into six river reaches defined in the ARSP remedial investigation (RI)[3] and three OUs identified in the IROD: Main Stem OU (Anacostia River main channel), Washington Channel OU, and Kingman Lake OU.

The interim remedy targets four constituents of concern (COCs) in sediment that pose risk to human health at or above 1E-05 (one-in-one hundred thousand) risk level or to ecological receptors as defined in the baseline ecological risk assessment (BERA) and human health risk assessment (HHRA) (Tetra Tech 2019)[4]. The COCs include total polychlorinated biphenyl (PCB) congeners (human health), dioxin toxic equivalent (TEQ) (ecological), chlordane (ecological), and dioxin-like PCB TEQ (human health and ecological). As stated in the IROD, non-COCs such as polycyclic aromatic hydrocarbon (PAH) constituents may be monitored to the extent necessary to support evaluation and interpretation of observed toxicity to ecological receptors. The interim remedy will address the subset of the contaminated sediment in the

[2] The IROD is currently being amended with an ESD to include potential on-site beneficial use (BU) as an option for handling dredged material. Selective dredging is not being eliminated by this ESD; instead, sediment from the selective dredging will be beneficially reused rather than being disposed off-site (assuming that the dredged sediment meets the DOEE beneficial use guidance acceptance criteria and National Park Service [NPS] criteria for aquatic use [DOEE 2022]). In-situ treatment by direct application of carbon amendment is being added to the remedy to replace selective dredging at the Kingman Lake OU and in the Main Stem OU where hydrodynamic conditions are favorable. An ESD is published when significant (but not fundamental) changes with respect to scope, performance, and cost are made to a previously selected remedy. The ESD is being prepared in accordance with Section 117(c) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Oil and Hazardous Substances Pollution Contingency Plan 40 Code of Federal Regulations 300.435(c)(2)(i).

[3] Reach 123 denotes the combination of Reach 1, Reach 2, and Reach 3 defined originally in the ARSP Work Plan (Tetra Tech 2014). Likewise, Reach 456 denotes the combination of Reach 4, Reach 5, and Reach 6. Retaining the original Reach numbers in the combined reach identifiers facilitates access to RI samples (i.e., the original reach numbers were incorporated into the RI sample identifier). For additional discussion of the rationale for the designated reach identifiers, please refer to Section 2.8 of the RI Report (Tetra Tech 2019a).

[4] The Proposed Plan noted that benzo(a)pyrene (BaPE) was identified as a COC in the ARSP HHRA at the 1E-06 target risk level. However, BaPE does not pose risk to human health at or above the 1E-05 risk level selected for the interim remedial action. Although BaPE is not a COC, concentrations of BaPE within the EAAs will be incidentally reduced by the interim remedial actions. BaPE may be addressed by future remedial action in the ARSP study area.

ARSP study area represented as early action areas (EAAs) within the OUs, defined as areas where total PCB congener concentrations are greater than 600 micrograms per kilogram (µg/kg), also known as the EAA remedial action level (RAL_{EAA}) (DOEE 2020).

The IROD was designed to make substantial progress toward cleanup of sediments in the ARSP study area to achieve overall remedial action objectives (RAOs), but it marks only the beginning of a comprehensive cleanup process for the river, which includes source control efforts and remediation at potential environmental cleanup sites (PECSes, plural of potential environmental cleanup site [PECS]) in the ARSP study area (**Figure 1.1**). DOEE determined that addressing a portion of the contamination was the appropriate strategy for cleaning up the river, due to the complexities and uncertainties associated with ongoing source control and contaminated sediment remediation. Although source control is not part of the selected interim remedy, DOEE in cooperation with the corresponding agencies from Prince George's County, Montgomery County, and the State of Maryland are engaged in efforts to control contaminant sources external to the ARSP study area in the upstream Anacostia River watershed. DOEE views such efforts as critical to achieving the overall cleanup. The interim remedial actions described in the IROD and ESD are not inconsistent nor will they preclude any further necessary remedial or source control actions. The interim remedy approach, with adaptive management and performance monitoring, provides a balance of implementing targeted cleanup actions and allows for flexible decision-making in the face of uncertainty (DOEE 2020).

The B/P Monitoring Plan was developed in accordance with guidance and recommendations from Interstate Technology & Regulatory Council (ITRC) (2014), U.S. Environmental Protection Agency (EPA) et al. (2017), EPA (2017b), Environmental Security Technology Certification Program (ESTCP) (2009), EPA (2006), EPA (2002), and best practices to establish protocols and approaches that DOEE will use to evaluate the success of interim remedial actions. The plan includes explicit provisions for assessing data and adjusting monitoring protocols within an adaptive management framework, so that decisions can be supported by the most robust, defensible data feasible.

1.1 Scope and Purpose

The RI and feasibility study (FS) phase of the ARSP included a BERA and HHRA that characterized risks to people and ecological receptors (Tetra Tech 2019a, Tetra Tech 2019c). Four RAOs served as the design basis for the remedies defined in the IROD:

- **RAO 1** – Reduce risks associated with the consumption of COCs in fish from the tidal Anacostia River by people with the highest potential exposure.
- **RAO 2** – Reduce risks associated with direct exposure of people to surface sediment in shallow water (fringe sediment) in the tidal Anacostia River (this RAO is satisfied at the 1E-05 cancer risk level, so no action is planned).
- **RAO 3** – Reduce risks associated with COCs in sediment to levels protective of benthic and aquatic invertebrates based on direct chronic exposure to surface sediment and surface water.
- **RAO 4** – Reduce risks associated with COCs in surface sediment to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey.

A conceptualized timeline for the project from the RI/FS to the Final Record of Decision (ROD) is shown in **Figure 1.2**. Establishment of the IROD transitions the ARSP from risk characterization and remedy selection to remedy design and implementation, both of which require monitoring of indicators. Both B/P monitoring and EAA characterization will occur as part of the establishment of the IROD; however, the objectives of these two monitoring programs differ, as described below:

- EAA characterization is focused on each individual EAA; the focus is the delineation to support remedial design and construction. EAA delineation is governed by pre-design investigation (PDI) Work Plans (Tetra Tech 2022a, 2022b, 2022c) and not addressed in this B/P Monitoring Plan.
- B/P monitoring is the long-term evaluation of remedy effectiveness and achievement of RAOs in each OU. B/P monitoring has two components:
    - Baseline monitoring establishes conditions prior to interim remedial action.
    - Performance monitoring documents changes from baseline conditions after interim remedial action.

This B/P Monitoring Plan identifies the relevant environmental indicators for B/P monitoring and defines the sampling locations, rationale, data collection methods, laboratory analyses, and procedures for ensuring that the data collected are of appropriate quality for adaptively managing the interim remedy. Indicators for B/P monitoring are specific environmental media or measures used to document progress toward attainment of the RAOs at defined timeframes. Indicators to be monitored include concentrations of COCs and PAHs in surface sediment. COCs will also be monitored in porewater, surface water, forage fish, and game fish as well as toxicity and bioaccumulation tests using benthic invertebrates (**Table 1.1)**.

Table 1.1 Relationship of B/P Monitoring Indicators to Remedial Action Objectives

Indicator	Remedial Action Objective[1]			
	RAO 1	RAO 2[2]	RAO 3	RAO 4
Surface sediment • Concentrations of COCs and PAHs in composited sediment samples	✓		✓	✓
Sediment porewater • Concentrations of COCs in *ex-situ* porewater passive samplers in composite sediment samples (*in-situ* porewater passive samplers may be used in EAAs depending on the remedial design)	✓		✓	✓
Surface water • Concentrations of COCs in *in-situ* surface water passive samplers	✓		✓	✓
Benthic invertebrate toxicity assessment • Laboratory toxicity test using benthic invertebrates (*Hyalella* and *Chironomus*) exposed to surface sediment	✓		✓	✓
Benthic invertebrate bioaccumulation assessment • Laboratory bioaccumulation test using *Lumbriculus* exposed to surface sediment	✓		✓	✓
Forage fish • Concentrations of COCs in whole-body forage fish tissue samples	✓		--	✓
Game fish • Concentrations of COCs in resident game fish tissue	✓		--	✓

1. Remedial Action Objectives

RAO 1: Reduce risks associated with the consumption of COCs in fish from the tidal Anacostia River by people with the highest potential exposure.

RAO 2: Reduce risks associated with direct exposure of people to surface sediment in shallow water (fringe sediment) in the tidal Anacostia River.

RAO 3: Reduce risks associated with COCs in sediment to levels protective of benthic and aquatic invertebrates based on direct chronic exposure to surface sediment and surface water.

RAO 4: Reduce risks associated with COCs in surface sediment to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey

2. At the 1E-05 risk level, RAO 2 is satisfied and thus not considered further in the B/P Monitoring Plan.

1.2 Objectives of Monitoring

Monitoring consists of the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective (EPA 2004). B/P monitoring is performed to generate data to assess long term remedy effectiveness within each OU, in fulfillment of commitments made in the IROD (specifically Table 4.1 of Section B.3.1.14) (DOEE 2020). To demonstrate effectiveness, the B/P Monitoring Plan addresses the following objectives within the limitations and uncertainty of the data:

- Document changes over time in concentrations of COCs and PAHs in surface sediment
- Document changes over time in concentrations of COCs in porewater and surface water
- Characterize relationships among chemical indicators in surface sediment, porewater, surface water, and tissues; secondarily support the ARSP surface water model (Tetra Tech 2019b) and bioaccumulation model (Ghosh et al. 2022).
- Document changes over time in toxicity to benthic invertebrates.
- Document changes over time in bioaccumulation of COCs in benthic invertebrates.
- Document changes over time in concentrations of COCs in forage fish and game fish tissue.

This B/P Monitoring Plan establishes protocols for comparing pre-remediation (baseline) conditions with post-remediation (performance) conditions so that the effectiveness of remediation can be documented and quantified. The following components are discussed in this plan:

- Specific, measurable, attainable, relevant, and time-bound (SMART) objectives (based primarily on ITRC [2014] and EPA [2017b]) embodied in formally defined data quality objectives (DQOs).
- Methods for obtaining and evaluating remedy performance and effectiveness.
- EPA-approved methods, certified analytical laboratories, and data validation by an independent third party (as specified in the ARSP quality assurance project plan [QAPP]). Stage 4 validation will be conducted on COCs and PAH constituents. A Stage 2B validation will be conducted on rinse blanks and ancillary parameters.
- Data interpretation and approaches for evaluating temporal trends in indicators.
- Adaptive management approach to use B/P monitoring results to evaluate the need for additional remedial action and to guide the project to a final ROD.

To support work on the ARSP and refine the conceptual site model (CSM), DOEE has funded numerous independent studies focused on improving DOEE's understanding of the source control, fate and transport, and trophic transfer of COCs in the ARSP study area and watershed**.** Results of the following studies were reviewed and incorporated into the B/P Monitoring Plan as warranted: Ghosh et al. 2020; Ghosh et al. 2022; Pinkney 2018; Pinkney et al. 2018; Pinkney 2020; Pinkney and Perry 2020; and Wilson 2019, 2020. DOEE is also engaged in other activities that will inform B/P monitoring, such as source control in upstream watersheds for outfalls and tributaries discharging to the study area; characterization and remediation activities at PECSes; DOEE Natural Resources Administration (NRA) environmental enhancement projects; and modification of the federal navigation channel.

1.3 Work Plan Organization

This work plan includes ten sections, including this introduction. Key terms are defined as they are introduced and summarized in a glossary immediately preceding **Section 1.0.**

- **Section 2: Site Description.** This section summarizes background information on contaminant sources, COCs, and the CSM.
- **Section 3: Interim Remedial Actions.** This section presents RAOs and preliminary remediation goals (PRGs) and describes the interim remedial actions defined in the IROD, including source control activities.
- **Section 4: Baseline and Performance Monitoring Within an Adaptive Management Decision Framework.** This section describes the adaptive management approach that guides the B/P Monitoring Plan, defines key terms in EPA (2017b) and other guidance, and establishes the sequence of remediation and monitoring activities.
- **Section 5: Approach to Baseline and Performance Monitoring**. This section presents DQOs that support the design of the B/P Monitoring Plan.
- **Section 6: Monitoring Locations and Protocols.** This section presents indicators and parameters to be monitored, sampling locations, sampling protocols, and expected adaptive management decision points for each indicator. The estimated cleanup timeframes and potential outcomes of adaptive management decisions are discussed.
- **Section 7: Sampling, Analysis, and Data Interpretation Methods.** This section presents methods for collecting and analyzing samples and methods to evaluate results. Methods for measuring adherence to DQOs and achievement of RAOs are discussed.
- **Section 8: Communication Plan.** This section discusses how monitoring results will be communicated to the public and other stakeholders.
- **Section 9: Project Management.** This section presents roles and responsibilities of the B/P Monitoring Plan management team, independent reviewers, analytical laboratories, toxicity laboratories, and data validators.
- **Section 10: References.** This section provides references cited in the B/P Monitoring Plan.

2. SITE DESCRIPTION

The ARSP study area covers 1,040 acres and includes approximately 9 miles of tidal portion of the Anacostia River that begins at the confluence of the Northwest Branch and Northeast Branch near Bladensburg in Prince George's County, Maryland and extends downstream to its confluence with the Potomac River (**Figure 1.1**). Parts of the Anacostia River are under the jurisdiction of the NPS. Federal law mandates that NPS preserve water flow and prevent pollution in the Anacostia and Potomac Rivers; in addition, NPS must preserve forests and natural scenery and provide recreational opportunities in and around Washington, DC.

The IROD identified 11 EAAs totaling 77.2 acres for interim remedial action in the ARSP study area. The EAAs were delineated during the 2022 PDI field program (Tetra Tech 2023b) and now include 11 EAAs, covering a total of 49.6 acres for interim remedial action in the 1040-acre study area, which includes river reaches in DC and Maryland (**Figure 2.1**). Detailed descriptions of the ARSP study area, PECSes, COCs, and human and ecological receptors are provided in numerous reports, including the RI (Tetra Tech 2019a), River-wide FS (Tetra Tech 2019c), Focused Feasibility Study (FFS) (Tetra Tech 2019d), Proposed Plan (DOEE 2019), and IROD (DOEE 2020), which are incorporated into this B/P Monitoring Plan by reference.

As described in the RI Report (Tetra Tech 2019a), the 9-mile ARSP study area was investigated as six reaches (called exposure units [EU] in the risk assessments) (**Figure 2.2**). The reaches were defined based on sediment characteristics, river hydraulics, and hydraulic connectivity to the main channel of the river. For the IROD and B/P Monitoring Plan, the study area is addressed as three OUs, primarily based on hydraulic conditions.

- **Main Stem OU** is the main channel of the Anacostia River. The Main Stem was partitioned into Reach 123/456[5] and Reach 67 to reflect differences in physical conditions in the river. Six EAAs are defined in the Main Stem OU Reach 123/456 (totaling 23.3 acres); no EAAs are identified in Main Stem OU Reach 67. The Main Stem OU is more complex than either Washington Channel or Kingman Lake primarily because it receives greater surface water and sediment inflows from tributaries and outfalls. The Northeast Branch, Northwest Branch, Hickey Run, Watts Branch, and Lower Beaverdam Creek discharge to the Main Stem along with nine minor tributaries and inputs from Kingman Lake, Washington Channel, and the Potomac River (during high tide). The Main Stem also receives surface water and sediment inputs from more than 35 municipal separate storm sewer system (MS4) outfalls, more than 14 combined sewer system (CSS) outfalls, at least two industrial outfalls, and at least two sanitary outfalls. Owing to the limited

[5] Reach 123/456 includes the Main Stem of the Anacostia River from its confluence with the Potomac River to the confluence of the Main Stem and Nash Run (**Figure 2.2**). Reach 123 (and Reach 456) denote the combination of Reach 1, Reach 2, and Reach 3 defined originally in the ARSP Work Plan (Tetra Tech 2014) into the final reach identifiers defined in the RI (that is, Reach 123; Reach 456 combined in the same way). Retaining the original Reach numbers in the combined reach identifiers facilitates access to RI samples (RI sample identifiers were included the original reach numbers). For additional discussion of the rationale for the designated reach identifiers, please refer to Section 2.8 of the RI Report (Tetra Tech 2019a).

movement of water from the Main Stem to Kingman Lake and Washington Channel, interim remedial actions in the Main Stem will be conducted separately from the other two OUs. Remediation in the Main Stem will include direct actions in the EAAs as well as control actions focused on reducing inputs of contaminated surface water and suspended sediment to the river.

- **Washington Channel OU**, referred to as EU-1 in the RI, has three EAAs totaling 14.3 acres, entirely within DC. Washington Channel is a 2-mile-long waterway extending northward from the mouth of the Anacostia River to the Tidal Basin, adjacent to the National Mall in Washington DC. Hydraulic interaction between the Washington Channel and the Main Stem is limited and sedimentation rates in Washington Channel are low relative to the Main Stem. The Washington Channel receives small inflows from the Tidal Basin and limited tidal influx from the Anacostia and Potomac Rivers, as described in the RI Report (Tetra Tech 2019a) and ARSP surface water model (Tetra Tech 2019b). Washington Channel also receives surface water and sediment inputs from more than 15 MS4 outfalls.
- **Kingman Lake OU**, referred to as EU-6 in the RI, having two EAAs totaling 12 acres, is entirely within DC. Kingman Lake is a 105-acre humanmade lake that runs parallel to a 2-mile portion of the Main Stem. Like Washington Channel, hydraulic interaction between Kingman Lake and the Main Stem is limited. Kingman Lake receives inflow from more than eight MS4 outfalls and a small (unnamed) tributary draining both the Langston Golf Course and an adjacent wooded portion of the National Arboretum. The relative hydrologic separation of Kingman Lake from the Main Stem makes it feasible to implement interim remedial actions in this OU independently of other OUs.

2.1 Constituents of Concern

The B/P Monitoring Plan focuses on COCs identified in the IROD as posing risks to ecological receptors or human health at or above the 1E-05 risk level (DOEE 2020). COCs include summations (such as total PCB and chlordane) and calculated values (such as TEQ). TEQ is a summation of specific analytes weighted for their relative toxicity.[6]

- **Total PCB congeners**: the sum of detected PCB congeners (total of 209 congeners)
- **Dioxin-like PCB TEQ**: the calculated TEQ value incorporating the 12 toxic dioxin-like PCB analytes
- **Dioxin TEQ**: the calculated TEQ value incorporating the 17 toxic dioxin and furan analytes
- **Chlordane**: the sum of detected alpha-chlordane, gamma-chlordane, trans-nonachlor, and heptachlor (representing a technical chlordane mixture)

[6] TEQ (total equivalent) is a summation of either the 12 dioxin-like PCB or 17 dioxin and furan analytes weighted for their relative toxicity as defined by the toxic equivalency factor (TEF). The TEF is the ratio of the analyte's toxicity to the toxicity of the two most toxic compounds (2,3,7,8-tetrachlorodibenzo-p-dioxin and 1,2,3,7,8-pentachlorodibenzo-p-dioxin). TEFs range from 1 to 0.0001. A TEQ is calculated by multiplying the actual grams (g) weight of each dioxin or dioxin-like compound by its corresponding TEF (for example, 10 g X 0.1 TEF = 1 g TEQ) and then summing the results (van den Berg et al. 2006).

Total PCB congeners and dioxin-like PCB TEQ were identified in the IROD as posing risk to human health. The IROD defined dioxin TEQ, dioxin-like PCB TEQ, and chlordane as ecological COCs.

The B/P Monitoring Plan will measure concentrations of COCs in surface sediment, porewater, surface water, and fish and invertebrate tissues (and PAHs in sediment, as discussed in **Section 1.1**) and assess sediment toxicity to demonstrate progress toward meeting the RAOs established in the IROD (DOEE 2020). The PRG for each COC is a risk-based concentration (RBC) in surface sediment that is expected to achieve the RAOs, as detailed in the River-wide FS Report (Tetra Tech 2019c). The selected PRG for each COC is the lower of the human health and ecological PRGs, bounded by the regional background threshold value (BTV), as shown in **Table 2.1**.

Table 2.1 Sediment Preliminary Remediation Goals

COC[1]	Site-Specific Surface Sediment 95UCL Concentrations [2]	Risk-Based Concentrations[4]					Selected PRGs	Notes
		BTV[3]	Human Health PRGs based on Subsistence Fish Ingestion			Ecological PRGs[5]		
			RSL = 1E-06	RSL = 1E-05	RSL = 1E-04			
Dioxin-like PCB TEQ [6] (µg/kg)	5.00E-02	5.50E-04	1.20E-04	1.20E-03	2.50E-03	2.50E-02	1.20E-03	Fish Ingestion
Total PCB (µg/kg)	5.00E+02	1.70E+01	7.00E+00	6.50E+01	6.50E+01	NA	6.50E+01	Fish Ingestion
Chlordane (µg/kg)	7.10E+01	1.10E+01	Not applicable	Not applicable	Not applicable	1.80E+01	1.80E+01	Benthic Invertebrates
Dioxin TEQ[6] (ng/kg)	3.80E+01	8.60E+00	Not applicable	Not applicable	Not applicable	2.50E+01	2.50E+01	Benthic Invertebrates

1. COCs include constituents that pose risk at 1E-05 risk level for human health or exceed the ecological probable effect concentration by a factor of 2 in one or more OUs.
2. The 95 percent upper confidence limit on the mean (95UCL) concentrations were calculated using ProUCL 5.1.002 (EPA 2015).
3. BTV is the estimated upper boundary (at the 95UCL) for the largest value of the background dataset calculated using ProUCL 5.1.002 (EPA 2015).
4. RBCs for human health were back calculated using site-specific forage fish and game fish using methods in EPA (2017a) at three EPA Regional Screening Levels (RSL). Fish consumptions rates were based on a local survey of anglers (OpinionWorks 2012, Gibson and McClafferty 2005); a consumption rate of 65 grams per day for adult subsistence angler was assumed for reasonable maximum exposure (RME). Child and adolescent fish ingestion rates were calculated as one-third and two-thirds of the adult rates, respectively. The lowest calculated human health PRGs for the Anacostia River were for subsistence fish ingestion.
5. Ecological PRGs are based on probable effect concentrations in NPS (2018) and EPA (2018).
6. TEQ calculations used toxicity equivalency factors from van den Berg et al. (2006). Note that dioxin TEQ results are reported as nanogram per kilogram (ng/kg). The other COCs are reported in micrograms per kilogram (µg/kg).

2.2 Conceptual Site Model

The ARSP CSM integrates the physical, chemical, and biological processes that govern the movement of contaminants and their potential exposure routes to various human or ecological receptors. The primary contaminant sources to the study area include tributary inflow (with associated) sediment loading, MS4 and CSS outfall inflows, and potential current or historical contaminant releases (including groundwater discharges) from the PECSes. The ARSP surface water model (Tetra Tech 2019b) and studies by Ghosh et al. (2014) show that desorption of COCs from sediment is a source of contamination to porewater and surface water. These studies further show that volatilization of COCs from the river outweighs atmospheric deposition, but overall, atmospheric interactions represent minor components of the river mass balance. The dominant exposure pathway for people to site contaminants is through the ingestion of fish caught in the river.

The CSM also focuses on pathways from contaminated media to ecological receptors. The Anacostia River supports a complex, multi-tiered food web, with phytoplankton, algae, and microbial films at the base. A diverse assemblage of small soft-bodied invertebrates (such as amphipods, chironomids, and other aquatic insect larvae) as well as larger hard-bodied invertebrates (such as crayfish, snails, clams, and mussels), support the diverse assemblage of fishes, turtles, birds, and mammals known to inhabit the river (Tetra Tech 2019a; DOEE 2015; NPS 2014). Invertebrates likely take up contaminants dissolved in surface water and porewater, as well as contaminants directly associated with ingested sediment. Transfer of contaminants from sediment to vertebrates is expected to be dominated by the ingestion pathway, especially ingestion of sediment and prey.

Environmental investigations are performed under existing legal agreements at the Potomac Electric Power Company (Pepco) Benning Road Facility, Washington Gas East Station, and Washington Navy Yard. At CSX Transportation Corporation (CSX) Benning Yard, upland cleanup is also being performed under a separate agreement. DOEE, NPS, and/or EPA Region 3 have authority as lead or support agency overseeing cleanups at these sites. Elevated surface sediment concentrations of total PCB and other chemicals in areas of the river proximate to each site are potential sources of contamination to the study area but are not included in the EAAs defined in the IROD (DOEE 2020). Although the timing for implementation of the remedial activities at these PECSes is set by the respective regulatory agreements for each site, DOEE intends for the remedies ultimately selected at these PECSes to conform with and complement remedies selected for the ARSP study area.

Together, the three largest tributaries (Northwest Branch, Northeast Branch, and Lower Beaverdam Creek) contribute 94 percent of the total flow of the Anacostia River (Wilson 2019). CSS outfalls account for approximately 1 percent of the sediment and 0.08 percent of PCB congener mass to the study area water bodies (Tetra Tech 2019b). MS4 outfalls contribute 5.5 percent of the sediment and 3 percent of the PCB mass to the study area (Tetra Tech 2019b). Active industrial outfalls at PECSes regulated via EPA National Pollutant Discharge Elimination System (NPDES) permits include two at Pepco Benning Road

Facility[7] and eight at Washington Navy Yard.[8] DOEE is conducting ongoing investigations of the influence of outfalls on long-term remediation and management of the Anacostia River.

[7]The Pepco Benning Road Facility has a total of eight outfalls: two NPDES outfalls (No. 013 and 101) and six MS4 outfalls (No. 005, 006, 014, 015, 016, and 401) that discharge to the Anacostia River (AECOM 2022).
[8] According to Proposed Plan for Washington Navy Yard, there are eight NPDES outfalls (No. 1, 5, 6, 7, 8, 9, 13, and 14) that discharge to the Anacostia River. Former Outfall 10 is not currently monitored under a NPDES permit because it was reconfigured in 1999. (Prior to 1999, Outfall 10 collected runoff from Washington Navy Yard and the Southeast Federal Center.) CSS Outfall No. 14, CSS Outfall No. 15, and MS4 Outfall No. 1 traverse the Washington Navy Yard and discharge to the Anacostia River. CSS Outfall No. 15 and MS4 Outfall No. 1 capture a portion of Washington Navy Yard's stormwater drainage (Naval Facilities Engineering Systems Command 2023).

3. Interim Remedial Actions

Remediation will be managed adaptively using a combination of sediment interim remedial actions (in the EAAs) and source control, potential follow-up sediment actions, and evaluations of the periodic monitoring data collected in accordance with this plan. The B/P Monitoring Plan established protocols for collecting the data needed to evaluate progress toward the achievement of the RAOs. The remedies to address COCs in the EAAs are briefly summarized in this section. Adaptively managing cleanup in the EAAs and source control in the upstream watershed will support transition of the IROD (DOEE 2020) to a final ROD.

3.1 Remedial Action Objectives

RAOs are foundational to the development and successful implementation of the interim remedial actions in the EAAs. Overall remedial goals for this project are to protect human health and the environment from risks associated with exposure to the COCs in sediment. The RAOs are discussed in detail in this section.

Four RAOs were developed in the River-wide FS Report based on results of the HHRA and BERA, and consideration of applicable or relevant and appropriate requirements (ARARs) and to be considered (TBC) criteria (Tetra Tech 2019c). The RAOs establish the goals to be achieved by the interim remedial action, which are focused on surface sediment as the primary exposure medium in the river. The RAOs are meant to be as detailed as possible without limiting the range of possible remedial alternatives. RAOs 1, 3, and 4 are the focus of the B/P Monitoring Plan. RAO 2 was based on direct contact exposure of people to fringe sediment. RAO 2 has been satisfied at DOEE's selected 1E-05 risk level. The remaining RAOs are discussed below, referred to by their original numbers to preserve continuity among documents:

RAO 1. Reduce risks associated with the consumption of COCs in fish from the tidal Anacostia River by people with the highest potential exposure.

The HHRA (reasonable maximum exposure [RME]) scenario with the highest risk estimates for the ARSP study area was consumption of fish by subsistence anglers. Subsistence anglers either consume the fish they catch or share their catch with others (University of Maryland and NPS 2019).

Meeting this RAO will require that the surface weighted average concentrations (SWACs) in surface sediments be reduced to achieve a corresponding reduction in the concentration of COCs in fish. A SWAC is the average concentration of a contaminant applicable to the area of interest. For the ARSP, SWACs were calculated using the Thiessen polygon method, which is based on the division of each reach into a series of polygons. Each polygon was centered on a concentration measurement point and the polygon area was used to weight the concentration at that point in the calculation of the SWAC for the reach.

Fish can be directly exposed to COCs within the biologically active surface sediments (and porewater) where eggs and larval fish are in contact with sediment. In many species, fish purposefully or incidentally ingest bed sediment that may contain adsorbed COCs. Fish are indirectly exposed to sediment-associated chemicals that have been accumulated by algae, invertebrates, and animal prey ingested by the fish. Deeper sediments do not contribute appreciably to these risks unless they are exposed by dredging, scour, or other disturbances of overlying sediments. In some areas, achieving and maintaining this RAO may therefore include addressing deeper sediments that could be subject to exposure in the future. Fish may also bioaccumulate dissolved concentrations of COCs in surface water via their gills.

RAO 3. Reduce risks associated with COCs in sediment to levels protective of benthic and aquatic invertebrates based on direct chronic exposure to surface sediment and surface water.

The BERA concluded that risks to benthic and aquatic invertebrates were unacceptable; that is, toxicity tests indicated effects on survival, growth, or reproduction and concentrations of COCs in sediment were above probable effect concentrations. Exposure of benthic and aquatic invertebrates to COCs occurs within the biologically active zone, which was defined as the top six inches of sediment in the ARSP RI, as well as in overlying surface water (Tetra Tech 2019a) but may be shallower in some locations. The interim remedial actions in the EAAs were based primarily on the PRGs for human health at a target risk level of 1E-05 for total PCB and dioxin-like PCB TEQ. Because the PRG for dioxin-like PCB TEQ for human health is lower than the PRG for ecological receptors, achieving the human health PRG will reduce risk to benthic invertebrates as well. In addition, laboratory toxicity tests will be conducted to monitor achievement of RAO 3.

RAO 4. Reduce risks associated with COCs in surface sediment to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey.

Achievement of RAO 4 is based on addressing unacceptable risk to fish by reducing the concentrations of bioaccumulative COCs in surface sediment (top six inches). This reduction will lead to lower concentrations of these chemicals in porewater, surface water, suspended sediment, and prey consumed by fish, which will in turn lead to reductions in fish tissue concentrations and reduced toxicity. It is recognized that zero (or non-detect) concentrations in fish may not be achievable for all COCs.

Ecological RAOs were developed to address the protection of specific ecological receptor groups. RAO 3 addresses protection of benthic invertebrates from direct exposure to sediment and RAO 4 addresses protection of fish. No RAOs were developed for birds or mammals because chemicals at the site were found to pose little to no unacceptable risk to these receptors (based on food chain modeling conducted in the BERA).

3.2 Early Action Areas and Interim Remedies

Interim remedial actions in the EAAs were designed to reduce sediment concentrations of total PCB congeners. Concentrations of dioxin-like PCB TEQ, dioxin TEQ, and chlordane are expected to decrease to the extent that these COCs are co-located with total PCB.

The B/P Monitoring Plan will measure concentrations of COCs (and PAHs, as discussed in **Section 1.1**) in surface sediment, porewater, surface water, and fish and invertebrate tissues and assess toxicity to demonstrate progress toward meeting the RAOs established in the IROD (DOEE 2020). The PRG for each

COC is an RBC in surface sediment that is expected to achieve the RAOs, as detailed in the ARSP River-wide FS Report (Tetra Tech 2019c). The selected PRG for each COC is the lower of the human health and ecological PRGs, bounded by the regional BTV, as shown in **Table 2.1**.

Sediment cleanup is achieved by reducing bioavailable concentrations of COCs in surface sediment to meet the selected PRGs. The River-wide FS Report evaluated compliance with PRGs using SWACs within each reach of the ARSP study area (Tetra Tech 2019c). PRGs applied on a SWAC basis represent the entire area rather than an individual point. A remedial action level (RAL) was developed for each reach of the river and for the whole ARSP study area (the river-wide RAL or RAL_{RW}). A RAL for a reach is the maximum concentration of a COC that can remain in sediment while achieving the PRG on a SWAC basis. The RAL_{RW} is the average of the RALs defined for each of the six reaches. The RAL_{RW} is the estimated cleanup level that would achieve the PRG on a river-wide basis (200 µg/kg total PCB). DOEE established the RAL for the EAAs (RAL_{EAA}) for the interim remedial actions based on the RAL_{RW}. As discussed in the IROD, DOEE's selected RAL_{EAA} is three times the RAL_{RW} (or 600 µg/kg total PCB). The RAL_{EAA} represents the best tradeoff between risk reduction, size of the remediated area, and cost. The RAL_{EAA} was determined to be optimal for EAA remediation to achieve significant risk reduction and control migration of contaminants while allowing for adaptive management decision-making.

When the SWAC and other indicators shows downward trends, then the interim remedial actions will be considered effective, and DOEE may consider transitioning from the IROD to a final ROD. Recovery of the ARSP will be dependent on the interim remedial action and the natural deposition of cleaner sediments in the river, allowing MNR to play an important role in downward contamination trends and overall reduction of monitoring indicators. At that time, DOEE will evaluate the extent to which RAOs have been achieved and determine the next course of action. The expected reductions in SWACs represent risk reductions of approximately 90 percent across the study area. This approach to estimating risk reduction assumes the following:

- The interim remedies will reduce concentrations of total PCB to below RALs or block biological exposure pathways to PCB in the EAAs. (For example, studies have shown that following carbon amendment application, uptake of hydrophobic contaminants by benthic organism can be reduced by 70 to 90 percent [Patmont et al. 2014]).
- MNR will play an important role in reducing PCB concentrations with the natural deposition of cleaner sediment. Although burial by cleaner sediment is often the dominant process in achieving MNR, multiple physical, biological, and chemical mechanisms frequently act together to reduce risk (EPA 2005).
- Control of COC inputs from the non-tidal watershed will be timely and effective.
- The interim remedies will reduce PCB concentrations in surface sediment and porewater.
- The post-remediation SWACs are expected to demonstrate reductions in concentrations of COCs in each OU.

The selected interim remedies identified in the IROD and the forthcoming ESD include cost-effective remedy enhancements through containment, selective dredging to accommodate the cap, or direct application of activated carbon to sequester COCs (DOEE 2020, 2023). These interim remedies will address the subset of the contaminated sediment in the ARSP study area represented by the EAAs. They will also be protective of human health and the environment and will attain ARARs determined to be pertinent to the actions included in the IROD. Addressing a portion of the contamination was determined to be the appropriate strategy for cleaning up the river due to the complexities and uncertainties associated with contaminated sediment remediation. The interim remedy approach with B/P monitoring provides a balance of implementing focused cleanup actions and allowing for flexible decision-making in the face of uncertainty. B/P monitoring (as defined herein) will provide information on the success of the interim remedial actions regarding RAO achievement, on the implementation of the same or similar remedies in other areas of the ARSP study area, and on the impact the focused cleanup actions have on the ARSP study area.

Containment of COCs with caps will provide an immediately effective mechanism to immobilize the COCs and to prevent direct contact with COCs. Augmentation of the caps with amendments, such as activated carbon or organoclay, will aid in the sequestration of the COCs. Sand caps are also effective at providing a clean substrate for colonization by biofilms and benthic fauna, and submerged aquatic vegetation are expected to recover and not have long-term impacts. In addition, the cap design can accommodate areas of the EAAs that may be subject to high-energy forces, such as storm water flow or propeller wash, with protective armoring. The selected remedy in all EAAs includes containment with or without selective dredging to accommodate the cap thickness (**Table 3.1).**

- **Containment.** EAAs in Kingman Lake, Main Stem, and Washington Channel OUs will be capped with clean sand that may be augmented with amendments, such as activated carbon or organoclay. The ESD will also allow for containment with direct application of activated carbon to wetland areas to sequester COCs (DOEE 2023). The shallow vegetated wetlands and deeper unvegetated channels provide important year-round food and shelter for fish, wading birds, ducks, aquatic mammals, and other wildlife, as well as providing recreational opportunities for people. The need for specialized cap design, mitigation for impacts to submerged aquatic vegetation and other resources, and the implementation of institutional controls to maintain cap integrity will be discussed in the remedial design.
- **Selective Dredging.** Dredging is necessary in the federal navigation channel of the Main Stem OU (and is necessary in Kingman Lake where channels are proposed). Specific areas to be dredged will be identified in the remedial design. Dredged sediments may be used in restoration or other beneficial use (BU) in accordance with DOEE’s BU Guidance document (DOEE 2022). Alternatively, dredged material will be dewatered and then disposed at an off-site facility.

Table 3.1 Interim Remedial Actions

Operable Unit	General Features
Main Stem OU (6 EAAs)	Containment potentially augmented with amendments (or direct application of carbon where favorable hydraulic conditions exist), selective dredging in the federal navigation channel to accommodate the cap, and off-site disposal of dredged material or BU in areas defined consistent with the DOEE BU Guidance (DOEE 2022)
Kingman Lake OU (2 EAAs)	Containment by thin layer cap placement augmented with amendments (or direct application of activated carbon), selective dredging to accommodate the cap (as needed) or in proposed channels, and off-site disposal of dredged material or BU in areas defined consistent with the DOEE BU Guidance (DOEE 2022)
Washington Channel OU (3 EAAs)	Containment potentially augmented with amendments (or direct application of carbon where favorable hydraulic conditions exist)

4. Baseline and Performance Monitoring Within an Adaptive Management Decision Framework

This section describes the benefits of adaptive management in B/P monitoring and presents the sequence of monitoring activities to be conducted. Concurrent but separate projects and actions on the river that may interact with B/P monitoring are briefly discussed. Key terms are defined as they are introduced and summarized in a glossary immediately preceding **Section 1.0.**

4.1 Benefits of Adaptive Management Framework

Data generated by the B/P Monitoring Plan will be assessed within an adaptive management decision framework to advance the project from the interim remedial actions to the issuance of a final ROD. As warranted, results in each OU will be evaluated separately to allow flexibility of producing separate final RODs. Separate cleanup actions at the PECSes bordering the ARSP study area will be conducted as required under other regulatory directives.

The iterative nature of B/P monitoring is well-suited to an adaptive management framework, as described in the River-wide FS Report (Tetra Tech 2019c) and the IROD (DOEE 2020). EPA also supports adaptive management at complex contaminated sediment sites by combining iterations of remediation and monitoring progress towards the RAOs (EPA 2022). Adaptive management practices, often described as "learning by doing" (Schreiber et al. 2004), acknowledge that long-term project goals may be achieved more efficiently when managers use a flexible evidence-based approach, or follow the science when making decisions, as summarized in a review by U.S. Geological Survey (USGS) on long-term monitoring associated with restoring impaired ecosystems (Hooper et al. 2016). Within an adaptive management framework, data are reviewed and evaluated to test hypotheses, clarify relationships, and revise initial assumptions so that the project can be optimized (Linkov et al. 2006). The adaptive framework is demonstrated in **Table 4.1**.

The iterative review and evaluation steps enhance data quality, maximize efficiency, and promote transparency with stakeholders. Adaptive management also reduces overall project costs, as elements of the monitoring program are retired once sufficient data are in hand. Consistent with EPA's guidance, the B/P monitoring components that will be implemented within the adaptive management framework are listed below and are developed in the remaining sections of this B/P Monitoring Plan (EPA 2022):

1. **Establish PRGs or remediation goals**. DOEE established sediment PRGs for the COCs in the IROD.
2. **Determine the action**. DOEE identified EAAs in the IROD.
3. **State the expectations**. Select specific *trigger criteria* for *key indicators.* A key indicator is a medium or process (for example, concentration of total PCB in surface sediment or toxicity to amphipods exposed to surface sediment) selected for its link to an RAO. A trigger criterion is a benchmark value of an indicator used to determine subsequent action. If concentrations of a COC in the monitoring area are less than the trigger criterion for the COC, DOEE may deem monitoring for that indicator no longer warranted. Conversely, if monitoring results are greater than the trigger criterion, DOEE may reconsider the extent of interim remedial actions or the timeframe in which the RAOS can be achieved.

4. **Monitor progress**. Monitor the response action, identify actions to be taken in response to *attainment or non-attainment* of trigger criteria, and implement the adaptive management plan.
5. **Evaluate and adapt**. Monitor and compare collected data to *timeframes* and trigger criteria. Take specified action if trigger criteria are not met (that is, remedial objectives are not achieved in stated timeframe).

4.2 Sequence of Remediation and Monitoring

The B/P Monitoring Plan includes baseline monitoring (prior to interim remedial action) and performance monitoring (following remediation).

- **Baseline monitoring** documents conditions in each OU immediately prior to interim remedial action. It answers the question "What is the current condition of the key indicators of river health that we are addressing through interim remedial action?"
- **Performance monitoring** evaluates the results of the interim remedial action by answering the question *"To what extent did the remedy have the desired effect on the selected indicators?"*

Following several intervals of performance monitoring, the combined data set may be analyzed statistically using validation monitoring techniques to test the assumptions of cause and effect (Hooper et al. 2016). As described in EPA (2017b), sediment and game fish monitoring must be conducted over many years to demonstrate the effectiveness of the remedy. Such information is useful in advancement of a final ROD as well as in developing approaches to remediate contaminated sediments at PECSes within DC.

Interim remedial actions for all EAAs within an OU will be completed as a single project. Work may be conducted in the three OUs concurrently or sequentially. In general, activities within each OU will occur as follows:

1. PDI
2. Remedial design
3. Baseline monitoring (during or immediately following the PDI and RD; called Time 0)
4. Remedial construction
5. Post-remedial construction (confirmation monitoring)
6. Performance monitoring (following completion of interim remedial action in that OU; called Time 1…$Time_n$)
7. Validation monitoring in a single OU or multiple OUs (to be determined)

4.3 Concurrent Projects and Changes to the River Ecosystem

Concentrations of COCs in sediment, surface water, and other media in the Anacostia River may be influenced during the performance monitoring period by events other than direct remediation in the EAAs. Four types of planned or anticipated projects expected to cause measurable changes in river conditions are discussed below: (1) source control; (2) remediation at one or more PECSes; (3) DOEE

NRA projects[9]; and (4) changes to the federal navigation channel dimensions that will minimize the amount of required maintenance dredging in the future.

4.3.1 Source Control in Tributary Watersheds

Source control is not explicitly identified as a remedy in the IROD, although DOEE considers such efforts critical to achieving the overall cleanup of the tidal Anacostia River since MNR will play an important role in downward contamination trends. Tributaries are the largest ongoing source of contaminants to the study area. Because most of the upstream nontidal watershed is in Maryland, source control in the tributaries requires close cooperation between DOEE, the Maryland Department of the Environment (MDE), and the governments of Prince George's and Montgomery Counties. Since 2019, DOEE initiated a Source Control Workgroup, which brings together local government agencies to discuss solutions in the watershed via source control. Members includes DOEE, EPA, MDE, Metropolitan Washington Council of Governments (MWCOG), NPS, U.S. Fish and Wildlife Services (USFWS), National Oceanic and Atmospheric Administration (NOAA), USGS, University of Maryland Baltimore County (UMBC), Montgomery County, Maryland National Park & Planning Commission, and Prince George's County. This group reports on their ongoing investigations, and DOEE will review the findings of the Source Control Work Group investigations of uncontrolled sources in the upper watershed, and will incorporate the findings, as warranted, into the B/P monitoring.

Current source control actions include outfall and tributary sediment sampling activities in DC tributaries (Watts Branch, Hickey Run, and Nash Run) and aerial infra-red (IR) surveying to identify surface and groundwater inflows. MDE is also working on remediation of the Lower Beaverdam Creek watershed and two upland sites on the tributary (Joseph Smith and Sons site and Pennsy Drive site) to address PCB migration (MDE 2023). At the Joseph Smith and Sons site, soils with PCB concentrations greater than 50 ppm were removed in March 2022, and the banks were stabilized to minimize erosion. In January 2023, the draft Site Wide Characterization Report for the Joseph Smith and Sons site was submitted to MDE and EPA for review. MDE is currently working on a Response Action Plan to control PCB migration from the site to Lower Beaverdam Creek. At the Pennsy Drive site, the draft field sampling and analysis plan is currently under review and is anticipated to include stormwater studies and sampling in Lower Beaverdam Creek. MDE continues to monitor PCB contamination on Lower Beaverdam Creek with annual surface water and fish samples (MDE 2023).

DOEE believes it is critical to the success of the Anacostia River cleanup that ongoing sources be identified and controlled to the extent practicable. As discussed in the IROD, ongoing sources will be addressed through adaptive management framework to monitor the influence of ongoing sources on the achievements of the interim remedial actions. The relative effectiveness of source control is one of the variables that adaptive management will consider. Specifically, it is uncertain how effective source identification and mitigation efforts will be, and whether source control will promote MNR downriver on the Anacostia River. Such efforts would be expected to speed cleanup progress toward by accelerating concentration reductions in study area environmental media (that is, reduced contributions from upstream sources will reduce concentrations in site surface sediment and other media). However, if the

[9] https://doee.dc.gov/page/natural-resources-administration

reductions achieved are insufficiently robust, adaptive management provides the approach for responding to this situation based on the available source control data amassed and experience gained. Possible outcomes might be that more comprehensive source control measures are warranted or that a refocusing of source control resources may be needed.

Several PECS have identified contaminant releases that may contribute to concentrations of COCs in the ARSP study area. The Pepco Benning Road Facility, Washington Gas Former East Station Manufactured Gas Plant (MGP) Site, and Washington Navy Yard are investigating the nature and extent of contaminated surface sediment associated with their respective sites. These PECS are expected to complete feasibility and treatability studies to evaluate potential remedial actions to reduce risk posed by contaminated sediment, and to then undertake on-site source control measures to reduce the release of COCs to the tidal river. The potential for other PECSes to be identified as sources of COCs to the ARSP study area will be evaluated using B/P monitoring results and other available evidence.

In addition, DOEE has funded studies (Wilson 2019; Ghosh et al. 2020) of potential sources or COC mass balance in the ARSP study area that provide independent data to inform source tracking efforts and support calibration of the ARSP surface water model (Tetra Tech 2019b). Ongoing Phase 2 USGS tributary studies are designed to measure contaminant inputs from upstream tributaries and outputs to the Potomac River with a newly installed gaging station at Buzzard Point (Wilson 2020). The ARSP surface water model will integrate data from the tributaries to enhance the interpretation of data collected during B/P monitoring. Additional study efforts include Anacostia River monitoring with passive samplers and mussels to refine the CSM and define baseline conditions and monitor sources from Lower Beaverdam Creek (Ghosh et al. 202, Lombard et al. 2022).

4.3.2 Cleanup at the Potential Environmental Cleanup Sites

Remedial actions at the PECSes are overseen by DOEE (either directly or in participation with NPS or EPA Region 3) but implemented by the responsible parties. DOEE anticipates that some cleanup activities will occur at the PECSes during the period of performance monitoring for the ARSP under agreements and according to schedules separate from the ARSP. Empirical results from investigations and studies at the PECSes will be evaluated as independent measures during the 5-year reviews of the ARSP performance monitoring (DOEE 2020). Any remedial activity at a PECS that reduces concentrations of COCs in sediment or water will contribute to DOEE's remediation efforts. Neither the extent nor timing of remediation at PECSes can be predicted at this time, but it is reasonable to expect a general downward trend in concentrations of COCs released by the PECSes.

4.3.3 DOEE Natural Resource Administration Projects

The DOEE NRA is engaged in several projects focused on restoring various environmental resources in the ARSP study area. Wetland preservation and restoration, shoreline restoration, re-establishment of mussels, expansion of submerged aquatic vegetation, and restoration of natural habitat are under consideration or in the planning stages (**Figure 4.1** shows proposed project areas, dated spring 2022). DC is planning to develop outdoor classroom platforms, boat docks, boardwalks, channels, and restoration areas in Kingman Lake, including Kingman Island and Heritage Island. DOEE's performance monitoring will be coordinated to the extent practicable with these restoration and development projects so that indicator data can be properly interpreted.

4.3.4 Federal Navigation Channel

A federal navigation channel extends through the Main Stem and Washington Channel OUs (**Figure 4.2**). Downstream of Pennsylvania Avenue, the federal navigation channel is referred to as the Washington Ship Channel. Because U.S. Army Corps of Engineers (USACE) no longer intends to actively dredge the channel, Congress has authorized a reduced width and depth of the channel in the Water Resources Development Act of 2020; channel dimensions are presented in **Figure 4.2** (dated January 2023). Changes to the federal navigation channel dimensions will minimize the amount of required maintenance dredging in the future.

5. Approach to Baseline and Performance Monitoring

The B/P monitoring is an integral part of the remedy set forth in the IROD (DOEE 2020). Unbiased monitoring data provide the basis for DOEE and other decision-makers to evaluate the effectiveness of the remedies and estimate the extent to which human health and ecological risks have been reduced (EPA 2017b). The B/P Monitoring Plan was developed in accordance with commitments made in the IROD, formal guidance, scientific publications (as cited throughout this plan), and best practices at other large river sediment sites (DOEE 2020, EPA et al. 2017, EPA 2017b, ESTCP 2009, ITRC 2014).

The IROD along with the forthcoming ESD present interim remedial actions selected to make progress toward achieving the RAOs by reducing concentrations of total PCB in sediment (DOEE 2020, DOEE 2023). Reducing the concentrations of bioaccumulative COCs in sediment is expected to decrease direct transfer of COCs to invertebrates and fish as well as to the water column, which would further reduce exposure of organisms to COCs. Decreased uptake of COCs by invertebrates and fish ultimately supports DOEE's goal of making game fish in the Anacostia River safe for human consumption.

The B/P Monitoring Plan was designed to document changes over time in key indicators of exposure and uptake of COCs to invertebrates and fish. The seven indicators selected for B/P Monitoring (that is, surface sediment, porewater, surface water, benthic invertebrate toxicity, benthic invertebrate bioaccumulation, forage fish, and game fish) provide a weight-of-evidence approach to monitoring changes over time, and the concurrent monitoring in the Reference Area provides the spatial resolution necessary to interpret trends. Evaluating interactions of indicators from the same location and across locations improves statistical robustness and minimizes the incidence of faulty conclusions based on limited monitoring data (Hooper et al. 2016).

5.1 Baseline/Performance Monitoring Design

The B/P Monitoring Plan is consistent with the baseline and post-remediation monitoring recommendations in EPA (2017b) and ITRC (2014). Such sampling designs are widely used to measure changes at a site resulting from a planned impact or modification of the site, including remedial actions. B/P monitoring differs from the typical RI sampling design, which focuses on characterizing the site relative to a putative unimpacted background area at a single point in time. Often, RI sampling designs are purposefully biased toward areas of known or suspected contamination, and data are collected in several phases over an unspecified duration. In contrast, the B/P monitoring examines changes within an area over time—before and after a planned remedial action. As recommended in EPA (2017b), baseline data will be collected in the appropriate media and used to evaluate post-remedial effectiveness.

The B/P Monitoring Plan was designed to document change in indicators (for example, a decline in concentrations of COCs in surface sediment or forage fish) following sediment remediation in the EAAs. Conditions in each OU will be monitored over time; results will be analyzed for each OU separately to allow flexibility of producing separate final RODs, if warranted, and will be combined for the river-wide assessment. In accordance with EPA (2017b), results of the performance monitoring will be used to document "no change from baseline" or "significant change from baseline" in each OU in support of the final ROD.

The set of site-specific remedial actions to be implemented in the study area represent a *singular event* that cannot be duplicated in time or location. Non-site-specific variables (for example, regional precipitation patterns, predator-prey interactions) cannot be controlled as they are in laboratory experiments or quantitative model runs. The remedial actions function as experimental treatments but are not amenable to the usual replication and randomization methods that ensure unbiased defensible results. The B/P Monitoring Plan will answer the question: *"To what extent was the remedial action effective in reducing concentration of COCs in selected media and decreasing risk to ecological and human receptors in the study area*?"

By carefully defining the "baseline" (pre-remediation) and "performance" (post-remediation) period for each OU, the B/P Monitoring Plan guards against falsely concluding success (or failure) of a remedial action by isolating the effect of the remediation from natural variability documented in an area outside the influence of remedial actions. Similar baseline and long-term monitoring sampling designs have been used for B/P Monitoring at multiple large river sediment sites (for example, Fox River [Anchor QEA et al. 2009]; Lower Duwamish [Winward LLC and Integral Consulting 2017]; Onondaga Lake [Parsons Corporation 2017], and Middle River [Tetra Tech 2017]).

5.1.1 Operable Units

As described in **Section 3.2**, EAAs will be remediated in three OUs (Main Stem OU, Washington Channel OU, and Kingman Lake OU). The EAAs were sampled and delineated under separate PDI Work Plans. The B/P monitoring design in each OU is stratified to account for both EAA and non-EAA locations because final decisions will be made based on the overall characterization of the OU after the remediation is deemed complete.

The EAA boundaries delineated during the PDI constitute EAA polygons for B/P monitoring so that results from the EAAs can be examined separately from the rest of the river. In each OU, the non-EAA remainder of the surface sediment is divided into approximately equal polygons, each representing a sampling area. The number of EAA and non-EAA polygons is discussed in **Section 6.0**. Discrete or composite samples of the various indicators will be collected, as described in **Section 6.0.**

5.1.2 B/P Monitoring Plan Reference Areas

B/P Monitoring Plan Reference Areas are used to support the unbiased evaluation of the effects of the action (EAA remedies) on the selected monitoring indicators (EPA 2017b, ITRC 2014). Reference Areas are upstream of the EAAs and are not subject to any remedial action. Reference Areas are used to measure temporal changes in indicators in the vicinity that cannot be attributed to the remedial actions in the EAAs (such as precipitation or species interactions). Changes detected in the Reference Areas inform the interpretation of changes detected in the OUs and provide a credible foundation for monitoring the efficacy of the remedial actions (refer to **Section 7.2.2** on proposed statistical analyses for interpreting the B/P monitoring data). For example, if PCB concentrations in surface sediments in the Reference Areas and the OUs decrease proportionally over time, the decreases may not be unequivocally attributed to the remediation itself. The B/P Monitoring Plan includes two Reference Areas: (1) Northwest Branch and (2) Northeast Branch.

The Northwest and Northeast Branches contribute most of the water and sediment in the tidal Anacostia River (Tetra Tech 2019b; Wilson 2019). These major tributaries are subject to the same weather, aerial deposition, and other nonpoint inputs as the OUs and support many of the same species. Previous sampling in Northeast and Northwest Branches indicate that total PCB in forage fish is at or near regional background concentrations, as described in the IROD based on data from Tetra Tech (2019a) and Pinkney and Perry (2020). Changes in concentrations that occur uniformly across monitoring sites and Reference Areas are generally interpreted to be independent of the action taken. In this case, if concentrations of total PCB in forage fish tissue decrease in the Northwest and Northeast Branches as well as in the ARSP OUs, the cause may be attributable to something that affects a larger regional area rather than to specific remedial action in the EAAs.

5.2 Data Quality Objectives

The DQOs for the study area were developed using EPA's multi-step, iterative process that ensures that the type, quantity, and quality of environmental data used in the decision-making process are appropriate for its intended application (EPA 2006). This section defines and provides justification for the DQOs that govern the B/P Monitoring Plan, as recommended by ITRC (2014). DQOs are qualitative and quantitative statements that clarify investigation objectives, define the appropriate types of data to collect, delineate the appropriate conditions within which to collect the data, and acceptable decision errors associated with a given sampling approach. The DQOs for the B/P Monitoring Plan are defined below and in **Table 5.1**.

- Demonstrate through monitoring that conditions are "improving" in the OUs by characterizing trends in key indicators such as the concentrations of COCs in surface sediment, porewater, surface water, and fish and invertebrate tissues and reduction in toxicity to benthic invertebrates.
- Characterize the relationship between concentrations of COCs in the surface sediment and tissues of forage fish and game fish.
- Estimate the timeframe for reducing COC concentrations in edible game fish tissues to allow DOEE to remove fish consumption advisories in the Anacostia River. The expected cleanup timeframe is discussed in **Section 6.7**.

Table 5.1 Data Quality Objectives Process for B/P Monitoring

Data Quality Objective Process for B/P Monitoring
STEP 1: State the Problem
The release of hazardous substances into the Anacostia River is adversely impacting human health and ecological receptors. Based on risk assessments completed for the ARSP RI, DOEE identified four COCs as posing risk to human health (1E-05 cancer risk level) or ecological receptors: total PCB congeners, dioxin-like PCB TEQ, dioxin TEQ, and chlordane. PAHs are also being evaluated, as discussed in **Section 1.0**. DOEE determined that the use of a limited-scope response action (embodied in the IROD) is appropriate for addressing areas with sediment having the most elevated concentration of total PCB, while continuing to monitor the overall study area. The IROD is designed to make substantial progress toward cleanup of the ARSP study area, but it is only the beginning for defining a final cleanup approach (satisfying all RAOs) in a final ROD. Following sediment

Data Quality Objective Process for B/P Monitoring
remediation, performance monitoring will support adaptive-management-based decision-making that will guide the ARSP to a final ROD.
B/P monitoring of key indicators (e.g., concentration of total PCB congeners in surface sediment; and growth of amphipods exposed to surface sediment) will support DOEE in evaluating progress of the cleanup and assessing the need for any refinements to the remedy.
STEP 2: Identify the goals of the study
The B/P Monitoring Plan was designed to answer the following questions: • What is the percent change in the key indicators over time? o After implementing the IROD and forthcoming ESD remedies, key indicators (such as COC concentrations in sediment) are expected to decrease (DOEE 2020, DOEE 2023). The plan will document changes in indicators over time and establish relationships among indicators to streamline and refine future monitoring events. • How do changes in indicators over time in the OUs compare with changes in the same indicators in the Reference Area? o Because the Reference Area is outside the influence of the remedies, monitoring serves to differentiate changes attributable to the interim remedial actions from changes due to unrelated processes. This comparison is essential for evaluating the success of the interim remedial action and identifying causal relationships that may inform DOEE of the need for additional action. • What is the relationship between concentrations of COCs in surface sediment and in tissues of organisms in the river? o The IROD assumes that reducing concentrations or bioavailability of COCs in surface sediment will lead to lower concentrations in tissues; B/P monitoring is designed to test this relationship so that additional remediation can be implemented if necessary. • When will concentrations of COCs in edible tissues of game fish be low enough to meet RAO 1 (unlimited consumption of fish)? o The HHRA RME scenario with the highest risk estimates for the ARSP study area was consumption of fish by subsistence anglers; evaluation of concentration trends in edible tissue from game fish is a key goal of B/P monitoring.
STEP 3: Identify information inputs
The B/P Monitoring Plan sampling design is presented in **Section 6.0**. Sampling inputs are summarized as follows: • At designated locations in each polygon, surface sediment samples will be collected, composited, and analyzed for the four COCs, PAHs, and total organic carbon (TOC). • A portion of the composited sediment from each sampling polygon will be used to measure concentrations of COCs in porewater using *ex-situ* passive samplers (*in-situ* porewater passive samplers may be used in EAAs depending on the remedial design). • A portion of the composited sediment from each sampling polygon will be used to test toxicity and bioaccumulation in benthic invertebrates. • At designated locations in each OU, concentrations of COCs will be measured in surface water using *in-situ* passive samplers. • Within areas of suitable habitat, concentrations of COCs in whole-body forage fish samples will be measured. • Concentrations of COCs in game fish samples collected by DOEE Fisheries will be monitored to assess risk to humans from fish ingestion. All indicator samples (surface sediment, porewater passive samplers, surface water passive samplers, *Lumbriculus* tissue residue, whole-body forage fish, and game fish tissue) will be analyzed for PCB congeners

Data Quality Objective Process for B/P Monitoring
(including dioxin-like congeners), dioxin and furan, and chlordane. Sediment samples will also be analyzed for PAH and TOC. Tissues will also be analyzed for percent lipids.
STEP 4: Define the boundaries of the study
The study area is the Anacostia River from the confluence with the Potomac River to the division into the Northeast and Northwest Branches in Prince George's County, Maryland. The study area also includes the Washington Channel and Kingman Lake. The B/P Monitoring Plan primarily addresses conditions in the EAAs in concert with the reference areas. Remedies will be implemented in all EAAs in DC; source control measures will be implemented throughout the study area. In each OU, baseline sampling will occur just prior to interim remedial action implementation and performance monitoring will begin after interim remedial actions are completed in the EAAs.
STEP 5: Develop the Decision Rule
A power analysis (**Section 5.3.1**) was conducted to determine the number of samples required to demonstrate a statistical difference between baseline and performance monitoring results. Concentrations of COCs and PAHs in composited surface sediment from each OU will be evaluated on a SWAC basis to assess progress toward achieving the PRG for each COC. In addition, SWACs in surface sediment and monitoring results for other indicators (for example, whole-body forage fish and game fish tissues) will be subjected to trend analysis to document progress toward achieving RAOs. As appropriate, other B/P monitoring indicators will also be evaluated as discussed in **Section 7.0**. If observations are congruent with expected cleanup timeframes (discussed in **Section 6.7**), the interim remedial actions will be considered effective at that stage, and the final ROD will be prepared. If observations indicate a delay in DOEE's expected cleanup trajectory, additional focused cleanup actions may be considered before the final ROD is prepared. Concentrations of total PCB congeners, dioxin-like PCB TEQ, dioxin TEQ, and chlordane in surface sediment, porewater, surface water, and fish and invertebrate tissues will be reported by EPA methods, as shown in **Section 7.0**. Other constituents measured incidentally by the selected methods will not be reported or evaluated.
STEP 6: Specify performance or acceptance criteria
Precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters will be used to characterize monitoring results. To ensure the quality and integrity of the B/P monitoring results, the precision and accuracy of the analysis, the representativeness of the results, the completeness of the data, the comparability of the data to existing data will be evaluated. Data that meet the DQOs and fulfill project goals will be deemed acceptable. Data that do not meet objectives and goals will be reviewed on a case-by-case basis to ascertain usefulness. To limit errors made based upon analytical data, the laboratory level of quantitation for target analytes will be equal to or less than applicable screening level whenever technically feasible. In general, statistical analysis will not be used to determine decision error tolerance limits. Sediment, porewater, surface water, and fish and invertebrate tissues will be analyzed by EPA or equivalent methods. Sediment toxicity and bioaccumulation tests will follow American Society for Testing and Materials (ASTM) methods. All chemical data will be validated by an independent subject-matter expert; sediment toxicity and bioaccumulation tests will be verified; and the data's usability assessed. The specific criteria for the PARCC parameters are specified in the ARSP QAPP (Tetra Tech 2023a).
STEP 7: Develop the plan for obtaining data
The B/P Monitoring Plan describes protocols, sample sizes, and sample locations for seven indicators (**Section 6.0)**. Sampling protocols and frequencies may be adjusted based on the data collected. Specifically, if a correlation of two or more indicators is reported (for example, surface sediment and porewater), the sampling design will be refined to maximize efficiency and cost effectiveness. Several types of equipment will be used to collect and analyze the required samples. Composited surface sediment samples will be used in laboratory-based toxicity (amphipod and midge) and bioaccumulation (*Lumbriculus*) tests. TOC will be measured in each composite surface sediment sample to support the interpretation and analyses of other B/P monitoring data.

5.3 Sample Sizes and Locations

The B/P Monitoring Plan is designed to achieve the DQOs presented in **Section 5.2.** In general, the DQOs are focused on detecting changes in key indicators over time and interpreting those changes in the context of concurrent changes in the Reference Areas. The numbers of samples required to detect change over time is a function of the variance in the underlying distribution of values and the selected sensitivity to detect change (such as significance level, power, and minimum detectable difference). The statistical methods used to select sample sizes are summarized below. Details of the power analysis are in **Appendix A**.

5.3.1 Statistical Power Analysis

Statistical power analysis is the evaluation of the ability to detect statistically significant results when real differences exist in the variable being considered. Use of power analysis evaluates the statistical implications of alternative sampling strategies (that is, the number of sample locations). Concentrations of total PCB in surface sediment in the River-wide FS Report (Tetra Tech 2019c) provided the input for this power analysis to satisfy the goals of the interim remedial actions in the IROD to reduce concentrations of total PCB congeners in sediment. The power attained for the other COCs (dioxin-like PCB TEQ, dioxin TEQ, and chlordane) is presented in **Appendix A**.

The recommended number of surface sediment samples for the B/P monitoring were derived through statistical power analysis in accordance with EPA (1996) guidance. Tetra Tech evaluated a range of values of false positive rate, power, and percent change (delta) to determine the most robust sample sizes. The recommended sample sizes for baseline (Time 0) surface sediment in each segment of the study area are shown in **Table 5.2**. Note that in practice, a 10-sample minimum is considered appropriate to cover uncertainty in quantifying the variance of future samples from the variance in the RI dataset. The theoretical number of six samples indicated by the power analysis for Kingman Lake OU was therefore adjusted to 10 samples (refer to **Table 5.2**). The minimum 10 samples will be collected in the Reference Area. The recommended sample sizes apply to the principal spatial indicator, which is surface sediment. The number of other samples will vary by indicator (discussed in **Section 6.0** below) and time period. Following baseline (Time 0) and the first year of monitoring (Time 1), DOEE will review and reevaluate the recommended number of samples needed for long-term performance monitoring.

Table 5.2 Surface Sediment Sample Sizes and Distribution

River Segment	Significance (%)	Power (%)	Delta[1] (%)	Minimum Number of Sediment Samples (Raw Calculated)	Minimum Number of Sediment Samples to be Collected for Baseline (Time 0) and First Year of Monitoring[2]
Reach 123/456	5	80	25	11	11
Reach 67	5	80	50	7	10
Washington Channel	5	80	25	20	20
Kingman Lake	5	80	25	6	10
Northeast and Northwest Branches Reference Area	Not applicable				10

1. Delta is the percent change expected to be detectable at the given power and sample number.
2. Following baseline (Time 0) and the first year of monitoring (Time 1), DOEE will review and reevaluate the recommended number of samples needed for long-term performance monitoring.

5.3.2 Sample Locations

At least one composite sediment sample will be collected within each predetermined polygon in each OU, as described in **Section 6.0**, with each polygon representing a fixed sampling area over the course of the monitoring program (unless intentionally altered by an adaptive management decision). The composite sediment sample will subsequently support *ex-situ* porewater analysis, toxicity testing, and bioaccumulation testing. Within the adaptive management framework, results obtained during the baseline sampling will be used to refine subsequent components of the performance monitoring. It is expected that over time, the number of sample polygons will be reduced to reflect field conditions (for example, attainment of the RAOs, low variability among adjacent polygons, or other metrics). Such situations are described for each indicator in **Section 6.0**. Forage fish, game fish, and surface water sampling locations will be pre-determined within the OU, as discussed in **Section 6.0**.

6. Monitoring Locations and Protocols

Baseline monitoring is designed to evaluate concentrations of COCs in the OUs and Reference Areas before any remediation is implemented; baseline sampling events are referred to as Time 0. The EAAs are included in the baseline monitoring as a separate stratum in each OU to support the interpretation of post-remediation concentrations. Baseline (Time 0) and repeated performance (Time 1, 2, etc.) samples from composited locations distributed within a polygon will support characterization and assessment of remedial efficacy. Contemporaneous monitoring of multiple indicators provides the best opportunity for detecting correlations between one or more indicators. However, variations to this general pattern are discussed as appropriate in the sections below.

Each section below presents the (1) reasons for monitoring; (2) sampling locations; (3) monitoring protocols and metrics; and (4) adaptive management decision points for the seven key indicators: surface sediment and porewater (**Section 6.1**); surface water (**Section 6.2**); toxicity to benthic invertebrates (**Section 6.3**); bioaccumulation in *Lumbriculus* (**Section 6.4**); forage fish (**Section 6.5**); and game fish fillets (**Section 6.6**).

6.1 Surface Sediment and Porewater

6.1.1 Reasons for Monitoring Surface Sediment and Porewater

Surface sediment and porewater are addressed together in this section because the sampling events will be co-located in place and time. Concentrations of COCs in sediment and porewater are separate indicators of potential exposure to benthic organisms. Analytical results for surface sediment and porewater samples will be used to further refine DOEE's food web model for forage fish and game fish (Bokare et al. 2021, Ghosh et al. 2022). Surface sediment will also be used to calculate the SWAC, which will allow DOEE to monitor the effectiveness of the remedy (refer to **Appendix A.3** for SWAC calculations).

6.1.2 Surface Sediment and *Ex-situ* Porewater Sampling in non-EAAs

Composited surface sediment samples will be collected from the non-EAA polygons by Tetra Tech from 0-6 inches below ground surface. The number of samples in the non-EAA polygons is based on power analysis (refer to **Section 5.3.1** and **Appendix A**) as follows: 11 non-EAA polygons in the Main Stem Reach 123/456 (**Figure 6.1**);[10] 10 non-EAA polygons in the Main Stem Reach 67 (**Figure 6.2**);[11] 20 non-EAA polygons in Washington Channel (**Figure 6.3**);[12] 10 non-EAA polygons in Kingman Lake (**Figure**

[10] For **Figure 6.1**, four sediment polygons were equally spaced along the channel from the confluence with the Potomac River to South Capitol Street Bridge, three polygons were then placed between the South Capitol Street Bridge, 11th Avenue Bridge, and the CSX Bridge, two polygons were equally spaced between the CSX Bridge and Benning Road Bridge, one polygon was positioned between the Benning Road Bridge and Hickey Run (tributary), and the last polygon was positioned between Hickey Run and Nash Run (tributary).

[11] For **Figure 6.2**, three sediment polygons were equally spaced along the channel from Nash Run to Lower Beaverdam Creek (tributary), three polygons were equally spaced between Lower Beaverdam Creek and Dueling Creek, and four polygons were positioned between Dueling Creek and Bladensburg Waterfront Park.

[12] For **Figure 6.3**, eight sediment polygons were equally spaced on either side of the centerline of the channel between Fort McNair and the confluence with the Anacostia River; the remaining 12 polygons were positioned around and in between the Washington Channel EAAs.

6.4);[13] and 10 polygons in the Reference Area **(Figure 6.5)**.[14] As currently presented in **Figures 6.1 through 6.4**, non-EAA polygons are adjacent to upland PECSes, which represented by the beige colored polygons called "Cleanup Site Boundary (land based portion)" in the figures. In the future, as these PECSes implement cleanup remedies in the river (as well as upland), the non-EAA polygons presented in this B/P Monitoring Plan will be adjusted to exclude any future areas remediated at a PECS.

One sediment composite sample will be collected from each of 61 non-EAA polygons, generating 61 sediment composite samples. Each sediment sample will be made up of a composite of six surface grabs from semi-randomly selected locations within the polygon. Care will be taken to ensure that the six locations that make up the composite sample provide adequate coverage of the polygon. Surface sediment samples will be collected from the top six inches of the river bottom to represent the most biologically active zone of the sediment (EPA 2005, Fetters et al. 2020). Incremental sampling methodology (ISM) was considered but rejected because of technical infeasibility and elevated costs. Each composite sediment sample will be analyzed for COCs, PAHs, and TOC (**Table 6.1)**. A portion of the composited sediment sample will then be tumbled with an *ex-situ* passive sampler, generating 61 *ex-situ* composite porewater samples, as shown in **Table 6.1**. It is anticipated that baseline porewater samples collected at Time 0 and porewater samples collected in 2021 and 2022 from UMBC will be evaluated together to examine PCB trends (UMBC passive samplers were not analyzed for chlordane or dioxins and furans; Lombard et al. 2022). (The same composite sediment samples will also be used to test for toxicity and bioaccumulation using benthic invertebrates [refer to **Sections 6.3** and **6.4,** respectively]).

Table 6.1 Surface Sediment and Porewater Locations and Samples in non-EAAs

River Segment	Number of Non-EAA Polygons	Corresponding Number of Non-EAA Sediment Composite Samples Analyzed by Laboratory	Corresponding Number of Non-EAA *Ex-situ* Porewater Samples Analyzed by Laboratory	Figure Reference
Reach 123/456	11	11	11	**6.1**
Reach 67	10	10	10	**6.2**
Washington Channel	20	20	20	**6.3**
Kingman lake	10	10	10	**6.4**
Northeast and Northwest Branches (Reference Areas)	10	10	10	**6.5**
Total Number of Samples Analyzed by Laboratory	--	61	61	--

6.1.3 Surface Sediment and *In-situ* Porewater Sampling in EAAs

Sediment and porewater sampling in the EAA polygons will be determined following the remedial design. Sampling techniques in the EAAs may vary depending on the remedy implemented. For example, if direct application of activated carbon is placed in the EAA on the sediment surface, then *in-situ*

[13] **For Figure 6.4**, three sediment polygons were equally spaced along the channel between the confluence with the Anacostia River and Heritage Island, three polygons were positioned around the Kingman Lake EAAs between Heritage Island and the Benning Road Bridge, and four polygons were positioned north of Benning Road Bridge.
[14] For **Figure 6.5**, five sediment polygons were placed in the Northeast Branch and five polygons were placed in the Northwest Branch, equally spaced along the channel.

porewater samplers (to measure the bioavailable COC concentrations in the porewater) would be more appropriate than a sediment sample, which would invariably include activated carbon. In addition, EAAs with a sand cap would require different sampling techniques than EAAs capped with armor.

For planning purposes, the B/P Monitoring Plan assumes that the two Kingman Lake EAAs will be treated with direct application of activated carbon and sampled with *in-situ* passive samplers (no sediment samples will be collected) during baseline sampling and performance monitoring sampling. Up to six *in-situ* passive samplers will be deployed in each Kingman Lake EAA (advanced 0-6 inches below the sediment surface). Following deployment, the samplers will be retrieved, and the samplers in each corresponding EAA will be composited, yielding two *in-situ* porewater samples, which will be analyzed for COCs. The B/P Monitoring Plan assumes that the remaining EAAs in Washington Channel and the Main Stem will be treated with a sand cap (for planning purposes, it assumes no armor[15]) and sampled with a composite sediment sample and *ex-situ* passive sampler for porewater (during baseline and performance monitoring sampling) as described in **Section 6.1.2**, yielding nine composite sediment samples that will be analyzed for COCs, PAH, and TOC and nine corresponding *ex-situ* porewater samples that will be analyzed for COCs, as shown in **Table 6.2**. It is anticipated that baseline porewater samples collected at Time 0 and porewater samples collected in 2021 and 2022 by UMBC will be evaluated together to examine PCB trends (UMBC passive samplers were not analyzed for chlordane or dioxins and furans; Lombard et al. 2022).

[15] The assumption of no armoring is strictly for planning purposes only to develop a sample count. The remedial design will determine the extent and need of armoring in each EAA. Sampling tools and techniques will be adjusted once the remedial design is completed.

Table 6.2 Surface Sediment and Porewater Locations and Samples in EAAs

River Segment	Number of EAA Polygons[1]	Corresponding Number of EAA Sediment Composite Samples Analyzed by Laboratory	Corresponding Number of EAA *Ex-situ* Porewater Samples Analyzed by Laboratory	Corresponding Number of EAA *In-situ* Porewater Samples Analyzed by Laboratory	Figure Reference
Reach 123/456	6	6	6	0	**6.1**
Reach 67	0	0	0	0	**6.2**
Washington Channel	3	3	3	0	**6.3**
Kingman lake	2	0	0	2	**6.4**
Northeast and Northwest Branches (Reference Areas)	0	0	0	0	**6.5**
Total Number of Samples Analyzed by Laboratory	--	9	9	2	--

1. Sediment and porewater sampling in the EAA polygons will be determined following the remedial design. Sampling techniques in the EAAs may vary depending on the remedy implemented. For planning purposes, the B/P Monitoring Plan assumes that the two Kingman Lake EAAs will be treated with direct application of activated carbon.

6.1.4 Surface Sediment and Porewater Monitoring Protocols and Metrics

Collection and analysis of the composite sediment and porewater for performance monitoring in non-EAA and EAA polygons (Time 1 and thereafter) will follow the same procedures as in Time 0. The B/P monitoring protocols for surface sediment and porewater are summarized in **Table 6.3**; analytical methods and data interpretation are discussed in **Section 7.1.**

Table 6.3 B/P Monitoring Protocol for Surface Sediment and Porewater

Time 0 (Baseline)	**Non-EAA Polygons**: One composite sediment sample and one corresponding *ex-situ* passive sampler from each non-EAA polygon. Baseline porewater samples collected at Time 0 and porewater samples collected in 2021 and 2022 from UMBC will be evaluated together to examine PCB trends (Lombard et al. 2022).
	EAA Polygons: One composite sediment sample and one corresponding *ex-situ* passive sampler from each EAA polygon in Washington Channel and the Main Stem. One composite *in-situ* passive sampler (no sediment) from each EAA polygon in Kingman Lake. Baseline porewater samples collected at Time 0 and porewater samples collected in 2021 and 2022 from UMBC will be evaluated together to examine PCB trends (Lombard et al. 2022).
Time 1 (Performance)	Collection and analysis of composite sediment and porewater in Time 1 will follow the same procedures as in Time 0, with composite samples comprising of sediment from six new semi-randomly selected locations within each polygon. If warranted, the sampling techniques in the EAAs will be adjusted to account for the implemented remedy.
Time 2 (Performance)	Performance monitoring will continue every two to three years until downward trends are observed in sediment and porewater. DOEE will also review and reevaluate the recommended number of samples needed for performance monitoring using the baseline (Time 0) and first year of performance monitoring (Time 1).

6.1.5 Adaptive Management Decision Points

The IROD identified surface sediment as the principal ecological exposure pathway and the target medium for remediation. The sediment PRGs for human consumption of fish were developed by modeling transfer of COCs from sediment through the food web to game fish. One pathway by which hydrophobic COCs enter the food web is through incidental consumption by benthic organisms of sediment and other organic particles contaminated through the sorption of these COCs. Many benthic invertebrates and fish ingest substantial amounts of sediment while burrowing, foraging, and spawning in the river. Although filter-feeding fish and invertebrates also bioaccumulate COCs adsorbed to suspended sediment as they feed (Zhai et al. 2020, Fadaei et al. 2017), the River-wide FS Report focused on sediment as the primary exposure route because bed sediment is more stable and amenable to remediation than suspended sediment or porewater (Tetra Tech 2019c). Reducing concentrations of COCs in bed sediment or interrupting exposure of organisms to COCs in bed sediment will reduce direct risk to benthic invertebrates and fish and limit transfer of COCs through the food web to human consumers of fish.

Porewater COC concentrations may represent the bioavailable COC concentrations in sediment under some conditions. Porewater is of interest as an exposure pathway to infauna separate from but related to sediment. Porewater is also included as an indicator in the B/P Monitoring Plan to document the correlation of concentrations of COCs in *ex-situ* porewater and sediment. If porewater and sediment concentrations of COCs covary predictably, DOEE may modify subsequent sampling events within the adaptive management framework. Equilibrium partitioning (EqP) theory states that dissolved concentrations of hydrophobic COCs (for example, PCB congeners and dioxin congeners) in porewater will correlate with the organic carbon content in sediment, with the type of organic carbon, plant material, or soot and chars that will influence the partitioning between sediment and porewater. Under the assumption of EqP, trends in sediment concentrations over time are expected to be reflected in porewater concentrations (DiToro et al. 1991, EPA 2012a and 2012b, Mayer et al. 2014). However, this expectation is not always met. Benthic organisms that ingest sediment can be exposed to and bioaccumulate concentrations of COCs higher than those predicted by refined EqP theory (Sormunen et al. 2008).

6.2 Surface Water

6.2.1 Reasons for Monitoring Surface Water

Surface water will be monitored to assess the direct exposure of fish and benthic invertebrates to COCs in surface water. The relative contribution of surface water as a bioaccumulation pathway for the COCS in the ARSP study area is unknown. Fewer than 10 percent of the RI surface water samples analyzed in the RI exceeded DOEE's surface water quality criterion (WQC) for aquatic life for dioxin-like PCB TEQ, dioxin TEQ, or PAHs; concentrations of total PCB in surface water did not exceed the chronic WQC (Tetra Tech 2019a). Effects on growth and behavior of newly hatched zebrafish fry exposed to surface water from the ARSP study area under laboratory conditions suggested long-term sublethal stress in these fishes (Wilken et al. 2020). Analytical results for surface water samples will be used as inputs to DOEE's food web model for forage fish and game fish (Bokare et al. 2021, Ghosh et al. 2022).

6.2.2 Sampling Locations and Number of Samples

One *in-situ* surface water sampler will be deployed and collected at each of 18 locations across the Study Area, as shown in **Table 6.4** and **Figure 6.6**. Surface water locations are co-located with locations previously sampled in 2021 and 2022 by UMBC. It is anticipated that baseline surface water samples collected at Time 0 and surface water samples collected in 2021 and 2022 by UMBC will be evaluated together to examine PCB trends (UMBC passive samplers were not analyzed for chlordane or dioxins and furans; Lombard et al. 2022). Surface water samplers will be deployed and collected by Tetra Tech or in collaboration with UMBC.

Table 6.4 Surface Water Sampling Locations and Samples

River Segment	Number of Surface Water Locations	Corresponding Number of Surface Water Samples Analyzed by Laboratory	Rationale for Selected Locations
Reach 123/456	6	6	Co-located to the extent possible with Lombard et al. 2022 surface water sampling locations (ARNK, ARX4, ARSK, ARX5, AR11ST, and ARHP)
Reach 67	3	3	Co-located to the extent possible with Lombard et al. 2022 surface water sampling locations (ARBL, ARX2, and ARLB)
Washington Channel	3	3	Co-located to the extent possible with Lombard et al. 2022 surface water sampling locations (WAC1 and WAC2) plus one location at Haines Point
Kingman Lake	4	4	Co-located to the extent possible with Lombard et al. 2022 surface water sampling locations (KL22-4, KL22-6, KL22-7, KL22-9)
Northeast and Northwest Branches Reference Area	2	2	Co-located to the extent possible with Ghosh et al. 2020 surface water sampling locations (NWB and NEB)
Total Number of Samples Analyzed by Laboratory	--	18	--

6.2.3 Surface Water Monitoring Protocols and Metrics

The surface water samplers will be placed 25 to 50 cm above the river bottom, in accordance with EPA guidelines (2012b). Passive samplers will be deployed for a minimum of 28 days by Tetra Tech or in collaboration with UMBC. The B/P monitoring protocols for surface water are summarized **Table 6.5.** Further details on sampling, analyses, and data interpretation are in **Section 7.1.**

Table 6.5 B/P Monitoring Protocol for Surface Water Monitoring

Time 0 (Baseline)	In Time 0, surface water will be deployed at select locations (refer to **Table 6.4**). At each location, an *in-situ* passive surface water sampler will be deployed for a minimum of 28 days; surface water passive samplers will be analyzed for all COCs. Baseline surface water samples collected at Time 0 and surface water samples collected in 2021 and 2022 from UMBC will be evaluated together to examine PCB trends (Lombard et al. 2022). Results will be compared with chronic surface WQC for aquatic organisms and wildlife in DOEE (2016), EPA (2018), and NPS (2018).
Time 1 (Performance)	The number of surface water samples in Time 1 will be determined by the range and variability in surface water results reported in Time 0. Any surface water location that exceeds one or more chronic WQC in Time 0 will be sampled again in Time 1 and analyzed for the COCs that exceeded the WQC.
Time 2 (Performance)	Performance monitoring will continue every two to three years until downward trends are observed in surface water. DOEE will also review and reevaluate the recommended number of samples needed for performance monitoring using the baseline (Time 0) and first year of performance monitoring (Time 1).

6.2.4 Adaptive Management Decision Points for Surface Water Monitoring

Concentrations of most COCs in surface water in the tidal river were higher in samples collected during the dry season than in wet season samples (Tetra Tech 2019a). The ARSP RI Report (Section 8) and the surface water passive sampling results in Ghosh et al. (2020) document variability seasonally and spatially in the ARSP water bodies. Data from DOEE's background study (Tetra Tech 2021a and 2021b) were reviewed to confirm the results of the RI and Ghosh et al. (2020) sampling results. Concentrations, availability, and toxicity of COCs in surface water are influenced by precipitation, runoff, and other dynamic processes in the river. Concentrations of COCs in surface water may increase immediately following events that disturb the bed sediment or increase suspended sediment, including the interim remedial actions themselves, extreme storm or flood events, or other construction/restoration events in the river. Once remediation is complete and sources have been controlled to some extent, pulses of COCs in surface water and suspended sediment are expected to decrease (Hooper et al. 2016).

Given the expected fluxes in concentrations of COCs in surface water following remediation, direct comparison of sample results with chronic WQC may not be given full weight in Time 1. Over time, however, *in-situ* surface water passive samplers are expected to show reduced concentrations of COCs. As shown in **Table 6.5**, Surface water monitoring protocols may be adjusted over time in response to previous monitoring results. The protocols for surface water sampling beyond Time 0 will be determined through an adaptive management decision process.

6.3 Benthic Invertebrate Toxicity

6.3.1 Reasons for Monitoring Benthic Invertebrate Toxicity

As discussed in the IROD, RAO 3 aims to reduce risks associated with COCs in sediment to levels protective of benthic and aquatic invertebrates based on direct chronic exposure to surface sediment and surface water (DOEE 2020). Infaunal invertebrates, which live in the sediment, are known to be sensitive to toxic effects of COCs (Ingersoll et al. 2014, Tetra Tech 2019a). Laboratory toxicity tests of chironomids, amphipods, and oligochaete worms exposed to surface sediment in the study area demonstrated adverse effects on survival, growth, and reproductive output (Tetra Tech 2019a).

Achieving RAO 4 (*Reduce risks associated with COCs in surface sediment to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey*) also requires that toxicity to benthic invertebrates be reduced because benthic invertebrates are critical components of riverine food webs. The role of benthic invertebrates in the tidal Anacostia River food web was demonstrated in the BERA through examination of the stomach contents of 61 individuals of eight species of forage fish and mid-trophic level fish (Tetra Tech 2019a). Stomach contents varied among fish species, as expected based on known dietary preferences, but soft-bodied infaunal species, such as chironomids were seen in most samples. The cyprinids and fundulids (that is, eastern silvery minnow [*Hybognathus regius*], mummichog [*Fundulus heteroclitus*], and banded killifish [*Fundulus diaphanus*]) ate predominately chironomids and other small soft-bodied infaunal invertebrates. All the centrarchids (such as pumpkinseed [*Lepomis gibbosus*], bluegill [*Lepomis macrochirus*], or redbreast sunfish [*Lepomis auritus*]) contained chironomids as well as mollusks and other invertebrates (Tetra Tech 2019a). Therefore, to achieve RAO 3 and RAO 4, toxicity to benthic invertebrates must be reduced to acceptable levels (relative to laboratory-provided clean control sample results for each test [ASTM 2006]).

6.3.2 Sampling Locations and Number of Samples

Half of the non-EAA surface sediment polygons described in **Section 6.1** will be randomly selected for toxicity testing during baseline monitoring (Time 0). Composite sediment samples will be collected as described in **Section 6.1,** but the volume of sediment in the composite will be increased so that the same composite material can be used for multiple tests including chemical concentrations, *ex-situ* porewater concentrations, five benthic invertebrate toxicity endpoints, and bioaccumulation. In total, 31 non-EAA polygons will be selected for toxicity testing: six polygons in Reach 123/456, five polygons in Reach 67, ten polygons in Washington Channel, five polygons in Kingman Lake, and five polygons in the Reference Area. Testing will be conducted in each selected non-EAA polygon, yielding 31 toxicity tests.

6.3.3 Benthic Invertebrate Toxicity Monitoring Protocols and Metrics

Toxicity tests will be conducted under controlled laboratory conditions, consistent with the ARSP RI and other freshwater sediment PCB sites (Steevens et al. 2020, Ingersoll et al. 2014). Survival, growth, and reproductive endpoints will be measured in a 42-day chronic test with the amphipod, *Hyalella azteca*. A 10-day test with the midge, *Chironomus dilutus*, will measure survival and growth. Test methods are described in **Section 7.1.4**.

Toxicity will be defined relative to the laboratory-provided clean control sample results for each test (ASTM 2006) and the Reference Area samples. Polygons in which the Time 0 composite sediment sample are identified as toxic will be retested in Time 1. Composite sediment samples from polygons that were indicated as toxic during Time 1 will be tested in Time 2. The B/P monitoring protocols are summarized in **Table 6.6.**

Table 6.6 B/P Monitoring Protocol for Invertebrate Sediment Toxicity Test

Time 0 (Baseline)	Composite sediment samples from selected (non-EAA) polygons will be tested for toxicity to benthic invertebrates measured by five endpoints (amphipod survival, growth, and reproduction; chironomid survival and growth).
Time 1 (Performance)	Sediment samples from polygons where any of the five endpoints indicate toxicity in Time 0 will be re-tested in Time 1. Polygons in which no endpoint indicates toxicity relative to laboratory-provided clean control samples in each test will be considered non-toxic and may be dropped from further benthic invertebrate toxicity monitoring.
Time 2 (Performance)	Performance monitoring will continue every two to three years until downward trends are observed in toxicity. DOEE will also review and reevaluate the recommended number of samples needed for performance monitoring using the baseline (Time 0) and first year of performance monitoring (Time 1).

6.3.4 Adaptive Management Decision Points

DOEE will continue to test toxicity of sediment in all polygons that previously showed toxicity every two to three years until downward trends are observed in toxicity. Other considerations that may affect the long-term performance monitoring may include: (1) toxicity is reduced to acceptable levels (relative to laboratory-provided clean control samples in each test); (2) a substantial decreasing trend in toxicity is observed within the OU; (3) a factor other than COC concentrations is identified as the toxic agent (refer to **Section 7.1.4**); or (4) a weak correlation is observed between the toxicity test and the sediment concentrations, suggesting that toxicity tests have limited utility as a performance indicator. Toxicity test results will be interpreted within the context of other indicators.

6.4 Bioaccumulation in Benthic Invertebrate Tissues

6.4.1 Reasons for Monitoring Benthic Invertebrate Tissue

Benthic invertebrates bioaccumulate hydrophobic COCs from surface water, porewater, and ingestion of contaminated sediment and food items. The relative importance of each of these pathways varies by species, COC, season, and other factors (for example, reproductive condition) (Fadaei et al. 2017, Knauer et al. 2017, Liebens et al. 2011, Sormunen et al. 2008; Leppanen and Kukkonen 1998). Infaunal and epifaunal benthic invertebrates have been shown to bioaccumulate all COCs identified in the IROD (DOEE 2020). Total PCB, dioxin-like PCB TEQ, dioxin TEQ, and chlordane were detected in all *Lumbriculus* samples in the ARSP RI, with the highest concentrations in the Main Stem OU Reach 123/456; PAHs were infrequently detected in invertebrate tissues (Tetra Tech 2019a).

Direct measures of tissue concentrations in the benthic oligochaete worm, *Lumbriculus variegatus,* serves two purposes in the B/P Monitoring Plan: (1) tracking the trend in tissue concentrations over time to evaluate the efficacy of interim remedial actions in reducing bioaccumulation of COCs; and (2) deriving OU-specific biota sediment accumulation factors (BSAFs) as inputs to the food web model that will be used to estimate future concentrations in game fish and forage fish (Bokare et al. 2021, Ghosh et al. 2022). To achieve RAO 4, one or more exposure pathways of COCs from sediment to fish must be reduced. Remediation of surface sediment by dredging or capping as discussed in the IROD or active treatment to immobilize COCs (discussed in the forthcoming ESD) is expected to reduce the transfer of

COCs from sediment and/or porewater to benthic invertebrates, forage fish, and game fish (DOEE 2020, DOEE 2023).

6.4.2 Sampling Locations and Number of Samples

The same composite surface sediment samples used for the amphipod and midge toxicity tests (refer to **Section 6.3**) will be used to measure bioaccumulation of COCs in a 28-day controlled laboratory bioaccumulation test with *Lumbriculus*. In total, 31 non-EAA polygons will be selected for bioaccumulation testing, including six polygons in Reach 123/456, five polygons in Reach 67, ten polygons in Washington Channel, five polygons in Kingman Lake, and five polygons in the Reference Area. Testing will be conducted in each selected non-EAA polygon, yielding 31 bioaccumulation tests.

6.4.3 Bioaccumulation Monitoring Protocols and Metrics

During baseline monitoring (Time 0), whole-body tissue concentrations of COCs in surviving *Lumbriculus* will be measured after 28 days of exposure to the corresponding composited sediment sample from each of the selected polygons. The invertebrate tissue results will be evaluated along with the corresponding sediment concentration and *ex-situ* porewater concentration (which will measure the amount of COC that is bioavailable). BSAFs will also be calculated as the lipid-normalized ratio of the concentration of a COC in *Lumbriculus* tissue to the organic carbon-normalized concentration in the composite sediment sample. An OU-specific BSAF will be calculated to use in the food web model (along with concentrations in forage fish tissue and other ingestion sources) to estimate the concentration of a COC in *Lumbriculus* tissue that would meet the human consumption guidelines for game fish and the wildlife protection values for other fish populations (Bokare et al. 2021, Ghosh et al. 2022). Using a standard laboratory organism such as *Lumbriculus* simplifies inputs to the food web model but may underestimate or overestimate the ingested dose to fishes that feed on chironomids and other benthic organisms. Laboratory-derived BSAFs for *Lumbriculus* were comparable to those in field-collected oligochaetes (Burkhard et al. 2012). However, generalizing *Lumbriculus* results to the river-wide food web is not straightforward because tissue concentrations vary widely among benthic species. The 95 percent upper confidence limit on the mean (95UCL) of laboratory-exposed *Lumbriculus* tissue and field-collected snails, clams, and crayfish varied widely in the ARSP study area. The 95UCL dioxin TEQ (0.00089 µg/kg) was higher in forage fish than in all invertebrates analyzed (Tetra Tech 2019a). As necessary, porewater concentrations (measured with passive samplers; refer to **Section 6.1**) may be used in the food web model as a surrogate of the amount of bioavailable PCB concentrations (Schmidt and Burgess 2020). Their study suggested that present methods for accurately predicting concentrations of dioxins, chlordane, and PAHs in fish and invertebrates from passive sampler results are limited.

Lumbriculus bioaccumulation tests will be repeated in Time 1, Time 2, and thereafter until a clear decreasing trend is observed or until the back-calculated target concentrations of COCs in *Lumbriculus* tissues are achieved (refer to **Section 6.4.4**). An uninterrupted decline in *Lumbriculus* tissue concentrations from Time 0 through Time 1 and Time 2 will be considered a meaningful trend. The B/P monitoring protocols are summarized **Table 6.7**; analytical methods and data interpretation are discussed in **Section 7.1.5**.

Table 6.7 B/P Monitoring Protocol for Invertebrate Sediment Bioaccumulation Test

Time 0 (Baseline)	The same composite sediment samples used to test toxicity to the amphipod and midge will be used for *Lumbriculus* bioaccumulation tests. BSAFs will be calculated at the OU level as inputs to the food web model (Bokare et al. 2021, Ghosh et al. 2022).
Time 1 (Performance)	Composite surface sediment samples from the same polygons tested in Time 0 will be tested in Time 1. *Lumbriculus* tissue concentrations from Time 1 will be compared with results from Time 0. BSAFs will be calculated to refine the food web model (Bokare et al. 2021, Ghosh et al. 2022).
Time 2 (Performance)	Performance monitoring will continue every two to three years until downward trends are observed in invertebrate tissue. DOEE will also review and reevaluate the recommended number of samples needed for performance monitoring using the baseline (Time 0) and first year of performance monitoring (Time 1).

6.4.4 Adaptive Management Decision Points

DOEE will continue to test bioaccumulation in all polygons that previously showed elevated levels of COCs in invertebrate tissue every two to three years until downward trends are observed. A decreasing trend in COC concentrations in invertebrate tissue over time would indicate that exposure of benthic invertebrates to bioavailable concentrations had been reduced and that the interim remedial action was effective.

The bioaccumulation data collected during each monitoring event will be used to establish site-specific BSAFs for the COCs. The *Lumbriculus* tissue concentrations will be input in generic dose estimates in food web model for forage fish, and the sample-specific BSAFs will be used to estimate *Lumbriculus* tissue concentrations in lieu of direct measurement in future scenarios. The food web model will be used to establish a tissue concentration goal for *Lumbriculus* that could potentially result in forage fish tissue concentration expected to meet RAOs (Bokare et al. 2021, Ghosh et al. 2022). Moreover, the food web model will use the *Lumbriculus* tissue concentrations to estimate trophic transfer of COCs through forage fish to game fish consumed by humans. This adaptive management decision point for benthic invertebrate tissue concentrations will be revisited following each monitoring event.

6.5 Forage Fish

6.5.1 Reasons for Monitoring COCs in Forage Fish

RAO 4 requires that risks associated with COCs in surface sediment be reduced to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey. Forage fish accumulate COCs from numerous sources, including sediment, porewater, surface water, suspended sediment, and prey. Total PCB concentrations in forage fish tissue (mummichog and banded killifish) collected in 2018-2020 by USFWS ranged from 29.3 µg/kg in forage fish collected in RI Reach 7 (Bladensburg Waterfront Marina) to 476 µg/kg in forage fish collected in the Anacostia River (adjacent to Pepco Cove). The highest total PCB (1,110 µg/kg) concentration in forage fish tissue was reported in samples collected from Lower Beaverdam Creek (Pinkney and Perry 2022). Total PCB, dioxin-like PCB TEQ, and dioxin TEQ were detected in all forage fish samples collected in the ARSP RI (Tetra Tech 2019a). Mean concentrations of total PCB in forage fish tissue samples (264 µg/kg) were intermediate between concentrations in laboratory *Lumbriculus* tissue (189 µg/kg) and field-collected clam tissue (491 µg/kg); the same pattern was observed for chlordane. Mean dioxin TEQ (0.00089 µg/kg) was higher in forage fish tissue than in all invertebrate tissue analyzed (Tetra Tech 2019a).

Forage fish in the B/P monitoring area are exposed to COCs throughout their lives. Many fishes in the river hatch from eggs laid directly on the sediment and are closely associated with sediment as newly-hatched fry. Bioaccumulation of COCs from sediment and other environmental media varies among fish species and within a species by life stage, season, and sometimes sex (Madenjian et al. 2016), although the relative importance of the pathways is not well understood for most species. Bioaccumulation and retention of COCs is influenced by physiochemical features of the sediment, selected prey sources, and behavior of species and individuals. In some forage species, such as the mummichog, females transfer PCB to their eggs, which can extend the potential for adverse effects to individuals prior to being exposed to sediment (Couillard et al. 2011). Maternal transfer of dioxin also occurs in the American eel (*Anguilla rostrata*) (Freese et al. 2017), the Pacific sand lance (*Ammodytes personatus*) (Liedtke and Conn 2021), and other fish. The effects of dioxin-like PCB and dioxin and furan congeners on fish are thought to be additive (Berninger and Tillett 2019).

Concentrations of COCs in passive samplers in surface sediment and surface water in the Passaic River, New Jersey, were compared with concentrations in fish to distinguish the relative contributions of surface water, porewater, and prey to tissue concentrations of forage fish (such as eastern silvery minnow and mummichog), mid-level predators (such as white perch [*Morone americana*] and sunfish [*Lepomis*]), and anadromous game fish (such as striped bass [*Morone saxatilis*] and American eel) (Khairy et al. 2014). The relative importance of water and sediment as transfer pathways varied by COC. The concentration of low molecular weight (LMW) PAHs in fish tissue most closely matched dissolved fractions in surface water and porewater. Conversely, concentrations of high molecular weight (HMW) PAHs and higher-chlorinated PCB and dioxin congeners were poorly predicted by dissolved concentrations. These heavier compounds were barely detected in surface water or porewater but appeared in both sediment and fish tissues at similar levels. Sediments were determined to be a substantial source of heavier organic compounds to fish (Khairy et al. 2014). In a subsequent study in the Passaic River, lipid-normalized concentrations of several dioxin and furans and PCB congeners (including dioxin-like PCB congener numbers 118 and 105) were too high to have been attributable to porewater alone, indicating that ingestion was an important bioaccumulation pathway in fish and decapod crustaceans (Khairy et al. 2019).

Behaviors of adult and juvenile fish that mobilize bed sediment (for example, nesting, spawning, foraging) can increase concentrations of suspended sediment in a localized area, thereby increasing the exposure of benthic forage fish to COCs adsorbed to fine particles. Filter-feeding fish and invertebrates ingest suspended sediment along with plankton from the water column as they feed (Fadaei et al. 2017, Sormunen et al. 2008). A recent study demonstrated the role of suspended sediment in transferring PAHs to fish fry when dissolved concentrations of PAHs were held constant; PAH transfer was related to the size of the suspended particles (Zhai et al. 2020).

Additional doses of sediment-associated COCs are ingested by fish that forage on snails, clams, and other benthic invertebrates that carry sediment loads in their digestive tracts (for example, pumpkinseed). One of the most common forage fish collected during the ARSP RI (eastern silvery minnow) ingests large amounts of sediment while foraging on plant material, benthic diatoms, algae, and detritus (Khairy et al. 2014). This fish has an exceptionally long intestine (Murdy and Musick 2013), indicating that sediment ingestion is a typical foraging behavior. The size and increased processing time of the eastern silvery minnow's gut can result in a substantial volume of sediment being transferred to the larger fish that eat them.

6.5.2 Sampling Locations, Number of Samples, and Target Species

Tetra Tech collected forage fish by electroshocking throughout the tidal Anacostia River to characterize species assemblages for the RI (Tetra Tech 2019a). Forage fish included banded killifish, eastern silvery minnow, pumpkinseed, and spottail shiner (*Notropis hudsonius*). All these species, except the spottail shiner, are closely associated with bed sediment throughout their lives, from egg to adult. **Figure 6.7** shows the distribution of forage fish collected during the RI. Banded killifish were predominantly collected in Washington Channel OU while eastern silvery minnow was predominately collected in Kingman Lake OU and in the Anacostia River above the CSX Bridge. Mummichog was predominately collected in the upper sections of the river. Forage fish for the B/P monitoring will include banded killifish and mummichog and may also include eastern silvery minnow and pumpkinseed, depending on species availability. Characteristics of the target forage fish collected during the RI are summarized in **Table 6.8**. It is recognized that while the forage fish were successfully collected during the RI, past fishing events are not an indicative of the success of future fishing events; for example, recent work conducted by the USFWS showed that forage fish samples were not attainable in Washington Channel in 2018-2020 (Pinkney and Perry 2022). Consequently, the number of forage fish samples collected will be dependent on fish catch.

Table 6.8 Suitable Forage Fish Species for Monitoring Whole Body Concentrations of COCs

				ARSP RI (Tetra Tech 2019a)		
Common Name	**Diet[1]**	**Home Range[2]**	**Life span (age at maturity) years[3]**	**n**	**Total Length (mm) Mean (Range)[4,5]**	**Mass (g) Mean (Range)[4,6]**
Banded killifish *Fundulus diaphanus*	benthic invertebrates (chironomids, nematodes) (a)	(a)	3-4 (<1) (a)	367	64 (36–115)	3.0 (0.9–4.7)
Mummichog *Fundulus heteroclitus*	benthic invertebrates (chironomids, nematodes), algae (a, b); opportunistic diet reflecting local habitat (c)	<30 m to 300 m over 166 days (b); 200 m (e)	3-4 (<1) (b)	165	74.5 (58–101)	6.3 (4.0–7.7)
Eastern silvery minnow *Hybognathus regius*	soft-bodied benthic invertebrates (chironomids) (a, d)	(a)	3 (2) (c)	348	105.2 (70–124)	10.5 (8.5–16.7)
Pumpkinseed *Lepomis gibbosus*	mollusks, chironomids (a)	~0.3 ha (~0.7 ac) in lake (c); 39 ha (96 ac) (d)	6-8 (1-3) (d)	213	70.4 (53–177)	32.2 (3.4–11.3)

1 **Diet references:**

(a) Tetra Tech 2019a. Remedial Investigation Report, Anacostia River Sediment Project, prepared for the DOEE.

(b) Brazner, J. and DeVita, W. 1998. PCBs, DDE (Dichlorodiphenyldichloroethylene), and mercury in young-of-the-year littoral fishes from Green Bay, Lake Michigan. *Journal of Great Lakes Research,* 24(1), 83-92.

(c) Crum et al. 2018. Growth and Movements of Mummichogs (*Fundulus heteroclitus*) Along Armored and Vegetated Estuarine Shorelines. *Estuaries and Coasts*, 41, S131-S143.

(d) New Hampshire Fish and Game. 2021b. Eastern Silvery Minnow (*Hybognathus regius*) wildlife.state.nh.us/fishing/profiles/eastern-silvery-minnow.html

2 **Home range references (refer to Section 6.5.4 for further discussion)**:

(a) Minns, C. K. 1995. Allometry of Home-Range Size in Lake and River Fishes. *Canadian Journal of Fisheries and Aquatic Sciences, 52*(7), 1499-1508. See **Section 6.5.4** for interpretation of this reference.

(b) Able, K.W., S.M. Hagan, and S.A. Brown. 2006. Habitat use, movement, and growth of young-of-the-year Fundulus spp. in southern New Jersey salt marshes: comparisons based on tag/recapture. Journal of Experimental Marine Biology and Ecology 335: 177–187

(c) Klinard, N. V., Fisk, A. T., Kessel, S. T., Halfyard, E. A., & Colborne, S. F. 2018. Habitat use and small-scale residence patterns of sympatric sunfish species in a large temperate river. *Canadian Journal of Fisheries and Aquatic Sciences, 75*(7), 1059-1069.

(d) McCairns, R. J. S., & Fox, M. G. (2004). Habitat and home range fidelity in a trophically dimorphic pumpkinseed sunfish (*Lepomis gibbosus*) population. *Oecologia, 140*(2), 271-279.

(e) Skinner, M. A., Courtenay, S. C., Parker, W. R., & Curry, R. A. 2005. Site fidelity of mummichogs (*Fundulus heteroclitus*) in an Atlantic Canadian estuary. *Water Quality Research Journal of Canada, 40*(3), 288-298.

3 **Life Span References**

(a) Life history information is limited (NatureServe 2004). Age at maturity assumed to be similar to *F. heteroclitus* because the two species hybridize (Dawley et al. 2000).

(b) Abraham, B. J. 1985. Species profiles, life histories and environmental requirements of coastal fishes and invertebrates of mid-Atlantic USA: Mummichog and striped killifish. *U.S. Fish and Wildlife Service*

(c) New Hampshire Fish and Game. 2021b. Eastern Silvery Minnow (*Hybognathus regius*) wildlife.state.nh.us/fishing/profiles/eastern-silvery-minnow.html
(d) Chesapeake Bay Program. 2021a. Pumpkinseed *Lepomis gibbosus* chesapeakebay.net/S=0/fieldguide/critter/pumpkinseed

4 Length/mass of individuals based on ARSP RI electroshocking samples in summer 2014.
5 Mean is the average of the average lengths of each sample. Range is the minimum and maximum lengths of individuals across all samples.
6 Mean is the total mass across all samples divided by the total number of individuals sampled. Range is the minimum and maximum average masses across all samples.

g	gram
m	meter
mm	millimeter
n	number of individual fish of a given species

Forage fish samples will be collected by Tetra Tech or in collaboration with USFWS. Depending on catch, up to four forage fish samples (each whole-body tissue composite will consist of a single species and sex) will be collected in each of the forage fish polygons (non-EAA and EAA) shown in **Figures 6.8 through 6.12** and **Table 6.9**. Forage fish polygons were created by joining adjacent sediment non-EAA polygons to create larger forage fish polygons to guide the field program.[16] However, within each polygon, forage fish will be collected within a half-mile of suitable habitat. When a polygon overlaps with an area previously sampled by USFWS for forage fish, Tetra Tech will (to the extent possible) focus on collecting forage fish at the same area; refer to **Figures 6.8 through 6.12** for forage fish polygons and USFWS forage fish locations (including 11A, A1, A2, BL, DC, KG, KH/KL, NE, and NW) previously sampled on the Anacostia River and Kingman Lake. It is anticipated that baseline forage fish samples collected at Time 0 and forage fish samples collected in 2020 from USFWS will be evaluated together to examine total PCB and chlordane trends (USFWS forage fish samples were not analyzed for dioxins/furans), assuming that species, sex, season, and location are consistent for Time 0 parameters.

[16] There is a total of eight EAA forage fish polygons. The two EAAs in Kingman Lake and three EAAs in Washington Channel will be sampled separately. In the Main Stem, the three EAAs in Reach 123 will be sampled together, and the two EAAs in Reach 456 south will be sampled together. The one EAA in Reach 456 north will be sampled separately.

Table 6.9 Forage Fish Sampling Locations and Samples

River Segment	Number of Forage Fish Polygons in Non-EAA	Number of Forage Fish Polygons in EAA	Corresponding Number of Forage Fish Samples Analyzed by Laboratory for All Polygons	Rationale for Selected Locations	Figure Reference
Reach 123/456	7	3	Up to 40	Within a half-mile of suitable habitat (within the polygon)	**6.8**
Reach 67	3	0	Up to 12		**6.9**
Washington Channel	5	3	Up to 32		**6.10**
Kingman Lake	3	2	Up to 20		**6.11**
Northeast and Northwest Branches Reference Area	2	0	Up to 8		**6.12**
Total Number of Samples Analyzed by Laboratory	--	--	Up to 112 (depending on catch)		

6.5.3 Forage Fish Monitoring Protocols and Metrics

The four target forage fish species were previously collected or observed in the tidal Anacostia River (Tetra Tech 2019a) and in contemporaneous DOEE-sponsored studies (Pinkney and Perry 2022). Although all mixed-species forage fish samples analyzed for the ARSP RI contained COCs, the relative whole-body concentrations of the individual target species were not reported separately. In a study of two of the species in the Anacostia watershed, Pinkney and Perry (2022) reported that banded killifish had consistently higher body burdens of total PCB and chlordane than mummichog; dioxins were not analyzed. To strengthen trend analyses and reduce uncertainty associated with interspecies variability, the B/P monitoring protocols call for the same species or set of species and same sex to be composited throughout an OU to the extent possible.

No single species is expected to be the most abundant throughout the B/P monitoring area, so flexibility in sampling in each OU is incorporated into the B/P Monitoring Plan. To reduce uncertainty associated with sex differences in bioaccumulation and tissue concentrations in forage fish, each sex will be analyzed separately (to the extent fish abundance allows). The critical element in B/P monitoring is that the *same* species and sex be sampled during the same season in a given OU over time to reduce the number of confounding variables affecting trends in concentrations of COCs attributable to interim remedial actions. For example, the eastern silvery minnow was most abundant in Kingman Lake in the ARSP RI samples (Tetra Tech 2019a). It was also collected in the Main Stem OU and is expected in the Reference Area, as it prefers sheltered backwaters with some vegetation. However, this species is not likely to be abundant enough to support monitoring In Washington Channel (Tetra Tech 2019a). Instead, the banded killifish is a more suitable target forage fish in the Washington Channel, based on collections in the ARSP RI (Tetra Tech 2019a). Conversely, the mummichog is rare in Washington Channel but abundant in the Main Stem OU Reach 67 and Reference Areas. The pumpkinseed made up about 20 percent of the forage fish collected in Kingman Lake in the ARSP RI (Tetra Tech 2019a) and is expected to support long-term monitoring there.

Sample collection will be tailored to the availability of fish. Any of the selected forage species that are abundant enough to make up a single-species, single-sex composite sample of adequate mass for the proposed analyses will be collected. At some locations, more than one sample will be collected. Decisions about which samples to analyze will be made once all samples are collected. Whole body forage fish samples will be collected by Tetra Tech or in collaboration with USFWS. The B/P monitoring protocols are summarized in **Table 6.10**; field methods, analytical protocols, and data interpretation are discussed in **Section 7.1.**

Table 6.10 B/P Monitoring Protocol for Forage Fish

Time 0 (Baseline)	Forage fish (eastern silvery minnow, mummichog, banded killifish, pumpkinseed) will be collected from suitable habitat within a polygon, representing a reasonable home range (approximately 0.5 mile of shoreline). Species may vary across OUs, and more than one forage species may be collected, but each sample will consist of a single species and sex. Species, sex, and size range will be held constant across sampling events in an OU or Reach. Baseline forage fish samples collected at Time 0 and forage fish samples collected in 2020 from USFWS will be evaluated together to examine total PCB and chlordane trends (USFWS forage fish samples were not analyzed for dioxins/furans), assuming that species, sex, season, and location are consistent for Time 0 parameters.
Time 1 (Performance)	Time 0 sampling protocol will be repeated in Time 1, matching the season, species, sex, and size of fish to the extent feasible.
Time 2 (Performance)	Performance monitoring will continue every two to three years until downward trends are observed in forage fish tissue. DOEE will also review and reevaluate the recommended number of samples needed for performance monitoring using the baseline (Time 0) and first year of performance monitoring (Time 1).

6.5.4 Adaptive Management Decision Points

DOEE will continue to monitor forage fish every two to three years until downward trends are observed in forage fish tissue. A decreasing trend in COC concentrations in forage fish tissue over time would indicate that exposure of forage fish to bioavailable concentrations had been reduced and that the interim remedial action was effective. When evaluating trends in forage fish tissue, the following collection parameters must remain consistent: same species, single sex, and consistent collection season.

Estimates of home ranges of selected forage fish in the Anacostia River were based on knowledge of fish movements, limited site-specific data, and published literature from other locations. For example, a mark-recapture study of almost 700 mummichog showed that 97 percent were recaptured within 200 m of the original capture location after 19 months (Skinner et al. 2005). Where no empirical data were available, as for the eastern silvery minnow, the general principal that home range size increases allometrically with body size in temperate freshwater fishes was applied (Minns et al. 1995). When extrapolating home range estimates from studies in lakes to the Anacostia River, the trend that fish home ranges are larger in lakes than in rivers was applied (Minns et al. 1995), as Klinard et al. (2018) demonstrated in pumpkinseed and bluegill sunfish.

The B/P Monitoring Plan calls for single sex composite samples of forage fish in recognition of the sex-related parameters that can influence tissue concentrations in fish. Within a species, female and male fish may differ in growth rate, exposure to COCs, bioaccumulation rates, site fidelity, and other parameters. Data reporting sex-specific differences are scattered throughout the published literature, often reported incidentally with the main study topic. Moreover, the type and extent of sex differences vary among species. For example, female and male mummichog were determined to have similar home ranges and diets (Skinner et al. 2012), but a large sample of mummichog collected from the Anacostia watershed reported females were consistently larger than males of a given age (Pinkney and Perry 2020). Males of several species have been shown to have higher concentrations of total PCB in muscle tissue than females (Liedtke and Conn 2021), but the inverse is also true (Madenjian et al. 2016). For these and other reasons, the most prudent B/P monitoring protocol is to analyze single-sex samples of fish. Within the adaptive management framework, single-species/single-sex samples collected in Time 0 will be evaluated for sex-linked variability in whole-body concentrations. If COC concentrations in females and males are found to be comparable and other key sample parameters (for example, percent lipid, size range) are similar, DOEE may adjust the sampling protocol as appropriate for future monitoring events.

The B/P monitoring protocol requires that forage fish samples in a given OU be collected during the same season during every monitoring event to reduce variability and uncertainty associated with annual cycles. A study of caged bluegill sunfish demonstrated seasonal differences in PCB bioaccumulation, with greater tissue concentrations in the summer than in the winter (McLeod et al. 2014). Both PCB and lipid concentrations varied substantially between spring and fall in Pacific sand lance (Liedtke and Conn 2021). A study of seasonal changes in seven small-bodied forage fish in tidal rivers in Atlantic Canada concluded that the best time to sample forage fish for monitoring environmental effects is in early spring, right before spawning (Barrett et al. 2015). Because seasonal variability in tissue concentrations in fish in the ARSP study area has not been characterized, removing seasonality as a confounding variable is prudent. As discussed above, holding season constant reduces the uncertainty in whole body COC concentrations associated with seasonal changes and allows DOEE to detect changes related to remediation rather than to extraneous uncontrolled environmental variables.

6.6 Game Fish

6.6.1 Reasons for Monitoring Game Fish Fillets

RAO 1 is to reduce risks associated with the consumption of COCs in fish from the tidal Anacostia River by people with the highest potential exposure (DOEE 2020). DOEE has implemented a fish consumption advisory for the Anacostia River, prohibiting any consumption of American eel, striped bass, or carp (*Cyprinus carpio*), and limiting the frequency of sunfish, white perch, brown bullhead, blue catfish (*Ictalurus furcatus*), Northern snakehead (*Channa argus*), and largemouth bass (*Micropterus salmoides*), meals (https://doee.dc.gov/service/fishdc). In a study conducted by USFWS, an overall decrease in total PCB concentrations (reported as a median) was observed in game fish (American eel, blue catfish, carp, largemouth bass, sunfish, and channel catfish [*Ictalurus punctatus*]) collected from 1993 to 2018. However, USFWS noted that differences in fish length (which is a surrogate for fish age) may have affected results (Pinkney 2018). Nevertheless, this study suggests that the Anacostia River is recovering due to watershed improvements across the jurisdictions.

COCs in the tissues and guts of invertebrates (crayfish, snails, clams) and forage fish prey (Tetra Tech 2019a) can be transferred to game fish through ingestion (Liedtke and Conn 2021). Achieving RAO 4 requires that risks associated with COCs in surface sediment be reduced to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey. Much of the research described in **Section 6.5** for forage fish applies equally to game fish.

6.6.2 Sampling Locations and Number of Samples

Game fish will be sampled throughout the ARSP study area and Reference Areas for the COCs. Game fish sampling will be conducted by DOEE Fisheries with their regularly scheduled sampling for fish consumption advisories. Game fish sampling locations and rationale are summarized in **Table 6.11** and shown on **Figure 6.13**. It is anticipated that DOEE Fisheries will collect edible fillet tissue (skin-off) and whole-body tissue samples. To the extent feasible, up to six game fish edible fillet (skin-off) tissue samples will be collected from each area and shared with Tetra Tech. Composite tissue samples will consist of a single species and where possible same sex. If authorized by DOEE, Tetra Tech may supplement the DOEE Fisheries catch with additional game fish samples or laboratory analyses.

Table 6.11 Game Fish Sampling Locations and Samples

River Segment	Number of Game Fish Areas	Corresponding Number of Edible Game Fish Tissue Samples	Rationale for Selected Locations	Figure Reference
Reach 123/456 and Reach 67	2	Up to 12	Separate samples from Main Stem OU above and below the CSX Bridge	**6.13**
Washington Channel	1	Up to 6	Each sample represents the entire segment	
Kingman Lake	1	Up to 6		
Northeast and Northwest Branches Reference Area	2	Up to 12	Separate samples from Northeast and Northwest Branches	
Total Number of Samples Analyzed by Laboratory	--	Up to 36 (depending on catch)	--	--

6.6.3 Game Fish Monitoring Protocols and Metrics

For game fish collected and analyzed by the DOEE Fisheries, Tetra Tech will review the available game fish (fillet and whole body) samples and select usable data to support and supplement the B/P monitoring. The ideal game fish selected for the B/P Monitoring Plan would meet the following criteria:

- Occurs in all OUs and Reference Areas at densities that can support B/P Monitoring
- Tissue composite sample consists of a single species and where possible same sex
- Is consumed by anglers on the Anacostia River

- Is exposed to sediment in early life stages (for example, eggs are laid on the river bottom)
- Has a relatively small home range
- Ingests sediment and sediment-containing prey
- Is known to bioaccumulate COCs
- Is large enough to analyze organs as well as fillets for critical body residue concentrations, should the need arise (refer to **Section 6.6.4**) (Berninger and Tillitt 2019).

No single game fish is abundant enough in all OUs and the Reference Area to support the B/P Monitoring Plan; however, three species together will satisfy the criteria above: brown bullhead, largemouth bass, and carp. Brown bullhead and carp (along with blue catfish) are commonly targeted and collected by DOEE Fisheries; however, DOEE Fisheries has noted that brown bullhead populations are in decline in recent years (Ryan 2022).

Home ranges (or foraging ranges) of game fish vary widely, exceeding several hundred miles in diadromous species (for example, striped bass and American eel) (Virginia Institute of Marine Science 2021, Chesapeake Bay Program 2021b) and between 15 and 70 miles in the nonindigenous blue catfish (Tuckey et al. 2017). Even "resident" game fish may move between the Anacostia and Potomac Rivers (Tetra Tech 2019a). Of the game fish known to be caught by anglers in the Anacostia River, the brown bullhead is reported to have a relatively small home range (about 0.7 mile) (Sakaris et al. 2005) and to bioaccumulate PCB (Pinkney 2018). Unfortunately, the brown bullhead may not be abundant or widespread enough to support B/P monitoring in all OUs (Pinkney 2021).

Like all centrarchids, the male largemouth bass shows site fidelity while digging and maintaining a nest, aerating and guarding the eggs, and protecting the hatched fry during a period of about four weeks in the spring/summer (Chesapeake Bay Program 2021c). In the Savannah River, South Carolina, the home range of largemouth bass was about 0.3 mile of shoreline; individuals remained in the original area for up to 263 days (Paller et al. 2005). A post hoc evaluation of tissue concentrations in largemouth bass from the tidal Anacostia River and the upstream Reference Areas (Northeast and Northwest Branches) in the ARSP RI showed statistically significant separation of the two populations (Tetra Tech 2019a; Table I.3.34), further supporting the assumption of limited home range in this species. The largemouth bass is the only one of the three target gamefish species expected to be abundant in the Reference Areas based on the ARSP RI (Tetra Tech 2019a). In the RI, concentrations of total PCB and dioxin TEQ were higher in largemouth bass collected in the tidal Anacostia River than in the Reference Areas; the reverse was reported for chlordane.

The carp is caught and consumed by people in DC; adults typically weigh more than 10 pounds and may range up to 30 pounds (Chesapeake Bay Program 2021d). The home range of the carp is not well-documented in U.S. rivers, but it is non-migratory and able to thrive in impoundments. The carp feeds by stirring up bottom sediments and picking detritus and small benthic invertebrates from the suspended particulates. A study of several game fish species with various diets reported highest concentrations of dioxin in the mullet (*Mugil cephalus*), likely owing to a diet high in detritus (Sezmis et al. 2014). In the Columbia River near the Hanford Superfund site, concentrations of PCB and dioxin-like

PCB congeners were higher in the carp than in other game fish (Delistraty 2013). The highest concentration of PAHs reported in game fish fillets in the ARSP RI (2019a) was in the carp.

The three target game fish species are known to bioaccumulate COCs (Pinkney et al. 2014, 2018; Delistraty 2013). As discussed in **Section 6.5** for forage fish, concentrations of COCs in game fish may vary by sex (Liedtke and Conn 2021, Madenjian et al. 2016), location (Monosson et al. 2003), season (Volta et al. 2009), diet (Johnson et al. 2007), and other parameters. To ensure that game fish fillets analyzed in the B/P Monitoring Plan are representative of the range of concentrations in fish anglers may encounter, game fish samples will be comprised of a single species and where possible same sex. To the extent feasible, both sexes of target game fish species will be collected and analyzed separately to support trend analyses over time; however, this protocol will be dependent on how DC Fisheries handles their samples.

All the selected game fish species in the B/P Monitoring Plan are consumed by anglers. Unlike the Fish Consumption Advisory studies, the characteristics of an ideal game fish for post-remediation monitoring must focus on variables that indicate a complete pathway of COCs in the ARSP study area to game fish. The nonindigenous blue catfish is popular with anglers in DC although even small individuals exceed unlimited human consumption limits for PCBs in the Potomac River. The blue catfish was excluded as a game fish indicator for the B/P Monitoring Plan because it moves extensively throughout the Chesapeake watershed (more than 62 miles) (Luellen et al. 2018; Tuckey et al. 2017). Other game fish species considered but eliminated as suitable indicators for B/P Monitoring Plan include striped bass, American eel, and yellow perch (*Perca flavescens*). Although these fish do bioaccumulate COCs and are consumed by anglers, they also spend substantial amounts of time outside the Anacostia River and so are not suitable for monitoring the efficacy of remedial actions in the ARSP study area.

Monitoring protocols for game fish are summarized in **Table 6.12**.

Table 6.12 B/P Monitoring Protocol for Game

Time 0 (Baseline)	Up to six edible (fillet) game fish samples will be collected by DOEE Fisheries (or by Tetra Tech) from each area shown in **Table 6-11**.
Time 1 (Performance)	Time 0 sampling protocols will be repeated in Time 1.
Time 2 (Performance)	Performance monitoring will continue every two to three years (or when DOEE Fisheries conducts sampling) until downward trends are observed in game fish tissue. DOEE will also review and reevaluate the recommended number of samples needed for performance monitoring using the baseline (Time 0) and first year of performance monitoring (Time 1).

6.6.4 Adaptive Management Decision Points

DOEE will continue to monitor game fish every two to three years (or when DOEE Fisheries conducts sampling) until downward trends are observed in game fish tissue. A decreasing trend in COC concentrations in edible game fish tissue over time would indicate that exposure of game fish to bioavailable concentrations had been reduced and that the interim remedial action was effective.

Reducing concentrations of COCs in game fish to meet RAO 1 is expected to take at least a decade and likely much longer, based on the history of fish consumption advisories in DC, the widespread contamination in the river, and the long lifespan of these species. Because even the most sedentary of the game fishes is likely to move among OUs, game fish concentrations will be evaluated at various spatial scales. The shortest life span of the target game fish is more than 10 years (largemouth bass), which sets a lower bound on the timeframe for observing reductions in concentrations following remediation in the EAAs and source control efforts. For example, a fish collected as a three-year-old during Time 1 would have been exposed to pre-remediation conditions as a juvenile, a period of rapid growth and organ development. PCB congeners and other hydrophobic COCs are not bioaccumulated at a steady rate; instead, the rate of uptake varies with growth rate, lipid deposition, temperature, prey assortment, and other factors. This variability in bioaccumulation rate interferes with the ability to model or predict the concentrations of COCs based on age or size of a fish. A substantial dataset collected over time will be required to adequately document the expected changes in concentrations in game fish.

Because of the extensive effort required to collect and analyze game fish, it is prudent to maximize the value of every sample. It is anticipated that DOEE Fisheries will collect both fillet and whole-body composite tissue samples. If only fillet samples are collected, Tetra Tech will request that DOEE Fisheries retain the carcass, and Tetra Tech will archive (by freezing) the carcass once the edible tissue has been collected for analysis to preserve the opportunity for DOEE or other entities to follow promising leads in the fillet results within the adaptive management decision framework. Concentrations of COCs are not necessarily equal in edible tissues and carcasses, and the relative concentrations are species and chemical dependent (Fliedner et al. 2018). For example, the carcass and edible portion of the fish together represent a whole-body concentration of COCs, which provides a line of evidence for RAO 4 separate from the forage fish whole-body results (Berninger and Tillitt 2019) and allows evaluation of exposure to people or wildlife that consume whole fish. Concentrations of COCs in the carcasses or individual organs could also provide site-specific input to DOEE's food web model and reduce uncertainty in the concentrations represented by samples comprised of predominantly muscle.

6.7 Estimated Cleanup Timeframe

The overall B/P Monitoring schedule reflects the ideal sequence of sampling and the most favorable season for each indicator. Baseline monitoring (Time 0) will be completed within a single year, to the extent possible, from early spring to late fall. In each OU, forage fish will be sampled in spring/summer, when they are most numerous and easily collected. Sediment sampling will be scheduled in late summer/fall to follow immediately after all forage fish samples have been collected. Sediment and indicators related to sediment will be monitored concurrently (*ex-situ* porewater, toxicity, and bioaccumulation) to the extent feasible. Surface water sampling will be monitored in the wet season (spring/summer). Sampling of each indicator in the Reference Area will be contemporaneous with the study area. Time 0 field sampling in a given OU will be completed by November (to the extent feasible), and remediation in the EAAs in that OU would begin within the following calendar year.

Construction of the interim remedial actions is expected to take no more than one year in each OU. The first Performance Monitoring event (Time 1) will begin the year following completion of interim remedial actions in a given OU, mirroring as nearly as feasible the same sampling dates as Time 0. For example, if forage fish were collected in Kingman Lake during March/April in Time 0, then forage fish sampling will occur during March/April in Time 1. Monitoring results will be evaluated for trends within each OU and Reference Area to identify changes over time. Empirical results will be incorporated into DOEE's food web model to improve predictions of the timeframe for achievement of RAO 1 (Bokare et al. 2021, Ghosh et al. 2022). Estimates at other sediment remediation sites indicate that it may take 20 years for edible game fish tissue to be reduced to acceptable levels (for example, Sheboygan Harbor [ITRC 2014]); however, remediation of game fish is site-specific and will depend on the game fish tissue concentrations observed during monitoring.

B/P monitoring for game fish was designed to measure COC concentrations in edible game fish tissues of select species to detect changes over time. Ideally, as sediment remediation is completed and source controls are implemented in the Anacostia watershed, game fish will be exposed to lower concentrations of COCs in sediment, porewater, surface water, and prey. Based on that assumption, concentrations of COCs in game fish fillets will also be reduced. Cleanup activities in other large rivers have demonstrated such a relationship, although the timeframe varies by location. Because game fish travel widely and can live for many years, detecting changes in COC concentrations in fillets is expected to be a long-term effort. For example, the brown bullhead reaches sexual maturity at age three (New Hampshire Fish and Game 2021a) and can live up to seven years (Chesapeake Bay Program 2021e). The largemouth bass begins reproducing within six months of hatching and may live for 25 years (Chesapeake Bay Program 2021c). Carp becomes mature at age three or four (Maryland Department of Natural Resources 2021) and typically lives 17 to 20 years (Chesapeake Bay Program 2021d). DOEE's goal is to develop quantitative tools to predict edible game fish tissue concentrations from whole forage fish to estimate tissue concentration trends in these long-lived game fish.

The time required to achieve the RAOs is influenced not only by the type of interim remedial actions implemented in the EAAs but also by source control efforts since MNR will also play an important role in downward contamination trends (refer to **Section 4.3.1).** Setting a target timeframe for meeting RAOs is primarily a policy decision that is made within the context of practical limitations on financial and logistical resources. However, the policy decision is inherently bounded by biological realities that set a minimum time for COCs to be eliminated from fish tissues. Concentrations of COCs in game fish are a function of exposure not just to sediment but to living prey. For example, mummichog larvae contain PCBs even before they hatch from the egg, and females continue to transfer PCBs to their eggs throughout their 4-year lifespan (Weis et al. 2003).

Reductions in fish tissue concentrations following remediation are not always linear; early results may show a disappointing increase in COCs due to mobilization from bed sediment. Longer term monitoring will then show the desired decreasing trends (Hooper et al. 2016). The sediment disturbance caused by active remediation (and subsequent habitat restoration, in the case of Kingman Lake) can cause a temporary surge (or an increase) in bioaccumulation of PCBs, as previously sequestered masses of PCBs are mobilized by dredging and other physical disturbances (Steuer 2000, Wenger et al. 2017). Once the environmental sources of PCBs are controlled or removed, it will take at least one generation (and likely more) of mummichogs to display the reduced body burdens of PCBs needed for the fish to be considered uncontaminated. The same process holds true for the longer-lived game fish.

DOEE developed a quantitative food web model to support estimates of how long it will take for game fish fillets to become safe for unrestricted consumption. These estimates are based on currently available input data; the baseline monitoring data will test the model predictions to actual observations. As more data becomes available, the model will be refined to predict fish concentration reductions with time (Bokare et al. 2021, Ghosh et al. 2022). However, model predictions in a given location are currently limited in number. Results of Time 0 and Time 1 monitoring of all indicators will be used to refine and strengthen modeled estimates of time to achievement of RAOs. Developers of models like Ghosh et al. (2022) have emphasized the importance of accurately accounting for fish movements and other ecological factors to improve estimates of PCB concentrations in fish tissue, particularly in complex watersheds such as the Anacostia (Li et al. 2019). Other factors that substantially influence the accuracy of modeled predictions, such as the relative importance of bed sediment, suspended sediment, porewater, surface water, and various prey types as exposure pathways, have been reported by others (Zhai et al. 2020; Fadaei et al. 2017; Khairy et al. 2014, 2019; Sormunen et al. 2008; and references within). Long-term effects of brief exposures to COCs may also confound model predictions. For example, dietary exposure to PCBs over a short term was shown to affect concentrations in tissues of channel catfish for several weeks; the increase in PCB toxicity was greatest when the fish had not eaten recently (White et al. 2020).

In summary, DOEE expects sediment and porewater to show decreasing trends in concentrations of COCs after remediation in the EAAs is completed. As source control measures are implemented, downward trends may become stronger due to MNR. Detecting the effects of remediation in forage fish will take longer (6 – 10 years) owing to (1) maternal transfer of PCBs to eggs; (2) the 4-year life span of fish; and (3) continued exposure to COCs in surface water and suspended sediment. Notable reductions in game fish will lag behind the short-term measures because of the long-life spans of these species and their movements outside the cleanup area. Largemouth bass are expected to show improvement before other game fish species first because they have the shortest life span (approximately 10 years) and a relatively small home range.

The value of performance monitoring lies in its continuity over time. No single monitoring event provides an accurate snapshot of conditions in the river. Together, though, data from repeated monitoring events can capture the variability in the natural river system and the positive effects of interim remedial actions through trend analysis (EPA 2017b, Hooper et al. 2016, ITRC 2014). B/P monitoring will continue until DOEE has adequate data to support a final ROD determining that the river is on track to meet long-term goals. If warranted, results in each OU will be evaluated separately to allow flexibility of producing separate final RODs. Actual realization of the game fish RAO may take longer to achieve, but progress toward the desired conditions is expected to be detectable within 10 years of the completion of interim remedial actions.

6.8 Summary of Indicators and Proposed Monitoring Intervals

By its nature, performance monitoring is an iterative process. Within the adaptive management framework, numerous decision points are built into the B/P Monitoring Plan so that DOEE can make the best use of all monitoring data. Intended uses of the results of each indicator and the proposed monitoring interval and duration are summarized in **Table 6.13.** When the SWAC and other indicators shows downward trends, then the interim remedial actions will be considered effective, and DOEE may consider transitioning from the IROD to a final ROD. Recovery of the ARSP will be dependent on the interim remedial action and the natural deposition of cleaner sediments in the river, allowing MNR to play an important role in downward contamination trends and overall reduction of monitoring indicators. At that time, DOEE will evaluate the extent to which RAOs have been achieved and determine the next course of action. Equations for SWAC calculations, including for two strata (for example, EAA and non-EAA portions of an OU), are provided in **Appendix A.3**.

Table 6.13 Summary of Proposed B/P Monitoring Indicator Data Use

Indicator	Monitoring Parameter	Intended Use of Data	Expected Monitoring Interval and Duration[2]
Surface Sediment	Concentrations of COCs and PAHs	Calculate OU-specific SWACs for comparison with PRGs; correlation with forage fish and game fish; trend analyses within the limitation and uncertainty of the data; input to bioaccumulation model[1]	Every two to three years until downward trends are observed in sediment
Porewater	Concentrations of COCs	Correlation with sediment, forage fish, and game fish; trend analyses within the limitation and uncertainty of the data; input to bioaccumulation model[1]	Every two to three years until downward trends are observed in porewater
Surface Water	Concentrations of COCs	Correlation with sediment, forage fish, and game fish; trend analyses within the limitation and uncertainty of the data; input to bioaccumulation model[1]	Every two to three years until downward trends are observed in surface water
Benthic Invertebrate Toxicity Tests	Survival and growth (midge and amphipod); reproduction (amphipod only)	Correlate with sediment and porewater analytical results; trend analyses within the limitation and uncertainty of the data; measure progress toward RAO 3	Every two to three years until downward trends are observed in toxicity
***Lumbriculus* Bioaccumulation Test**	Concentration of COCs in whole-body tissues	Correlate with sediment, porewater, forage fish, and game fish; refine sediment RSL for game fish ingestion[2]; input to bioaccumulation model[1]; trend	Every two to three years until downward trends are observed in invertebrate tissue

Indicator	Monitoring Parameter	Intended Use of Data	Expected Monitoring Interval and Duration[2]
		analyses; measure progress toward RAO 3 and RAO 4	
Forage Fish Tissue	Concentrations of COCs in whole-body fish tissue	Estimate cleanup timeframe; correlate with game fish; refine sediment RSL for game fish ingestion; input to bioaccumulation model[1]; trend analyses; measure progress toward RAO 4	Every two to three years until downward trends are observed in forage fish tissue
Game Fish Tissue	Concentrations of COCs in edible tissues	Estimate cleanup timeframe; correlate with forage fish; refine sediment RSL for game fish ingestion; ground truth bioaccumulation model[1]; trend analyses; measure progress toward RAO 1	Every two to three years (or when DOEE Fisheries conducts sampling) until downward trends are observed in game fish tissue

1: Bokare et al. 2021, Ghosh et al. 2022

2: Under an adaptive management framework, the process used to calculate sediment cleanup goal (which is based on game fish ingestion) may be adjusted as new information becomes available or our understanding of the link between fish and sediment is refined. Refer to Appendix A of the River-wide FS Report for more information on the calculated sediment cleanup goal (Tetra Tech 2019c).

3: Monitoring Intervals are not pre-set. Intervals will be adaptively established for the indicators based on the changes observed over time to make decisions for next sampling round and revisited during the 5-year review.

6.9 Potential Outcomes from Adaptive Management Decision Framework

Results of each B/P monitoring event will be used within an adaptive management framework to adjust and refine subsequent monitoring events. The overarching goal of such intentional learning is to continually refine monitoring protocols to acquire the most robust data possible within the schedule and budgetary confines of the project (Hooper et al. 2016). Methods and results that yield insight into processes that will support the final ROD may be refined and enhanced to increase their effectiveness while methods or indicators that are deemed redundant may be eliminated. DOEE will share any changes to the B/P Monitoring Plan with key stakeholders, including EPA and NPS, along with supporting data and rationale. Key data gaps identified during B/P monitoring will be addressed as warranted by the data.

In general, review of B/P monitoring results may indicate that DOEE should take one or more of the following actions:

- **Adjust sampling time intervals for one or more indicators.** The nature of the indicator places natural boundaries on the sampling interval to some extent. Because the target forage fish live less than five years, decreases in tissue concentrations can be detected more quickly than in longer-lived game fish. The sampling intervals for sediment and surface water are less constrained and may be adjusted based on other factors. For example, the interval between sediment sampling events could be increased if no change is detected between Time 1 and Time

2. Alternatively, if substantial change occurs between Time 1 and Time 2, DOEE will adaptively alter the frequency based on observed trends.

- **Adjust monitoring period for one or more indicators.** The B/P Monitoring Plan includes protocols for three sampling events: baseline (Time 0), initial performance interval (Time 1), and second performance interval (Time 2). The need for continued monitoring of a given indicator will be determined by the data collected. For example, if a given RAO is achieved during Time 2, the associated indicator may be dropped for future monitoring events. Conversely, if a desired trend in an indicator is observed by Time 2, but the RAO is not met, monitoring of that indicator may be continued (for example, Time 3, Time 4) with feedback from 5-year reviews.
- **Implement additional interim remedial actions.** DOEE may determine that the preponderance of evidence collected in Time 1 and 2 indicates the need for further action, or "course correction" (Hooper et al. 2016). For example, if toxicity is clearly above expectations in a given area, and COCs in sediment and porewater are unusually elevated, it may be prudent to understand the source of the influx and determine next course of action. DOEE will make such decisions as necessary to advance the project forward.
- **Refine PRGs and RALs**. Based on results of B/P monitoring and review of published research, DOEE may determine that the concentrations have reached equilibrium conditions and any additional amount of monitoring would not change the outcome. In such cases, it would be impracticable to achieve the PRGs or RALs. DOEE would initiate a discussion with stakeholders to consider revising benchmarks.
- **Modify source control efforts**. Various source control measures will be carried out by DOEE and numerous entities outside DOEE's jurisdiction until the inputs are reduced at the source(s). To the extent feasible, B/P monitoring results will be used to document and interpret the efficacy of these source control efforts. Based on the available data, if upstream sources impact remediated EAAs with recontamination potential, DOEE will initiate discussions with these entities to rethink innovative methods to implement focused source control measures, if needed.

7. Sampling, Analysis, and Data Interpretation Methods

Methods for collecting and analyzing independent representative samples for each indicator are presented in **Section 7.1**. Details are in the ARSP QAPP (Tetra Tech 2023a). Data interpretation and methods are discussed in **Section 7.2.**

7.1 Protocols and Methods for Key Indicators

Analytical protocols, methods, and standard operating procedures (SOPs) are introduced here and detailed in the ARSP QAPP (Tetra Tech 2023a).

7.1.1 Surface Sediment

Sample collection. Sediment samples will be collected and analyzed per the ARSP QAPP. One composite sample from each polygon will be comprised of surface sediment from six locations in the polygon. The anticipated total volume of sediment per sample required for each analysis or test is shown in **Table 7.1** (refer to ARSP QAPP for details on laboratory analysis and sample handling; Tetra Tech 2023a).

Table 7.1 Anticipated Volume of Sediment per Composite Sample

Indicator	Analysis	Test Method	Approximate Container Size or Mass in Liter	Minimum Analytical Mass Required (g)
Sediment concentrations	PCB Congeners	EPA Method 1668C	One 4 oz jar (or 0.12 liter)	10
	Dioxin and furan congeners	EPA Method 1613B		10
	Chlordane	EPA Method 1699	One 4 oz jar (or 0.12 liter)	5
	PAHs	SW846 Method 8270E		15
	TOC	Lloyd Kahn		1
Benthic Invertebrate Toxicity	42-day *Hyalella azteca* test (survival, growth, and reproduction); 12 replicates	ASTM E1706-05	One 5-gallon bucket (or 19 liters)	none
	10-day *Chironomus dilutus* test (survival and growth); 8 replicates	ASTM E1706-05		none
	28-day *Lumbriculus variegatus* (bioaccumulation test); 8-10 replicates	ASTM E1688		25
Passive Porewater Sample	PCB Congeners, Dioxin and Furans, and Chlordane	EPA Methods 1668C, 1613B, and 1699	2 liters	3 polyethylene strips
Total Composite Sample Volume (approximate)		--	22 liters	--

Chemical analyses. Composite sediment samples will be analyzed for COCs, PAHs, and TOC as indicated in **Table 7.1**. The B/P Monitoring Plan specifies analysis of PCB congeners using Method 1668C to make use of research on congener-specific partitioning, bioaccumulation, and toxicity. Results of sediment toxicity and bioaccumulation tests will be evaluated for relationships with total PCB as well as with individual PCB congeners. Congeners differ in both toxicity and bioaccumulation potential. For example, heavier PCB and dioxin congeners were barely detected in surface water or porewater but were reported in sediment and small fish tissues at similar levels (Khairy et al. 2014). Likewise, heavier PCB congeners in Portland Harbor sediment were differentially taken up by benthic biota (Rodenburg and Delistraty 2019). Because the rate at which PCB and dioxin and furan are bioaccumulated varies by congener and by organism, calculation of total PCB or dioxin TEQ in tissue should be based on field data whenever feasible (Liebens et al. 2011). In Kingman Lake, PCB congener profiles (defined as the relative proportion of each congener to total PCB) collected for the RI were similar in surface water, sediment, and three trophic guilds of fish, but the percentage of dioxin-like PCB congeners increased from surface water to sediment to forage fish to mid-trophic-level fish to top predator fish. Information on the selective bioaccumulation of PCB congeners by fish of different trophic levels may be used to adjust subsequent monitoring events and/or suggest more focused remedial actions.

7.1.2 Porewater

Porewater passive samplers will be deployed, collected, and analyzed per the ARSP QAPP (Tetra Tech 2023a). Passive samplers will be used to measure concentrations of COCs in porewater. In selected EAA polygons (refer to **Section 6.1.3**), *in-situ* passive samplers will be deployed. Low-density polyethylene (LDPE) passive samplers will be deployed in the top six inches of sediment. Samplers with lines and floats will be installed using a stainless-steel push pole and an underwater camera. Following deployment (minimum of 28 days), the samplers will be retrieved and shipped to the analytical laboratory for extraction and analysis of PCB congeners and chlordane; dioxins and furans will be analyzed after a minimum of a 63-day deployment. *Ex-situ* porewater passive samplers will be deployed in composited sediment samples. Sediment samples will be homogenized, then placed in a tumbler or shaker with a polyethylene passive sampler for 28 days (Khairy and Lohmann 2020, EPA 2017c, Ghosh et al. 2014). Tumbling the sample promotes the exchange of chemicals across sediment, water, and sampler. Passive porewater samplers (*ex-situ* and *in-situ*) will be analyzed for congeners of dioxins and furans, PCB congeners, and chlordane (**Table 7.2**). Trends in concentrations of these COCs in passive samplers over time will be considered representative of changing conditions. However, Schmidt and Burgess (2020) point out that present methods for accurately predicting concentrations of dioxins, chlordane, and PAHs in fish and invertebrates from passive sampler results are limited.

Table 7.2 Analytical Methods for Porewater and Surface Water Passive Samplers

Test/Analyses	Passive Sampler Analytical Method
PCB congeners	EPA Method 1668C
Dioxins and Furans	EPA Method 1613B
Chlordane	EPA Method 1699

7.1.3 Surface Water

In-situ surface water passive samplers will be deployed, collected, and analyzed per the ARSP QAPP or in collaboration with UMBC. (PCB data previously collected by UMBC in 2021 and 2022 will be considered comparable and usable for the B/P monitoring.) *In-situ* surface water passive samplers will be analyzed for the COCs using the methods shown above in **Table 7.2**.

7.1.4 Benthic Invertebrate Toxicity

Toxicity tests on composite sediment samples will be conducted per the ARSP QAPP (Tetra Tech 2023a). The survival, growth, and reproduction of *Hyalella azteca* exposed to sediment will be tested using 42-day tests following EPA guidance (EPA 2000b, ASTM 2006). The survival and growth of *Chironomus dilutus* exposed to sediments will be tested using the 10-day toxicity tests (EPA 2000b, ASTM 2006). Toxicity will be defined relative to the laboratory-provided clean control sample results for each test. The acceptance criterion for the control sample in the 42-day *Hyalella* toxicity test is >80 percent survival after 28 days. The criterion for the control sample in the 10-day *Chironomus* toxicity test is >70 percent survival after 10 days with a minimum mean weight. The short-term amphipod and chironomid toxicity tests were identified as effective monitoring tools following remediation in the Calumet River, Indiana. The 42-day reproductive endpoint for amphipods was found to be a sensitive indicator of effectiveness of interim remedial actions, but the longer-term chironomid test did not add value to the study (Steevens et al. 2020).

Concentrations of COCs in the composite sediment samples and the *ex-situ* porewater passive samples will be evaluated using correlation analysis to identify any potentially causal relationships between COCs and toxicity. Although identification of a direct risk driver in laboratory toxicity tests would reduce uncertainty, numerous studies, including the ARSP RI (Tetra Tech 2019a), have shown only weak correlations between hydrophobic COCs and toxicity results (Steevens et al. 2020, Ingersoll et al. 2014).

7.1.5 Bioaccumulation in Benthic Invertebrate Tissues

Bioaccumulation tests will be conducted, and invertebrate tissue samples will be analyzed per the ARSP QAPP (Tetra Tech 2023a). Bioaccumulation in worms exposed to composite sediment samples under laboratory conditions represents one pathway by which COCs are transferred from sediment and/or porewater to benthic organisms. The composite sediment samples described in **Section 7.1.1** will be used to test bioaccumulation in *Lumbriculus variegatus*, an oligochaete worm, using ASTM E1688 and EPA guidance “Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates” (EPA 2000b). At the completion of the bioaccumulation test, the tissue will be analyzed for PCB congeners via Method 1668C, dioxin and furans, and percent lipid via Method 1613B, and chlordane via Method 1699. The anticipated total volume of tissue per sample required for each analysis or test is shown in **Table 7.3** (refer to ARSP QAPP for details on laboratory analysis and sample handling; Tetra Tech 2023a). If tissue mass is limited, DOEE will implement an analytical hierarchy of analyses (prioritizing PCB congeners).

Table 7.3 Analytical Methods for Whole Body Concentrations in Tissue Samples

Chemical	Method	Anticipated Tissue Volume
PCB congeners	EPA Method 1668C	10 grams
Dioxins/Furans and Percent Lipid	EPA Method 1613B	10 grams
Chlordane	EPA Method 1699	5 grams

7.1.6 Forage Fish

Forage fish will be collected and analyzed per the ARSP QAPP or in collaboration with USFWS. (PCB and chlordane forage fish tissue data collected in 2020 by USFWS will be considered comparable and usable for the B/P monitoring, assuming that species, sex, season, and location are consistent with Time 0 parameters.) Forage fish will be collected using methods described in the ARSP RI (Tetra Tech 2019), including electroshocking, unbaited minnow traps, seines, and other gear suited to the variety of microhabitats in the OUs. Single species, single-sex samples of whole-body forage fish will be prepared for chemical analysis of tissues as described in the ARSP QAPP and consistent with EPA "Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories" (EPA 2000a). During Time 0, samples of both females and males of the most abundant forage species in the collection will be analyzed. The B/P monitoring protocol may be adjusted in Time 1 and thereafter based on observed sex differences in concentrations of COCs in the Time 0 samples. Forage fish samples will be analyzed for COCs using the methods in **Table 7.3**.

7.1.7 Game Fish

DOEE Fisheries will collect and analyze game fish samples. It is anticipated that DOEE Fisheries will limit analysis of game fish tissue to total PCB and chlordane. PCB and chlordane game fish tissue data collected by DOEE Fisheries will be considered comparable and usable for the B/P monitoring, assuming that species and location are consistent with Time 0 parameters. If authorized by DOEE, Tetra Tech may supplement the DOEE Fisheries catch with additional game fish samples, which will be analyzed for all COCs per the ARSP QAPP (Tetra Tech 2023a). DOEE may also request that Tetra Tech coordinate with DOEE Fisheries to obtain a portion of the tissue composite to perform additional chemical analyses or to accept custody of the fish carcass (if DOEE only collects fillet samples). The carcass will consist of the remaining tissue, skin, bones, and entrails. The carcass sample will be archived (frozen) for future analysis. The fillets represent portions typically consumed by humans, and the fillet plus carcass (calculated whole fish) represent what a wildlife predator would consume. Provided there is enough tissue mass, fish samples will be analyzed for PCB congeners, dioxin and furans, chlordane, and percent lipids (**Table 7.3**). In some cases, specific organs may be analyzed separately to augment other studies of interest to DOEE. For example, livers of brown bullhead may be sampled to support ongoing studies by USFWS if samples are sufficient.

7.2 B/P Data Interpretation

The B/P Monitoring Plan is designed to generate independent, unbiased datasets for the indicators that will be analyzed to assess progress of the interim remedies toward achieving RAOs and establish the final ROD. This section summarizes the monitoring parameters, approaches, and metrics that will support DOEE's decisions to implement additional remedial actions, continue monitoring, or develop the final ROD. As warranted, results in each OU will be evaluated separately to allow flexibility of producing separate final RODs.

Statistical tools may be used to evaluate the data collected for each indicator monitored in the baseline and performance sampling events in accordance with the DQO study questions defined in **Section 5.2.** Possible statistical methods and tests are identified in **Section 7.2.2** and **Appendix A** for each data set. The total number of baseline samples to be analyzed by the laboratory per OU is provided in **Table 7.4.**

Table 7.4 Total Number of Baseline Samples per Operable Unit

Indicator	Number of Baseline Samples to be Analyzed by the Laboratory[1,2]					
	Main Stem OU Reach 123/456	Main Stem OU Reach 67	Washington Channel OU	Kingman Lake OU	Reference Area	Total Number of Samples
Surface sediment and ex-situ porewater (non-EAA and EAA)	17	10	23	10	10	70
In-situ porewater (EAA only)	0	0	0	2	0	2
Surface water	6	3	3	4	2	18
Benthic invertebrate toxicity test	6	5	10	5	5	31
Bioaccumulation in benthic invertebrate tissue	6	5	10	5	5	31
Forage fish (sample count is “up to” and depends on catch)	40	12	32	20	8	112
Game fish (sample count is “up to” and depends on catch)	6	6	6	6	12	36

1. Sediment and porewater sampling in the EAA polygons will be determined following the remedial design. Sampling techniques in the EAAs may vary depending on the remedy implemented. For planning purposes, the B/P Monitoring Plan assumes that the two Kingman Lake EAAs will be treated with direct application of activated carbon.
2. Following baseline (Time 0) and the first year of monitoring (Time 1), DOEE will review and reevaluate the recommended number of samples needed for long-term performance monitoring.

A breakdown of number of locations and the corresponding number of samples to be analyzed by the laboratory for each baseline indicator per OU is provided in **Table 7.5**. *Sample numbers may be decreased in Time 2 and subsequent monitoring events based on adaptive management decisions described throughout this plan.*

Table 7.5 Number of Baseline Locations and Samples per Operable Unit

Operable Unit	Indicator	Non-EAA Locations (Time 0)	EAA Locations (Time 0)	Total Number of Samples Analyzed by Laboratory for EAA and Non-EAA Locations[1,2]	Figure Reference
Main Stem OU Reach 123/456	Surface sediment/*Ex-situ* porewater	11 polygons	6 polygons	17	6.1
	In-situ Porewater	0	0	0	--
	Surface Water	6 locations	0	6	6.6
	Benthic Invertebrate Toxicity, Bioaccumulation Tests (Invertebrate Tissue)	6 randomly-selected polygons	0	6	6.1
	Forage Fish Tissue	7 polygons	3 polygons	Up to 40 (four samples per polygon)	6.8
	Game Fish Tissue	1 area (below CSX Bridge)	0	Up to 6 (six samples per area)	6.13
Main Stem OU Reach 67	Surface Sediment/*Ex-situ* Porewater	10 polygons	0	10	6.2
	In-situ Porewater	0	0	0	--
	Surface Water	3 locations	0	3	6.6
	Benthic Invertebrate Toxicity, Bioaccumulation Tests (Invertebrate Tissue)	5 randomly-selected polygons	0	5	6.2
	Forage Fish Tissue	3 polygons	0	Up to 12 (four samples per polygon)	6.9
	Game Fish Tissue	1 area (above CSX Bridge)	0	Up to 6 (six samples per area)	6.13
Washington Channel OU	Surface Sediment/*Ex-situ* Porewater	20 polygons	3 polygons	23	6.3
	In-situ Porewater	0	0	0	--
	Surface Water	3 locations	0	3	6.6
	Benthic Invertebrate Toxicity, Bioaccumulation Tests (Invertebrate Tissue)	10 randomly-selected polygons	0	10	6.3
	Forage Fish Tissue	5 polygons	3 polygons	Up to 32 (four samples per polygon)	6.10

Operable Unit	Indicator	Non-EAA Locations (Time 0)	EAA Locations (Time 0)	Total Number of Samples Analyzed by Laboratory for EAA and Non-EAA Locations[1,2]	Figure Reference
	Game Fish Tissue	1 area	0	Up to 6 (six samples per area)	6.13
Kingman Lake OU	Surface Sediment/*Ex-situ* Porewater	10 polygons	0	10	6.4
	In-situ Porewater	0	2 polygons	2	6.4
	Surface Water	4 locations	0	4	6.6
	Benthic Invertebrate Toxicity, Bioaccumulation Tests (Invertebrate Tissue)	5 randomly-selected polygons	0	5	6.4
	Forage Fish Tissue	3 polygons	2 polygons	Up to 20 (four samples per polygon)	6.10
	Game Fish Tissue	1 area	0	Up to 6 (six samples per area)	6.13
Reference Area	Surface Sediment/*Ex-situ* Porewater	10 polygons	0	10	6.5
	In-situ Porewater	0	0	0	--
	Surface Water	2 locations	0	2	6.6
	Benthic Invertebrate Toxicity, Bioaccumulation Tests (Invertebrate Tissue)	5 randomly-selected polygons	0	5	6.5
	Forage Fish Tissue	2 polygons	0	Up to 8 (four samples per polygon)	6.11
	Game Fish Tissue	2 areas	0	Up to 12 (six samples per area)	6.13

1. Sediment and porewater sampling in the EAA polygons will be determined following the remedial design. Sampling techniques in the EAAs may vary depending on the remedy implemented. For planning purposes, the B/P Monitoring Plan assumes that the two Kingman Lake EAAs will be treated with direct application of activated carbon.
2. Following baseline (Time 0) and the first year of monitoring (Time 1), DOEE will review and reevaluate the recommended number of samples needed for long-term performance monitoring.

Relevant data collected by other parties or under programs outside the ARSP (for example, tributary sampling, fish consumption advisory) will be included in the discussion of effectiveness in the 5-Year Review Report.

7.2.1 B/P Data and Metrics

Cleanup progress will be gauged using multiple indicators evaluated against applicable metrics, as described elsewhere in this plan. **Table 7.6** lists the B/P monitoring indicators monitoring parameters, statistical approaches, and applicable metrics.

Table 7.6 Statistical Approaches for B/P Indicators

Indicator	Monitoring Parameter	Statistical Approach	Target Metric
Surface Sediment (Composite)	Concentrations of COCs and PAHs	Comparison to target metric	Sediment PRG
		Trend analysis within the limitation and uncertainty of the data	Congruence of actual and expected cleanup timeframe
Porewater (*in-situ* and *ex-situ*)	Concentrations of COCs	Comparison to target metric	Chronic WQC
Surface Water	Concentrations of COCs	Comparison to target metric	Chronic WQC
Forage Fish Tissue	Concentrations of COCs in whole-body fish tissue	Trend analysis within the limitation and uncertainty of the data	Congruence of actual and expected cleanup timeframe
Game Fish Tissue	Concentrations of COCs in edible tissue	Comparison to target metric	DOEE Fish Advisory concentrations for unlimited consumption
		Trend analysis within the limitation and uncertainty of the data	Congruence of actual and expected cleanup timeframe
Benthic Invertebrate Toxicity Testing (midge, amphipod)	Survival and growth (midge and amphipod); reproduction (amphipod only)	Comparison to target metric	Relative to laboratory-provided clean control samples
		Trend analysis within the limitation and uncertainty of the data	Congruence of actual and expected cleanup timeframe
Bioaccumulation in Benthic Invertebrate Tissue (oligochaete)	Concentration of COCs in whole-body tissue	Comparison to target metric	Relative to laboratory-provided clean control samples
		Trend analysis within the limitation and uncertainty of the data	Congruence of actual and expected cleanup timeframe

7.2.2 Statistical Analyses

Progress of the B/P monitoring program may be evaluated using quantitative statistical methods. Three broad categories of testing will be conducted: (1) comparison to a fixed metric, (2) trend analysis within the limitations and uncertainty of the data, and (3) exploring the relationship among indicators through correlation analysis. The general statistical approaches that may be used are summarized in this section; more detail is provided in **Appendix A**.

Comparison to Fixed Metric

If used, statistical evaluations of this type would address questions (on an OU basis) such as "*Have sediment COC concentrations been reduced sufficiently to achieve the PRG*?" A similar question can be posed regarding COC concentrations in game fish edible tissue compared to the fish advisory concentration for unlimited human consumption.

For comparisons against a fixed or target metric, EPA has long recommended the use of confidence intervals (EPA 2009a). Standard confidence intervals provide estimates of the population meanwhile accounting for sample size, population variability, and a desired degree of accuracy. When a confidence interval is entirely below the fixed metric, it can be asserted with high statistical confidence that the true, but unknown, average has met the target.

Confidence bands are a recommended variant of confidence intervals in situations where data have been collected over time and trends might exist. A confidence band is essentially a confidence interval stretched out and wrapped along an estimated trend line. Vertical cross-sections of the confidence band at particular points in time correspond to point-in-time confidence intervals that can be used to test compliance with fixed standards or metrics.

Because the sediment data are being collected over time, appropriate linear or non-linear trends will be estimated for each COC, along with a confidence band around each trend. At each decision point or project update, the cross-section of the confidence band at the most recent sampling event would be compared to its respective PRG. If the confidence interval cross-section is fully below the PRG, the target may have been met. If not, the target can be re-checked at the next update.

Results of the PRG comparisons will be presented as tables of the up-or-down comparison test outcomes at specific points in time, along with graphs of the confidence bands matched against the observed data and overlaid with the relevant PRGs.

Trend Analyses

If used, trend analyses would be conducted and evaluated within the limitation and uncertainty of the data. Statistical evaluations of this type would address the following questions:

- "Within an OU, is there a downward trend in COC concentrations in sediment?"
- "Are there trends in concentrations of COCs in game fish tissue or whole-body forage fish?"
- "How do COC concentration trends in an OU compare with trends in the Reference Area?"

Linear regression can be used for each COC and medium to assess any trends over time. Downward trends will not be identified unless the p-value associated with each trend test is sufficiently small (for example, $p < 0.05$). These trends can be computed in conjunction with the confidence bands discussed above (that is, comparison to a target metric) because a confidence band cannot be constructed without first estimating a trend line. Further, the trend estimates will not be regarded as valid until the key assumptions associated with linear regression — especially patterns of variability in the residuals — are checked and verified.

Data will be transformed as necessary to better satisfy the regression prerequisites. Linear trend estimates will also be computed in the Reference Areas and compared to site trends. In particular, the directions and magnitudes (that is, slopes) of associated OU and Reference Area trends will be compared over the same time frames to check for any differences. A t-test or similar two-sample test can be employed to check for differences in the slopes.

If the PRG for a COC has not been met at a given update, the constructed trend for that COC will be extrapolated to estimate how long it may take for the target metric to be achieved. Of note, because trend extrapolation can invoke significant uncertainty, the confidence band around the trend will also be extrapolated. This confidence band will provide more realistic bounds on the time-to-complete estimates.

The trend testing results will be presented as tables of the equations and coefficients of each regression model, along with graphs showing each trend and confidence band matched against the observed data, and also showing any possible extrapolation of the trend until the target metric may be met.

Correlation

If used, correlations may be used to explore the potential for one indicator to be a reliable indicator of another. Remedy performance is assessed by sampling and evaluating the data for seven indicator parameters because, at present, it is unknown which indicator or group of indicators will most efficiently and cost effectively serve to accurately gauge cleanup progress. Following adaptive management, the number and/or monitoring frequency of a specific indicator(s) could be reduced if another indicator provides the same information. For example, the correlations between COC concentrations in forage fish, game fish, and sediment will be tested.

To assess the associations between multiple indicators, robust correlation measures can be used in place of the common Pearson's r correlation coefficient. Robust correlations are much less sensitive to outliers and more accurately reflect the nature and magnitude of the true association. Correlation measures are used primarily as descriptive and screening tools to reflect which, if any, indicators have an identifiable relationship.

Linear regression and multiple linear regression can be used to predict with accuracy the value of an indicator based on the value of one or more other indicators. These techniques construct equations that reveal not only which indicators are useful predictors of a target indicator, but also how much numerical change might be expected in the target indicator given a specific change in one or more of the predictors.

As with the trend analysis discussed above, each regression or multiple regression model must be checked for relevant prior assumptions, particularly those relating to the regression residuals and potential outliers. Note that any regression model is likely to be highly uncertain and of limited usefulness when the sample size is less than 10 observations.

Results from these analyses will be presented as tables and color-coded charts of the correlations, tables of the regression equations and statistical strength of the regression models, and graphs of each regression model showing how well it fits the observed data.

8. Communication Plan

DOEE will follow the established ARSP protocols for communicating B/P monitoring results to the public. Community involvement activities for the ARSP are governed by the ARSP Community Involvement Plan, the latest version of which was released in December 2016 (DOEE 2016). DOEE maintains a dedicated website (https://restoretheanacostiariver.com/) for posting public meeting announcements and general information, soliciting public input and feedback (for example, public surveys), and providing the repository for the documents comprising the Administrative Record for the project. ARSP documents including the IROD, proposed plan, and reports and work plans prepared to support the RI/FS are available in the project Administrative Record (https://restoretheanacostiariver.com/library). In addition to public communications regarding the ARSP, DOEE either directly convenes, helps facilitate, or supports stakeholder meetings and other public interactions regarding cleanup status and progress at the PECSes.

8.1 Public Meetings

DOEE seeks public engagement by periodically convening public meetings with various groups of stakeholders and the general public. The meetings include project status meetings for the general public and Leadership Council for a Cleaner Anacostia River (LCCAR) meetings with LCCAR members and concerned governmental and nongovernmental organizations (selected by the office of the Mayor with DOEE consultation). The LCCAR meetings are also attended by various governmental and private entities associated with the PECSes.

8.1.1 General Public Meetings

As it has throughout the ARSP, DOEE will convene public meetings as appropriate to communicate monitoring results, progress toward establishment of the final ROD, and the estimated timeline for completing overall cleanup of the river. The ARSP public meetings will take place in venues close to Metro stations and in the communities near the river, or alternatively meetings will be held virtually to make it easy and convenient for people to attend from their home or office. Each meeting will be announced via the *Restore the Anacostia River* website (https://restoretheanacostiariver.com), social media, and email notices to all stakeholders.

8.1.2 LCCAR Meetings

Established in 2015 by Mayor Muriel Bowser, the LCCAR serves as a multi-jurisdictional advisory group for the project. The council consists of 20 members comprised of officials from federal, state, and local government, representatives from environmental and other nongovernmental organizations, and representatives of communities adjacent to the Anacostia River. The council meets quarterly, and meetings are open to the public. LCCAR meetings are the primary forum DOEE will use for communicating B/P monitoring results and cleanup progress assessments to ARSP stakeholders.

In September 2016, DOEE and the NPS launched the Consultative Work Group (CWG) consisting of DOEE, NPS, and various PECS parties that chose to participate. The principal participating members are Pepco, Department of the Navy, DC Water, Washington Gas, Washington Suburban Sanitary Commission, and Prince George’s County, Maryland. The purpose of the CWG was to provide a forum for sharing technical information and viewpoints pertaining to ARSP processes, coordinate efforts to identify additional PECS parties, and initiate a process for allocating costs. Since 2018, to ensure consistency in the information disseminated to all stakeholders, DOEE opened the LCCAR meetings to CWG members.

8.2 Documentation

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) § 121 and District of Columbia Brownfields Revitalization Act (DCBRA) § 8-634.05 require reviews (statutory reviews) of response actions no less often than each 5 years after the initiation of the response action ("5-year review"), where the action does not achieve concentrations of hazardous substances acceptable for unlimited use/unrestricted exposure (which is true for the IROD). In addition to stakeholder communication through direct meetings, fact sheets, and web postings, a standard DCBRA and CERCLA 5-year review will be conducted for each OU, which will include evaluation of the performance monitoring data collected in accordance with this work plan. DOEE will issue 5-year review report(s) (either for each OU individually or a single report covering the three OUs collectively) that will document the sampling performed, analysis results, data evaluation, and interpretation. The report will make recommendations for additional interim remedial action(s), as warranted, within the adaptive management decision framework. The 5-year reviews will assess observed progress toward achieving RAOs in each OU and evaluate the potential for transition to the final ROD. Reports from the 5-year review will be provided for public review in hard copy at selected DC community libraries and in electronic format in the project Administrative Record (https://restoretheanacostiariver.com/library).

9. Project Management

B/P monitoring will be implemented by a DOEE-managed team consisting of DOEE and Tetra Tech staff supported by various laboratories and specialty-service subcontractors and in collaboration with UMBC and USFWS. Quality assurance (QA) and quality control (QC) procedures will be implemented to ensure that the data generated are of sufficient quality to support project objectives.

9.1 Management Team

Figure 9.1 shows the project organization chart and the lines of communication between DOEE, Tetra Tech, the analytical laboratory, and other supporting entities. **Table 9.1** summarizes the responsibilities for the key personnel from each organization, and the names of the responsible individuals at the outset of B/P monitoring. Because B/P monitoring will likely continue for several years (or for more than a decade for some indicators), individuals in each position may change over time.

The DOEE remedial project manager is the project leader and top decision-making authority for the project. Through communication with the Tetra Tech project manager, the DOEE manager ensures that the project is performed consistent with DOEE's vision and objectives. The DOEE remedial project manager can receive input from the Tetra Tech program manager and from outside governmental, nongovernmental, and academic organizations. The Tetra Tech project manager reports directly to the DOEE remedial project manager and to the Tetra Tech program manager and is responsible for ensuring that project tasks are appropriately executed consistent with project quality standards and within schedule and budget constraints. The Tetra Tech project manager can receive input from various project technical discipline leads (for example, passive sampling, statistical trend analysis, etc.) and oversees Tetra Tech task leads for database management, field sampling, data interpretation, and laboratory analyses. Prior to release to the DOEE project manager, project documents such as reports, technical memoranda, slide presentations, etc. will be reviewed internally by a team of QA reviewers comprised of senior Tetra Tech technical staff. The QA reviewers will communicate with the Tetra Tech project manager and program manager to resolve any technical issues prior to submittal of deliverables to the DOEE project manager.

Table 9.1 Key Roles and Responsibilities

Staff	Position	Organization	Responsibilities
Dev Murali, P.G.	DOEE Remedial Project Manager	DOEE	DOEE is the funding agency for this project and has overall responsibility for project activities. The DOEE Remedial Project Manager has overall responsibility for project activities.
Jeremy Travis, CHMM	Program Manager	Tetra Tech	The Program Manager is responsible for general oversight and QA/QC for the project. He will communicate primarily with DOEE management and Project Manager.
Outside Entities	Outside Entities	Government Entities, Academic Institutions, etc.	Various outside entities defined by DOEE will provide independent review of B/P monitoring data and results at the direction of DOEE. Example government entities include the USFWS and EPA Region 3; example academic institutions include UMBC and George Mason University.
Mark Shupe, P.G.	Project Manager	Tetra Tech	The Project Manager is responsible for project implementation and has the authority to commit the resources necessary to meet project objectives and data quality requirements. The Project Manager will report to the DOEE Remedial Project Manager and the Program Manager.
Subject Matter Experts	Discipline Leads	Tetra Tech	Discipline Leads are senior Tetra Tech technical staff and subject matter experts, who will advise the Project Manager regarding specific technical topics including (but not limited to) passive sampling, statistics, and risk assessments. Discipline Leads will oversee the review, evaluation, and interpretation of the data generated from B/P monitoring.
Steve Delhomme, P.E.	Technical Engineering Lead	Tetra Tech	The technical engineering lead will provide QA review of the relevant sampling approaches, sampling results, and data analysis and interpretation and will be in communication with the Project Manager.
Rebecca Zvoleff	QA Reviewer	Tetra Tech	The QA Reviewer's primary role is to provide an overall quality review of deliverables resulting from the investigation.
AmyMarie Accardi-Dey, PhD, P.G., CPC	Quality Manager	Tetra Tech	The Quality Manager's primary role is to provide an overall quality control on sample integrity, data quality, and review of deliverables resulting from the investigation. The Quality Manager will work with the project team to define analytical requirements, validation guidelines, delivery schedules, and logistics. The Quality Manager will resolve laboratory non-conformances and validation issues and will communicate issues to the Project Manager. The Quality Manager will coordinate with the Analytical Coordinator on logistics and field coordination.

Staff	Position	Organization	Responsibilities
Allison O'Neill	Tetra Tech	Analytical Coordinator	The Analytical Coordinator will communicate logistics to the Field Oversight Coordinator, laboratory, and validator. The Analytical Coordinator is responsible for data tracking from collection in the field, shipping, laboratory receipt. The Analytical Coordinator will review COCs and ensure sample IDs and analysis are consistent with the work plan. The Analytical Coordinator will review sample logs and laboratory reports to ensure requested analysis are run. The Analytical Coordinators is responsible for coordinating data verification/validation and will be in communication with the Quality Manager, Field Coordinator, Data Manager, and Project Manager.
Antoine Muller	Field Manager/Health and Safety Lead	Tetra Tech	The Field Manager is responsible for observing field sampling activities and ensuring that sampling is conducted in accordance with the work plan specifications. The Field Manager will also serve as the on-site Health and Safety Lead and is responsible for training staff on project tasks and safe work practices. The Field Manager will report to the Project Manager.
Peter Song, P.E.	Tetra Tech	Field Coordinator	The Field Coordinator is responsible for oversight of all field activities and documenting that work is being done in accordance with the ARSP QAPP. The Field Coordinator will work with the Field Manager and communicate daily with the Project Manager regarding the progress of the field work and potential issues requiring resolution. In addition, the Field Coordinator will report any deviations from the work plan to the Project Manager and Quality Manager. The Field Coordinator will work with the Analytical Coordinator to ensure sample bottles are ordered and received for sampling activities.
Kristen Jenkins	Data Manager	Tetra Tech	The Data Manager is responsible for maintaining and updating the ARSP database as validated data are received and reviewed by the Quality Manager. The data manager will work closely with the Quality Manager, Field Coordinator, and Analytical Coordinator.
Joel Peters	Geographic Information System (GIS) Lead	Tetra Tech	The GIS Lead is responsible for generating updated figures for reporting progress during the B/P monitoring. The GIS Lead is also responsible for preparing graphical presentations of the data and results of the investigation.
Stella Cuenco	Data Validator	Laboratory Data Consultants	Data validator is responsible for managing third party data validation according to the ARSP QAPP. Data validator will work with Analytical Coordinator to confirm sample delivery schedule. Non-conformances will be reviewed by Quality Manager.
Laura Turpen	Laboratory Project Manager	Eurofins	Analytical laboratory will analyze samples. The laboratory project manager is responsible for delivering analytical services, reviewing the ARSP QAPP to understand analytical requirements, and working with the Analytical Coordinator to confirm sample delivery schedules. Non-conformances will be reviewed with Quality Manager.

Staff	Position	Organization	Responsibilities
Marcus Bowersox	Laboratory Project Manager	Tetra Tech Ecological Testing Facility	Analytical laboratory will conduct biological testing. The laboratory project manager is responsible for delivering analytical services, reviewing the ARSP QAPP to understand analytical requirements, and working with the Analytical Coordinator to confirm sample delivery schedules. Non-conformances will be reviewed with Quality Manager.
Brent G. Pautler, PhD	Laboratory Project Manager	SiREM	Analytical laboratory will analyze passive samplers. The laboratory project manager is responsible for delivering analytical services, reviewing the ARSP QAPP to understand analytical requirements, and working with the Analytical Coordinator to confirm sample delivery schedules. Non-conformances will be reviewed with Quality Manager.

9.2 Independent Reviewers

DOEE will document B/P monitoring results for the IROD-defined interim remedial actions in postings to the DOEE ARSP website, presentations to stakeholders (for example, LCCAR meetings), and one or more reports. As noted in **Section 1.2**, DOEE funded several independent studies by USFWS, UMBC, and USGS that focused on improving the understanding of the source control, fate and transport, and trophic transfer of COCs in study area water bodies and the watershed in general. The DOEE remedial project manager can receive input from outside these entities in the form of comments on documents or meeting materials prepared by Tetra Tech or as independent data reviews as appropriate.

DOEE will formally document remedial progress through the performance of 5-year reviews and issuance of a 5-Year Review Report, as discussed in **Section 8.2**. The 5-Year Review Report will be issued for review to NPS, EPA Region 3, stakeholders, the general public, and the above-noted governmental and academic entities (USFWS, UMBC, and USGS). Reviewers may include the PECS and LCCAR stakeholders and their consultants.

9.3 Certified Laboratories

Laboratory-based chemical analyses will be conducted by an environmental laboratory (Eurofins) certified by the National Environmental Laboratory Accreditation Program (NELAP). Eurofins will be responsible for measuring chemical concentrations in sediment, porewater, surface water, and fish and invertebrate tissue. Specialized laboratories will be used for conducting benthic invertebrate toxicity and bioaccumulation testing and handling passive samplers. Analytical methods associated QA/QC procedures and SOPs for the laboratory testing identified in this work plan are defined in the ARSP QAPP (Tetra Tech 2023a).

Primary Laboratory. Only trained personnel will perform laboratory tasks. All laboratory staff will be trained in the procedures for analyzing samples for their assigned parameters. Laboratory training is the responsibility of the respective laboratory management organization and includes familiarity with laboratory SOPs, routine QC practices, and ongoing demonstration of capabilities and performance. Analyst proficiency is demonstrated through review of available reference methods and SOPs, and supervised performance of the methods and analytical measurements on a defined number of control samples and reference materials, or third-party performance evaluation samples for assessment. Recovery data and acceptance criteria form the basis of documentation of analyst proficiency.

Specialized Laboratories. A specialized laboratory could be used to measure concentrations of COCs in surface water and porewater obtained using passive sampling. In addition, benthic invertebrate testing including toxicity tests and bioaccumulation tests will be conducted by a specialized laboratory. Analyst training requirements, QA/QC procedures and SOPs for passive sampling and benthic invertebrate testing analyses are provided in the ARSP QAPP (Tetra Tech 2023a).

9.4 Quality Assurance/Quality Control and Field Auditing

QA/QC procedures for this project are documented in detail in the ARSP QAPP (Tetra Tech 2023a). This section provides a summary of field- and laboratory-based QA/QC sampling and procedures for auditing field sampling activities.

This section presents the QA/QC activities that will be implemented in the field and laboratory. Field QA activities include field data verification and collection of field QC samples. The Tetra Tech field oversight coordinator is responsible for the daily QC review of field-data collection and field activity documentation. Field QC samples will involve preparing and submitting field duplicates (or replicates) and appropriate blanks. Field QC samples inform decision makers about the data usability and the robustness of the sampling design. Field QC samples expected to be collected under this investigation include field duplicates, field replicates, rinsate blanks, matrix spike/matrix spike duplicates, and temperature blanks.

Details regarding laboratory QA activities and laboratory QC sampling are provided in the ARSP QAPP (Tetra Tech 2023a). Laboratory QA activities include the collection and analysis of laboratory QC samples and daily review of analyses results and supporting data. The laboratory QC samples include laboratory control samples, matrix spike, matrix spike duplicate samples, and other laboratory check samples.

As necessary, field assessments or audits will be conducted to ensure that QA requirements are being followed and met and to foster continuous improvement of field data collection systems. Field assessments will be conducted by a Tetra Tech staff member experienced in the performance of environmental sampling but not directly affiliated with the project. The project manager will select the individual to perform the field assessment. The baseline information and observations required during a typical assessment will include the following:

- Availability of approved project planning documents (for example, ARSP QAPP, applicable SOPs, any applicable sampling plan amendments)
- Documentation of personnel qualifications and training
- Sample collection, identification, preservation, handling, and shipping procedures
- Sampling equipment calibration
- Completeness of field data collection forms, logbooks, and other field records (including nonconformance documentation)

The field auditor will be experienced in performing audits of field activities. The auditor will document deficiencies in accordance with the bulleted list above and will identify and document corrective actions as appropriate. The field auditor will report his or her observations to the project manager and document them in the auditor's field logbook. A copy of the field audits will be submitted to DOEE within 15-days of completion of the field audit.

9.5 Data Validation

Data validation will be performed by Laboratory Data Consultants, Inc. Validation will be conducted on 100 percent of the laboratory-generated data in accordance with current EPA National Functional Guidelines (EPA 2000c, 2000d, 2000e), the laboratory SOPs, and the ARSP QAPP (Tetra Tech 2023a). Stage 4 validation will be conducted on COCs, PAH, and TOC constituents; Stage 2B validation will be conducted on rinse blanks and ancillary parameters (EPA 2009b). Data validation consists of a review of critical QA/QC information provided by the laboratory, including holding times, calibration results, blank results, QC sample results, and spike recovery accuracy. In addition, QA/QC criteria and the raw data will be used to check calculations and analyte identifications.

9.6 Data Management

Effective data management is essential for ensuring that the B/P data generated are readily available for efficient data evaluation and interpretation to support adaptive management decision-making. Data management involves the incorporation of electronic data deliverables (EDDs) from the analytical laboratories into a searchable database for statistical and spatial evaluation.

The analytical laboratories will provide EDDs for all analytical results. Specific requirements regarding the EDD format are specified in the ARSP QAPP (Tetra Tech 2023a). An automated laboratory information management system must be used to produce the EDDs. The laboratory will verify EDDs internally before they are delivered to Tetra Tech. The EDDs will correspond exactly to the associated hard-copy data reports (or portable document format electronic versions of the hard-copy data reports). No duplicate data will be submitted. All EDDs will include the following:

- Target analyte results for each sample and associated analytical methods requested on the chain-of-custody form.
- Method and instrument blanks and preparation and calibration blank results reported for each sample delivery group (SDG).
- Percent recoveries for the spike compounds in the matrix spike, matrix spike duplicates, blank spikes, and laboratory control samples.
- Matrix duplicate results reported for the SDG.
- Raw data documentation.

The EDD will include all re-analysis, re-extractions, or dilutions reported for the SDG, including any associated with samples and the specified laboratory QC samples. Electronic and hard-copy data must be retained for a minimum of five years after final data have been submitted.

Tetra Tech will import the B/P data into a geodatabase for storage and analysis. The database will be queried for chemical data needed to prepare reports and graphic presentations. Additional data acquired from field activities will be recorded on field forms. Once a quality review of these documents is completed by the field oversight coordinator, the analytical coordinator will oversee the importation of the data on these forms into the project geodatabase. Electronic copies of field forms, field logbooks, chain-of-custody records, laboratory data packages, and laboratory reports will be archived at the Tetra Tech Chantilly, Virginia office.

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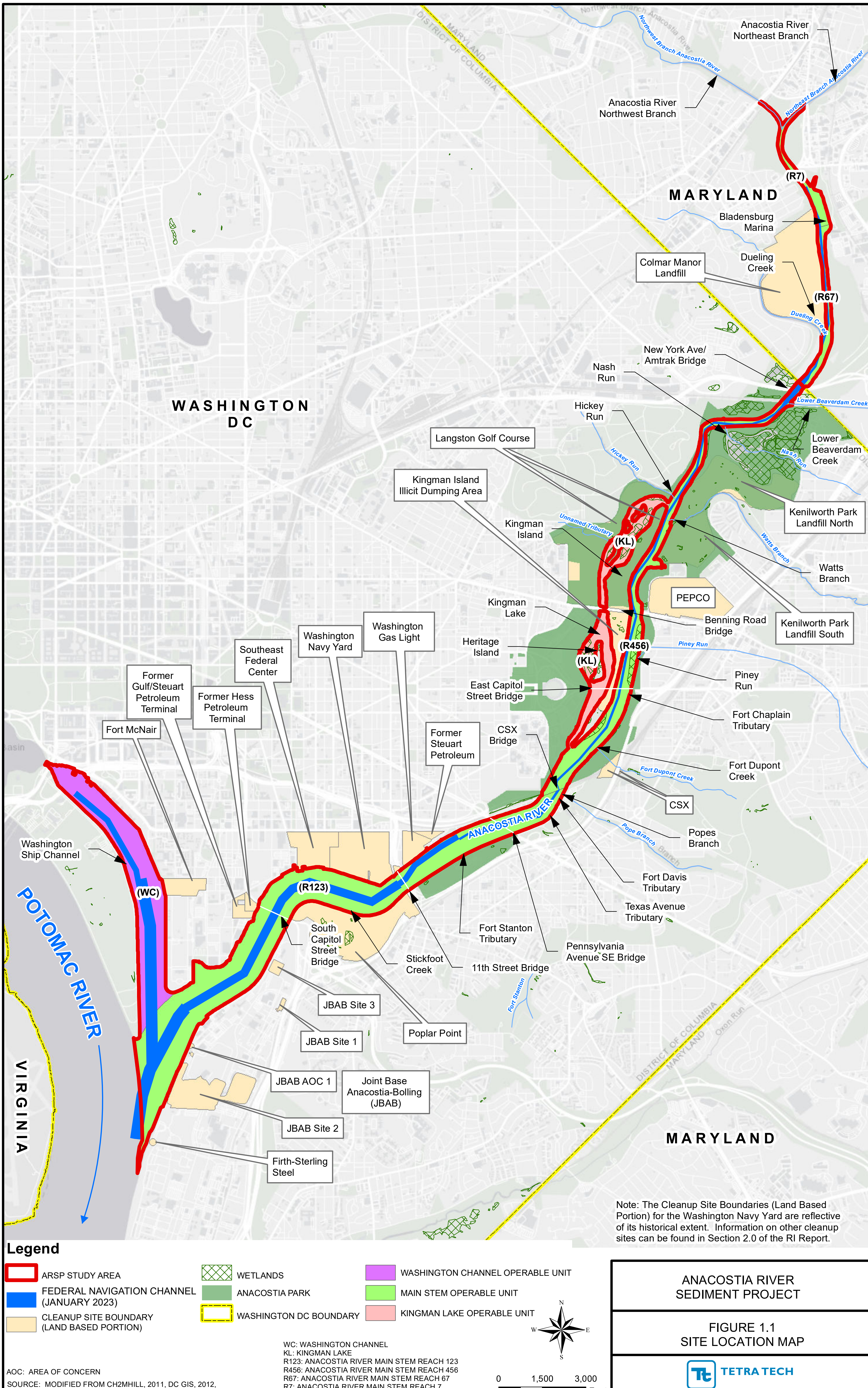
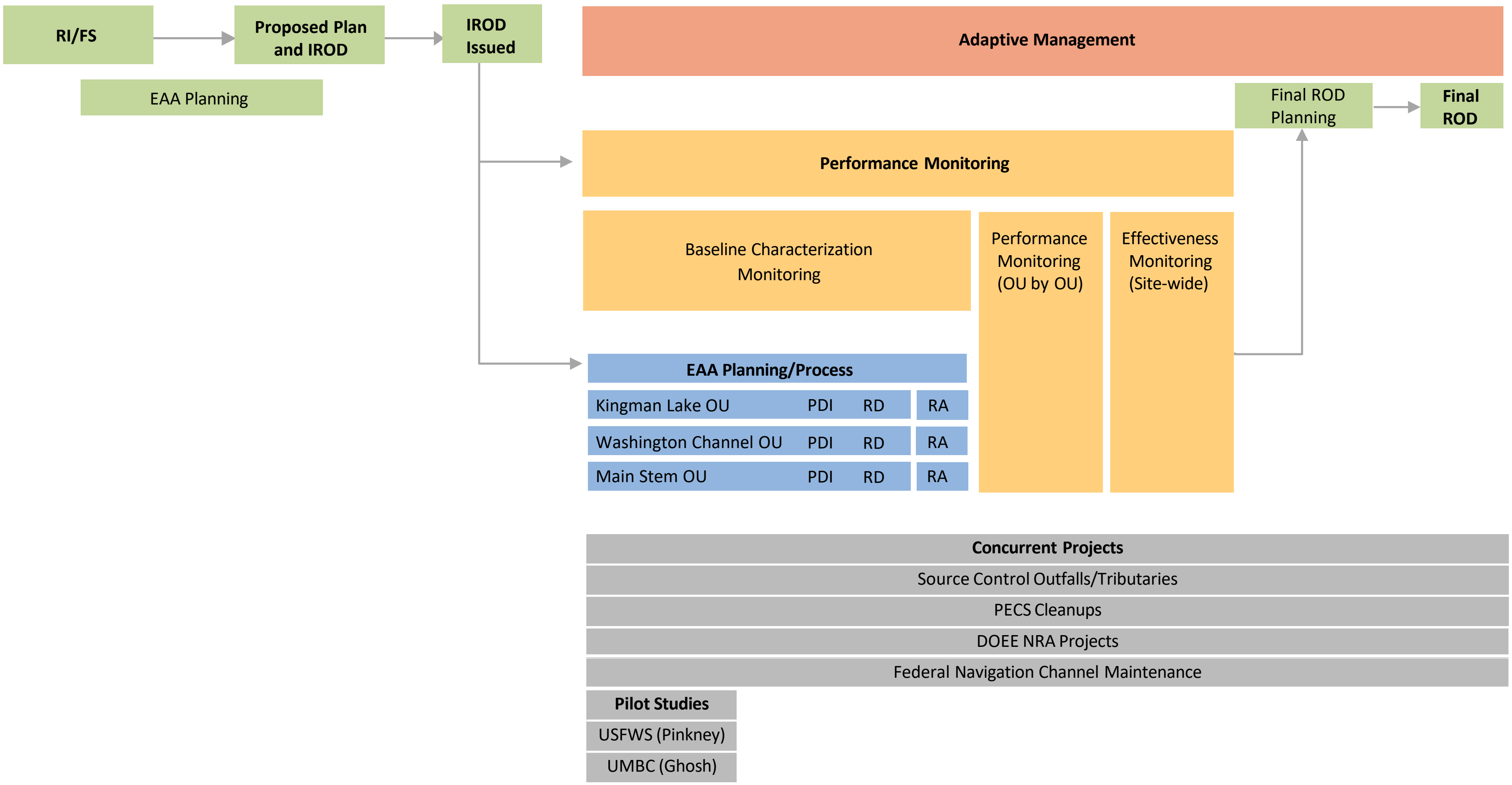
FIGURES



ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 1.1
SITE LOCATION MAP



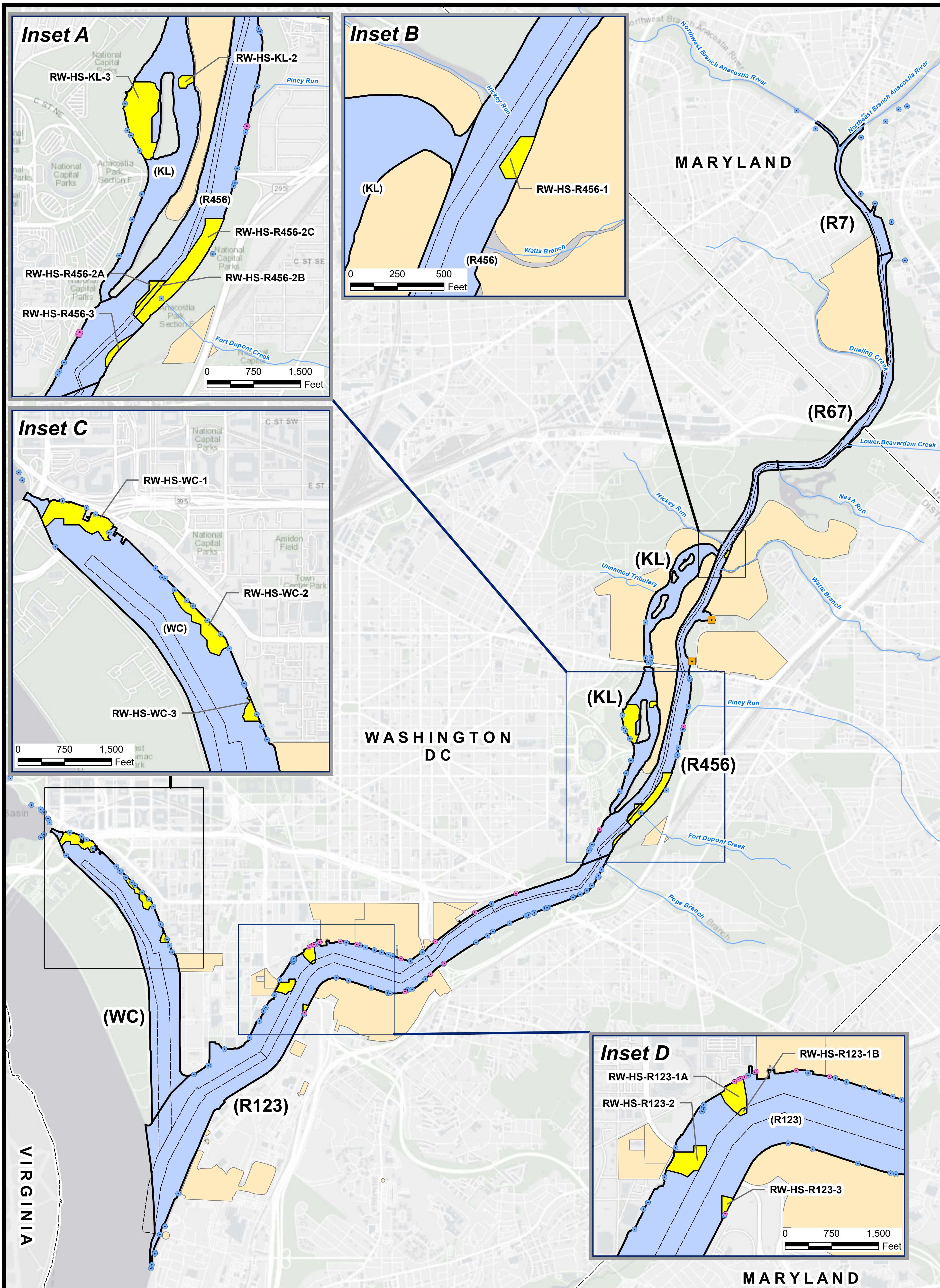
Abbreviations and Acronyms

DOEE	District of Columbia Department of Energy and the Environment
EAA	Early action area
FS	Feasibility study
IROD	Interim Record of Decision
NRA	Natural Resources Administration
OU	Operable unit
PDI	Pre-design investigation
PECS	Potential environmental cleanup site (plural: PECSes)
RA	Remedial action
RD	Remedial design
RI	Remedial Investigation

ANACOSTIA RIVER
SEDIMENT PROJECT

FIGURE 1.2
COMPONENTS OF THE ARSP FROM RI TO FINAL ROD WITHIN AN ADAPTIVE MANAGEMENT FRAMEWORK

TETRA TECH



Legend

WC: WASHINGTON CHANNEL
KL: KINGMAN LAKE
R123: ANACOSTIA RIVER MAIN STEM REACH 123
R456: ANACOSTIA RIVER MAIN STEM REACH 456
R67: ANACOSTIA RIVER MAIN STEM REACH 67
R7: ANACOSTIA RIVER MAIN STEM REACH 7

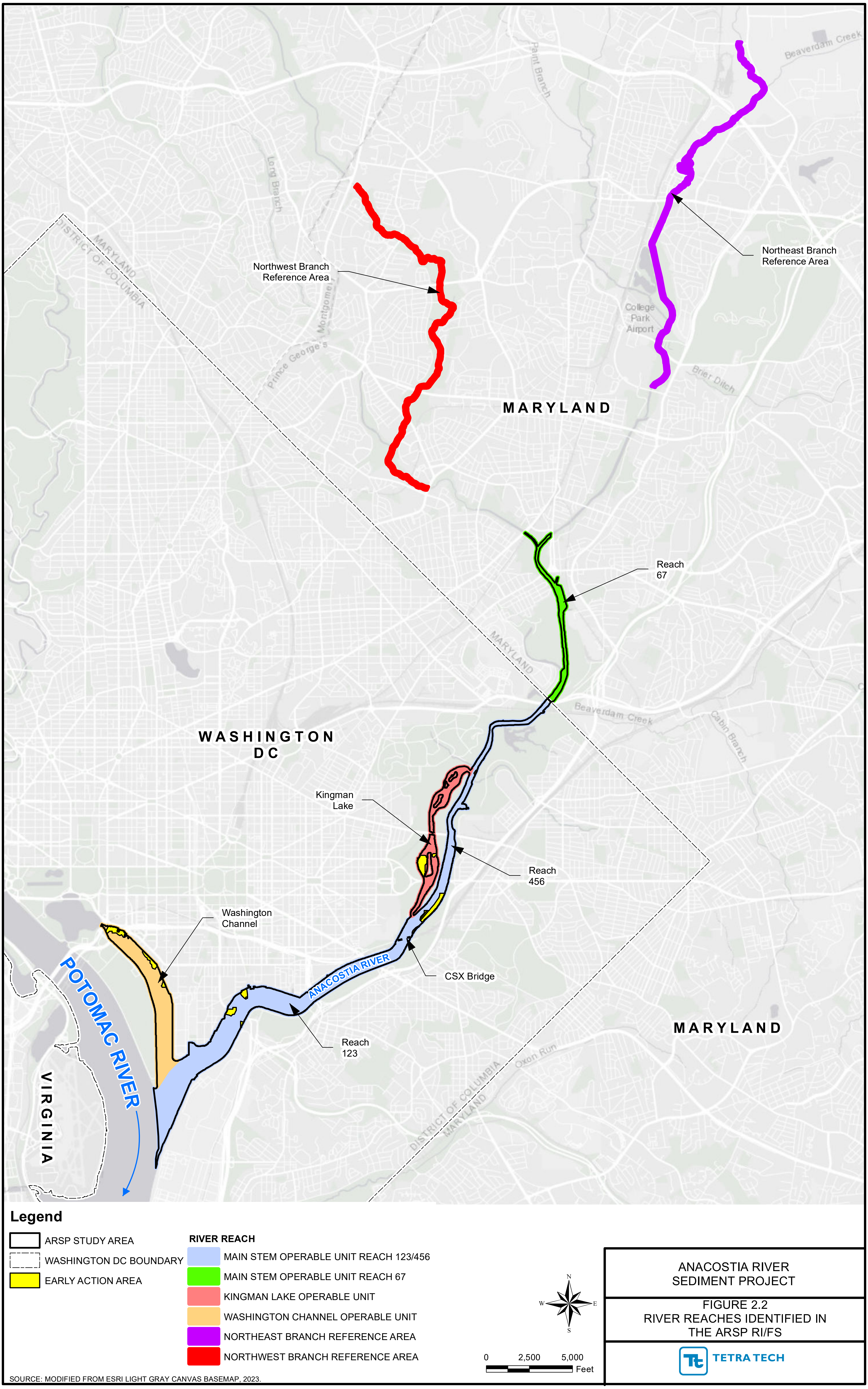
SOURCE: MODIFIED FROM CH2MHILL, 2011, DC GIS, 2012, DC WATER, 2016, PRINCE GEORGE'S COUNTY, 2013, AND ESRI LIGHT GRAY CANVAS BASEMAP, 2023.

0 1,500 3,000 Feet

ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 2.1
EARLY ACTION AREAS DELINEATED IN THE PDI

TETRA TECH



SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.

ANACOSTIA RIVER
SEDIMENT PROJECT

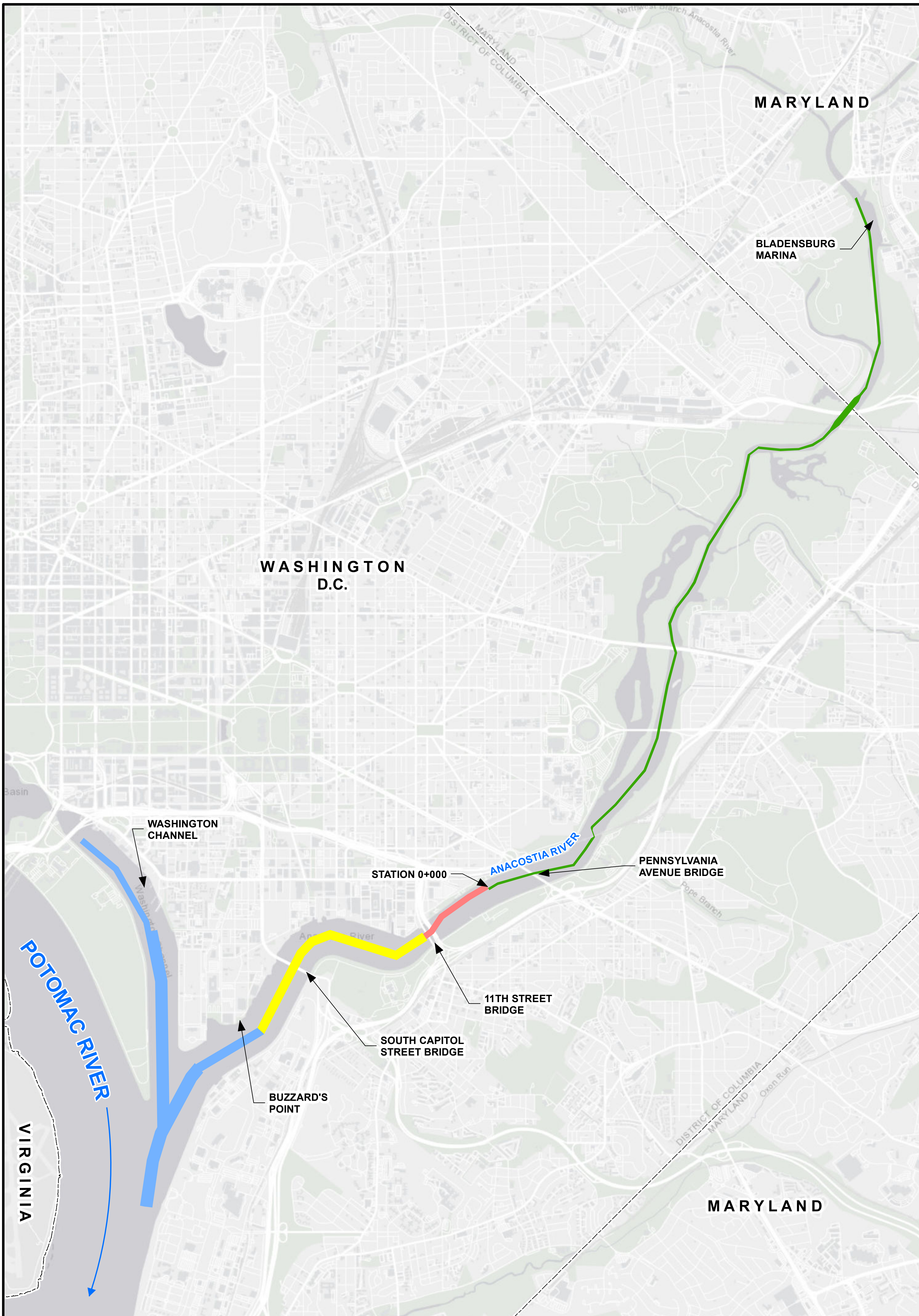
FIGURE 2.2
RIVER REACHES IDENTIFIED IN
THE ARSP RI/FS

TETRA TECH

BENEFICIAL USE GUIDANCE

FIGURE 4.1
POTENTIAL DOEE RESTORATION AND CONSERVATION AREAS
SPRING 2022

TETRA TECH



Legend

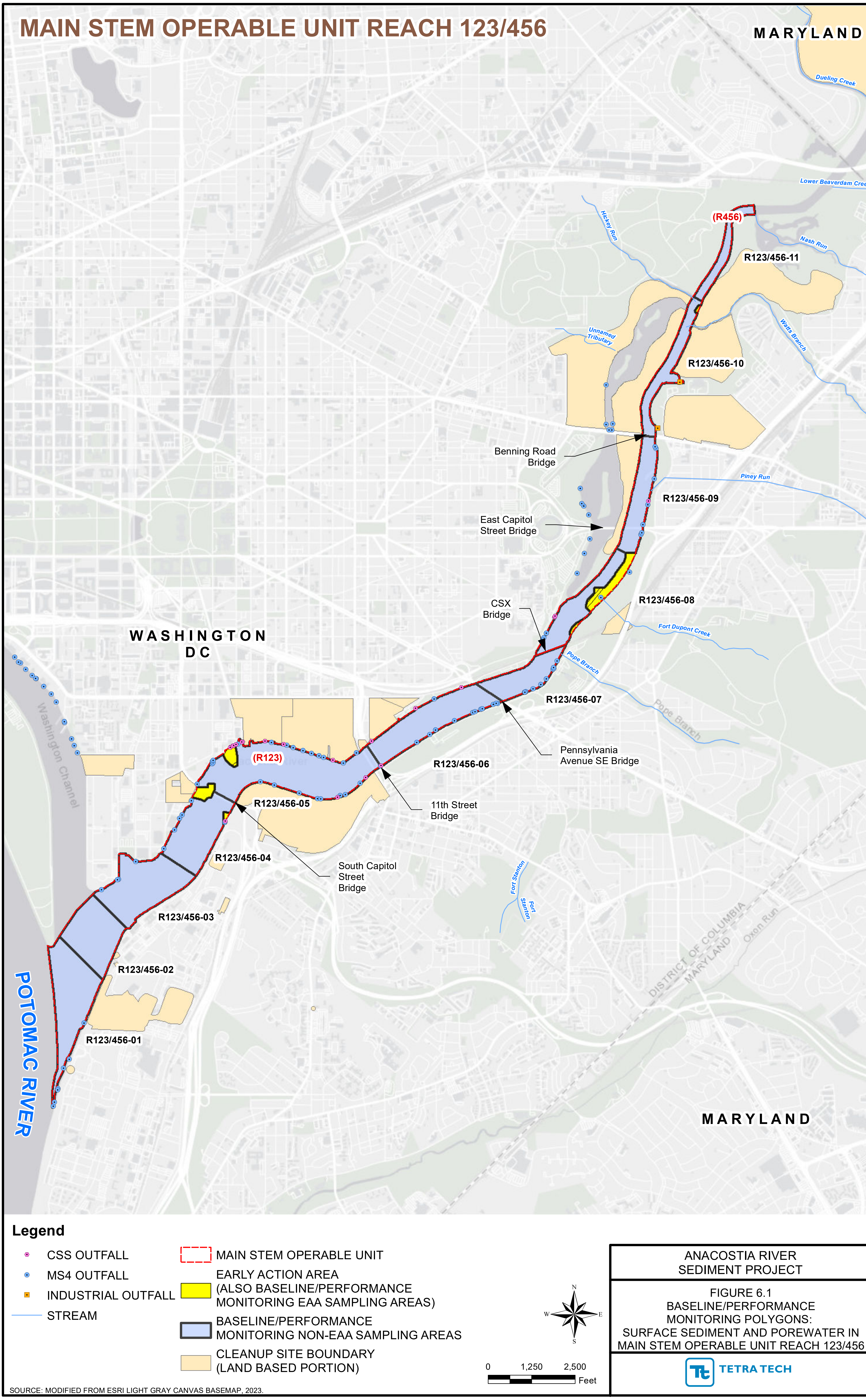
- MAXIMUM LEGISLATIVE DEPTH 8 FEET
- MAXIMUM LEGISLATIVE DEPTH 12 FEET
- MAXIMUM LEGISLATIVE DEPTH 15 FEET
- MAXIMUM LEGISLATIVE DEPTH 24 FEET
- WASHINGTON DC BOUNDARY

SOURCE: MODIFIED FROM DC GIS, 2012, AND ESRI LIGHT GRAY BASEMAP, 2023.

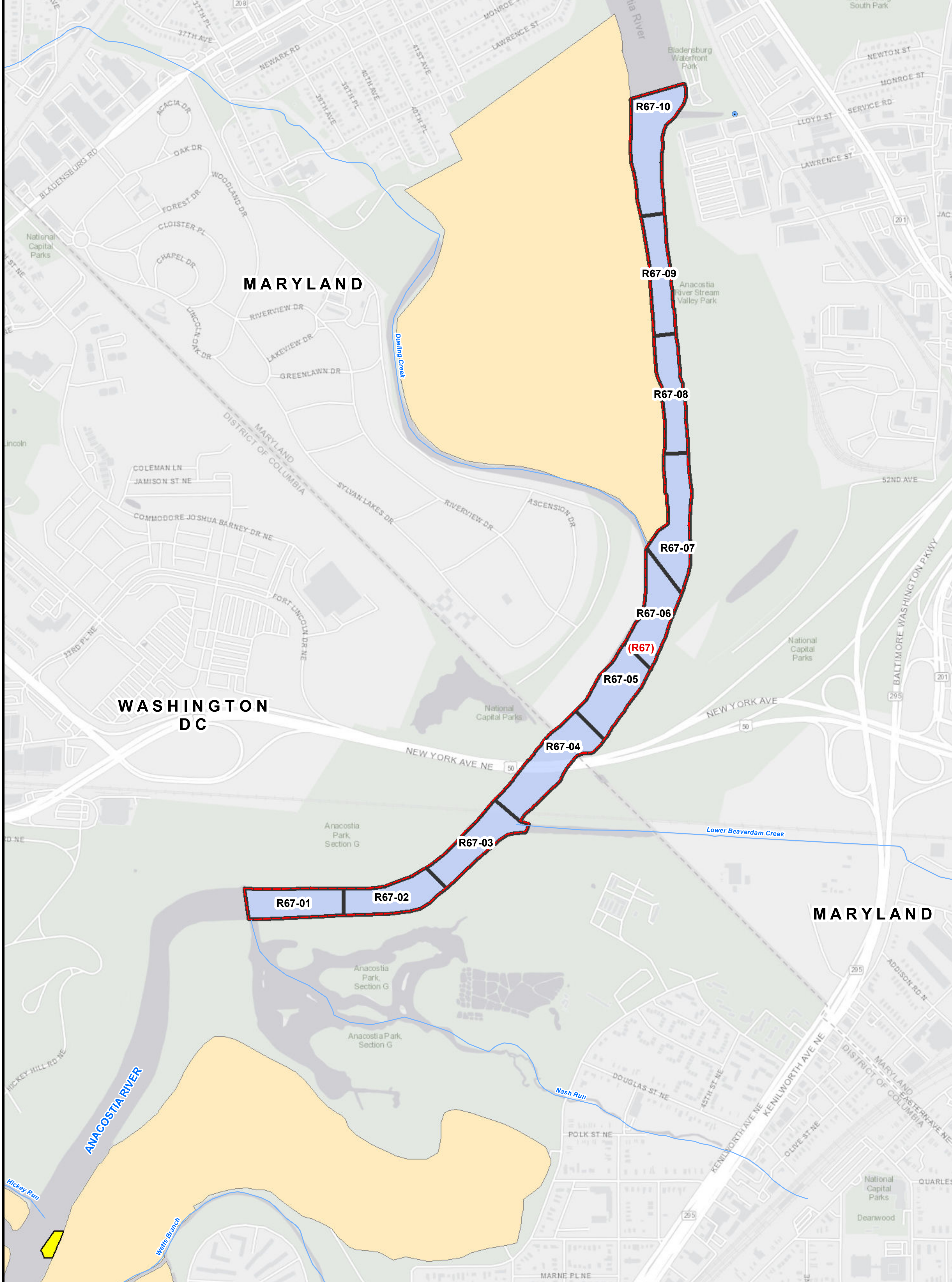
ANACOSTIA RIVER
SEDIMENT PROJECT

FIGURE 4.2
MODIFIED FEDERAL NAVIGATION CHANNEL DEPTHS (JANUARY 2023)

TETRA TECH


MAIN STEM OPERABLE UNIT REACH 123/456
MARYLAND
Dueling Creek
Lower Beaverdam Creek
(R456)
Hickey Run
Nash Run
R123/456-11
Unnamed Tributary
Watts Branch
R123/456-10
Benning Road Bridge
Piney Run
R123/456-09
East Capitol Street Bridge
R123/456-08
CSX Bridge
Fort Dupont Creek
WASHINGTON DC
Pope Branch
R123/456-07
Washington Channel
(R123)
Pennsylvania Avenue SE Bridge
R123/456-06
R123/456-05
11th Street Bridge
R123/456-04
South Capitol Street Bridge
R123/456-03
Fort Stanton
R123/456-02
DISTRICT OF COLUMBIA
MARYLAND
Oxon Run
POTOMAC RIVER
R123/456-01
MARYLAND
Legend
CSS OUTFALL
MS4 OUTFALL
INDUSTRIAL OUTFALL
STREAM
MAIN STEM OPERABLE UNIT
EARLY ACTION AREA
(ALSO BASELINE/PERFORMANCE
MONITORING EAA SAMPLING AREAS)
BASELINE/PERFORMANCE
MONITORING NON-EAA SAMPLING AREAS
CLEANUP SITE BOUNDARY
(LAND BASED PORTION)
N
W
E
S
0
1,250
2,500
Feet
ANACOSTIA RIVER
SEDIMENT PROJECT
FIGURE 6.1
BASELINE/PERFORMANCE
MONITORING POLYGONS:
SURFACE SEDIMENT AND POREWATER IN
MAIN STEM OPERABLE UNIT REACH 123/456
TETRA TECH
SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.

MAIN STEM OPERABLE UNIT REACH 67



Legend

- MS4 OUTFALL
- STREAM
- MAIN STEM OPERABLE UNIT
- EARLY ACTION AREA (ALSO BASELINE/PERFORMANCE MONITORING EAA SAMPLING AREAS)
- BASELINE/PERFORMANCE MONITORING NON-EAA SAMPLING AREAS
- CLEANUP SITE BOUNDARY (LAND BASED PORTION)

0 400 800 Feet

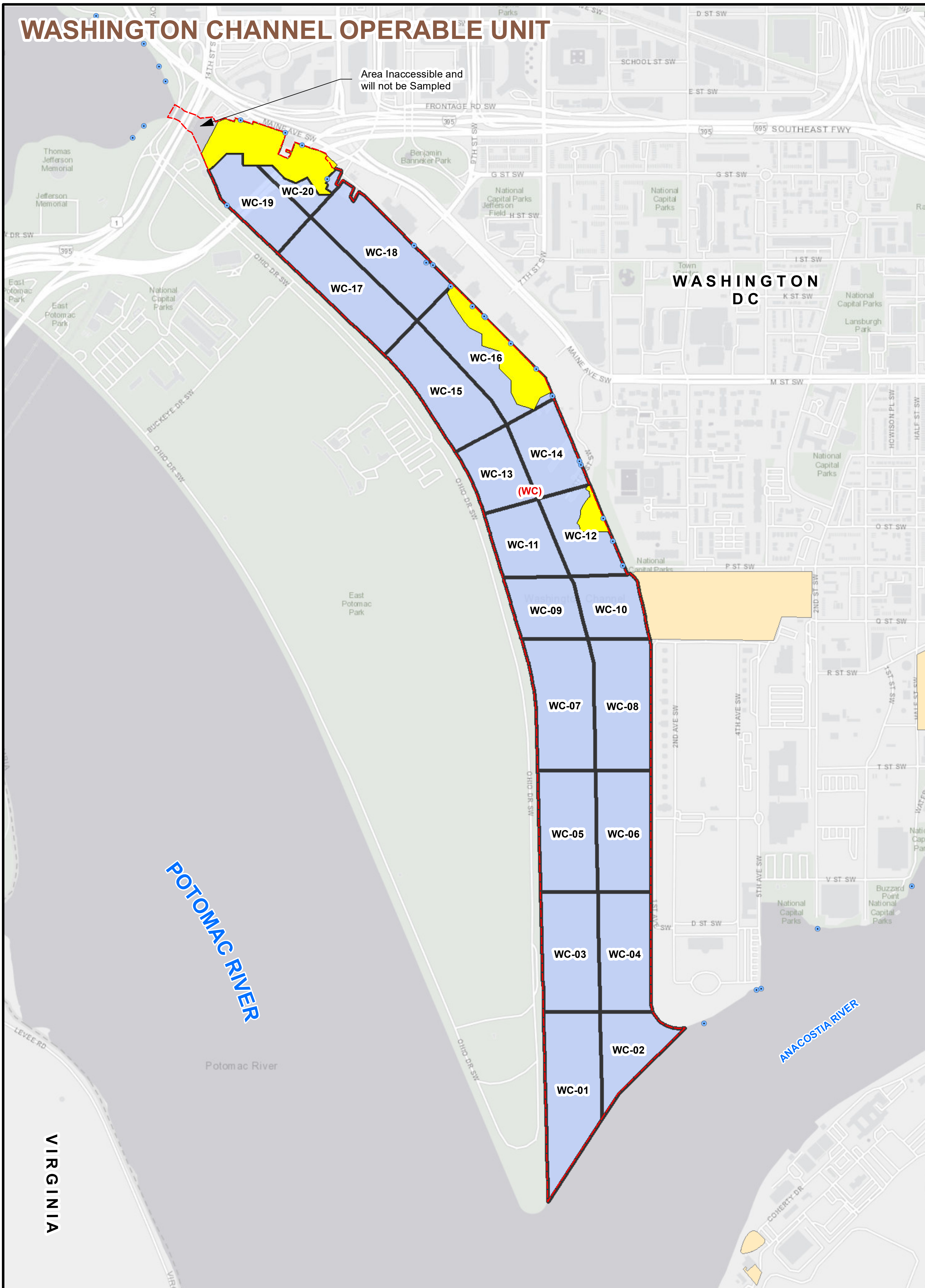
ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 6.2
BASELINE/PERFORMANCE MONITORING POLYGONS: SURFACE SEDIMENT AND POREWATER IN MAIN STEM OPERABLE UNIT REACH 67

TETRA TECH

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.

WASHINGTON CHANNEL OPERABLE UNIT



Legend

- MS4 OUTFALL
- WASHINGTON CHANNEL OPERABLE UNIT
- EARLY ACTION AREA (ALSO BASELINE/PERFORMANCE MONITORING EAA SAMPLING AREAS)
- BASELINE/PERFORMANCE MONITORING NON-EAA SAMPLING AREAS
- CLEANUP SITE BOUNDARY (LAND BASED PORTION)

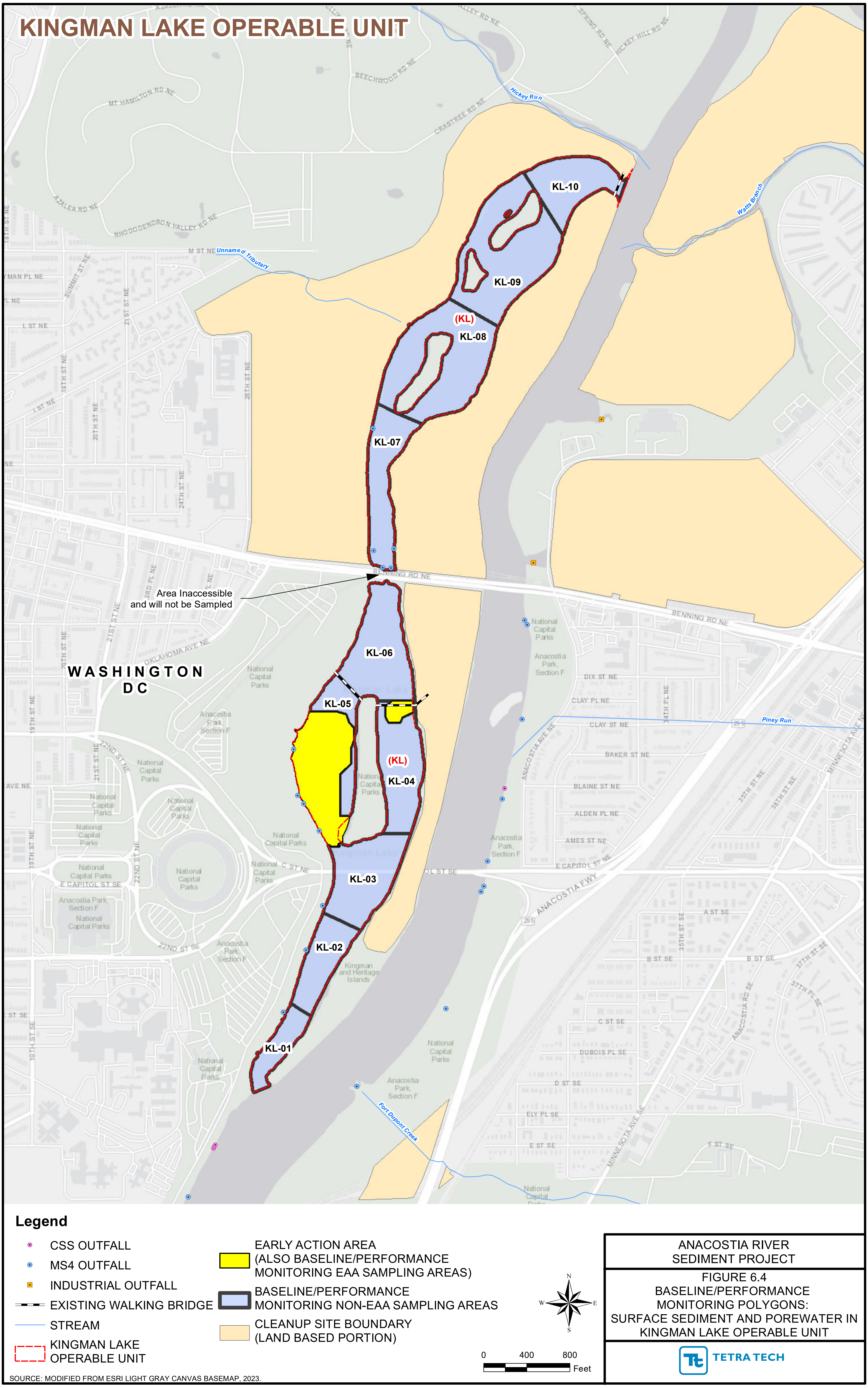
0 400 800 Feet

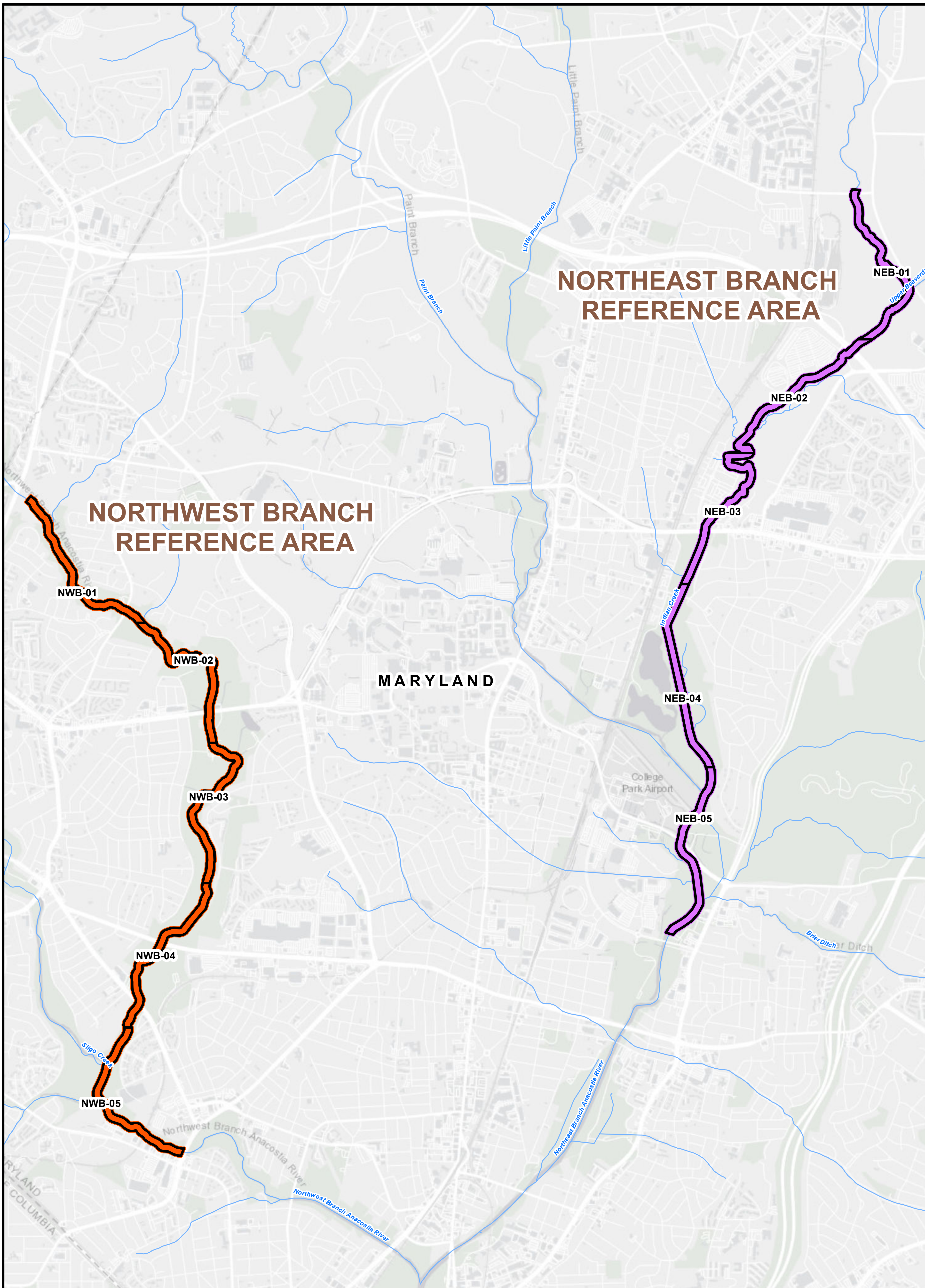
ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 6.3
BASELINE/PERFORMANCE MONITORING POLYGONS: SURFACE SEDIMENT AND POREWATER IN WASHINGTON CHANNEL OPERABLE UNIT

TETRA TECH

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.


KINGMAN LAKE OPERABLE UNIT
KL-10
KL-09
(KL)
KL-08
KL-07
Area Inaccessible and will not be Sampled
KL-06
KL-05
(KL)
KL-04
KL-03
KL-02
KL-01
WASHINGTON DC
Hickey Run
Watts Branch
Unnamed Tributary
Piney Run
Fort Dupont Creek
BENNING RD NE
Legend
CSS OUTFALL
MS4 OUTFALL
INDUSTRIAL OUTFALL
EXISTING WALKING BRIDGE
STREAM
KINGMAN LAKE OPERABLE UNIT
EARLY ACTION AREA (ALSO BASELINE/PERFORMANCE MONITORING EAA SAMPLING AREAS)
BASELINE/PERFORMANCE MONITORING NON-EAA SAMPLING AREAS
CLEANUP SITE BOUNDARY (LAND BASED PORTION)
N
S
E
W
0 400 800
Feet
SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.
ANACOSTIA RIVER SEDIMENT PROJECT
FIGURE 6.4
BASELINE/PERFORMANCE MONITORING POLYGONS: SURFACE SEDIMENT AND POREWATER IN KINGMAN LAKE OPERABLE UNIT
TETRA TECH



Legend

BASELINE/PERFORMANCE MONITORING SAMPLING AREA IN THE NORTHEAST BRANCH

BASELINE/PERFORMANCE MONITORING SAMPLING AREA IN THE NORTHWEST BRANCH

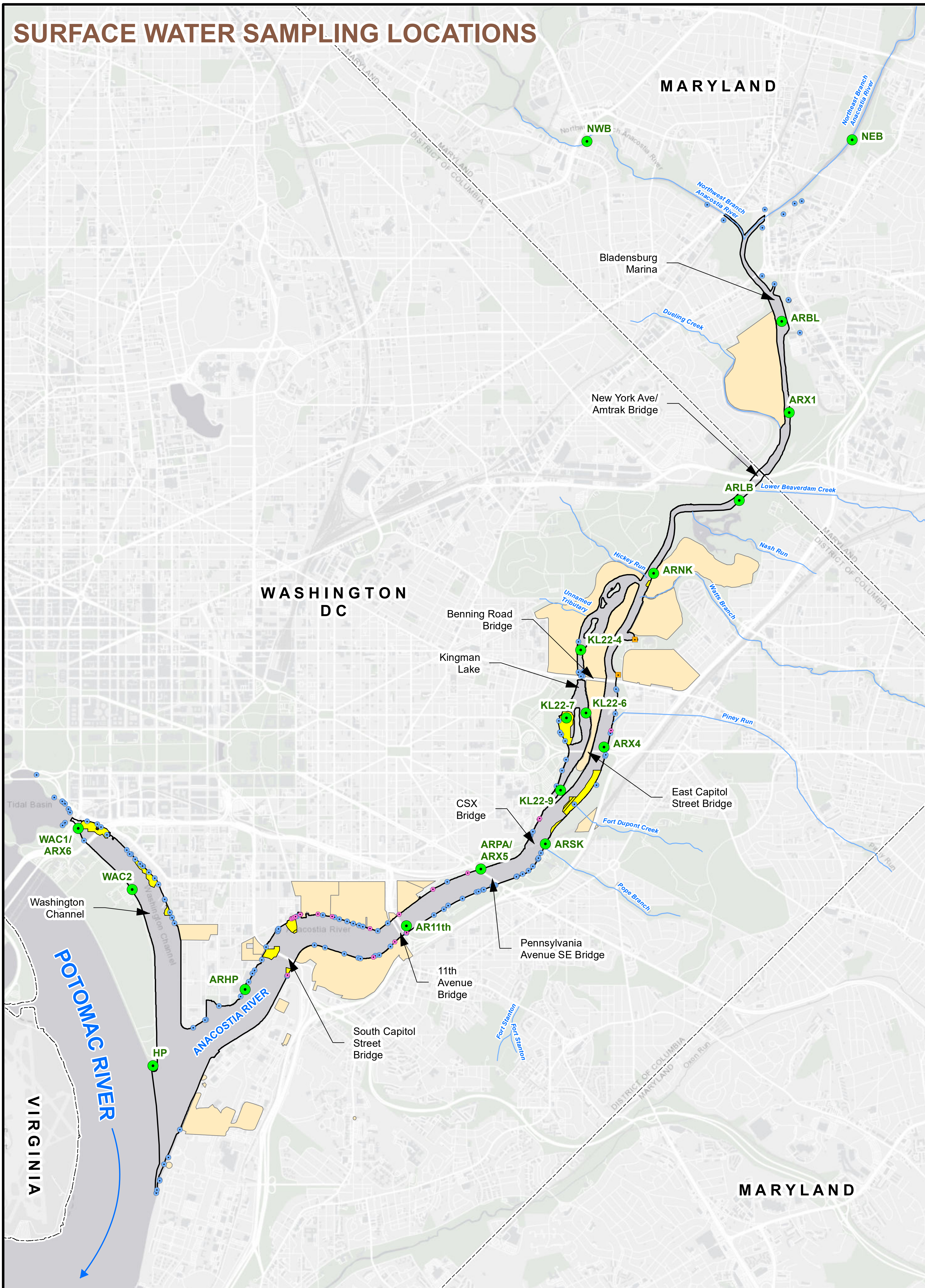
0 1,500 3,000 Feet

ANACOSTIA RIVER
SEDIMENT PROJECT

FIGURE 6.5
BASELINE/PERFORMANCE MONITORING POLYGONS: SURFACE SEDIMENT AND POREWATER IN REFERENCE AREAS

TETRA TECH

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.



Legend

- SURFACE WATER SAMPLING LOCATION
- CSS OUTFALL
- MS4 OUTFALL
- INDUSTRIAL OUTFALL
- STREAM
- EARLY ACTION AREA
- ARSP STUDY AREA
- WASHINGTON DC BOUNDARY
- CLEANUP SITE BOUNDARY (LAND BASED PORTION)

N E S W

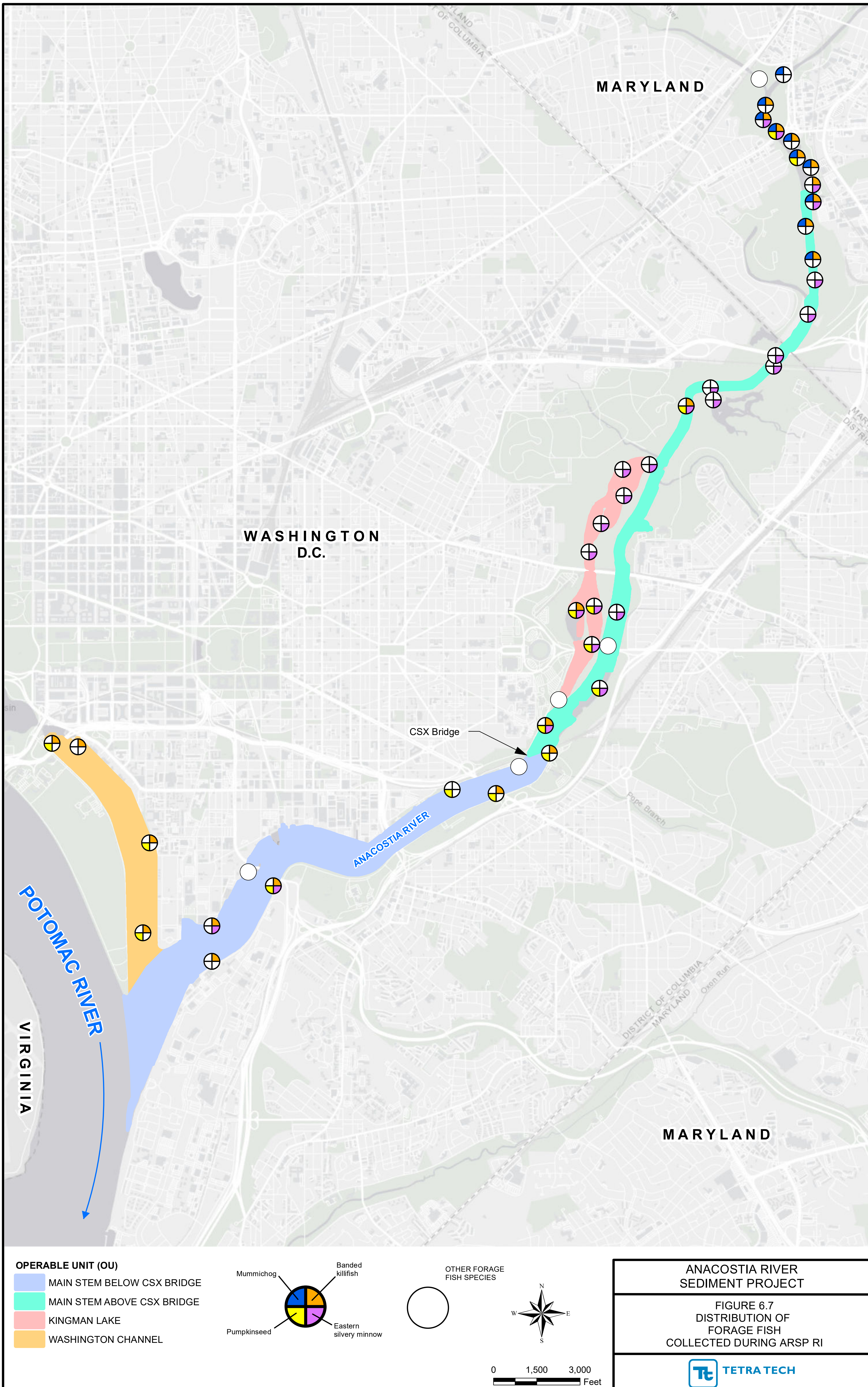
0 1,500 3,000 Feet

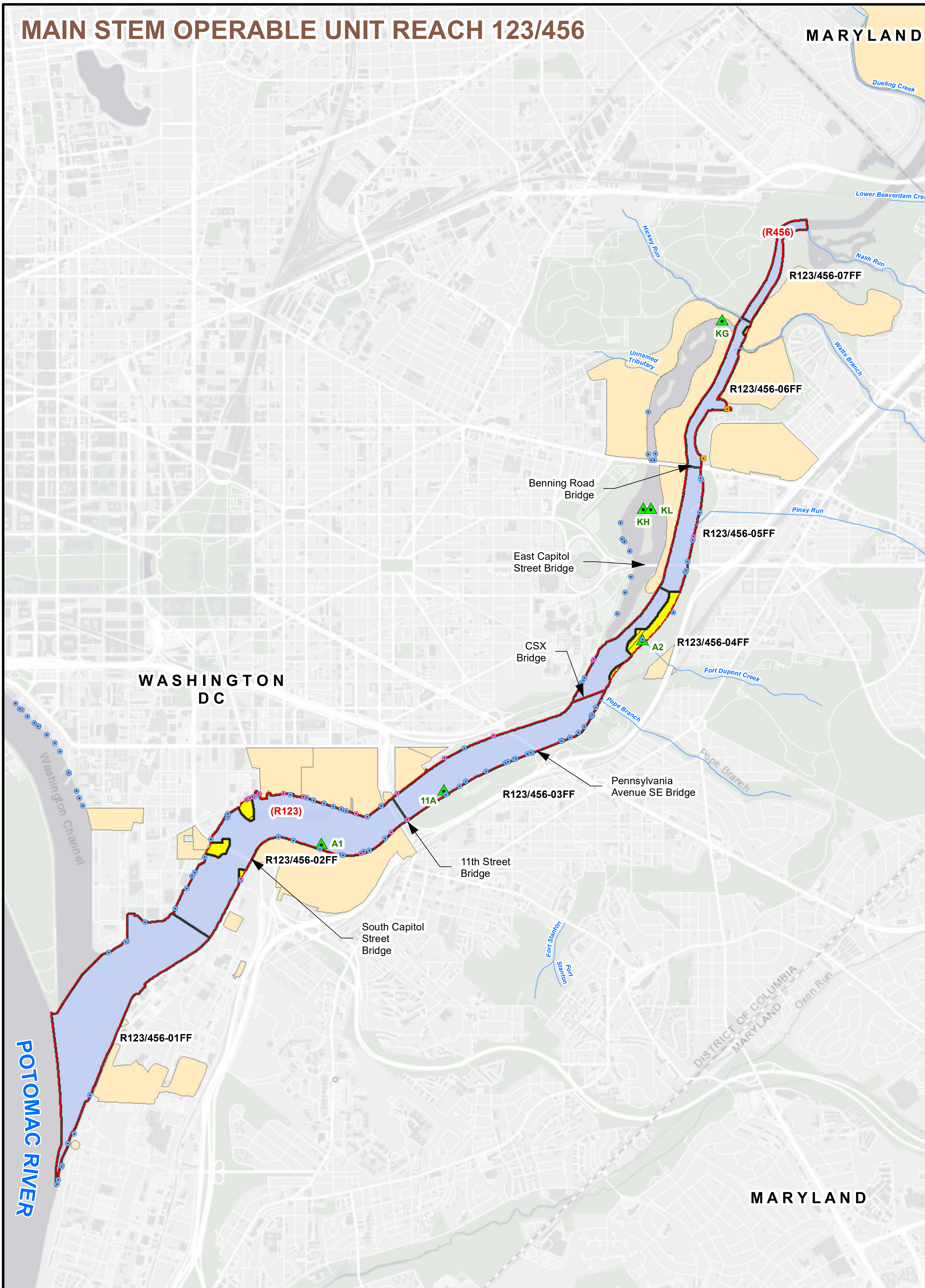
ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 6.6
B/P MONITORING
SURFACE WATER SAMPLING LOCATIONS

TETRA TECH

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.


MARYLAND
WASHINGTON D.C.
CSX Bridge
ANACOSTIA RIVER
POTOMAC RIVER
VIRGINIA
MARYLAND
OPERABLE UNIT (OU)
MAIN STEM BELOW CSX BRIDGE
MAIN STEM ABOVE CSX BRIDGE
KINGMAN LAKE
WASHINGTON CHANNEL
Mummichog
Banded killifish
Pumpkinseed
Eastern silvery minnow
OTHER FORAGE FISH SPECIES
0
1,500
3,000
Feet
SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.
ANACOSTIA RIVER SEDIMENT PROJECT
FIGURE 6.7
DISTRIBUTION OF FORAGE FISH COLLECTED DURING ARSP RI
TETRA TECH



Legend

- CSS OUTFALL
- MS4 OUTFALL
- INDUSTRIAL OUTFALL
- STREAM
- PREVIOUS USFWS (PINKNEY) FORAGE FISH SAMPLING LOCATIONS
- MAIN STEM OPERABLE UNIT
- EARLY ACTION AREA (ALSO BASELINE/PERFORMANCE MONITORING EAA SAMPLING AREAS)
- BASELINE/PERFORMANCE MONITORING NON-EAA FORAGE FISH SAMPLING AREAS
- CLEANUP SITE BOUNDARY (LAND BASED PORTION)

N W E S

0 1,250 2,500 Feet

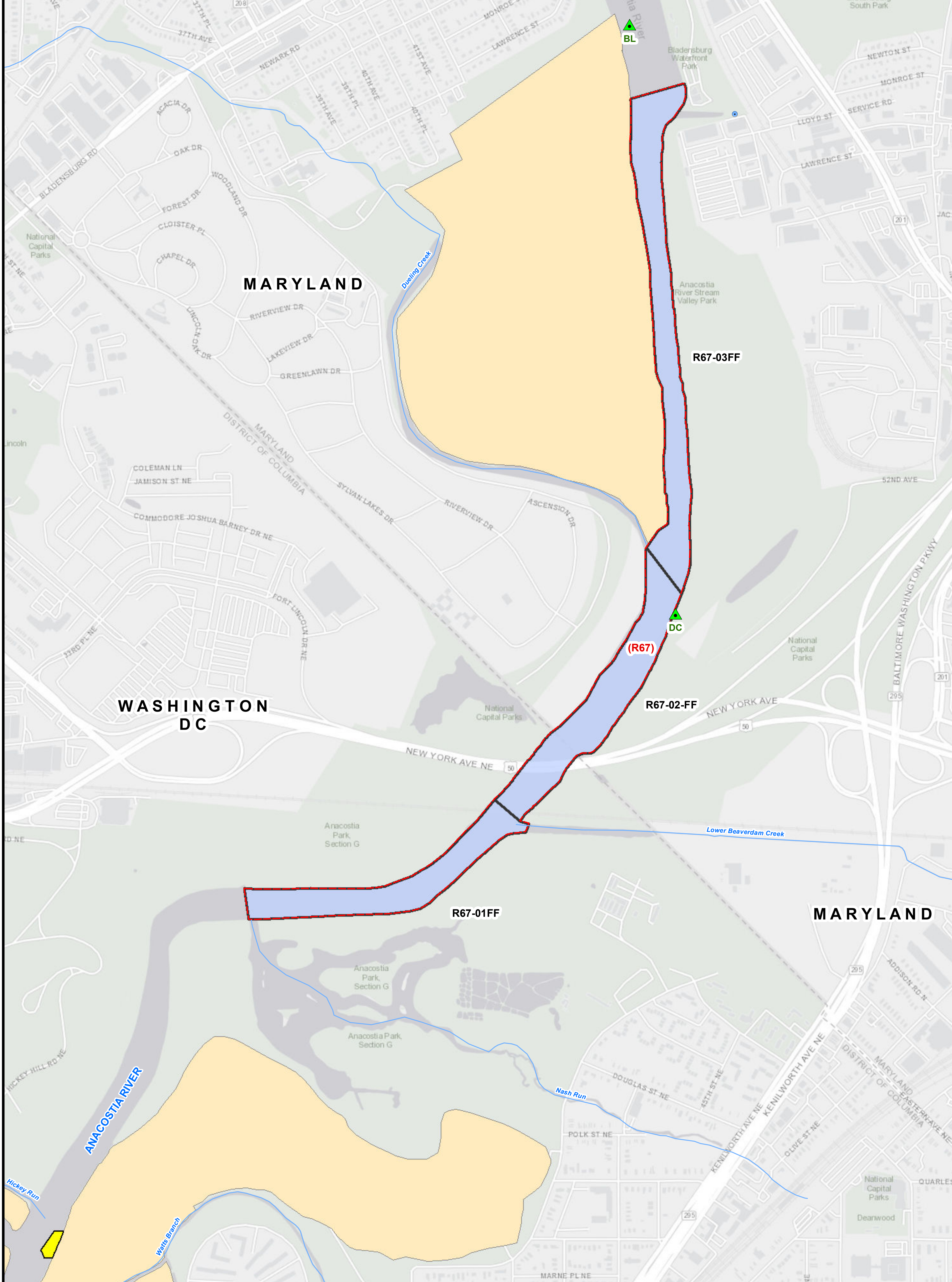
SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.

ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 6.8
BASELINE/PERFORMANCE MONITORING POLYGONS: FORAGE FISH IN MAIN STEM OPERABLE UNIT REACH 123/456

TETRA TECH

MAIN STEM OPERABLE UNIT REACH 67



Legend

- MS4 OUTFALL
- STREAM
- PREVIOUS USFWS (PINKNEY) FORAGE FISH SAMPLING LOCATIONS
- MAIN STEM OPERABLE UNIT
- EARLY ACTION AREA (ALSO BASELINE/PERFORMANCE MONITORING EAA SAMPLING AREAS)
- BASELINE/PERFORMANCE MONITORING NON-EAA FORAGE FISH SAMPLING AREAS
- CLEANUP SITE BOUNDARY (LAND BASED PORTION)

0 400 800 Feet

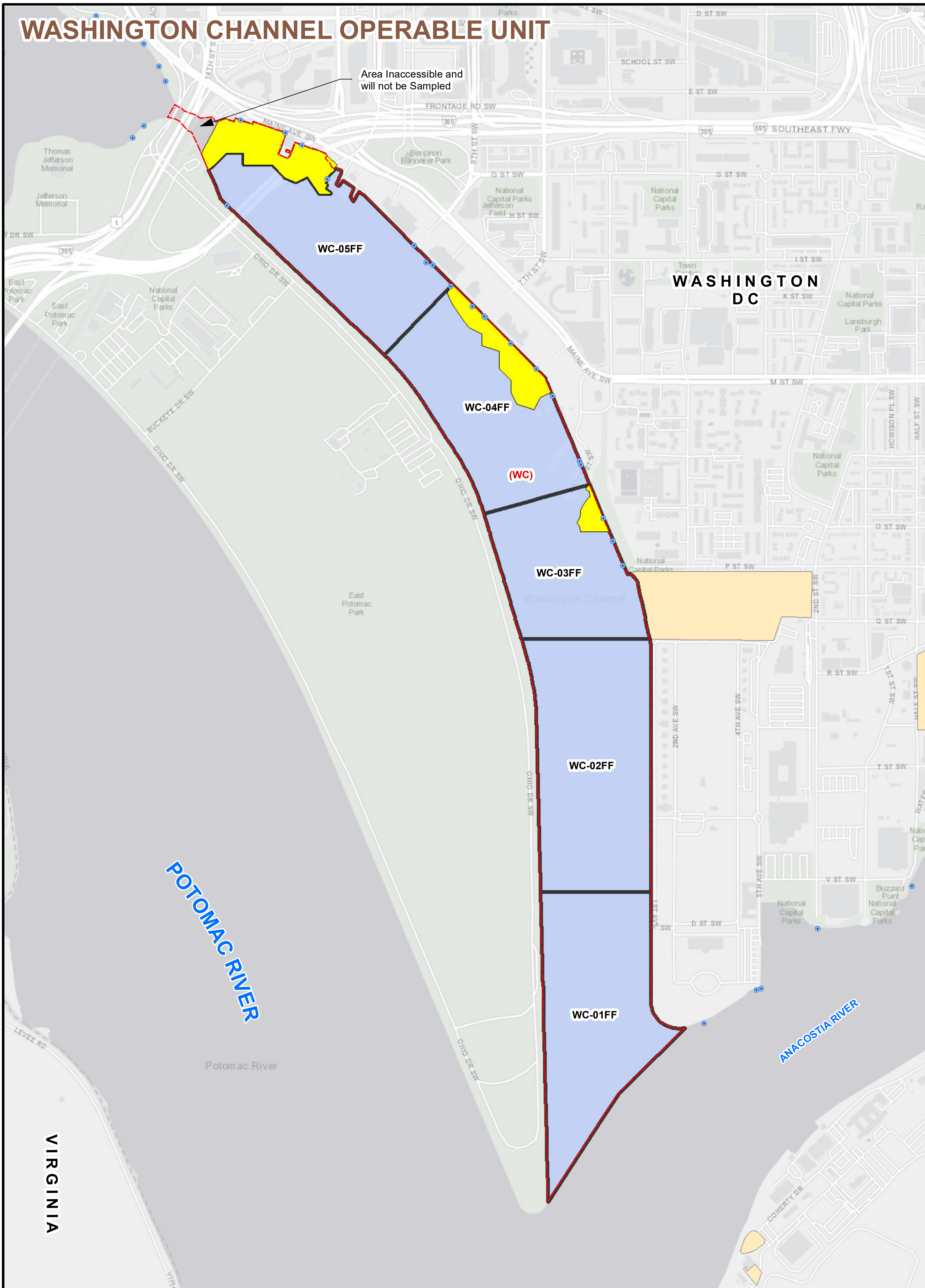
ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 6.9
BASELINE/PERFORMANCE MONITORING POLYGONS: FORAGE FISH IN MAIN STEM OPERABLE UNIT REACH 67

TETRA TECH

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.

WASHINGTON CHANNEL OPERABLE UNIT



Legend

- MS4 OUTFALL
- WASHINGTON CHANNEL OPERABLE UNIT
- EARLY ACTION AREA (ALSO BASELINE/PERFORMANCE MONITORING EAA SAMPLING AREAS)
- BASELINE/PERFORMANCE MONITORING NON-EAA FORAGE FISH SAMPLING AREAS
- CLEANUP SITE BOUNDARY (LAND BASED PORTION)

N E S W

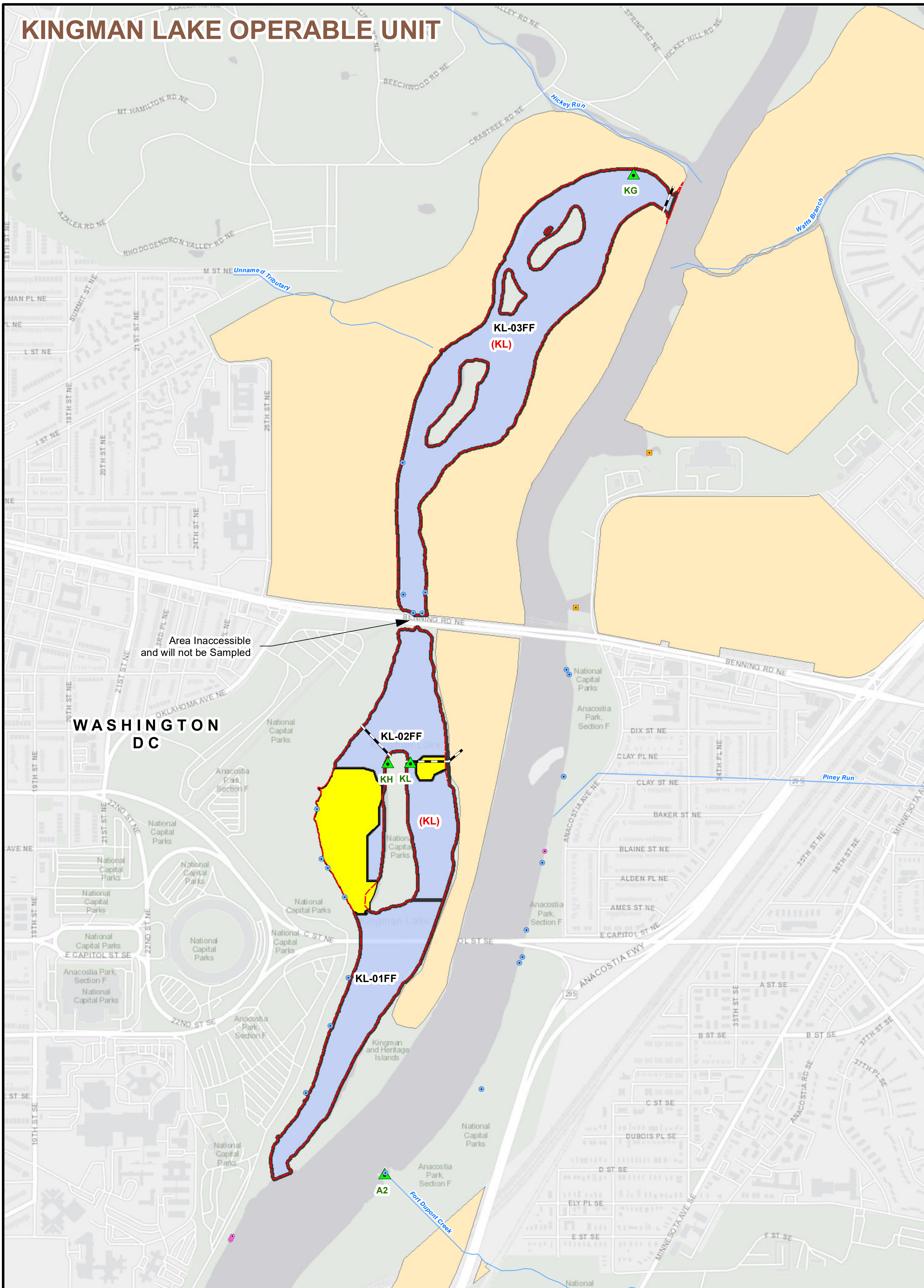
0 400 800 Feet

ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 6.10
BASELINE/PERFORMANCE MONITORING POLYGONS: FORAGE FISH IN WASHINGTON CHANNEL OPERABLE UNIT

TETRA TECH

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.



Legend

- CSS OUTFALL
- MS4 OUTFALL
- INDUSTRIAL OUTFALL
- EXISTING WALKING BRIDGE
- STREAM
- PREVIOUS USFWS (PINKNEY) FORAGE FISH SAMPLING LOCATIONS
- KINGMAN LAKE OPERABLE UNIT
- EARLY ACTION AREA (ALSO BASELINE/PERFORMANCE MONITORING EAA SAMPLING AREAS)
- BASELINE/PERFORMANCE MONITORING NON-EAA FORAGE FISH SAMPLING AREAS
- CLEANUP SITE BOUNDARY (LAND BASED PORTION)

N S E W

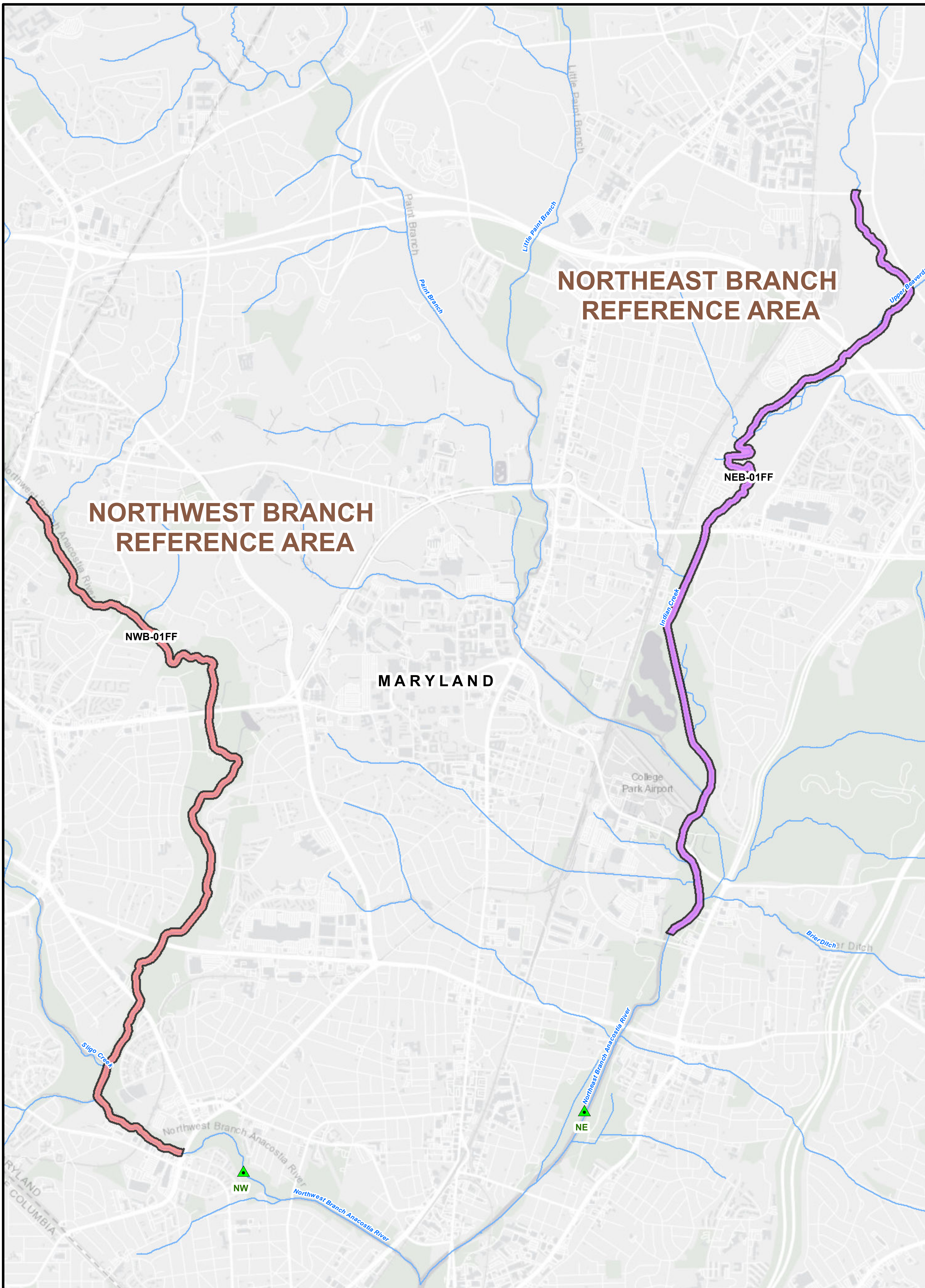
0 400 800 Feet

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.

ANACOSTIA RIVER
SEDIMENT PROJECT

FIGURE 6.11
BASELINE/PERFORMANCE MONITORING POLYGONS: FORAGE FISH IN KINGMAN LAKE OPERABLE UNIT

TETRA TECH



Legend

- PREVIOUS USFWS (PINKNEY) FORAGE FISH SAMPLING LOCATIONS
- BASELINE/PERFORMANCE MONITORING FORAGE FISH SAMPLING AREA IN THE NORTHEAST BRANCH
- BASELINE/PERFORMANCE MONITORING FORAGE FISH SAMPLING AREA IN THE NORTHWEST BRANCH

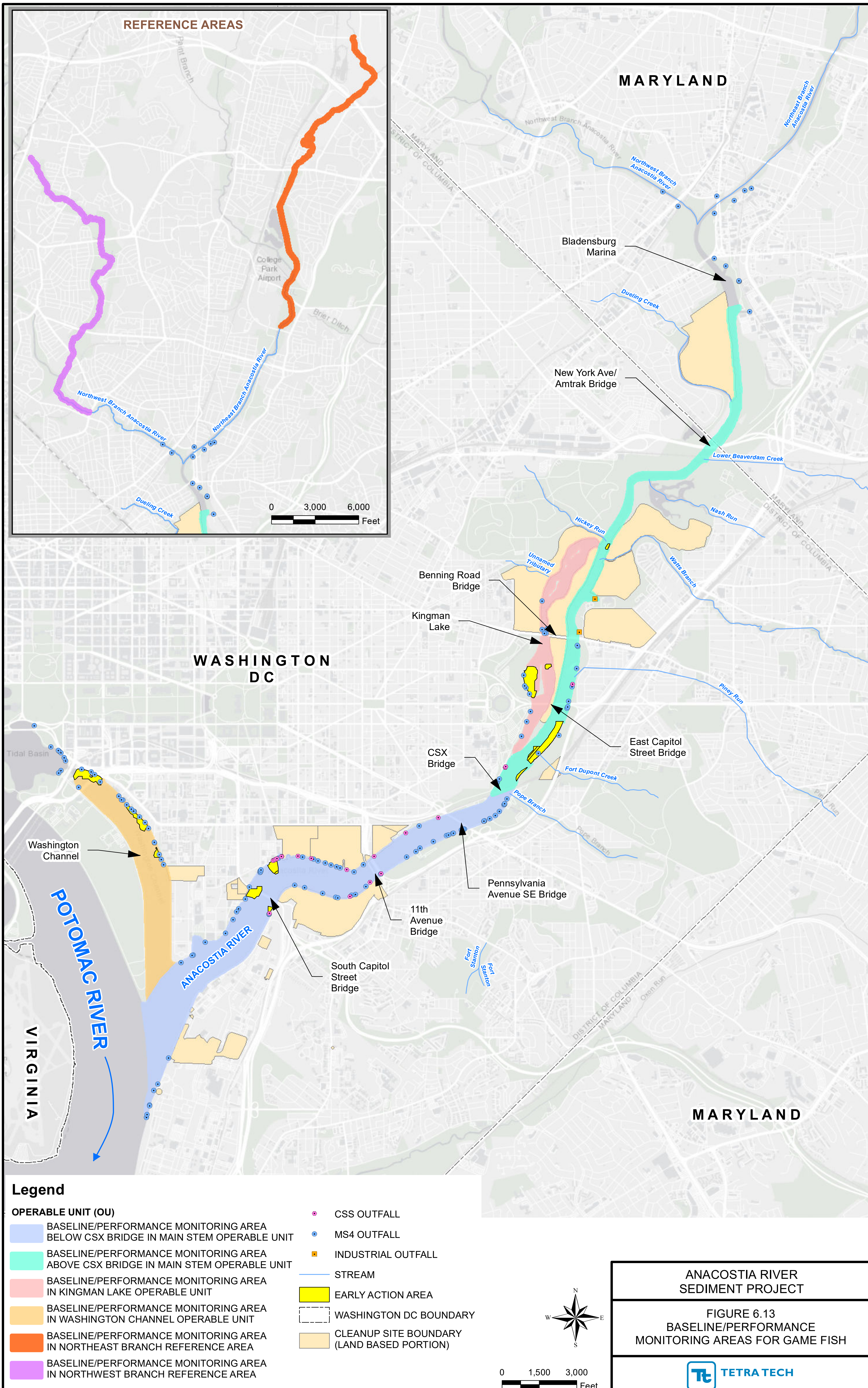
0 1,500 3,000 Feet

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.

ANACOSTIA RIVER SEDIMENT PROJECT

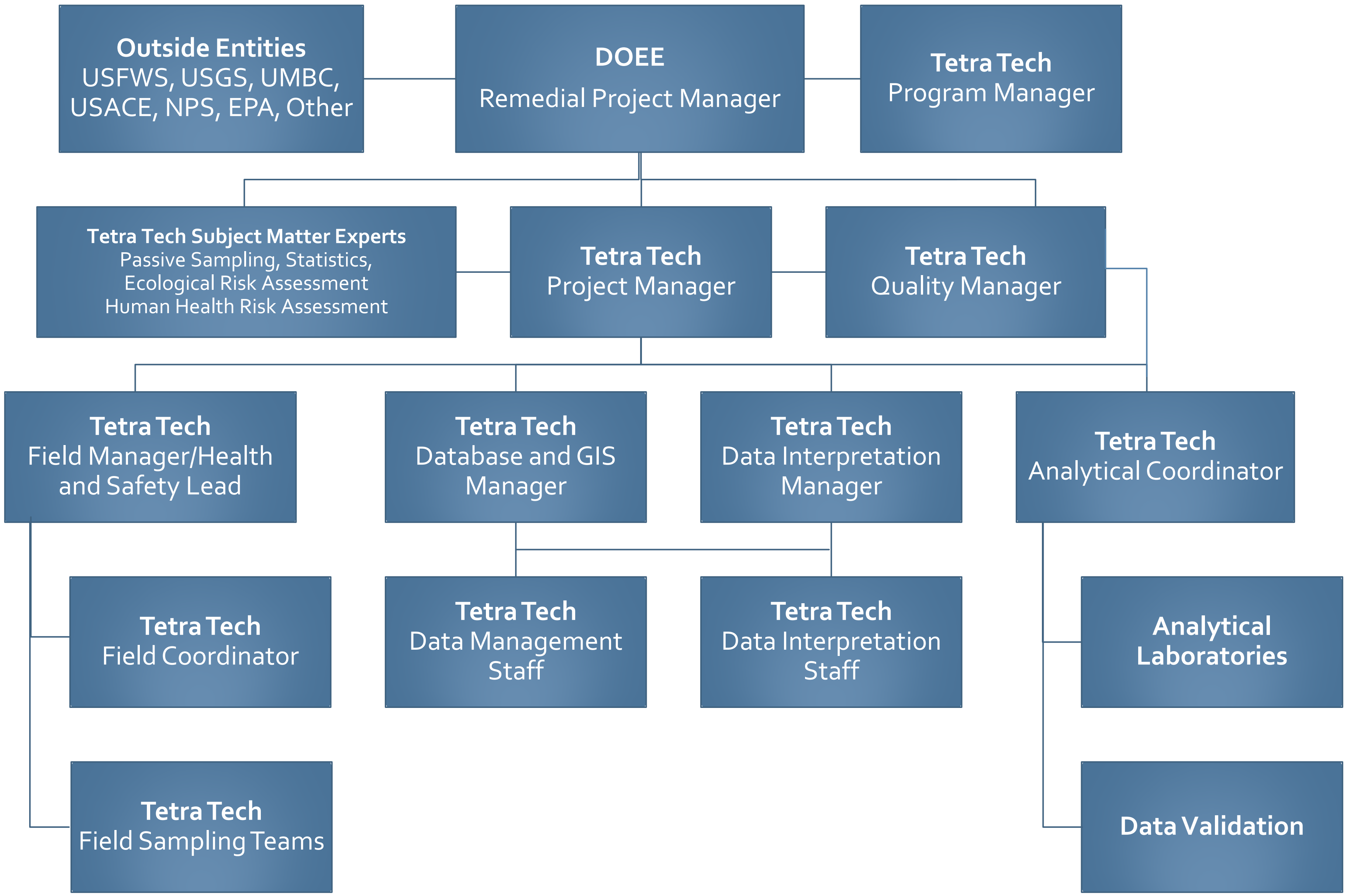
FIGURE 6.12
BASELINE/PERFORMANCE MONITORING POLYGONS: FORAGE FISH IN REFERENCE AREAS

TETRA TECH



ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE 6.13
BASELINE/PERFORMANCE MONITORING AREAS FOR GAME FISH



ANACOSTIA RIVER
SEDIMENT PROJECT

FIGURE 9.1
BASELINE/PERFORMANCE MONITORING
PROJECT ORGANIZATION CHART

TETRA TECH

APPENDIX A
STATISTICAL METHODS

APPENDIX A

STATISTICAL METHODS

Appendix A.1
Baseline and Performance (B/P) Statistical Analyses Plan

1. Introduction

The Baseline/Performance Monitoring Plan (B/P Monitoring Plan) presents the rationale and sampling that the District of Columbia Department of Energy and Environment (DOEE) will use to document and evaluate baseline conditions and performance of the remedial actions defined for the Anacostia River Sediment Project (ARSP) study area. DOEE's Interim Record of Decision (IROD) for the ARSP study area identified early action areas (EAAs) in three operable units (OUs) for remediation of sediment with the highest concentrations of polychlorinated biphenyls (PCBs) in the river (DOEE 2020).

The B/P Monitoring Plan is designed to generate independent, unbiased datasets for the indicators that will be statistically analyzed to assess progress of the interim remedies (i.e., cleanup of the constituents of concern [COCs] in the EAAs) toward achieving remedial action objectives (RAOs) and establishment of the final record of decision (ROD). Cleanup progress will be gauged using multiple indicators evaluated using applicable metrics, as described in the main text of the B/P Monitoring Plan. **Table A-1** lists the B/P indicators, intended use of the data, and proposed statistical approaches.

Table A-1 Summary of B/P Monitoring Indicators and Intended Data Use

Indicator	Monitoring Parameter	Intended Use of Data	Proposed Statistical Approach
Surface Sediment	Concentrations of COCs and PAHs	Calculate OU-specific surface weighted average concentration (SWACs) for comparison with PRGs; correlation with forage fish and game fish; trend analyses; input to bioaccumulation model	Comparison to target metric and trend analysis
Porewater	Concentrations of COCs	Correlation with sediment, forage fish, and game fish; trend analyses; input to bioaccumulation model	Comparison to target metric
Surface Water	Concentrations of COCs	Correlation with sediment, forage fish, and game fish; trend analyses; input to bioaccumulation model	Comparison to target metric
Benthic Invertebrate Toxicity Tests	Survival and growth (midge and amphipod); reproduction (amphipod only)	Correlate with sediment and porewater analytical results; trend analyses; measure progress toward RAO 3	Comparison to target metric and trend analysis
***Lumbriculus* Bioaccumulation Test**	Concentration of COCs in whole-body tissue	Correlate with sediment, porewater, forage fish, and game fish; refine sediment Regional Screening Level (RSL) for game fish ingestion; input to bioaccumulation model; trend analyses; measure progress toward RAO 3 and RAO 4	Comparison to target metric

Indicator	Monitoring Parameter	Intended Use of Data	Proposed Statistical Approach
Forage Fish Tissue	Concentrations of COCs in whole-body fish tissue	Estimate cleanup timeframe; correlate with game fish; refine sediment RSL for game fish ingestion (see Note 1); input to bioaccumulation model; trend analyses; measure progress toward RAO 4	Trend analysis
Game Fish Tissue	Concentrations of COCs in edible tissue	Estimate cleanup timeframe; correlate with forage fish; refine sediment RSL for game fish ingestion; ground truth bioaccumulation model; trend analyses; measure progress toward RAO 1	Comparison to target metric and trend analysis

Note 1: Under an adaptive management framework, the process used to calculate sediment cleanup (which is based on game fish ingestion) may be adjusted as new information becomes available and/or our understanding of the link between fish and sediment is refined. Refer to Appendix A of the River-wide Feasibility Study (FS) Report for more information on the RSLs calculated to support sediment cleanup (Tetra Tech 2019).

Data interpretation will involve three types of statistical analyses: comparison to a fixed value (e.g., preliminary remedial goal [PRG]) (Section 2), trend testing (Section 3), and correlation (Section 4). All statistical analyses will be completed within the limitations and uncertainty of the data. Statistical tools will be used to evaluate the data collected for each indicator monitored in the B/P sampling event. The 'R' Statistical Analysis package (www.r-project.org) in conjunction with R-Studio (www.rstudio.com) — both public domain software products — and other analytical tools will be used in the production of the statistical values and graphs during this project.

2. Comparison to Target Metric

The first task of the statistical analysis is to periodically compare sediment data for each COC against fixed, pre-defined metrics (e.g., a sediment PRG). The goal of this analysis is to determine whether concentrations have been sufficiently reduced to establish with statistical confidence that PRGs have been achieved.

For comparisons against a fixed or target metric, EPA has long recommended the use of confidence intervals (EPA 2009). Standard confidence intervals provide estimates of the population mean while accounting for sample size, population variability, and a desired degree of accuracy (e.g., 95 percent statistical confidence). When a confidence interval is entirely below the fixed metric, it can be asserted with high confidence that the true, but unknown, average has met the target.

Results of comparing the confidence intervals with the PRGs will be presented as tables listing the comparison test outcomes (i.e., whether or not each confidence interval exceeds the PRG), along with graphs of the confidence intervals matched to the observed data and overlaid with the relevant PRGs to present visual confirmation of the tabular results.

To construct appropriate standard confidence intervals, the periodically collected sediment data will be grouped for each COC and certain assumptions checked. These assumptions include the following: (1) the sample data are approximately normally distributed (refer to **Section 2.1**) and the sample data exhibit statistically significant trends within the limitation and uncertainty of the data (refer to **Section 2.2)**.

2.1 Sample Data are Approximately Normally Distributed

Confidence intervals estimating the population mean are derived as a function of the sample mean and standard deviation, whereby a multiple of the standard deviation is added and subtracted from the sample mean. The accuracy of this calculation depends substantially on how closely the observed data are to a normal distribution model. If the data differ greatly from the model, the achieved statistical confidence (accuracy) may be much lower and more uncertain than the target accuracy.

To test this assumption, normal probability plots will be constructed on the sample data, and a normality test, Filliben's probability plot correlation coefficient test (Filliben 1975), will be run on these observations. Filliben's test judges the strength of the correlation between the quantities on the probability plot, namely the degree of association between the standard normal quantiles (or Z-scores) and the sorted data values. A correlation exceeding Filliben's threshold implies the data adequately fit the normal model, while a lower correlation suggests the data do not match the model.

Because environmental data often fail to closely fit a normal distributional model, it is anticipated that the standard confidence interval formula frequently will not be sufficient to allow accurate comparisons with sediment PRGs. In such cases, consideration will be given to a transformation of the sample data prior to constructing the confidence interval. A transformation can be used to normalize the data and satisfy the normality assumption. However, a confidence interval using normalized data must be back-transformed to the nominal data scale prior to any statistical comparison with the fixed metric. In doing so, the back-transformed confidence interval no longer estimates the population mean, but estimates a different population statistic, typically the median. In other words, the transformation induces a statistical bias in the confidence interval result, which can have the effect of lowering the statistical accuracy with which the population mean is estimated.

To minimize the risk of bias when a normal distribution model cannot be used, a bootstrap confidence interval will be constructed. Bootstrapping is a resampling technique that allows for estimation of confidence intervals even when the underlying data model is unknown — like standard non-parametric intervals — but that often yields greater accuracy.

The presence of chemical analysis results reported below the laboratory level of quantitation (LOQ); also referred to as non-detects) can affect both the accuracy of confidence intervals and the extent to which observed data can be fit to a distributional model. Non-detects in the dataset for a COC increase uncertainty in the sample data and make accurate distributional modeling more difficult as the number of non-detects in the dataset increases. Non-detects also affect standard non-parametric confidence intervals, especially the lower confidence limit (LCL), which is selected as a small, observed data value. When that observation is a non-detect, which is known only as being no greater than the LOQ, the accuracy of the lower confidence interval bound may be suspect.

Cases with non-detects will be analyzed using Monte Carlo imputation (i.e., assigning a random value between zero and the LOQ for each non-detect) prior to constructing confidence intervals (Cameron 2017). To ensure that any given set of random imputations does not bias the final interval estimate, the algorithm of generating imputations and computing each confidence interval will be repeated 500 times, with the final estimate taken as the average of the 500 runs.

Results of the PRG comparisons will be presented as tables listing the comparison test outcomes (i.e., whether or not each confidence interval exceeds its respective PRG), along with graphs of the confidence interval matched to the observed data and overlain with the relevant PRGs to visually confirm the tabular results.

2.2 Sample Data Exhibit Statistically Significant Trends

Standard confidence interval formulas assume the sample data are drawn from a stable (non-trending) population. When no trend exists, standard confidence intervals will be constructed and compared with their respective PRGs.

If a trend does exist, the population mean is no longer a fixed population quantity, but rather a value that changes with time. Further, a trend will induce additional variation in the data over and above what would be expected from a stable population, thus biasing standard confidence intervals and making them too wide.

As an alternative, “confidence bands” are a recommended variant of confidence intervals in cases with data collected over time where a trend may exist. A confidence band is essentially a confidence interval stretched out and wrapped along an estimated trend line. Vertical cross-sections of the confidence band at points in time correspond to point-in-time confidence intervals that can be used to test compliance with fixed standards or metrics.

Because the sediment data are being collected over time, appropriate linear or non-linear trends will be estimated for each COC, along with a confidence band around each trend. Linear trends will be estimated using linear regression, while visually non-linear trends will be constructed using the local non-linear regression technique known as LOESS (Cleveland 1979, 1981). Confidence bands can be estimated around either trend method. EPA's guidance (2009) presents confidence bands for linear trends in Equations [21.24] and [21.25] of Section 21.3, while Cleveland (1979, 1981) discusses confidence bands for LOESS trends.

Trend estimation with associated confidence bands for datasets with non-detects will be accommodated like the approach for standard confidence intervals with non-detects. Monte Carlo imputation will be used to generate random values between zero and its LOQ for each non-detect. The imputations will be combined with the detected observations to construct the trend estimate and its confidence band. The process will then be repeated 500 times and the results averaged to get the final confidence band.

To assess attainment of the PRGs at each evaluation point, the cross-section of the confidence band at the most recent sampling event will be compared with its respective sediment PRG. If the confidence interval cross-section is fully below the PRG, the target will be declared to have been met. If not, the target will be re-checked with the new data generated by the next sampling event.

Results of the PRG comparisons will be presented as tables listing the comparison test outcomes at specific points in time (i.e., whether or not the cross-section of the confidence band at a specific time point exceeds the PRG), along with graphs of the confidence bands matched to the observed data and overlain with the relevant PRGs to visually confirm the tabular results.

3. TREND TESTING

The second task of the statistical analysis is to identify statistically significant trends in the sediment concentrations during the period of remedial activities within the limitations and uncertainty of the data. This trend analysis is designed to answer the following questions:

(1) *Within an OU, is there a downward trend in COC concentrations in sediment?*

(2) *Are there trends in concentrations of COCs in game fish tissue or whole-body forage fish?*

(3) *How do COC concentration trends in an OU compare with trends in the Reference Area?*

3.1 Identifying Downward Trends

Linear regression will be used to assess any trends over time for each COC in each OU within the limitation and uncertainty of the data. A downward trend will be identified when the slope is negative and the p-value associated with a test of the slope is sufficiently small (e.g., $p < 0.05$). Trends with larger p-values will be identified as non-significant.

Trends will be computed in conjunction with the confidence bands discussed in **Section 2.2** as a preparatory step in constructing confidence bands. However, in cases where the trend is visually non-linear and a non-linear LOESS trend has been constructed, the non-parametric Sen's slope test will be used to evaluate the linear portion of the trend (i.e., the slope that would result if a linear trend line had been estimated instead of the non-linear LOESS trend). Sen's slope method computes the linear change between all possible pairs of the sample data, setting the slope estimate to the median of the pairwise slopes. If Sen's slope estimate is negative and the p-value of Sen's slope test is sufficiently small (e.g., $p < 0.05$), a downward trend will be identified.

Prior to reporting trend estimates, key assumptions associated with linear regression will be checked. These checks will assess whether the trend line residuals satisfy normality and homoscedasticity requirements (i.e., stable variation along the trend line) and whether any significant outliers are present in the dataset. Violations of the first two assumptions can indicate the presence of a non-linear trend and the need to use either a data transformation prior to linear regression or LOESS trend modeling instead of linear regression.

The impact of outliers will be assessed by computing standard measures of influence and leverage. Data points with high leverage and/or influence will be further examined to gauge their impact on the trend estimates; field and laboratory records will be reviewed for transcription errors or other anomalies. Values with quality control/quality assurance (QC/QA) errors or sampling issues will be excluded from the final trend estimates. A sensitivity analysis will be conducted for outliers with no identifiable data quality problems. The sensitivity analysis will compute trend estimates both with and without the outlier data. If the comparative estimates differ substantially, the outlier points will be excluded from the final trends. Otherwise, the apparent outliers will be retained.

3.2 Comparison to Estimated Cleanup Timeframes

If COC concentrations are downward trending but still exceed the PRG, the constructed linear trend for that COC will be extrapolated to estimate the time for the target metric to be achieved (e.g., PCBs attain the PRG in 10 years). Since trend extrapolation can invoke uncertainty, the confidence band around the trend will also be extrapolated. This extrapolation will provide more realistic bounds on the time-to-completion estimates.

If the trend estimate is non-linear or constructed via LOESS, the linear portion of the most recent subset of the data will be estimated using linear regression, along with an associated confidence band. This estimation will provide a consistent strategy with which to construct the time-to-completion estimates.

Because of the inherent uncertainty of trend extrapolations, time-to-completion will be reported with projected uncertainty bounds. To do this, the time-to-completion estimate will represent the first date at which the extrapolated trend line drops below the PRG. The uncertainty bounds will be computed by similarly calculating the first dates at which the lower and upper confidence bounds drop below the target. The time-to-completion will be reported as a time range between the earliest and latest of these projected dates.

The trend testing results will be presented as tables of the equations and coefficients of each regression model, along with graphs showing each trend and confidence band matched to the observed data. The graphs will also show any possible extrapolation of the trend until the target metric is projected to be met.

3.3 Comparison to Reference Areas

To better assess whether apparent trends in the OUs represent remedial improvement or simply natural variation over time, similar linear trend estimates will be computed using sediment data collected from the reference area. If the reference area trends document changes in COC levels comparable in magnitude and direction to the OU trends, further analyses of the effect of the remedy will be conducted. Conversely, if concentration trends are declining in the OU trends but not in the reference area, the remedial effort is shown to be working as intended.

To compare the OU and reference area trends, two components of each set of trends will be examined: (1) trend direction and (2) trend magnitude (i.e., slope). These components will be compared over the same time frames to check for any differences, including:

- A difference in trend direction will be identified whenever the OU and reference area slopes have different signs and at least one slope statistically differs from zero
- OU and reference area slopes have the same sign but only one slope differs from zero
- Cases where both slopes are non-significant will be treated as statistically indistinguishable

A difference in trend magnitude will be gauged via a t-test. Slope estimates derived from linear regression have an associated standard error (s.e.) and degrees of freedom (df). This allows a direct statistical comparison between two slope estimates to test whether they differ. Cases where the OU slope is more steeply downward will tend to indicate the remedy is working. All other outcomes may suggest otherwise, or that the evidence is insufficient to demonstrate remedial effectiveness.

4. Correlations and Predictions

Correlation is a descriptive tool useful for quantifying relationships between pairs of statistical variables. Such pairs might represent different COCs measured in a single medium; the same COC measured across different media (e.g., sediment versus porewater); or even different COCs measured in different media. Prediction is using a relationship established from a correlation or regression analysis as a tool to predict one variable from one or more other variables.

4.1 Correlation

Variables having a quantitative relationship or association will tend to have a larger, non-zero correlation coefficient, while those with no apparent association will have small correlations closer to zero. For B/P monitoring, a range of correlations will be of potential interest. Some of them include the following:

- Concentrations of COCs in forage fish tissue versus surface sediment
- Concentrations of COCs in forage fish tissue versus game fish tissue
- Concentrations of COCs in porewater versus surface sediment
- Concentrations of COCs in porewater versus invertebrate toxicity
- Concentrations of COCs in surface sediment versus invertebrate toxicity
- Concentrations of COCs in *Lumbriculus* tissue versus forage fish tissue

To assess the associations between multiple pairs of indicators, as in the list above, the most commonly used correlation statistic is the Pearson's r coefficient. Unfortunately, Pearson's r has the disadvantage of being highly sensitive to outliers. When outliers exist, the calculated correlation may badly miss the actual strength of the overall relationship, rendering it either too high or too low.

To avoid this problem, robust correlation measures will be utilized as an alternative to Pearson's r. Robust correlations are much less sensitive to outliers and more accurately reflect the nature and magnitude of the true association. This is accomplished by down weighting the influence of any apparent outliers, while still capturing the thrust of the association among the non-outlier data pairs.

Since correlation measures are mostly used as descriptive or screening tools to reflect which indicators, if any, have an identifiable relationship, tables listing the correlation estimates will be prepared. Those correlation results that significantly differ from zero — thus indicating a likely real association — will be highlighted and color-coded on these tables, using a standard test of statistical significance for the correlation coefficient (Helsel & Hirsh, 2002).

4.2 Prediction

Identifying correlations is important, but a further step is to determine whether one (or more) indicator might be a good predictor of another. Particularly when sampling data may be missing, unavailable, or difficult to obtain, it can be beneficial to have a proxy measurement that closely predicts the measurement of interest. For example, *can it be shown that measuring COC concentrations in sediment accurately predicts concentrations in porewater?* Or perhaps there will be cases where a single indicator does not serve as an adequate proxy, but the joint results from a set of indicators that does.

To predict the levels of one indicator from the values of one or more other indicators, linear regression and multiple linear regression will be employed. These techniques construct equations that estimate the numerical relationship between the target indicator and what is called the predictor variable or variables. Such regression models reveal not only which indicators are useful predictors of a target indicator, but also how much numerical change might be expected in the target indicator given a specific change in one or more of the predictors.

Predictive regression models will be constructed for target indicators of interest whenever (1) there is a plausible or known theoretical or empirical relationship between the target indicator and one or more other indicators, or (2) the observed correlations are high between the target and one or more other indicators.

As with the trend analysis discussed in **Section 3**, each standard linear regression or multiple regression model must be checked for relevant prior assumptions, particularly those relating to the model residuals (i.e., normality and homoscedasticity) and potential outliers (i.e., influence and leverage). Note that any regression model is likely to be highly uncertain and of limited usefulness when the sample size is less than 10 observations.

The best regression models — especially those for multiple regression — are developed by first randomly dividing the observed data into training and test subsets. The training data are used to estimate the regression equations, while the test data are then used to check how well the model predicts the test measurements. While highly recommended, this model-building algorithm only works when there is a sufficient number of observations to enable division into adequately sized subsets (e.g., at least 20-30 observations per subset). The initial regression models may not allow this strategy, but once enough data have been collected, refinement of the predictive models will be considered by utilizing training and test data subsets.

Results from these analyses and model-building exercises will be presented as tables of the regression equations, further indicating the statistical strength of each regression model, and also depicting graphs of each model showing how well it fits the observed data.

5. REFERENCES

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APPENDIX A.2
STATISTICAL POWER ANALYSIS FOR SAMPLE SIZE DETERMINATIONS

1. Introduction

The Baseline/Performance Monitoring Plan (B/P Monitoring Plan) presents the rationale and sampling that the District of Columbia Department of Energy and Environment (DOEE) will use to document and evaluate baseline conditions and performance of the remedial actions defined for the Anacostia River Sediment Project (ARSP) study area. DOEE's Interim Record of Decision (IROD) for the ARSP study area identified early action areas (EAAs) in three operable units (OUs) for remediation of sediment with the highest concentrations of polychlorinated biphenyls (PCBs) in the river (DOEE 2020).

B/P monitoring for the Anacostia River Sediment Project (ARSP) will include sediment, porewater, benthic invertebrate toxicity tests, benthic invertebrate tissue (via bioaccumulation tests), forage fish tissue, and game fish fillet tissue. This appendix documents the analyses used to develop recommendations for the number of sediment samples needed for baseline and performance monitoring. The objective is to define the appropriate number of samples needed in each reach-based calculation area[1] (RBCA), so that statistical analysis of the collected data will enable demonstration of site contaminant concentration reductions with a high degree of statistical assurance. Sample numbers (and frequencies) needed for the other four media (pore water, benthic invertebrate tissue, forage fish tissue, and game fish fillet tissue) are defined in the main text.

Sediment sampling for baseline and performance monitoring will be polygon-based with the number of polygons set equal to the number of samples defined from this analysis. For each sampling event (both the initial baseline sampling event and the performance monitoring events conducted in each RBCA after the early action area [EAA] cleanups in the RBCA are completed), six samples will be collected at semi-randomly distributed locations within each polygon. For a given sampling event, therefore, the sampling locations are semi-randomized (within each polygon) to ensure complete, unbiased spatial coverage of each RBCA, thereby allowing statistical inferences about the concentration distribution within the RBCA as a whole.

Statistical testing will use the surface-weighted average concentrations (SWAC) calculated for each RBCA using the polygon-based composite concentrations and associated polygon areas. The weights will be assigned based on the areal extent represented by each polygon relative to the total surface area of the RBCA.

[1]For the purposes of the RI, the 9-mile study area was divided into six reaches, defined based on sediment characteristics, river hydraulics, and hydraulic connectivity. The six reaches are Reach 7 (Northwest Branch/Northeast Branch confluence to downstream end of Bladensburg Marina), Reach 67 (downstream end of Bladensburg Marina to Nash Run), Reach 456 (Nash Run to the CSX Railroad Bridge), Reach 123 (mouth of the river to CSX Railroad Bridge), Kingman Lake, and Washington Channel. The four RBCAs for this analysis are (1) Reach 123 and Reach 456 combined (Reach 123/456), (2) Reach 67, (3) Kingman Lake, and (4) Washington Channel.

2. Inputs to Sample Size Calculation

Projecting the appropriate sample size for documenting a statistically significant reduction in contaminant concentrations during a site cleanup requires consideration of a number of factors. Specifically, the fundamental inputs (significance level [Type I error] and false negative rate [Type II error]) to hypothesis testing-based statistical inference must be selected. Hypothesis testing in an environmental context typically consists of defining the null hypothesis as "no reduction in contaminant concentrations" versus the alternative that a reduction has, in fact, occurred. The four possible outcomes from a hypothesis test are shown in **Figure A-1** and are summarized below:

- The null hypothesis is true and is accepted
- The null hypothesis is true and but is rejected (Type I error or significance level)
- The null hypothesis is false and but is accepted (Type II error)
- The null hypothesis is false and is rejected (power of the statistical test)

The shaded areas in **Figure A-1** represent incorrect decisions. Statistical power analysis is the evaluation of the ability to detect significant statistical results when real differences exist in a particular monitoring variable. Use of power analysis enables the investigation of the statistical implications of alternative sampling strategies (e.g., number of sampling locations [i.e., number of polygons in this analysis]).

This power analysis documents, given various choices of statistical significance and power, a range of potential numbers of samples appropriate for B/P monitoring in each RBCA. The specific testing considered in the analysis is the comparison of the dataset generated by a single performance monitoring event to the dataset generated during the baseline event for an RBCA. The null and alternative hypotheses in the test are defined as "no change from baseline" and "significant change from baseline," respectively. As discussed further in the next section, the power analysis explores the effect on the calculated sample number of varying the false positive rate (Type I or significance level) and the statistical power of the test (**Figure A-1**).

The existing surface sediment dataset collected for the RI is used to characterize study area concentrations and associated variances. In addition to selecting the significance level (false positive rate) and power of the test, other key inputs to the power analysis include the statistical pattern of dataset, the type of statistical testing to be performed, the minimum reduction in concentration *considered to be meaningful*, the number of constituents of concern (COCs) that need to be included in the calculations, and the kind of statistical comparison to be employed. Each of these inputs are further discussed below:

1. **Statistical Pattern of the Dataset.** The statistical pattern of the dataset in each RBCA, particularly the variance and degree to which the data are skewed, is a key driver in sample number calculations. Large variance and skewness will result in a higher number of samples projected to be needed while lower numbers of samples will result from smaller variance and skewness. As noted above, the existing RI dataset was used to approximate the statistical pattern of the dataset.

2. **Type of Statistical Testing to be Performed.** The kind of statistical test that will be used to evaluate the data and decide whether a significant change in COC concentrations has been achieved is a consideration. To evaluate the data collected during each performance monitoring event against baseline, a spatially-weighted trend testing approach, along with periodic statistical comparisons between the performance monitoring and baseline data, will be conducted to identify any significant changes in sediment concentration levels. This approach requires the simultaneous consideration of two separate datasets (baseline dataset and the given performance monitoring event dataset). Testing involving two datasets requires more samples than testing one dataset against a fixed cleanup level (e.g., comparing the data from a performance monitoring event for a given COC to the associated preliminary remediation goal [PRG]).

3. **Selected False Positive Rate.** As noted in the previous section, the false positive rate and the degree of statistical power are two parameters that can be adjusted to control the expected performance of the statistical testing method. They enable site managers to balance the potential for a Type I or Type II error and the sample size needed to assess remedy performance. The false positive decision amounts to *declaring* remedial success that a statistically significant change in concentration was achieved (due to the EAA cleanups, a concentration decrease is anticipated) when in fact such a change had not (yet) occurred. To minimize the potential for an incorrect conclusion, the false positive rate is kept low, usually at 5 percent.

4. **Selected Statistical Power.** The degree of statistical power, in contrast to the false positive rate, reflects the chance that the statistical test will correctly assess that a concentration reduction has occurred, when in fact the concentration levels of the COCs *have* dropped sufficiently to reflect a significant change. High statistical power ensures that successful remedial actions will not be 'missed' during the statistical evaluation. Statistical power in the neighborhood of 80-90 percent is typically considered both practical and useful for ensuring a sound statistical protocol.

5. **Selected Minimum Detectable Difference.** The minimum meaningful detectable difference, sometimes called delta, is a third input parameter (in addition to the selected false positive rate and statistical power) requiring site manager consideration and input. In EPA's discussion of Data Quality Objectives (DQO) (EPA 2006), delta represents the 'gray area' or 'region of indifference', essentially a range of values where two separate things are true: a) the numerical difference from the target or baseline is small relative to the desired change and b) the statistical effort needed to distinguish a COC level in the 'gray area' from the baseline level likely would be very costly. For a given dataset (and holding other inputs constant), detecting a small change from baseline requires more samples than detecting a large one. A site manager must balance the cost of sampling against the minimum difference below baseline that should have a high chance of being identified. Note that the minimum detectable difference (delta) is defined in this analysis as the minimum percentage change in the baseline mean that should be detected with high power.

6. **Number of COCs**. Another consideration is the number of COCs that need to be included in the sample number analysis. Because the statistical pattern (i.e., variance and skewness) associated with one contaminant may not be the same as for the other COCs, the minimum sample size needed for both statistical accuracy (i.e., low false positive rate) and sensitivity to identifying significant changes (i.e., high statistical power) may differ from one contaminant to the next. The minimum sample size per OU may be set large enough to satisfy the sample size requirements for *all* COCs simultaneously. Alternatively, the sample number determined for a representative COC can be selected and the power to detect significant reductions in the other COCs independently considered.
7. **Kind of Statistical Comparison**. Because the statistical comparisons will involve collections of surface-weighted composite samples, rather than discrete samples, the expected degree of skewness and variability among the composites are much less than would be expected of discrete samples. This in turn tends to lower the number of composites needed to assure a pre-specified level of statistical power while also being representative of the planned field sampling procedures.

3. Calculation Approach

The power analysis relied on the surface sediment dataset collected for the ARSP RI. To perform the analysis, surface sediment samples collected during the RI were grouped by RBCA. The datasets for each of the four COCs (total polychlorinated biphenyl [PCB] congeners, dioxin-like PCB total equivalent [TEQ], dioxin TEQ, and chlordane), exhibited asymmetry with pronounced positive (right-tailed) skewness. This statistical pattern was addressed by removing the following: (1) pre-2014 data (may not be adequately representative of current conditions), (2) Reach 7 data from the analysis (Reach 7 is of coarser grain size which is dissimilar from the rest of the study area), and (3) concentrations greater than 600 ug/kg (the IROD-defined cleanup level for surface sediment) to account for sediment cleanup in each of the EAAs.

After making the above-noted adjustments to the dataset, in order to approximate the statistical behavior of the surface-weighted composites that will be used to perform statistical testing, a Monte Carlo simulation was conducted. In each of the four RBCAs (Reach 123/456, Reach 67, Kingman Lake, and Washington Channel), 50,000 simulated surface-weighted composites were constructed, each composed of 6 randomly chosen discrete samples. Surface-weighted composites were generated by constructing a Thiessen polygon network covering all discrete samples within a RBCA and then performing the following for each realization: (1) randomly select six samples from the area and (2) use the polygon areas associated with each of the six selected samples for each realization to construct the weighted average for that realization (because the six weights will not add up to 1, the weighted average was computed by multiplying each selected discrete sample by its weight, summing these six products, and then dividing by the sum of the weights).

The composite averages from the Monte Carlo simulations were then used to calculate a grand average and grand variance for the RBCA. As expected, the distribution of the simulated composites was much less skewed than that of the discrete samples. The power analysis was conducted after a square root-transformation of the data which stabilized the variances and allowed for more precise comparisons.

The power analysis focused on total PCB (sum of congeners) to determine sample sizes because the IROD EAAs were focused on reducing concentrations of total PCBs in sediment. The use of PCB data for the analysis was based the results documented in the River-wide Feasibility Study Report (Tetra Tech 2019) which showed that the distribution of elevated concentrations of total PCBs in the ARSP study area closely align with the distributions of elevated concentration levels of dioxin TEQ and dioxin-like PCB TEQ. Although the distribution of elevated chlordane concentrations does not closely compare with that of total PCBs, reductions in chlordane concentrations are anticipated based on analyses presented in the IROD.

4. Analysis and Results

Table A-2 lists projected minimum composite sample sizes *per sampling round* for total PCBs based on the RI datasets for each of the RBCAs. EPA guidance recommends defining the false positive rate (or significance) and power at 5 and 80 percent, respectively (EPA 1996). **Table A-2** shows for total PCBs, a false positive rate (or significance) of 5 percent, and a power of 80 percent for the sample sizes that would result for a delta of 25 percent. The numbers of samples shown in the “Minimum Samples (Planned)” column were used as the basis for defining the sampling locations in the B/P monitoring plan.

Table A-2. Minimum Number of Sediment Polygons for B/P Monitoring

Reach-Based Calculation Area	Significance (%)	Power (%)	Delta (%)	Minimum Samples (Raw Calculated)	Minimum Samples (Planned)
Kingman Lake	5	80	25	6	10
Reach 123/456	5	80	25	11	11
Reach 67	5	80	50	7	10
Washington Channel	5	80	25	20	20

Although the power analysis yielded a sample count of 6 for Kingman Lake, this count was raised to 10. In practice, a minimum of 10 samples is considered appropriate to cover uncertainty in quantifying the variance of samples to be collected in the future from the variance generated from the RI dataset. As the sample size within a calculation area decreases, the stochastic influences on the data increase. For example, means based on a sample size of 10 are considerably more reliable than means based on a sample size of three, especially when the goal is to detect changes in the means over time. To ensure that the monitoring data are rigorous enough to support a Final ROD, the slight increase in sample size is considered prudent. In addition, the Northeast Branch and Northwest Branch reference area (defined in the B/P monitoring plan main text), was assigned 10 samples to be consistent with the minimum number of samples. Note that the reference area is not presented in Table A-2.

The recommended sample counts in **Table A-2** strictly apply only to the collection of sediment samples to characterize baseline and evaluate the performance of the remedy. Other indicators (porewater, benthic invertebrate toxicity tests, benthic invertebrate tissue, forage fish tissue, and game fish tissue) will be included in B/P monitoring and will be based on the number of sediment samples. Specific sample counts for these media are documented in Section 6 of the main text.

As shown in **Table A-2**, a delta of 50 percent was selected for Reach 67 based on the relatively lower concentrations present in this reach in comparison with the other reaches. For Reach 67, the evaluation of sample count is based on a baseline mean concentration of 76 µg/kg and geometric mean of 73 µg/kg, compared to baseline and geometric means for Reach 123/456 of 160 µg/kg. The lower baseline concentrations for Reach 67 results in a much lower absolute reduction for the delta of 25 percent than for the other reaches. Based on the small absolute reduction target of less than 20 µg/kg in Reach 67, a target delta of 50 percent is selected for the planned minimum number of samples (adjusted upward from 7 to 10 samples using the same rationale as discussed for Kingman Lake) which is similar to the absolute reduction of 40 µg/kg as for the other reaches.

5. References

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Decision	Hypothesis: Actually True	Hypothesis: Actually False
Accept	$1 - \alpha$	β
Reject	α	$1 - \beta$

Figure A-1. Hypothesis testing: possible outcomes

Appendix A.3
Stratified Surface Weighted Average Concentration (SWAC) Calculation

1. Introduction

The Baseline/Performance Monitoring Plan (B/P Monitoring Plan) presents the rationale and sampling that the District of Columbia Department of Energy and Environment (DOEE) will use to document and evaluate baseline conditions and performance of the remedial actions defined for the Anacostia River Sediment Project (ARSP) study area. DOEE's Interim Record of Decision (IROD) for the ARSP study area identified early action areas (EAAs) in three operable units (OUs) for remediation of sediment with the highest concentrations of polychlorinated biphenyls (PCBs) in the river (DOEE 2020).

Surface sediment concentrations measured in each of the polygons defined in the three OUs will be averaged to form a single value. The surface weighted average concentration (SWAC) will represent the entire OU. SWACs will be calculated using a stratified sampling design. Stratification supports evaluation of a population of samples in terms of smaller sub-groups (strata) For the B/P monitoring, two strata are defined: one stratum in the EAA, which will be subjected to remediation, and another stratum outside the EAAs (or non-EAAs). Sampling polygons in the EAA strata and non-EAA strata for sediment and porewater are shown on Figures 6.1 through 6.5 of the main text.

SWAC calculation for an OU must account for the different post-remedial condition of the EAA versus the non-EAA polygons. As a result of the remedial actions in the EAAs, post-baseline constituent of concern (COC) concentrations will be reduced to zero, or to a fraction of pre-remedial levels, depending on the remedial technology selected (e.g., dredging, capping, carbon amendment, or a combination). The non-EAA polygons represent the portion of the OU not subjected to remedial actions, and the measurement of post-baseline changes in COC concentrations in these areas (as determined in each performance monitoring event) is a key B/P monitoring objective.

2. SWAC Calculation Approach

The SWAC calculation for a single stratum is obtained using the following equation:

$$SWAC = \frac{\sum_{h=1}^{n}(A_h * \bar{x}_h)}{\sum_{h=1}^{n} A_h} \quad (1)$$

Where:

n	= Total number of polygons in OU
A_h	= Area of polygon h
$\bar{x}_h$	= COC concentration for polygon h

For the two-strata design, the SWAC from Equation 1 is incorporated into the following equation that accounts for the EAA and non-EAA percentages of the OU's total area:

$$SWAC_{strat} = (SWAC_{\frac{B}{P}polygons} * \%Area_{\frac{B}{P}}) + (\overline{Conc}_{EAA} * \%Area_{EAA}) \quad (2)$$

Where:

$SWAC_{strat}$	= Stratified SWAC
$SWAC_{\frac{B}{P}polygons}$	= SWAC for B/P polygons from Equation 1
$\%Area_{\frac{B}{P}}$	= Percentage of OU that is B/P polygons
$\overline{Conc}_{EAA}$	= Arithmetic average of concentrations measured in EAA polygons
$\%Area_{EAA}$	= Percentage of OU that is EAA polygons

EXAMPLE STRATIFIED SWAC CALCULATION

Kingman Lake OU provides an example of the application of the above calculations to the determination of a stratified SWAC. **Figure A.2** (reprint of Figure 6.4 from the main text) shows Kingman Lake OU and the ten non-EAA polygons and the two EAA polygons. Table A.3 below shows the input (assuming total polychlorinated biphenyls [PCBs] as the COC being evaluated) to the stratified SWAC calculation:

Table A-3. Example Calculation of Kingman Lake OU Stratified SWAC Input

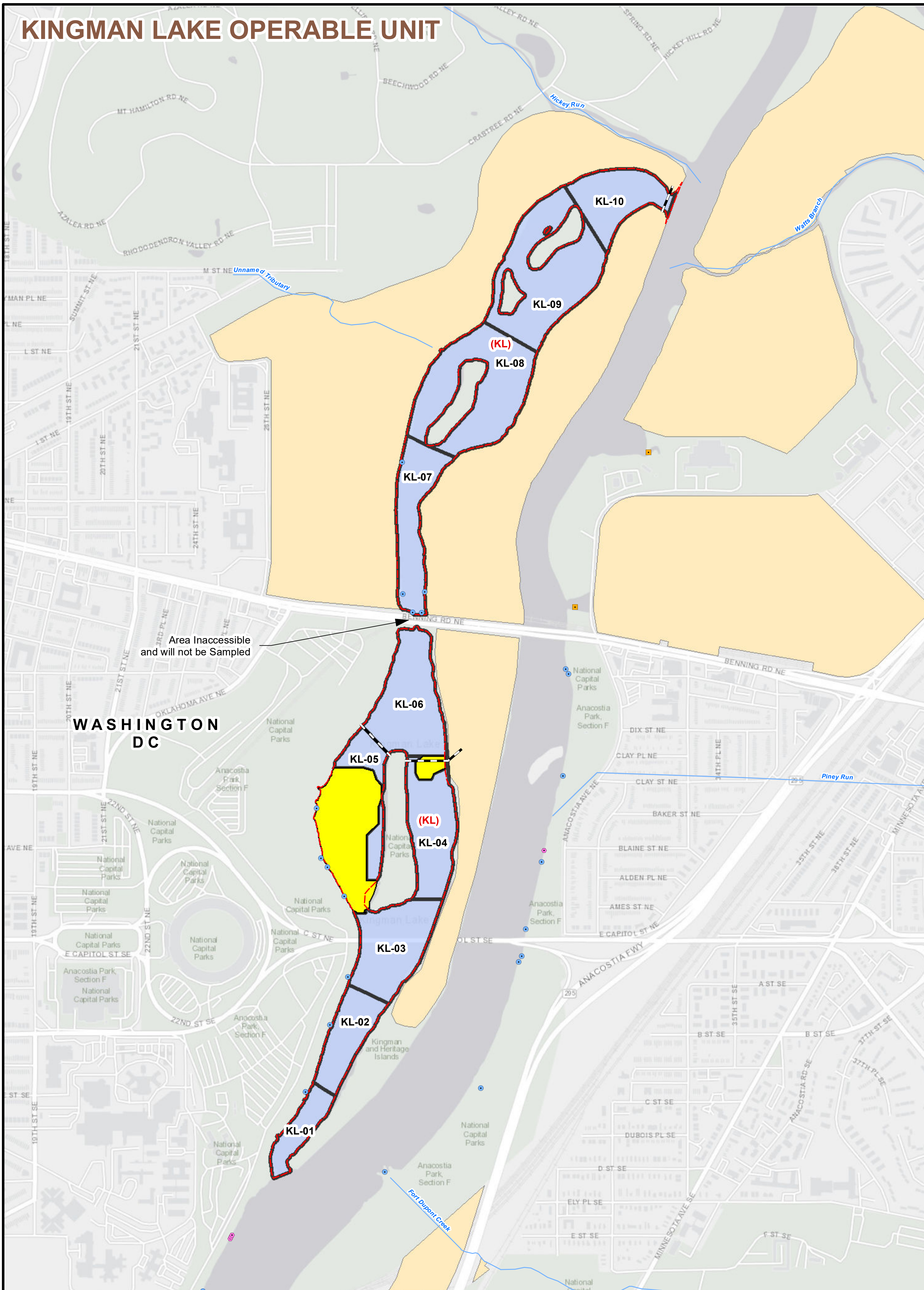
	Area (Acres)	Area Fraction	Example Post-Remedy Concentration (µg/kg)	Source
Non-EAA (B/P) Polygons	93.7	0.89	184	$SWAC_{B/P}$
EAA Polygons	12.0	0.11	65	EAA Average

$$SWAC_{strat} = (SWAC_{\frac{B}{P}polygons} * \%Area_{\frac{B}{P}}) + (\overline{Conc}_{EAA} * \%Area_{EAA})$$

171 µg/kg = (184 µg/kg * 0.89) + (65 µg/kg * 0.11)

In this example, the EAAs are assumed to be remediated to an arithmetic average concentration level equivalent to the PCB preliminary remediation goal (PRG) of 65 µg/kg. The example post-remedial SWAC via Equation 1 from the ten non-EAA polygons is 184 µg/kg. Given the area fractions of 89 and 11 percent for the non-EAA and EAA portions of the OU, respectively, and the above-noted EAA and non-EAA post-remedial concentrations, the resulting stratified SWAC for Kingman Lake OU is 171 µg/kg in this example.

KINGMAN LAKE OPERABLE UNIT



Legend

- CSS OUTFALL
- MS4 OUTFALL
- INDUSTRIAL OUTFALL
- EXISTING WALKING BRIDGE
- STREAM
- KINGMAN LAKE OPERABLE UNIT
- EARLY ACTION AREA (ALSO BASELINE/PERFORMANCE MONITORING EAA SAMPLING AREAS)
- BASELINE/PERFORMANCE MONITORING NON-EAA SAMPLING AREAS
- CLEANUP SITE BOUNDARY (LAND BASED PORTION)

0 400 800 Feet

ANACOSTIA RIVER SEDIMENT PROJECT

FIGURE A.2 (reprint Figure 6.4) BASELINE/PERFORMANCE MONITORING POLYGONS: SURFACE SEDIMENT AND POREWATER IN KINGMAN LAKE OPERABLE UNIT

TETRA TECH

SOURCE: MODIFIED FROM ESRI LIGHT GRAY CANVAS BASEMAP, 2023.