Appendix C

Ecological Risk Assessment Work Plan

Contents

List of Figures

List of Tables

Appendix C

Ecological Risk Assessment Work Plan

1.0 Introduction

1.1 Site Background

The Anacostia River has been identified for several years by American Rivers as one of the 10 most contaminated rivers in the country and one of three areas of concern for the Chesapeake Bay (http://www.americanrivers.org/endangered-rivers/previous/). The River has been affected by nutrient loading, trash, on-going sedimentation, and moderate oil spills and receives significant input of metals and organic contaminants from urban nonpoint sources (SRC, 2000). The destruction of wetlands and marshes within the River and tributaries has resulted in the loss of the watershed's filtering capacity. These losses have resulted in the River acting as a sink for contaminants (AWTA, 2002).

The concerns in the River go beyond the contaminants found in the sediments and surface water. The urban history of the River has degraded the biological condition of the River and the surrounding landscape. Impervious surfaces have altered the River's normal hydrologic cycle. The loss of riparian zones and wetlands, excess runoff from impervious surfaces and loss of groundwater recharge have contributed to a general degradation of the watershed's ecological health (Anacostia River Watershed Restoration Partnership [AWRP], 2010). Combined sewer overflows (CSOs) and stormwater outfalls (SWOs), combined with landscape fertilizers and pet wastes have contributed to an excess of nutrients, causing algal blooms. These algal blooms produce areas of very low dissolved oxygen, which contribute to the overall stress on the system (AWRP, 2010; Metropolitan Washington Council of Governments, 2007).

As summarized in a 2009 NOAA White Paper (NOAA, 2009) it has been demonstrated that polychlorinated biphenyls (PCBs), metals, other inorganic contaminants, organochlorine (OC) pesticides such as dichlorodiphenyltrichloroethane (DDT) and its metabolites (Velinsky and Cummins 1994; Velinsky and Cummins 1996; Pinkney et al. 2001), PAHs, and to a lesser degree VOCs are found in sediment samples collected throughout the River, upstream and downstream of the WG East Station Site.

Available biological data for the Anacostia River in the vicinity of the Washington Gas East Station Site (Site, as defined in the Work Plan) have been compiled to develop an understanding of the overall conditions. Initial review of these data indicates that Anacostia River sediments have been impacted from decades of heavy industrial use, including physical (i.e., dredging, channel alteration, and habitat loss) and chemical impacts. These impacts extend beyond the boundaries of the River at the Site. The following studies are relevant to the ERA process:

- McGee et al. (2008) sampled 20 stations in the Anacostia River from Bladensburg, Maryland to the confluence with the Potomac River for macroinvertebrates, chemistry, and laboratory toxicity testing. Using an index of benthic biotic integrity, the authors found 40% of the stations were ranked as impaired compared to USEPA Chesapeake Bay Program's Benthic Community Restoration Goals. A sediment quality triad (chemistry, toxicity testing, and benthic macroinvertebrate community) was developed and only one station exhibited significant reduction in test organism survival. Three stations were located near the Site: #59,approximately 1,750 feet upstream; #65, approximately 500 feet downstream; and #68, approximately 1,000 feet downstream. The stations near the Site did not demonstrate reduced survival or growth in test organisms (the midge *Chironomus dilutus* and the amphipod *Hyalella azteca*) compared to the control sediments (collected from an offsite freshwater pond). The authors found little linkage between results and sediment chemistry, indicating a number of stressors may be acting on the system.
- USFWS (Pinkney et al., 2004) noted a prevalence of liver and skin tumors in brown bullhead (*Ameiurus nebulosus*) caught in the Anacostia River. The authors indicated that there was evidence of higher PAH exposure to fish in the Anacostia River, but a cause-effect relationship could not be established (Pinkney, et al., 2001). Fish collected nearest the Site (O Street outfall, approximately 5,000 feet downstream of the Site) did not have any markers of PAH-induced toxicity greater than those collected further upstream, indicating a ubiquitous presence of PAHs in the River. USFWS conducted another survey of tumors in brown bullhead in 2009-2011 (Pinkney, et al., 2013). These data indicate a significant decrease (approximately 50%) in the prevalence of liver tumors in fish from the Anacostia River over the group of fish sampled 1996-2001. Furthermore, skin tumors decreased by 40% (although not statistically significant). In the most recent survey, the liver and skin tumors from bullhead caught in the Anacostia River were nearly equal to those from the Potomac River and Piscataway Island (Pinkney et al., 2013).
- Gregory Foster, Professor of Chemistry and Biogeochemistry at George Mason University, presented data at the October 28, 2008 AWTA meeting that indicated the highest levels of PCBs and PAHs in Chesapeake Bay sediments occurs in the Anacostia River and Baltimore harbor. Base- and storm-water river flow PAHs from the Northeast Branch of the River were as high as 250 nanograms per liter (ng/L) for the dissolved phase, and as high as 2,500 ng/L for the particle phase, indicating a substantial continuing source of PAHs to the lower part of the River. The greatest inputs were from particle flow during storm events. These results indicate that there are continuing PAH inputs to the Anacostia River from upstream sources.
- A recent study by Velinsky et al. (2011) provides valuable information on vertical contaminant trends in the Anacostia River. This study, which included sediment coring (4 to 5 meter cores) for chemical and radiodating analysis, indicated that in general, total PAHs were present at higher concentrations in deeper sediments, while lower concentrations were found towards the surface (i.e., top 6 feet) of the sediment column. Other contaminants generally showed a similar profile, although some inorganic contaminants were more enriched in mid-depth and surficial samples. Based on the cesium coring data presented in this study, sedimentation rates were estimated to range from 1.1 to 2.8 inches/year.

1.2 Document Purpose

This appendix presents a Baseline Ecological Risk Assessment (BERA) Work Plan as part of the Remedial Investigation (RI) and Feasibility Study (FS) for Operable Unit 2 (OU2) of the Washington Gas (WG) Site located in southeast District of Columbia (District). The OU2 portion of the Site is defined in the Consent Decree as "groundwater, surface water, and sediments of the Anacostia River where hazardous substances released at or from the Washington Gas East Station Property have come to be located."

This BERA Work Plan has been prepared to present the methodology that will be used to evaluate potential ecological risks in the Anacostia River (the River) at the Site. The results of the BERA will be used to help inform the need for any additional evaluation and/or remedial action in the River at the Site.

The BERA will follow the *Ecological Risk Assessment Guidance for Superfund* (USEPA, 1997) process and be consistent with District Department of Energy and Environment (DOEE; formerly called District Department of the Environment or DDOE) (2011) *Risk-Based Corrective Action Technical Guidance*, USEPA (1998) *Guideline for Ecological Risk*, and various *USEPA EcoUpdates* (1991, 1992, 1994a, 1994b, 1994c, 1994d, 1996a, 1996b, 2001, 2008). The eight-step ERA process is outlined on Figure 1-1, and will correlate with the overall RI/FS process. Each successive tier of ERA requires more detailed and quantitative data analysis and interpretation. Conducting assessments in a tiered, step-wise manner allows the risk assessor and risk manager to maximize the use of available information and sampling data, while providing the opportunity to reduce the uncertainties inherent in the ERA process through the use of focused supplemental data collection to fill key data gaps identified in the previous tier of the assessment, as necessary. As each of the steps is completed, the results will be evaluated and communicated by the risk assessors to the risk managers. The risk assessment process is frequently iterative, and new information brought forth during the risk characterization phase may lead to a review of the problem formulation phase, or additional data collection and analysis. Scientific/Management Decision Points (SMDPs) occur at key points in the process and are used by the risk assessor and risk manager to determine if the process should continue, and if enough data have been evaluated to determine the outcome of the ERA. The ERA steps are outlined below:

- **Screening Level Ecological Risk Assessment (SLERA) (Steps 1 and 2)**

  Recognizing that the available data for the site are historical in nature (i.e., may not be representative of current conditions) and the spatial distribution of the samples available for consideration are from within 0.25 miles upstream and downstream of the site (i.e., samples may not be representative of the Site), a formal SLERA will not be conducted at this time. Rather, an initial screening evaluation of newly collected data will be performed as part of the BERA in order to further refine the COPECs for each ecological receptor evaluated.

- **Baseline Ecological Risk Assessment (BERA) Problem Formulation (Step 3)**

  The BERA Problem Formulation is presented in Section 3 of this Work Plan. The goal of the BERA Problem Formulation step is to:

  – Define the goals, breadth, and focus of the BERA based on the initial screening evaluation and ongoing feedback from USEPA and stakeholders

  – Establish assessment endpoints (receptors and attributes) and exposure pathways to be evaluated under current and/or reasonable future conditions

  – Develop the conceptual site model (CSM) and formulate risk questions

  At the conclusion of the BERA Problem Formulation, there is a SMDP, which consists of agreement on four items: the assessment endpoints, the exposure pathways, the risk questions, and conceptual model integrating these components. The products of Step 3 are used to select measurement endpoints and to develop the ecological risk assessment work plan (WP) and sampling and analysis plan (SAP) in Step 4.

- **Study Design and DQO Process (Step 4)**

  Step 4 of the USEPA 8-step process is provided in Section 4 of this Appendix. The deliverable for Step 4 is the framework for the BERA Work Plan, which describes the assessment and measurement endpoints, exposure pathways, questions and testable hypotheses, measurement endpoints and their relation to assessment endpoints, data reduction and interpretation techniques, and uncertainties and assumptions. It also describes the data needs, a scientifically valid and sufficient study design, data analysis procedures, study methodology and protocols, data reduction and interpretation techniques (including statistical analyses), and quality assurance (QA) procedures and quality control techniques. Information for Step 4, including the overall field study design and data quality objectives, is presented in the RI/FS Work Plan.

- **Field Verification Design (Step 5)**

  The objective of Step 5 of the USEPA 8-step process is to ensure the data collection plan outlined in Step 4 can be practically achieved. Since the Anacostia River is a well-studied area, there are anticipated to be few, if any, barriers to field data collection. At the end of Steps 4 and 5, the BERA Work Plan is finalized.

- **Site Investigation and Data Analysis (BERA Field Program) (Step 6)**

  The Site Investigation and Data Analysis step of the BERA (Step 6 of the eight-step process) is the implementation of the BERA Work Plan in the BERA Field Sampling Program. The outcome of the Step 6 field investigation will be evaluated and presented in the BERA Report (Step 7). A SMDP is only needed in this step if there are changes to the BERA Work Plan. However, ongoing interaction with National Park Service (NPS), the District, and stakeholders is anticipated to ensure that the BERA is meeting the overall project objectives.

- **Risk Characterization (Step 7)**

  Step 7, Risk Characterization, integrates data on exposure and effects into a statement about risk to the assessment endpoints established during BERA Problem Formulation (USEPA, 1997). The outcome of Step 7 will also be presented in a deliverable, the BERA Report, which constitutes the SMDP for Step 7 of the ERA process, and the end of the formal ERA.

- **Risk Management (Step 8)**

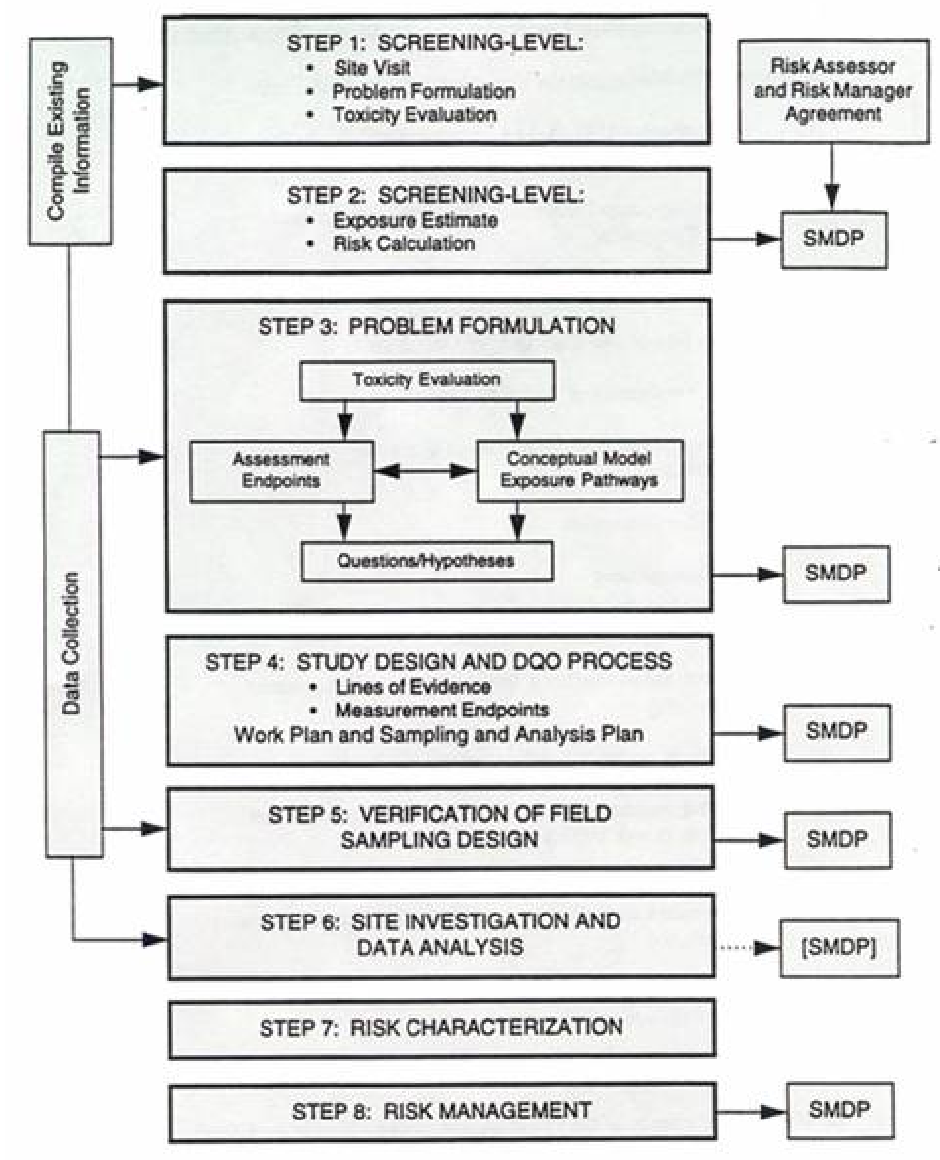
  The final step in the ERA process is risk management. Risk management is “ultimately the responsibility of the site risk manager, who must balance risk reductions associated with cleanup of contaminants with potential impacts of the remedial actions themselves” (USEPA 1997). While risk management differs from risk assessment, it is the final step of the risk analysis process for CERCLA sites.

This Work Plan describes the general approach for the BERA. The remainder of the document includes:

- **Section 2** presents the BERA Problem Formulation (Step 3) and includes identification of ecological receptors and exposure pathways, assessment endpoints to be considered in the BERA, and the CSM.
- **Section 3** presents Step 4 the ERA process. Measures of effect are identified and the field sampling design and data quality objectives are referenced. The RI/FS Work Plan provides the details of the field sampling plan and data quality objectives.

- **Section 4** presents Step 5 of the ERA process. In this step, reference locations are selected, and the field sampling design is verified.
- **Section 5** presents the BERA Work Plan. The BERA Work Plan includes the planned field investigation to support Risk Analysis, and BERA Risk Characterization, and includes a discussion of how the results of the environmental risk analysis will be analyzed and interpreted and how uncertainty associated with the analysis will be evaluated. The results of the BERA will be used to help inform the need for any additional evaluation and/or remedial action in the River.
- **Section 6** presents the references cited in this document.

Figure 1-1. Eight Step Process for Ecological Risk Assessment for Superfund Operable Unit 2 – Remedical Investigatin and Feasibility Work Plan Washington Gas East Station Site



Source: USEPA, 1997

2.0 Step 3: BERA Problem Formulation

Problem Formulation provides the framework for the BERA and serves to define the risk assessment objectives and the geographic area to be considered and identifies the ecological receptors, exposure pathways, and endpoints to be evaluated.

The risk assessment objective for this BERA is to evaluate whether or not populations of ecological receptors are potentially at risk due to the exposure to Site-related chemical contaminants in surface water and sediment in the River.

2.1 Preliminary COPECs

Based on a review of available Site data and with the knowledge of common contaminants at (manufactured gas) MG facilities, the following contaminants are considered to be preliminary COPECs for surface water, porewater, sediment:

- Phenolics,
- PAHs,
- Benzene, toluene, ethylbenzene, and xylenes (BTEX),
- Cyanide, and
- Inorganic contaminants

Sampling for PCBs will be performed to confirm that they are not present at the Site. PCB Aroclors will be sampled in NAPL accumulating in existing monitoring and recovery wells and of NAPL saturated soils. If the results of these NAPL samples show that the Site is a potential source of PCBs, PCB congeners will be included in the analysis of other media (i.e., groundwater and sediment) and PCBs may be identified as COPECs.

2.2 Literature Search on Known Ecological Effects

For most of the preliminary COPECs, absolute concentrations in water or sediment likely do not provide the most appropriate benchmark for potential toxicity. For the organic contaminants in particular, binding phases such as organic carbon may severely limit the bioavailability of these preliminary COPECs to ecological receptors. For the inorganic contaminants, sulfides, anions (e.g., carbonate), and fine particles can limit bioavailability. In an urban system such as the River at the Site, many of these factors are ubiquitous.

USEPA has indicated that PAHs are often found at high concentrations at MG sites, while BTEX and metals are found at lower concentrations (USEPA, 2013a). As such, PAHs are often the primary stressor of concern identified in the risk assessment process at MG sites. The toxicology profile of PAHs is well understood. PAH toxicity is usually additive and produces effects such as narcosis and liver tumors in fish that has been studied and documented. Given that PAHs are likely to be the primary COPEC in the River at the Site, the toxicological profile of PAHs is given additional consideration. All preliminary COPECs will be given equal consideration in the BERA.

The following sub-sections provide information on the ecological effects of these preliminary COPECs in the aquatic and benthic environment.

2.2.1 PAHs

PAHs are ubiquitous environmental contaminants that can form by incomplete combustion of organic materials (e.g., wood, fossil fuels) or as a result of forest fires, microbial synthesis, and/or volcanic activities. Anthropogenic environmental PAH sources include the widespread use of asphalt, the iron and steel industry, heating and power generation, and petroleum refining (Eisler, 2000). In general, PAHs are soluble in lipids and essentially insoluble in water. The physical and chemical properties of PAHs are governed by the size and shape of the individual molecule. The aqueous solubility and volatility decreases with increasing molecular weight. In aquatic systems, PAHs are generally sorbed to particulates and organic matter.

Except for naphthalene, PAHs have very low water solubility and low vapor pressures. Their octanol-water partition coefficients (K_{ow}) are relatively high, indicating a relatively high potential for adsorption to suspended particulates in the air and in water (NRCC, 1983; Slooff et al., 1989). PAHs that have higher molecular weights are relatively immobile due to their size, low volatility, and low solubility (Eisler, 2000).

The molecular weight of PAHs can also be used to generalize how toxic these compounds are in the environment. The higher molecular weight PAHs (4 to 7 benzene rings) are generally less acutely toxic than the lower molecular weight PAH compounds (<4 rings). PAH compounds with 2 or 3 benzene rings demonstrate significant acute toxicity (i.e., mortality) levels and other adverse effects to a number of organisms. However, higher molecular weight compounds demonstrate carcinogenic, mutagenic, or teratogenic properties to a wide variety of organisms, including fish and other aquatic life, amphibians, birds, and mammals (Eisler, 2000).

PAHs are among the group of chemicals characterized as Type I narcotic chemicals and the toxicity of mixtures of PAHs is generally considered to be additive (USEPA, 2003b). It is uncommon for exposure to be to a single PAH compound; rather exposure usually occurs as a mixture of PAHs (NPS, 1997a). Narcosis theory predicts that the non-polar hydrophobic contaminants (Type 1 narcotic chemicals) will produce a narcotic effect on exposed organisms. This effect is thought to occur when hydrophobic contaminants partition into the lipid phase of the organism, including the lipid bilayer of the cellular membrane, and cause a physical deformation or swelling of the membrane (van Wezel and Opperhuizen, 1995). For example, the narcosis theory approach predicts that, for fish with a lipid content of about 5 percent, narcosis should be observed at concentrations of 2 to 8 micromols (µmol) of narcotic chemicals per kilogram (kg) wet weight of animal (McCarty and Mackay, 1991). Equilibrium partitioning theory (EqP) provides an approach for deriving sediment quality guidelines for PAH mixtures based on the theory that a chemical partitions into a state of equilibrium between sediment organic carbon, organism lipid, and porewater (USEPA, 2009; DiToro and McGrath, 2000). The basis of EqP is the notion that bulk sediment is not the exposure medium of concern. Rather, it is the fraction of these contaminants in sediment porewater that is the primary cause of exposure. Additional work has suggested that PAHs produce mortality by non-polar narcosis in aquatic organisms and act additively when in a mixture in the absence of phototransformation (USEPA 2009; Swartz et al., 1995; DiToro et al., 2000).

2.2.1.1 PAHs in Water

Although most PAHs have low water solubility, lower molecular weight PAHs may be present in a dissolved phase in water. Certain lower molecular weight PAHs may be acutely toxic (i.e., mortality) to aquatic organisms or may produce deleterious sublethal responses at environmentally realistic levels (Rand and Petrocelli, 1985). Teratogenic or carcinogenic responses have been induced in sponges, planarians, echinoderm larvae, teleosts, amphibians, and plants by exposure to carcinogenic PAHs (Neff, 1979). Toxicity is most pronounced among crustaceans and least among teleost fish (Neff, 1979). The reduced toxicity in fish is due to their ability to metabolize PAHs using mixed function oxygenase (MFO) enzymes. Organisms with a well-developed MFO system, such as fish, rapidly metabolize PAHs; those with poor MFO systems, such as bivalve mollusks, may accumulate PAHs (Albers, 1995; Elder and Dresler, 1988). Since most higher trophic level aquatic organisms (i.e., fish) have well developed MFO systems, significant bioaccumulation through trophic levels does not occur.

2.2.1.2 PAHs in Sediment

Sediments are an environmental sink for PAHs (Payne et al., 1988; Vandermeulen, 1989), where they accumulate and biodegrade slowly, particularly in the absence of penetrating radiation and oxygen (Suess, 1976). PAHs in sediments are relatively stationary and require a force upon the sediment to support the transfer of PAHs. Forces such as water circulation and bioturbation can enhance the rate of PAH desorption from the sediment. Sediments may be partially resuspended and are then subject to transport processes (Windsor and Rites, 1979; Larsen et al., 1986).

In PAH contaminated environments, bottom dwelling fish, such as brown bullhead (*Ameiurus nebulosus*) may be subject to liver tumors (Baumann and Harshbarger, 1998; Metcalfe et al., 1988; Hawkings et al., 1990; Pinkney, et al., 2004). Using regression analysis on English sole and sediments collected on the west coast of the United States, Horness et al. (1998) linked sediment concentrations to hepatic lesions. A weaker correlation to skin disorders, presented as tumors on the mouths of fish and damaged or missing barbels, has also been documented (Pinkney, et al, 2004). In a 1996 study of fish in the Anacostia River (Pinkney et al., 2001), liver tumors occurred in 55% and orocutaneous tumors in 23% of brown bullhead surveyed. Shortened, clubbed, or missing barbells were documented in 23-56% of fish in the River. A similar rate of tumors occurrence was noted in large bullhead sampled from the Anacostia River in 2000-2001. Smaller bullhead had a much lower occurrence of tumors (Pinkney, et al., 2004, 2013). While a linkage between these effects and PAHs has been documented, there is currently insufficient evidence to provide a direct link between sediment PAH concentrations and these endpoints.

The rate of elimination of PAHs in aquatic invertebrates is much lower than the rate of uptake (NRCC, 1983), indicating that benthic organisms are more likely to accumulate PAHs to some degree when exposed to PAH-contaminated sediments. One study found that the midge, *Chironomus riparius*, accumulated PAHs when exposed to spiked sediments in laboratory microcosms (Clements et al., 1994). The same study also showed that the PAHs could be transferred to fish in the laboratory via consumption of the benthos. USEPA (2009) notes that for invertebrate risk assessment, there is “no clear relationship between body burdens of PAHs and effects, and hence tissue residues are seldom used as measures of exposure.” NOAA National Marine Fisheries Service (NMFS) has stated that PAH compounds readily metabolize in finfish; because of this efficient metabolism, there is a low potential for PAHs to accumulate in muscle tissue, and consequently a low potential for transfer of PAHs up the food chain to human consumers (Stein, 2010).

2.2.2 Phenolic Compounds

Phenolic compounds are often associated with pulp and paper manufacturing waste, as well as mineral, steel and petroleum industries (Environment Canada, 1999; Breton et al., 2003). Phenols generally have a low affinity to lipid/organic carbon, with partitioning coefficient values increasing with level of methylation. The K_{oc} values for phenol, 2-methylphenol, and 2,4-dimethylphenol used in the calculation of USEPA's Soil Screening Levels are 28.8, 91.2 and 209, respectively (USEPA, 2002a). USEPA's (1980) Ambient Criteria for Water for Phenols indicates a bioconcentration factor of 1.2 to 2.3, indicating that tissue residue should not be a concern for phenol.

Phenolics often disassociate from sediment and are transported through the water column. Breton et al. (2003) conducted a risk assessment of phenolics in an aquatic environment and determined that phenolics may be present near point sources, but that levels of phenolics outside a point source are, in general, often not adequate to represent more than a minor risk to aquatic biota.

2.2.3 BTEX

BTEX compounds are organic chemicals with high vapor pressures, low to medium water solubility, and low molecular weights (Zogorski, et al., 2006). BTEX evaporates under normal indoor atmospheric conditions of temperature and pressure. BTEX typically enter the environment by volatilization or by dissolving into water. They are mobile and ubiquitous in ecosystems worldwide as they are found in variety of household products (e.g., solvents, paints, and cleaning solutions) and chlorinated solvents have been used in industry for decades.

BTEX compounds are most often associated with gasoline and light fuel spills, but may be a product of MG operations. BTEX compounds tend to demonstrate toxicity in short term, high dose exposures, such as those associated with direct spills in a confined area, such as a small pond or other lentic habitats (NPS, 1997b). In general, hazards from BTEX are more commonly associated with human exposure than to wildlife. BTEX are not readily accumulated in plants, fish, or birds due to the tendency of BTEX compounds to evaporate rather than persist in surface waters (NPS, 1997b).

While BTEX compounds are often of concern as an indoor air pollutant, they may also impact aquatic ecosystems (USGS, 1997). The effects of BTEX in the natural environment are not well understood and the volatile nature of these compounds makes evaluations of toxicity in the laboratory challenging. In general, the USEPA Region 3 screening levels for BTEX compounds in surface water and sediment are higher than the screening levels for PAHs and the Site-related inorganic contaminants (USEPA, 2006a,b).

2.2.4 Inorganic Contaminants and Cyanide

Heavy metals and other inorganic compounds occur naturally in the environment. In aquatic systems, inorganic contaminants tend to adsorb strongly to clays, muds, humic, and organic materials. However, depending upon the pH, hardness, salinity, oxidation state of the element, and other factors, inorganics may be readily soluble.

Mercury is one of the few metals which strongly bioconcentrates and biomagnifies, has only harmful effects with no useful physiological functions when present in fish and wildlife, and is easily transformed from a less toxic inorganic form to a more toxic organic form in fish and wildlife tissues. Mercury concentrations of about 1 milligram per kilogram (mg/kg) or more often have been associated with toxic effects on sediment invertebrates (Irwin, et al., 1998).

The other Site-related inorganic contaminants (arsenic, barium, cadmium, chromium, lead, selenium, and silver) and cyanide tend to have primary modes of toxicity related to direct contact rather than the bioaccumulation/food chain pathway. Some of these inorganic contaminants (e.g., cadmium, selenium) may bioaccumulate within the aquatic food web, but to a much lesser extent than mercury. Direct effects of these contaminants on fish and invertebrates include reduced fecundity and survival, growth inhibition, abnormal movement patterns, loss of equilibrium and other neurological disorders, liver damage, chromosomal aberrations (Irwin, et al., 1998).

Many chemical forms of cyanide are present in the environment, including free cyanide, metallocyanide complexes, and synthetic organocyanides, but free cyanide (HCN and CN-) is the primary toxic form in the aquatic environment. Cyanide has relatively low persistence in surface water and biomagnification in food webs has not been reported, possibly due to rapid detoxification of sublethal doses by most species, and death at higher doses. Fish are considered one of the more sensitive aquatic organisms (Irwin, et al., 1998).

2.3 Contaminant Fate and Transport, Ecosystems Potentially at Risk, and Complete Exposure Pathways

The following sub-sections provide a summary of the available contaminant fate and transport information, ecosystems potentially at risk, and potentially complete exposure pathways.

2.3.1 Contaminant Fate and Transport

Details of the contaminant fate and transport are found in Section 3 of the RI/FS Work Plan. The following presents an overview of the general fate of Site-related preliminary COPECs in the River.

Site-related contaminants can potentially migrate to the River via dissolved-phase groundwater transport, or as a NAPL (if mobile). The pathway for this potential migration from the Site to the River depends on a number of factors, including the geologic units present beneath the Site, the volume of NAPL, the extent and location the NAPL. Details are provided in Section 3.3 of RI/FS Work Plan.

Based on historical RI efforts, preliminary COPECs include Site-related contaminants such as cyanide, phenolics, PAHs, BTEX and some inorganic contaminants. Site-related contaminants are the focus of the BERA. The transport of Site-related contaminants to the surface water and sediment of the River is presumed to have historically occurred via groundwater and, possibly, non-aqueous phase liquid (NAPL) discharge, and from overland flow. The RI is investigating if this transport is continuing. Several other sources of these contaminants may exist in the vicinity of the Site, including:

- Historical discharges through groundwater flow, stormwater outfalls and overland flow from other non-Site related landside areas;
- Storm sewers from other facilities, combined sewer outfalls, and other sites nearby on the River; and
- Upstream industrial and urban activities in the anthropogenically-impacted River, its main branches and its tributaries.

Several of the Site-related preliminary COPECs (i.e., PAHs and inorganic contaminants) are frequently found in sediments within urbanized rivers and reflect contributions from various point and non-point sources within the watershed. Therefore, non-Site-related sources may also contribute to the sediments in the River at the Site.

Once in the surface water and sediments of the Anacostia River, movement of PAHs is likely to be dominated by the movement of suspended materials. PAHs are likely to be bound to the organic materials in the sediments and suspended materials in the water column. Wolska et al. (2003) observed that PAHs in river systems are almost entirely adsorbed on particles of suspended materials and accumulate in bottom sediments. It is likely that the phenolics associated with MG wastes will follow a similar pattern of movement.

Due to their physical properties, VOCs are generally not persistent in the aqueous environment. VOCs present in bottom sediments are weakly bound and will disassociate into the water column.

Inorganic contaminants are likely to be present in sediment and surface water. The distribution and speciation of inorganic contaminants in the River depends on the particle size distribution, mineralogy, acidity, and other factors. It is anticipated that inorganic contaminants may be found in both compartments (sediment and water) in the River and because inorganic contaminants are primary elements, they do not break down or metabolize into other compounds.

2.3.2 Ecosystems Potentially at Risk

2.3.2.1 Ecological Setting

The Site is a former MG plant located along the Anacostia River. The River at the Site is urbanized and industrialized, including extensively modified shoreline and nearshore areas. Bulkheads and riprap revetments armor nearly all of the shoreline. Navigational dredging has occurred in the Anacostia River, altering the natural bathymetry. According to the United States Army Corps of Engineers (USACE) (2007), the current day authorized dredge channel extends approximately 1,200 linear feet upstream of the Site where it forms a small turning basin and in the immediate area of the Site, the north edge of the dredge channel is located as close as approximately 100 linear feet from the Site seawall. As a result of the extensive urban and industrial development, the natural habitat for ecological populations is limited and this development has promoted species that can successfully adapt to highly urbanized environments. The structural habitat for fish and wildlife species is also severely limited with few wetlands and other refugia present in the River.

The River is a freshwater tidal estuary, with tidal influence extending some distance into the Northeast and the Northwest branches. Additional information about the tidal cycle and sedimentation rates within the River can be found in the RI/FS Work Plan.

2.3.2.2 Ecological Receptors

The aquatic species present in the vicinity of the Site include algae, amphibians, aquatic (water-dwelling) and benthic (sediment-dwelling) invertebrates, fish, and some aquatic birds. Surveys conducted by the USFWS and others in the lower Anacostia River indicated that the invertebrate and fish communities were composed of species typical to large, tidal, urban rivers. Fish species observed in the River include white perch (*Morone americana*), striped bass (*Morone saxatilis*), river herring (which include blueback herring [*Alosa aestivalis*] and alewife [*A. pseudoharengus*]), American and hickory shad (*Dorosoma* spp.), American eel (*Anguilla rostrata*), bluegill (*Lepomis macrochirus*), pumpkinseed (*L. gibbosus*), and carp (*Cyprinus carpio*), channel catfish (*Ictalarus punctatus*), blue catfish (*Ictalarus furcatus*), brown bullhead, smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and yellow perch (*Perca flavescens*) (Pinkney, 1993 and 2014; AWTA, 2002).

The benthic community in the River reflects the degraded water quality resulting from decades of industrial and urban activities. The benthic community is typically characterized by low diversity, low abundance, and dominance by pollution-tolerant worms (AWTA, 2002). Benthic community sampling conducted by the USFWS at 20 stations within the Anacostia River found that all locations were dominated by oligochaetes, which ranged from 42% to 92% of the organisms at a given station. Other taxonomic groups included midges, mollusks, crustaceans, leeches, and other insects. Results of the Benthic Index of Biotic Integrity (B-IBI) indicated that 8 of 20 stations (40%) were classified as "degraded" (B-IBI < 3). However, qualitative and quantitative comparisons with sediment quality benchmarks indicated no clear relationship between benthic community health and contaminant concentrations (McGee, et al., 2009). The non-native red swamp crayfish, native and introduced freshwater clams, and freshwater mussels also likely occur in the river (AWTA, 2002).

Exposure to ecological receptors may occur through direct contact with COPECs in media such as sediment and water or indirectly through the incidental ingestion of either sediment particles, surface water, or organisms. Most avian and mammalian wildlife, including piscivorous birds such as belted kingfisher, are unlikely to be exposed to Site-related contaminants due to the lack of shallow foraging habitat in the River at the Site. The home ranges of such wildlife are large and any potentially impacted food items are likely to represent a minimal portion of a receptor's diet. In addition, loss of amphibian, avian, and mammalian wildlife habitat due to the urban and industrial land uses and channelization of the river further limit the likelihood of these receptors being exposed to Site-related contaminants in the River. The USFWS, DOEE, and NOAA NMFS have been contacted to determine if any federally listed species or other sensitive receptors exist at or in the vicinity of the Site. To date, a response has been received from NMFS that there are no known occurrences of short-nosed or Atlantic sturgeon in the Anacostia River (Vaccaro, 2014). An online review of USFWS Information, Planning, and Conservation System (IPaC) website [http://ecos.fws.gov/ipac/] indicated that no federally listed species likely occur in the Anacostia River. Responses from the USFWS and DOEE have not yet been received. A more exhaustive review will be included in the BERA.

2.3.3 Complete Exposure Pathways

Potentially complete ecological exposure pathways in the River at the Site will be evaluated in the BERA. Each exposure pathway includes a potential COPEC source, an environmental medium, and a potential exposure route. In accordance with agency guidance, incomplete routes of exposure will not be evaluated in the BERA. This approach is used to focus the risk evaluation on exposure pathways that are considered to be potentially complete and for which there are adequate data pertaining to the receptors, exposure, and toxicity for completion of the risk analysis.

Historical industrial use of the waterways in the Anacostia River watershed, including the River itself, has led to a highly impacted water body. In addition to chemical stressors from a variety of sources, loss of habitat through shoreline development and channelization of the River, combined with a high sedimentation rate, has resulted in a severely stressed ecological system. Site-related COPECs may have entered the River from overland flow or groundwater discharge. If the River is impacted by Site-related MG residuals, the impacted sediments and/or surface water may pose a potential risk to benthic invertebrates, aquatic invertebrates, pelagic and bottom-dwelling fish through ingestion of sediment or surface water or direct exposure to the bioavailable fraction of contaminants in sediments or surface water.

Based on the available data and the CSM described in Section 3 of the RI/FS Work Plan, the ecological exposure pathways to be evaluated in the BERA include:

- Dermal or direct contact with surficial sediment in the River at the Site by benthic invertebrates, aquatic invertebrates, bottom-dwelling fish, and pelagic finfish
- Dermal or direct contact with surface water in the River at the Site by benthic invertebrates, aquatic invertebrates, bottom-dwelling fish, and pelagic finfish

- Dermal or direct contact with surficial sediment porewater in the River at the Site for benthic invertebrates and bottom-dwelling fish

Food web exposure pathways for amphibian, avian, and mammalian wildlife are not included because the Site and surrounding area is heavily urbanized. The large home ranges of most fish-eating wildlife are greater than the exposure area of River at the Site. In addition, loss of amphibian, avian, and mammalian wildlife habitat due to the urban and industrial land uses and channelization of the river may further confound the exposure to Site-related COPECs. While exposure pathways for amphibian, avian, and mammalian wildlife may be complete, these pathways are considered insignificant and are not included in the BERA.

2.4 Selection of Assessment Endpoints

Ecologically-based assessment endpoints and measures of effect were designed to evaluate potential ecotoxicological effects associated with exposure to preliminary COPECs. According to USEPA (1998), assessment endpoints are formal expressions of the actual environmental value to be protected. They usually describe potential adverse effects to long-term persistence, abundance, or production of populations of key species or key habitats. Typically, assessment endpoints and receptors are selected for their potential exposure, ecological significance, economic importance, and/or societal relevance.

Because assessment endpoints often cannot be measured directly, a set of surrogate endpoints (measures of effect) are generally selected for ecological risk assessment that relate to the assessment endpoints and have measurable attributes (e.g., comparison of media concentrations to screening levels, results of food web models) (USEPA, 1997, 1998). These measures of effect provide a quantitative metric for evaluating potential effects of contaminants on the ecosystem components potentially at risk. Since each measurement endpoint has intrinsic and extrinsic strengths and limitations, several measurement endpoints will be used to evaluate each assessment endpoint.

The assessment endpoints selected for the BERA are outlined below, and the measures of effect are presented in Section 4.1:

Assessment Endpoint 1 – Protection and maintenance of freshwater benthic invertebrate communities in the River at the Site typical of comparable aquatic habitats in the River with similar morphology, hydrology, and urban setting (i.e., the reference condition).

Assessment Endpoint 2 – Protection and maintenance of freshwater aquatic invertebrate communities in the River at the Site typical of comparable aquatic habitats in the River with similar morphology, hydrology, and urban setting (i.e., the reference condition).

Assessment Endpoint 3 – Protection and maintenance of bottom-dwelling fish communities in the River at the Site typical of comparable upstream aquatic habitats with similar morphology, hydrology, and urban setting (i.e., the reference condition).

Assessment Endpoint 4 – Protection and maintenance of freshwater pelagic fish communities in the River at the Site typical of comparable aquatic habitats in the River with similar morphology, hydrology, and urban setting (i.e., the reference condition).

2.5 Conceptual Model and Risk Questions

The end product of the problem formulation step is the development/refinement of the CSM. The CSM helps to describe the COPEC origin, fate, transport, exposure pathways, and receptors of concern. A detailed description of the current preliminary CSM for the River at the Site (including Site history and hydrogeology) is found in Section 3 of the RI/FS Work Plan. Figure 22-1 presents the ecological CSM developed based on a review of the historical data and reports.

As described in Section 1, historical industrial use of the waterways in the Anacostia River watershed, including the River itself, has led to a highly impacted water body and the loss of habitat. This has occurred through shoreline development and channelization of the River. These impacts, combined with a high sedimentation rate, have resulted in a severely stressed ecological system. Site-related contaminants may have entered the River from overland flow or groundwater discharge. If sediments in the River at the Site are impacted by MG residuals, the impacted sediments and/or surface water may pose a potential risk to benthic invertebrates, aquatic invertebrates, and pelagic and bottom-dwelling fish through direct exposure to the bioavailable fraction of contaminants in sediments, surficial porewater or surface water. The complete exposure pathways to be considered in the BERA are described in Section 2.3.3 and depicted in Figure 2-1**.**

Ecological risk questions for the BERA are questions about the relationship(s) between assessment endpoints and their predicted responses when exposed to Site-related COPECs. Thus, the primary ecological risk question for this BERA focuses on the relationships between assessment endpoints and ecological responses to COPEC exposure:

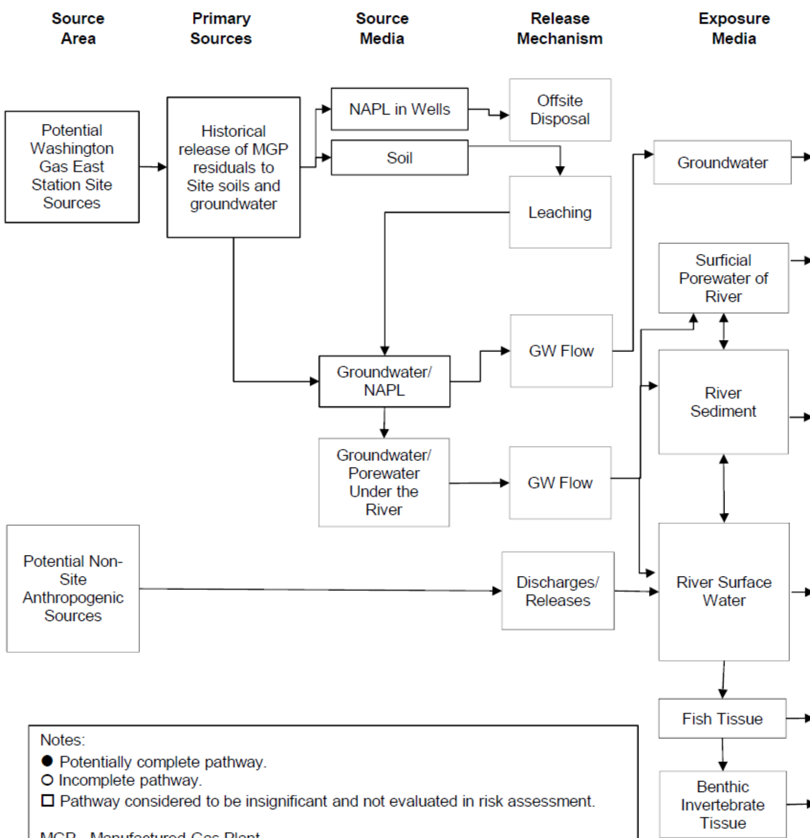
> *Do potential exposures to Site-related COPECs in surface water, surficial sediment, or surficial sediment porewater in the River at the Site adversely affect benthic and aquatic invertebrates or pelagic and bottom-dwelling fish?*

2.6 Scientific/Management Decision Point

At the conclusion of Step 3, there is an SMDP that consists of agreement on the following four items: contaminants of concern, assessment endpoints, exposure pathways, and risk questions.

- The preliminary COPECs to be evaluated in the BERA include Site-related contaminants potentially derived from the Site. Specifically, the list of preliminary COPECs includes: phenolics, PAHs, BTEX, cyanide, arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver.
- The CSM presented in Figure 2-1 identifies the potentially complete exposure pathways and the assessment endpoints presented in Section 2.4 are related to the protection and maintenance of the benthic and aquatic invertebrate and fish communities within the study area.
- The risk question for the BERA is: What are the potential current and future risks to ecological receptors associated with exposure to Site-related contaminants in River sediments and surface water?

Figure 2-1 Ecological Conceptual Site Model
Operable Unit 2 – Remedial Investigation and Feasibility Study Work Plan
Washington Gas East Station Site



Exposure Media	Potential Exposure Route	Benthic Invertebrate Community	Aquatic Invertebrate Community	Bottom Dwelling Fish Community	Pelagic Finfish Community	Amphibians	Birds and Mammals
		Potential Ecological Receptors					
Groundwater	Dermal / Direct Contact	○	○	○	○	○	○
	Incidental Ingestion	○	○	○	○	○	○
Surficial Porewater of River	Dermal / Direct Contact	●	○	●	○	○	○
	Bioaccumulation	□	○	□	○	○	○
River Sediment	Incidental Ingestion	●	○	●	○	○	□
	Dermal / Direct Contact					□	□
	Inhalation (a)	○	○	○	○	□	□
River Surface Water	Incidental Ingestion	●	●	●	●	○	□
	Dermal / Direct Contact					□	□
	Inhalation	○	○	○	○	○	□(a)
	Bioaccumulation	○	□	□	□	□	□
Fish Tissue	Ingestion	○	○	○	□(b)	□	□(b)
Benthic Invertebrate Tissue	Ingestion	○	○	□(b)	○	□(b)	□(b)

Notes:
- ● Potentially complete pathway.
- ○ Incomplete pathway.
- □ Pathway considered to be insignificant and not evaluated in risk assessment.

MGP - Manufactured Gas Plant
NAPL - Non-Aqueous Phase Liquid
(a) Inhalation of volatiles in outdoor air volatilized from sediment and surface water is likely insignificant.
(b) Pathway not evaluated in risk assessment.

3.0 Study Design, Data Quality Objective Process, and Field Verification of Sampling Design

The product of Step 4 of the ERA process, Study Design and Data Quality Objective (DQO) Process, is the BERA Work Plan and Sampling and Analysis Plan (SAP). This step includes development of measures of effect and describes the details of the site investigation as well as the data analysis methods and DQOs. The proposed data collection that will be used to identify and characterize ecological exposure and effects in the BERA are described in the RI/FS Work Plan. The following subsections present the measures of effect for the BERA and general quantitative methods that will be used to evaluate potential risks.

3.1 Establishing Measures of Effect

Because the assessment endpoints identified in Section 2.4 cannot be measured directly, a set of surrogate endpoints (measures of effect) are generally selected for ERA that relate to the assessment endpoints and have measurable attributes (e.g., comparison of media concentrations to screening levels) (USEPA, 1997, 1998). These measures of effect provide a quantitative metric for evaluating potential effects of contaminants on the ecosystem components potentially at risk. Since each measurement endpoint has intrinsic and extrinsic strengths and limitations, several measurement endpoints are typically used to evaluate each assessment endpoint.

3.1.1 Benthic Invertebrate Assessment and Measurement Endpoints

Benthic organisms (e.g., those living in sediment) may potentially be exposed to COPECs from direct contact with surficial porewater, surface water, and surficial sediment. Several measures of effect will be used to evaluate the assessment endpoint developed for the benthic macroinvertebrate community within the study area.

Assessment Endpoint 1 – Protection and maintenance of freshwater benthic invertebrate communities in the River at the Site typical of comparable aquatic habitats in the River with similar morphology, hydrology, and urban setting (i.e., the reference condition).

- Measure of Effect 1a – Comparison of bulk sediment concentrations (phenolics, PAHs, BTEX, inorganic contaminants, and cyanide) to sediment benchmarks, which are based on threshold effect levels. Maximum concentrations above screening values will be considered indicative of a potential for ecological risks, and will require further evaluation as COPECs. Since exceedences of threshold effect levels are likely in urban riverine settings, the benchmarks used in the BERA risk characterization will include both threshold and probable effect levels. This will allow the potential exceedences to be described relative to the urban setting of the Anacostia River, and will also facilitate interpretation of the biological and toxicological data from sediment samples collected in the River impacted by the Site.
- Measure of Effect 1b – Bulk sediment invertebrate toxicity tests will be used to evaluate potential lethal and sub-lethal effects associated with exposure to sediment. Sediment toxicity tests will include two species: a midge (*Chironomus dilutus*) and an amphipod (*Hyalella azteca*). Results from samples collected in the River impacted by the Site will be compared to results from laboratory controls and upstream reference locations.

- Measure of Effect 1c – Evaluation of porewater concentrations of PAHs in the sediment narcosis model (DiToro and McGrath 2000; USEPA 2009). Calculation of toxic units greater than one may be an indication of ecological risk, and may require further evaluation. These data will also be used to support interpretation of the toxicological data from sediment samples collected in the River impacted by the Site.
- Measure of Effect 1d – Evaluation of the bioavailable fraction of divalent metals will be conducted using simultaneously extracted metals and acid volatile sulfide (SEM/AVS) analysis and measurements of total organic carbon (TOC). This evaluation will be conducted in conjunction with the laboratory toxicity testing (Measure of Effect 1b) to help determine if sample toxicity is due to the presence of metals.
- Measure of Effect 1e – Comparison of estimated and measured surficial sediment porewater COPEC concentrations to both chronic and acute surface water screening values. Concentrations above screening values will be used to provide a preliminary indication of areas of potential concern where undiluted porewater may pose a potential risk to benthic invertebrates.
- Measure of Effect 1f – Comparison of surface water concentrations (phenolics, PAHs, BTEX, dissolved inorganic COPECs, and cyanide) to ecological screening levels protective of benthic invertebrates. Maximum concentrations above screening values will be considered indicative of potential ecological risks, and will require further evaluation as COPECs.
- Measure of Effect 1g – A benthic invertebrate community study will be conducted to evaluate potential impacts on density and diversity. Community study results from locations within the River at the Site will be compared to results from upstream reference locations.

3.1.2 Aquatic Invertebrate Assessment and Measurement Endpoints

Aquatic invertebrates are an essential part of the ecosystem. They may potentially be exposed to COPECs from direct contact with surface water.

Assessment Endpoint 2 – Protection and maintenance of freshwater aquatic invertebrate communities in the River impacted by the Site typical of comparable aquatic habitats in the River with similar morphology, hydrology, and urban setting (i.e., the reference condition).

- Measure of Effect 2a – Comparison of surface water concentrations (phenolics, PAHs, BTEX, dissolved inorganic COPECs, and cyanide) to ecological screening levels protective of aquatic invertebrates. Maximum concentrations above screening values will be considered indicative of potential ecological risks, and will require further evaluation as COPECs.

3.1.3 Fish Assessment and Measurement Endpoints

Fish may potentially be exposed to COPECs from direct contact with surface water, sediment, and surficial porewater (bottom-dwelling only). Studies conducted by the USFWS (Pinkney, et, al, 2002; 2004; 2013) found that brown bullhead catfish collected from the Anacostia River in Washington, DC had high rates of both liver and skin tumors and that PAHs appear to play a role in tumor formation. Several measures of effect will be used to evaluate the assessment endpoint developed for the warm water fish community in the in-river investigation area.

Assessment Endpoint 3 – Protection and maintenance of bottom-dwelling fish communities in the River impacted by the Site typical of comparable upstream aquatic habitats with similar morphology, hydrology, and urban setting (i.e., the reference condition).

- Measure of Effect 3a – Comparison of surface water concentrations (phenolics, PAHs, BTEX, dissolved inorganic COPEC, and cyanide) to ecological screening levels protective of fish. Maximum concentrations above screening values will be considered indicative of a potential for ecological risks, and will require further evaluation as COPECs.
- Measure of Effect 3b – Comparison surficial sediment porewater concentrations to surface water screening benchmarks protective of fish. Concentrations of PAHs in surficial sediment porewater that exceed concentrations linked to development of tumors in other freshwater fish may indicate that the bioavailable fraction of Site-related COPECs in River sediments warrants further evaluation relative to bottom dwelling fish.
- Measure of Effect 3c – Evaluation of measured surface water concentrations and estimated and measured surficial sediment porewater concentrations of PAHs in the water narcosis model (DiToro et al., 2000). Calculation of screening benchmarks that are lower than concentrations observed in the River at the Site may be an indication of ecological risk, and may require further evaluation.

Assessment Endpoint 4 – Protection and maintenance of freshwater pelagic fish communities in the River impacted by the Site typical of comparable aquatic habitats in the River with similar morphology, hydrology, and urban setting (i.e., the reference condition).

- Measure of Effect 4a – Comparison of surface water concentrations (phenolics, PAHs, BTEX, dissolved inorganic COPECs, and cyanide) to ecological screening levels protective of fish. Maximum concentrations above screening values will be considered indicative of potential ecological risks and will require further evaluation as COPECs.

3.2 Data Quality Objectives

The DQOs for the data to support the BERA are provided in Section 4 of the RI/FS Work Plan. A detailed description of these DQOs is provided below.

3.2.1 Step 1 – State the Problem

As noted in Section 2.5, historical industrial use of the waterways in the Anacostia River watershed, including the River itself, has led to a highly impacted water body and the loss of habitat. This has occurred through shoreline development and channelization of the River. These impacts, combined with a high sedimentation rate, have resulted in a severely stressed ecological system. Site-related contaminants may have entered the River from overland flow or groundwater discharge. If sediments in the River at the Site are impacted by MG residuals, the impacted sediments and/or surface water may pose a potential risk to benthic invertebrates, aquatic invertebrates, and bottom-dwelling and pelagic fish through direct exposure to the bioavailable fraction of contaminants in sediments, surficial porewater or surface water. Measured data are needed to support the completion of a BERA for the Site. The SAP that will be developed will include information regarding the planning team members, identification of decision makers, principal data users within the planning team as well as a summary of available resources and relevant deadlines for the study, including budget, availability of personnel, and schedule.

3.2.2 Step 2 – Goal of the Investigation

The goal of the BERA is to estimate potential current and future risks to aquatic ecological receptors at the Site associated with the exposure to contaminants in the sediment, porewater, and surface water. This investigation will collect the necessary data to evaluate multiple lines of evidence in the

BERA to determine if estimated risks to aquatic receptors are unacceptable and, if so, response actions are needed to protect these receptors from Site-related contaminants.

The principal study question is as follows:
What are the potential current and future risks to ecological receptors associated with exposure to Site-related contaminants in River sediment, porewater, and surface water?

3.2.3 Step 3 – Identify Information Inputs

3.2.3.1 Previous Data Useability

Historical surficial sediment data are available in NOAA's DARRP Anacostia River Watershed Database and Mapping Project database, which contains records from 35 Anacostia River studies spanning 20 years of research.[1] This database includes a number of studies conducted over a wide spatial extent (beyond the boundaries of the Site) and temporal scale. Surface water sample data are available for the Site and were collected during an outgoing tide at seven locations in June 1996 and at three locations in February 1997 as part of RI activities at the Site (Hydro-Terra, 1999). No sediment porewater data are available for inclusion in the BERA. Due to the uncertainties in the age of the available RI data and the spatial distribution of the samples, additional data are needed in support of the BERA.

3.2.3.2 Data to be Collected in Support of the BERA

Several types of information are needed to support a decisions regarding potential risks to aquatic receptors. As noted above, the BERA will use multiple lines of evidence to evaluate potential risks. Data needed for the BERA for aquatic receptors can be divided into four basic categories:

- Site-specific sediment toxicity tests
- SEM/AVS analysis and measurement of TOC in sediment
- Chemical concentrations in environmental media (i.e., surface water, sediment, porewater) for the derivation of hazard quotients (HQs) and use in the sediment narcosis model and fish tissue narcosis model
- Observations of benthic invertebrate community demographics

HQ Approach

It is common to begin by an assessment of risks using the HQ approach. In this approach contaminant concentrations in environmental media are compared to respective toxicity benchmarks. If the value of an HQ is less than or equal to 1 (either those based on maximum exposure or those calculated for each sampling location), risk of unacceptable adverse effects in exposed organisms is judged to be acceptable. If the HQ exceeds 1, the risk of adverse effects in exposed organisms may be of concern, with the probability and/or severity of adverse effect tending to increase as the value of the HQ increases.

---

[1] http://www.darrp.noaa.gov/partner/anacostia/restore.html

When interpreting HQ results for non-threatened or endangered receptors, it is important to remember that the assessment endpoint is usually based on the sustainability of exposed populations, and risks to some individuals in a population may be acceptable if the population is expected to remain healthy and stable. In these cases, population risk is best characterized by quantifying the fraction of all individuals that have HQ values greater than 1, and by the magnitude of the exceedences. The fraction of the population that must have HQ values below a value of 1 in order for the population to remain stable depends on the species being evaluated and on the toxicological endpoint underlying the toxicity benchmark. Consequently, reliable characterization of the impact of a chemical stressor on an exposed population risks requires knowledge of population size, birth rates, and death rates, as well as immigration and emigration rates. Because this type of detailed knowledge of population dynamics is generally not available on a site-specific basis, extrapolation from a distribution of individual risks to a characterization of population-level risks is generally uncertain. However, if all or nearly all of the HQs for individuals in a population of receptors are below 1, it is very unlikely that unacceptable population-level effects will occur in the exposed population. Conversely, if many or all of the individual receptors have HQs that are above 1, then unacceptable effects on the exposed population are likely, especially if the HQ values are large. If only a small portion of the exposed population has HQ values that exceed 1, some individuals may be impacted, but population-level effects are not likely to occur. As the fraction of the population with HQ values above 1 increases, and as the magnitude of the exceedences increases, risk that a population-level effect will occur also increases. This concept is illustrated schematically in Figure 3-1.

Although the simple "hazard quotient" approach to be used in this ERA provides a useful but conservative measure of the potential for risk based on a "snapshot" of site conditions; it should be noted that the hazard quotient approach has no predictive capability. Tannenbaum, et al (2003) presented a summary of limitations of the HQ approach deriving from the nature of the mathematical computation (i.e., the ratio) and general uncertainties associated with describing a receptor’s chemical intake and a receptor’s chemical sensitivity:

- The HQ is not a measure of risk. HQs are not probabilities in the mathematical sense, an HQ of 0.1 does not mean that there is a one in ten chance that an effect will occur (U.S. EPA, 1989).
- The HQ is not a population-based measure. HQs do not refer to the number of individuals or percentage of the exposed population that is expected to be impacted.
- HQs are not linearly scaled. The level of concern for a receptor with an HQ of 10 may not be twice the concern over an HQ of 5.
- Extremely low chemical concentrations in environmental media can “trigger” an HQ of >1.0. Elevated HQs are often calculated at background levels of naturally occurring inorganic contaminants.

HQs are often generated that are unrealistically high and toxicologically impossible. Conservative TRVs and exposure assumptions (e.g., 100% bioavailability) may result in compounded conservatism that produces unreasonably elevated HQs not supported by field observations (e.g., NOAEL-based HQs indicating that receptors are consuming acutely toxic levels of contaminants, but populations are present on-site). For these reasons, the BERA relies on several lines of evidence, not just HQs.

To employ the HQ approach in the BERA, measured data are needed which provide representative concentrations of preliminary COPECs in surface water, sediment, and sediment porewater. For metals in surface water, concentrations are needed for the dissolved fraction (as this is a more important determinant of aquatic toxicity).

The HQ approach also requires the availability of suitable toxicity benchmarks for the contaminants of concern. *The NPS Protocol for the Selection and Use of Ecological Screening Values for Non-Radiological Analytes* (NPS 2014) provides a summary of approved sources for each media type. Such benchmarks do exist for most analytes, and the HQ approach will be used as the first line of evidence for these contaminants. Additional details regarding the HQ evaluation can be found in Section 5.

Site-Specific Toxicity Tests

In Site-specific toxicity tests, ecological receptors are exposed to site media of known concentrations in order to observe whether the media causes adverse effects on growth, survival, and/or reproduction in laboratory test species. Site-specific toxicity testing will be completed with Site sediments.

Data from the toxicity test results will be used to establish a reliable Site-specific exposure response curve. Using this relationship, it may be possible to identify the threshold concentrations of contaminants in sediment that represent the boundary between acceptable and unacceptable effects for benthic invertebrates. If so, then these toxicity threshold concentrations may be used in the evaluation of other Site sediments that have not been tested. To accommodate this objective, it will be necessary to evaluate multiple (three or more) sediment samples, which encompass the full range of contaminant exposure conditions at the Site. Additional details regarding this evaluation can be found in Section 5.

SEM/AVS Analysis and Measurement of TOC in Sediment

To account for the potential for divalent metals bioavailability to be limited in sediment, SEM, AVS, and TOC can be measured in sediments. USEPA (2005) guidance on metals bioavailability evaluates possible binding of metals by both AVS and organic matter. Therefore, data can be evaluated using a specified scale to examine whether or not the organic carbon binding phase (represented as fraction organic carbon or f_{oc}), in conjunction with the AVS, is affecting the bioavailability of divalent metals in sediments. This evaluation will be conducted in conjunction with the laboratory toxicity testing to help determine if sample toxicity is due to the presence of metals.

Sediment Narcosis Model

The principal form of toxicity elicited by PAHs to benthic invertebrates is narcosis. Narcotic toxicants frequently demonstrate additive toxicity, in other words, the effects of narcotic toxicants can be added together to summarize the total toxicity present in a mixture of PAHs. Evaluation of porewater concentrations of PAHs in the sediment narcosis model will be performed (DiToro and McGrath 2000; USEPA 2009). The bioavailable concentration of each PAH is then converted to toxic units based on narcosis theory. A summation of toxic units greater than one may be an indication of ecological risk, and may require further evaluation. These data will also be used to support interpretation of the toxicological data from sediment samples collected in the River impacted by the Site. Additional details regarding this evaluation can be found in Section 5.

Community Demographics

Measurements of community demographics are made in the field to identify if any receptor population has unusual numbers of individuals (either lower or higher than expected) or whether the diversity (number of different species) or composition of species is different than expected (e.g., the absence or presence of pollution tolerant species). Community demographic information will be collected for benthic invertebrates. These data will be compared to reference area information. Additional details regarding this evaluation can be found in Section 5. Samples will be collected according to EPA's Rapid Bioassessment Protocol (RBP) method. Invertebrates will be identified to the genus level and the relative abundance of each taxon will be determined (Plafkin et al. 1989, Barbour et al. 1999).

3.2.4 Step 4 – Boundaries of the Investigation

3.2.4.1 Spatial Boundaries

The investigation that will be conducted in support of the BERA will be focused to the "in-river" portion of the Site, no sampling will be conducted on the landside portion. The area that will be investigated to evaluate the Site will be inclusive of the area of the River that is at the seawall, approximately 1,000 ft. in length at the government property and extending approximately 100 feet into the River. This area may be expanded or contracted based on the results of the landside investigation or based on the results of the groundwater investigation beneath the River. Specific sampling locations will be selected following, and partially based on, a hydrographic survey and review of results from the landside investigation, including drive point profiling and monitoring well installation and sampling analysis. Additionally, samples will be collected from reference areas, upstream of the Site in order to determine Site attribution of risks.

Surficial sediment and porewater samples will be collected from the biologically active zone (BAZ), the depth of which is assumed to be 0.5 ft, but will be verified by visually evaluating sediment cores for indications of bioactivity. This BAZ depth limit is considered adequate for risk assessment purposes unless the sediment stability analysis and dredging plans indicate that deeper exposure depths could be reasonably expected. Additionally, subsurface sediment samples will be collected from between 0.5 ft. and 20 ft below the surface, unless a greater sampling depth is appropriate based on the landside and/or sediment investigation results. These samples will be used to evaluate potential future risks from exposure to sediments that may be exposed from dredging activities, propeller wash, or storms in the uncertainty section of the BERA.

3.2.4.2 Temporal Boundaries

All samples will be collected during one mobilization event. Bioavailable concentration of COPECs in sediments are expected to be higher during the spring when acid volatile sulfide concentrations (which have the potential to bind divalent metals) are typically at their lowest following the winter months, due to elevated cold water dissolved oxygen and redox conditions. Additionally, mid-Atlantic macroinvertebrate sampling guidance (e.g., Maryland Biological Stream Survey Guidance, Maryland Department of Natural Resources, http://www.dnr.state.md.us/streams/pdfs/ea-07-01b_fieldRev2013.pdf) requires sampling during the Spring Index Period (March 1 through April 30 to representatively sample the community composition and relative abundance. The Spring Index Period has been demonstrated to provide benthic macroinvertebrate data most suited for identifying anthropogenic stressors at a site.

3.2.4.3 Sampling Unit

The BERA is focused on a the exposure pathways identified in the SCM for ecological receptors. The receptor groups and exposure pathways to be addressed include exposure of benthic invertebrates to contaminants in surficial sediments and surficial sediment porewater, exposure of aquatic invertebrates to surface water, and exposure of fish to contaminants in surface water, pore water and sediments.

3.2.4.4 Decision Unit

The decision unit for the BERA is OU2 of the Site.

3.2.5 Analytic Approach

In the BERA, risks to aquatic ecological receptors from a particular chemical in a particular medium will be evaluated using a weight-of-evidence approach, combining the results from up to five possible lines of evidence:

- Calculation of Hazard Quotient (HQ) values based on measured concentration values and available toxicity benchmarks
- Exposure of test organisms to sediment samples collected from the Site to evaluate the magnitude and frequency of any effects on growth, reproduction or survival
- SEM/AVS analysis and measurements of TOC in Site sediment samples to determine the bioavailable fraction of metals
- Calculation of toxic units using the sediment narcosis model and fish tissue narcosis model
- Direct surveys of receptor community demographics in comparison to appropriate reference areas

The weight-of-evidence conclusions will take many factors into account, including the strengths and weaknesses of each line of evidence, and the degree of agreement between the different lines. Thus, no statistical or quantitative decision rule can be stated *a priori*. The following qualitative guidelines will be applied when interpreting risks to each ecological receptor of concern:

- *All lines of evidence agree that risk is within an acceptable range.* If the calculated HQ does not exceed 1; there are no significant growth, mortality or reproduction effects observed in site-specific toxicity tests (compared to reference and laboratory controls); the sediments are presumed to "not likely" be toxic according to the SEM/AVS evaluation; the sum of the toxic units using the narcosis model is less than one; and there are no ecologically relevant differences observed in direct surveys of community demographics (compared to reference), then it will be concluded that potential aquatic receptor risks are likely to be within an acceptable range and remedial actions are not necessary.
- *All lines of evidence agree that there is an unacceptable risk.* If the calculated HQ exceeds 1; there is evidence of adverse growth, survival, or reproduction effects in the Site-specific toxicity tests; the sediments are presumed to "likely" be toxic according to the SEM/AVS evaluation, the sum of the toxic units using the narcosis model is greater than one; and there is evidence of an adverse impact on community structure and function, then it will be concluded that potential aquatic receptor risks are likely to be within an unacceptable range and alternative response actions to protect ecological receptors will be evaluated.

- *The results from each line of evidence are mixed*. If the calculated HQs exceed 1, but direct toxicity is not observed in Site-specific toxicity tests or based on the community surveys, then the weight assigned will be in proportion to the confidence in the data for each line of evidence. If the weight-of-evidence indicates that adverse effects on ecological receptors are occurring, and that these effects are likely to result in a meaningful decrease in the growth, reproduction or survival of local populations compared to what would be expected in the absence of Site-related contamination, then alternative response actions to protect ecological receptors will be evaluated.
- *The lines of evidence are very limited, weak or absent.* If it is not possible to assess possible effects on growth, reproduction, or survival of local populations, then the potential scope of the problem will be weighed to consider the costs and benefits of additional data collection to support one or more lines of evidence versus the costs and benefits of the presumptive remedial action.

3.2.6 Decision Error Limits

It is recognized that decision error limits are not applicable to many of the lines of evidence that will be used to evaluate risks to ecological receptors (e.g., chemical data used to derive sample-specific hazard quotients, invertebrate population data used to develop qualitative impact rankings). However, decision error limits can be applied in terms of the sediment toxicity testing. In particular, as the number of replicates per treatment increases, so does the power to detect a 20% response relative to the control mean or reference mean. USEPA (2000) will be used as a guide for determining the minimum number of replicates per treatment such that a response can be reliably detected, if present.

It is possible, however, to specify a quantitative or statistical approach for limiting decision errors within specified bounds for individual lines of evidence depending on the characteristics of the data. Two types of decision errors are possible:

- A false negative decision error occurs when it is decided that risk is acceptable when the true risk is actually above the level of concern
- A false positive decision error occurs when it is decided that risk is not acceptable when the true risk is actually below the level of concern

Of these two types of errors, the primary concern is with avoiding false negative errors, since an error of this type can leave ecological receptors exposed to unacceptable levels of contamination and risk. Traditionally, acceptable values for false negative decision errors have ranged from 0.1 to 0.01, with 0.05 or 5% used most commonly. For the purposes of this BERA, 5% has been selected.

A false positive decision error does not leave ecological receptors at risk, but is also of concern because this type of error may result in the expenditure of resources (time, money) that might be better invested elsewhere. The goal is as follows for the BERA: if the true level of risk is less than ½ the acceptable risk level, then there should be no more than a 20% chance that the risk will be declared to be unacceptable.

As the number of replicates per treatment increases, so does the power to detect a 20% reduction in treatment response relative to the control mean or reference mean. USEPA (2000) will be used as a guide for determining the minimum number of replicates per treatment such that this reduction can be detected if present.

3.2.7 Optimize the Design

Section 3.3 presents an overview of the study design, including sampling station locations, number of samples to be collected, etc. In general, the study design will be optimized as necessary based on Site conditions and any deviations would be documented and approved prior to implementation. The sections below provide details regarding the optimization for the sampling design for each line of evidence to be utilized in the BERA.

Optimize the Sampling Design for HQs

Application of the HQ approach requires the collection of reliable and representative measurements of the concentration of contaminants as a function of both time and space. This type of data is valuable both to support risk evaluations as well as to identify sources of contaminant releases. As the strength of the HQ approach will be increased by comparison of HQ values from the Site locations to reference locations not impacted by releases from the Site; surface water, sediment, and sediment porewater analytical data will be collected from the identified reference areas that have yet to be identified. Prior to sampling of the reference locations, locations will be selected after a field reconnaissance. The field reconnaissance will identify if access to the locations can be made and then upon direct inspection if the sampling locations are comparable as expected.

Optimize the Sampling Design for Site-Specific Toxicity Testing

The objective of the toxicity testing is to identify if Site sediments are toxic to benthic invertebrate test species. If toxic, a second objective of the toxicity testing is to provide toxicity information for a weight-of-evidence evaluation of risks for aquatic receptors at individual sampling locations. The toxicity testing information along with benthic invertebrate community data will be used to evaluate risk. A third objective of the toxicity testing is to provide data that may be used to develop a site-specific exposure-response curve for toxicity to Site-related contaminates to benthic invertebrates. In order to understand if other factors may influence sediment toxicity, it is also necessary to test sediments that do not contain contamination (i.e., reference locations).

Recognizing that variance among replicate exposure chambers is difficult to control, this variance can be minimized by selecting test organisms that are as biologically similar as possible while maintaining test conditions within the prescribed quality control limits.

Optimize the Sampling Design for Data Inputs into the Narcosis Model

As mentioned for the HQ approach, application of the narcosis model requires the collection of reliable and representative measurements of the concentration of contaminants as a function of both time and space. This type of data is valuable to support risk evaluations as well as to identify sources of contaminant releases. As the strength of the HQ approach will be increased by comparison of the summation of the toxic units from the Site locations to reference locations not impacted by releases from the Site; surface water and sediment porewater analytical data will be collected from the identified reference areas that have yet to be identified. Prior to sampling of the reference locations, locations will be selected after a field reconnaissance. The field reconnaissance will identify if access to the locations can be made and then upon direct inspection if the sampling locations are comparable as expected.

Optimize the Sampling Design for Community Demographics

Community demographic information will be collected for benthic invertebrates and compared to those collected in reference areas. The objective is to identify if any receptor population has unusual numbers of individuals (either lower or higher than expected), or whether the diversity (number of different species) is different than expected.

The benthic community will be sampled at locations along the Site that are concurrent with the surface water, sediment , and porewater sampling locations. This will optimize the ability to interpret community metrics versus contaminant concentration. The objective is to identify if metrics are different in comparison with reference areas and if any observed changes could result from contaminant exposures. The specific reference locations will be identified during the reconnaissance to match as closely as possible the habitat variables present at the aquatic sites being evaluated. The methods for benthic invertebrate collections will include those that have been used in other benthic invertebrate surveys conducted along the Anacostia River. This will optimize comparison of data collected at other locations if desired.

3.3 Study Design

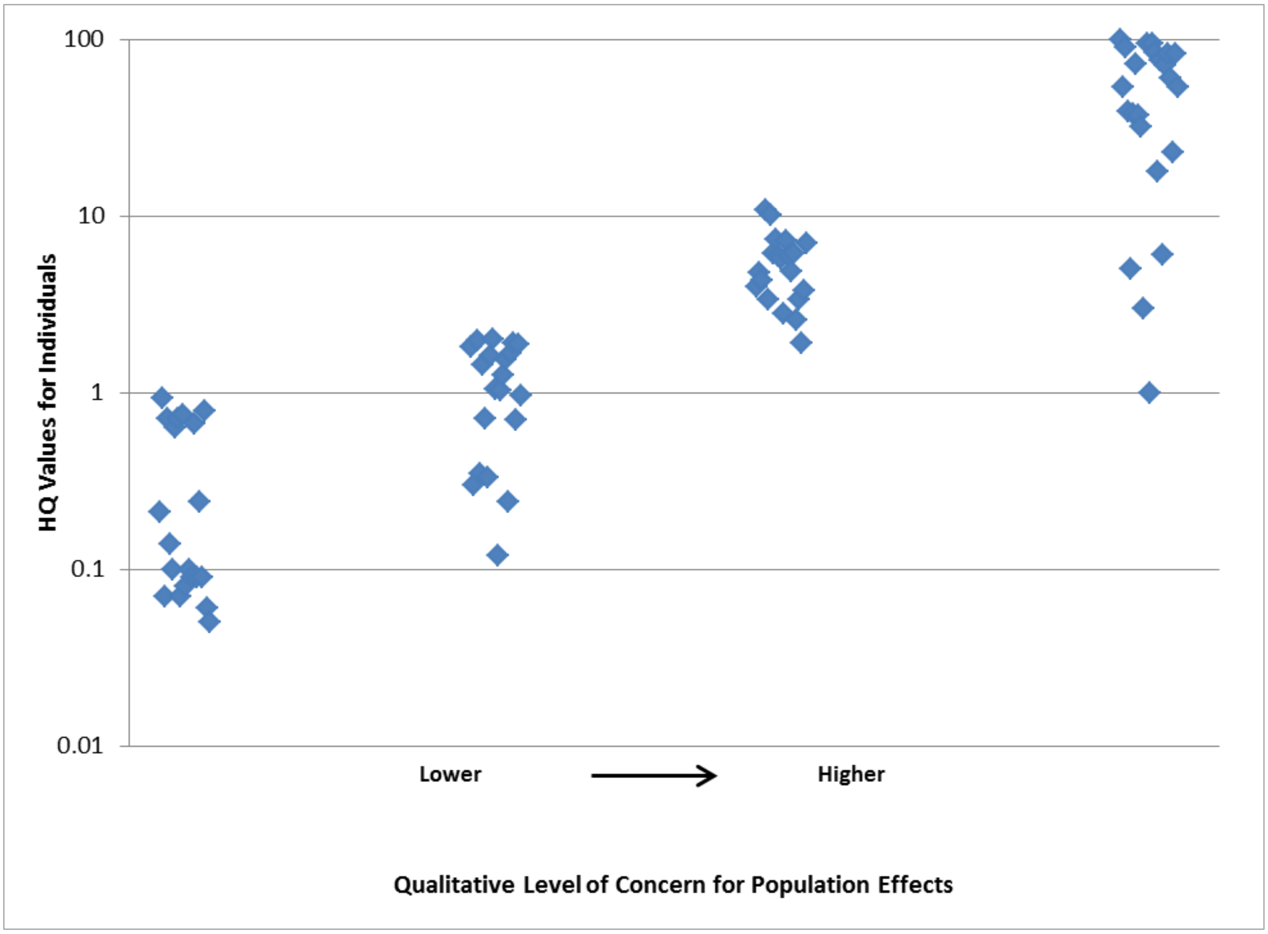
The study design, including rationale for sample counts, is provided in the RI/FS Work Plan. Concentrations of COPECs will be measured in surface water, sediment (surface and subsurface), porewater, Site-specific sediment toxicity tests will be performed, and benthic invertebrate community composition will be determined to support the evaluation of potential risks to aquatic receptors at the Site. In summary, the sample design for the BERA includes:

1) Collection of 22 surficial (0-0.5 ft) sediment samples from the River at the Site for analysis of COPECs, TOC, and grain size.
2) Collection of 22 subsurface (0.5 ft to a maximum depth of 20 ft) sediment samples from the River at the Site for analysis of COPECs, TOC, and grain size.
3) Collection of 10 surface water samples from the River at the Site for analysis of COPECs and hardness.
4) Analysis of 7 to10 of above mentioned surficial sediment samples for:
    a. Laboratory benthic invertebrate toxicity testing
    b. SEM/AVS
    c. Surficial porewater analysis of COPECs plus alkyl PAHs, and SEM metals not included as COPECs (copper, nickel and zinc)
    d. Alkyl PAHs
5) Collection of benthic invertebrates for analysis of community composition from 10 sediment sampling locations in the River at the Site.
6) Collection of 3 reference condition surficial (0-0.5 ft) sediment samples for analysis of:
    a. Laboratory benthic invertebrate toxicity testing
    b. SEM/AVS
    c. Surficial porewater analysis of COPECs plus alkyl PAHs, copper, nickel and zinc
    d. Alkyl PAHs

7) Collection of 3 reference condition surface water samples for analysis of COPECs and hardness.
8) Collection of benthic invertebrates for analysis of community composition from 3 reference locations.

Figure 4-2 of the RI/FS Work Plan presents the locations of the surface water, sediment samples and preliminary benthic invertebrate community data collection locations.

Figure 3-1 Conceptual Approach for Characterizing Population-Level Risks
Operable Unit 2 – Remedial Investigation and Feasibility Study Work Plan
Washington Gas East Station Site



4.0 Field Verification of Sampling Design

The primary purpose of Step 5, Field Verification of Sampling Plan, is to ensure that the samples specified in Step 4 can be collected, and that the field sampling plan is appropriate and implementable.

The Anacostia River is a large and well-studied water body. Collection of sediment and surface water from the River has been achieved to support the Washington Gas East Station investigations and other projects for several decades. Therefore, sampling of sediment, surface water, and porewater to support the ERA is implementable.

4.1 Selection of Reference Locations

Reference locations will be selected such that they are representative of comparable environmental conditions with the Site, but with the absence of Site-related impacts. Of particular concern is the selection of reference locations for surficial sediment that will be used in the laboratory toxicity tests. Ideally, according to USEPA, the reference sediments should be collected near the Site being investigated but outside the zone of potential impacts from the Site. To the extent possible, physical conditions such as grain size and organic carbon content from the sediment samples collected from the River at the Site should be matched in the reference sediments. The reference conditions to support the laboratory toxicity testing have been selected based on information regarding grainsize and TOC content of available samples from the DARRP database. TOC and grainsize (as percent fines; the sum of the silt and clay fractions) in DARRP database surficial sediment samples were mapped (Figures 4-1 and 4-2). Samples collected from the River near or at the Site generally contain 1 to 5% organic carbon and >50% fine grained sediments. This pattern appears to be consistent throughout much of the Anacostia River upstream of the Site.

A review of the AWTA (2002) Areas of Concern (AOC) and physical characteristics of sediment samples was conducted. The area between south of Benning Road and John Phillip Sousa Bridge has been identified for collection of reference samples. Reference sample locations are presented in Figure 4-3. The AWTA AOCs in this reach of the Anacostia River will not be sampled. Kingman Lake, located on the west side of the Burnham Barrier (or Kingman Island) may also be investigated for appropriate physical match to the sediments from the River at the Site. Field verification of these stations is absolutely necessary. A field geologist will evaluate the sediments collected from the reference locations and compare the color and texture to those collected from the River at the Site. Should the results of field inspection of these sediments indicate that they are inappropriate for use as laboratory toxicity testing reference locations, NPS will be consulted prior to moving to a new location.

4.2 SMDP

NPS review of Steps 3 and 4 will provide the necessary SMDP. The following have been described above and in more detail in the RI/FS Work Plan and Sampling and Analysis Plan (pending) for decision:

1) Selection of measures of effect
2) Selection of investigation methods
3) Selection of data reduction and interpretation techniques.

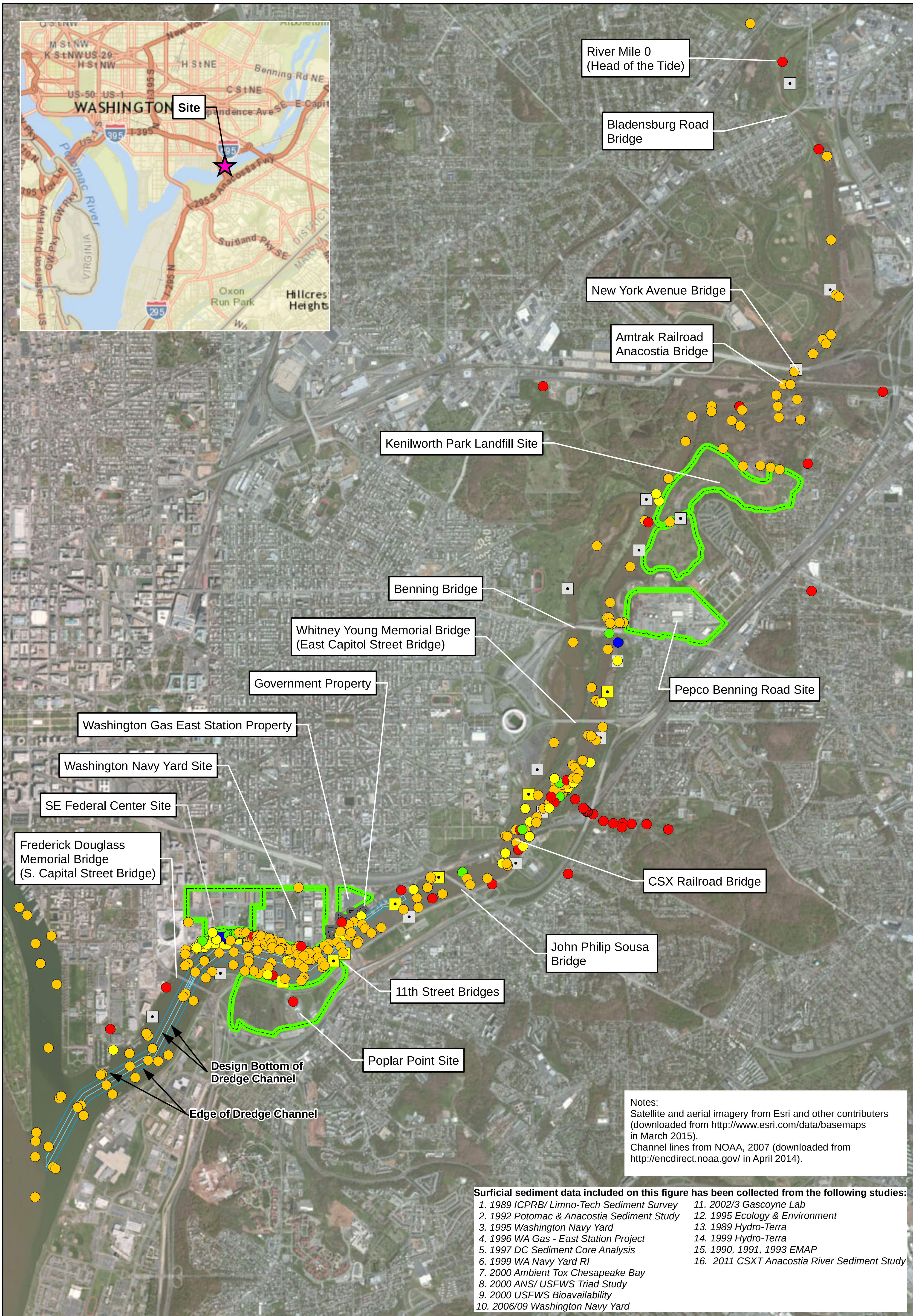


Figure 4-1
Anacostia River Surficial Sediment Total Organic Carbon (TOC)
Operable Unit 2 - Remedial Investigation and Feasibility Study Work Plan
Washington Gas East Station Site

Legend
- CSOs*
- Storm Sewer Outfalls*

* Locations approximate based on information from WNY Background Evaluation

Total Organic Carbon
- <1%
- 1-5%
- 5-10%
- 10-50%
- >50%

0 0.5 1 Miles

AECOM

Path: \\Uswtf1fp001\JOBS\Indl_Service\Project Files\Washington Gas MGP\GIS\MXD\RI_FS_Work_Plan\MXD\ERA\Fig_4_1_TOC.mxd

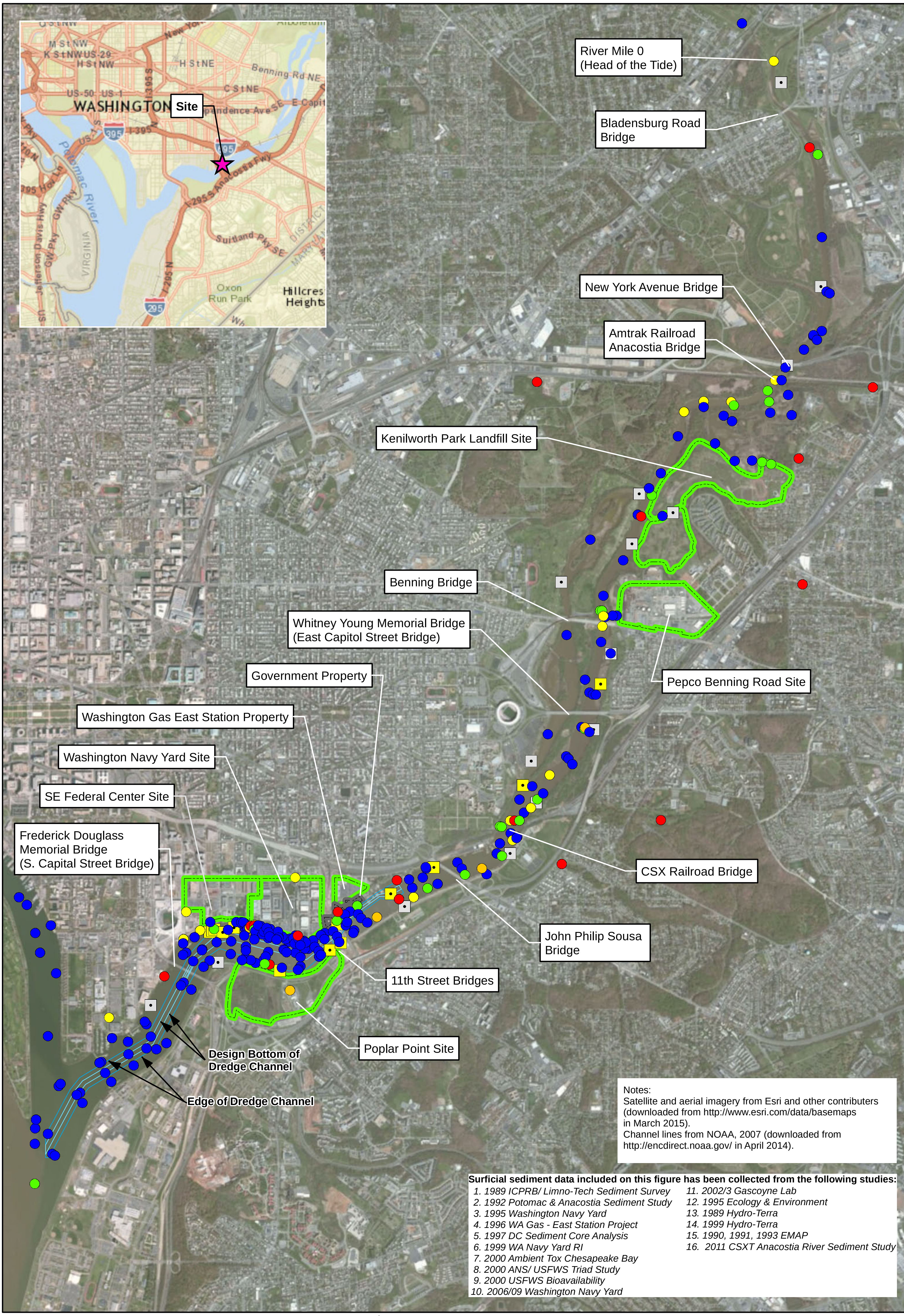


Figure 4-2
Anacostia River Surficial Sediment Grainsize (% Fines)
Operable Unit 2 - Remedial Investigation and Feasibility Study Work Plan
Washington Gas East Station Site

Legend
- CSOs*
- Storm Sewer Outfalls*

* Locations approximate based on information from WNY Background Evaluation

Percent Fines
- <10%
- 10-20%
- 20-30%
- 30-50%
- >50%

0 0.5 1 Miles

AECOM

Path: \\Uswtf1fp001\JOBS\Indl_Service\Project Files\Washington Gas MGP\GIS\MXD\RI_FS_Work_Plan\MXD\ERA\Fig_4_2_PercentFines.mxd

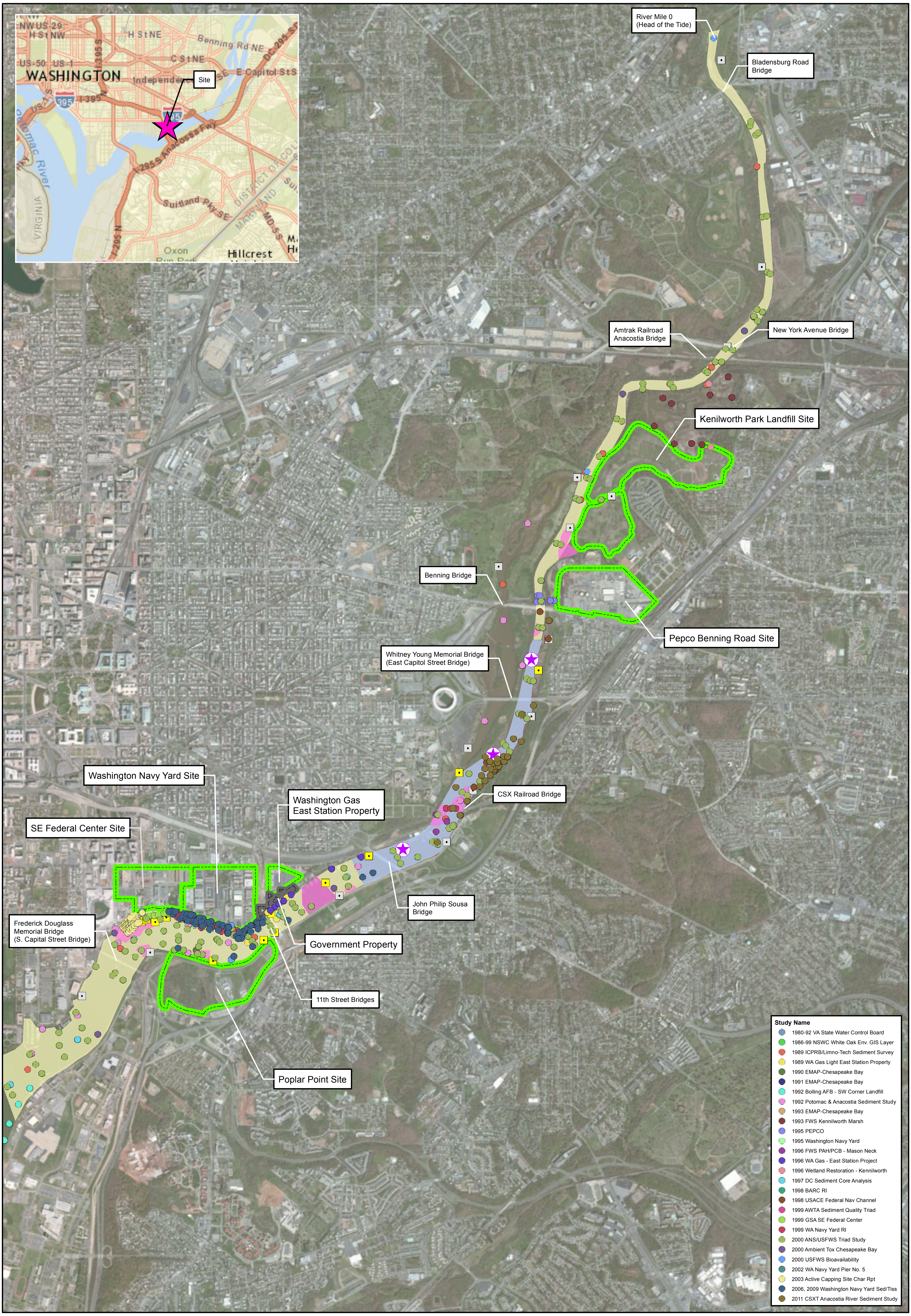


Figure 4-3
Reference Locations for Benthic Toxicity Testing Program
Operable Unit 2 - Remedial Investigation and Feasibility Study Work Plan
Washington Gas East Station Site

- Reference Location
- CSOs*
- Storm Sewer Outfalls*

* Locations approximate based on information from WNY Background Evaluation

- Sediment Area of Concern - as defined by AWTA
- Area Excluded from Background Sediment Evaluation
- Area Proposed to be Included in Background Sediment Evaluation

Notes
Satellite and aerial imagery from Esri other contributers (downloaded from http://www.esri.com/data/basemaps in March 2015).

N

AECOM

0 0.25 0.5 1 Miles

Path: \\Uswtf1fp001\JOBS\Indl_Service\Project Files\Washington Gas MGP\GIS\MXD\RI_FS_Work_Plan\MXD\ERA\Fig_4_3_Reference_Loc_for_Benthic_Toxicity_Testing_Program.mxd

5.0 BERA Work Plan

This section presents the approach for conducting the BERA. The currently available data and the data to be collected by future studies described in the RI/FS Work Plan provide information necessary to evaluate the potential for adverse effects on aquatic receptors in the River impacted by the Site. A description of the proposed sampling program and associated DQOs is presented in the RI/FS Work Plan. The results of the BERA will be used to help inform the need for any remedial action.

5.1 Risk Analysis

The risk analysis phase of the BERA is based on the CSM developed in problem formulation. Risk analysis includes the characterization of potential ecological exposure and effects. The ecological exposure assessment involves the identification of potential exposure pathways and an evaluation of the magnitude of exposure of identified ecological receptors. The ecological effects assessment describes the potential adverse effects associated with the identified COPECs to ecological receptors and reflects the type of assessment endpoints selected. The data and methods that will be used to identify and characterize ecological exposure and effects are described in the following subsections.

5.1.1 Concentration Data Treatment

All analytical data (collected upon Work Plan approval) will be compiled and tabulated in a database for statistical analysis. Data for samples and their duplicates will be averaged before summary statistics are calculated, such that a sample and its duplicate will be treated as one sample for calculation of summary statistics (including maximum detection and frequency of detection). Where both the sample and the duplicate are not detected, the resulting values are the average of the sample-specific quantitation limits (SSQLs). Where both the sample and the duplicate are detected, the resulting values are the average of the detected results. Where one of the pair is reported as not detected and the other is detected, the detected concentration is used. Rejected (R-qualified) data will not be used in the BERA.

USEPA's ProUCL Version 5.0 software (or the most currently available version, available from http://www.epa.gov/osp/hstl/tsc/software.htm, Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations) will be used to perform comparisons of concentrations of COPECs measured at the Site with those measured at reference locations and reported in background data.

5.1.2 Benthic Macroinvertebrate Community Risk Analysis

The protection and maintenance of freshwater benthic invertebrate communities in the River impacted by the Site is one of the assessment endpoints identified in Section 2.4. As indicated in Section 3.1, several measures of effect will be used to evaluate the assessment endpoint developed for the benthic invertebrates. To assess potential risks to these receptors, sediment,surficial porewater, and surface water will be evaluated as well as benthic invertebrate community data as described in the following subsections.

5.1.2.1 Surficial Sediment Benchmark Screening

Twenty-two surficial sediment samples will be collected from the River at the Site to characterize sediments. In addition, three reference samples will also be collected to help place conditions in the River at the Site into regional context within the urbanized River corridor. All surficial sediment samples will be analyzed as described in the body of the RI/FS Work Plan for phenolics, PAHs, arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, cyanide, BTEX, TOC, and grain size. Samples used in laboratory toxicity testing (see Section 5.1.2.3 below) will also be analyzed for alkyl PAHs, SEM, and AVS.

Potential risks to benthic invertebrates from exposure to potential COPECs in sediment will first be evaluated by comparing maximum concentrations for samples collected from the River at the Site to screening benchmarks for sediment, as provided in *The NPS Protocol for the Selection and Use of Ecological Screening Values for Non-Radiological Analytes* (NPS 2014). The outcome of this initial benchmark screening will be a refined list of COPECs.

5.1.2.2 Surficial Sediment COPEC HQ Evaluation

COPECs that have been selected as a result of the benchmark screening described above will then be evaluated as follows:

For each sediment sample, concentrations for the COPECs will then be compared to available threshold effect and probable effect levels (Table 5-1) selected using a hierarchy of the following sources:

- USEPA Region 3 Freshwater Sediment Screening Benchmarks (USEPA, 2006b);
- Freshwater sediment values presented by the National Oceanic and Atmospheric Administration (NOAA) in Screening Quick Reference Tables (SQUIRT) (Buchman, 2008);
- MacDonald et al. (2000) Consensus-Based Sediment Quality Guidelines;
- USEPA Region 5 Ecological Screening Levels for sediment (USEPA, 2003a); and
- Ontario Ministry of the Environment (OMOE) Provincial Sediment Quality Guidelines (Persaud et al., 1993).

Evaluating the distribution of HQ values allows for an assessment of the frequency and magnitude of HQ values above 1, as well as a comparison of the distribution of HQ values in Site areas to appropriate background or reference areas. Additionally, the use of two effect levels (i.e., threshold and probable effect levels) provides a range of potential risks in this urban environment.

5.1.2.3 Laboratory Toxicity Testing

In addition to comparison of bulk sediment concentration data to threshold and probable effect levels, the sediment will be subject to an evaluation of Site-specific factors that better represent a true indication of potential risk in the environment. In particular, the risk analysis of the BERA will focus on the potential bioavailability of the COPECs in the sediment. As described below, the BERA will include laboratory toxicity testing to provide a direct measure of the potential bioavailability and toxicity of COPECs in sediment, as well as analysis of SEM/AVS. Factors such as organic carbon will be used to better determine the potential bioavailability of organic COPECs in sediment. Surficial porewater analysis will allow for a more direct measure of potentially bioavailable COPECs in sediment.

Laboratory toxicity tests will be used to help determine if exposure to surficial sediments impacted by the Site pose a potential risk to benthic invertebrates. Laboratory toxicity tests will be performed to evaluate the impacts of COPECs to benthic invertebrate receptors, represented by *Chironomus dilutus* (midge) and the amphipod (*Hyalella azteca*). All toxicity tests will be conducted under specified laboratory conditions using whole environmental media.

The *Chironomus* test will be implemented in accordance with the short–term test described by USEPA (2000; Method 100.2).The sediment toxicity test begins with eight replicates per sample, each containing 10 second to third instar larvae. On Day 10, the test is terminated and data collected for survival and growth (ash free dry weight [AFDW]) measurements. Test endpoints include survival and growth. Laboratory control organisms must meet the following test acceptability criteria: mean control survival must be ≥70% with minimum mean weight/ surviving control organism of 0.48 mg AFDW.

The *Hyalella* test will be implemented in accordance with the short–term test described by USEPA (2000; Method 100.1).The sediment toxicity test begins with eight replicates per sample, each containing 10 seven to ten day old larvae (one to two day range in age for all organisms). On Day 10, the test is terminated and data collected for survival and growth measurements. Test endpoints include survival and growth. Laboratory control organisms must meet the following test acceptability criteria: mean control survival must be ≥80% with measurable growth of test organisms in the control sediment.

Sediment samples collected for laboratory toxicity testing will be co-located in time and space with sediment chemistry samples, and will permit a detailed evaluation of the co-occurring data in existing data sets. In the field, adequate surficial sediment will be collected from each location (i.e., all 22 surficial sediment sampling locations) to conduct sediment chemical analysis, laboratory toxicity testing, and porewater analysis. Subsamples of sediment will be collected for toxicity testing from all locations and will be shipped to the toxicity testing laboratory, where they will be held cold (4°C), in the dark and under appropriate chain of custody.

Chemical analysis of all 22 surficial sediment samples will be conducted on a rapid turnaround (see RI/FS Work Plan). Once preliminary chemical analysis of the sediments has been received from the analytical laboratories, the data will be reviewed. Sediment samples for the toxicity tests will be selected from a minimum of 7 (up to 10) locations in the River at the Site. The selection of samples will encompass a range of concentration of Site-related contaminants, and will be designed to provide both spatial coverage of the River at the Site and a concentration range so that concentration response data are available from the toxicity tests. In addition to these 7 to10 Site samples, the 3 pre-determined upstream reference locations will be included in the laboratory toxicity testing program.

Standardized statistical tests, such as analysis of variance (ANOVA) will be conducted to determine if significant differences in survival or growth are observed. The ANOVA will evaluate potential differences of the toxicity testing results between samples collected from the River at the Site, samples from the reference stations, and laboratory control samples as recommended in EPA (2000). Comparison against test acceptability criteria will also be considered to provide context to the test results. The toxicity results will be evaluated in the context of measured concentrations of target chemicals to develop potential associations between observed toxicity and chemical concentrations.

5.1.2.4 Surficial Porewater

Sediment for surficial porewater analysis will be collected from all surficial sediment stations and held under appropriate conditions until bulk sediment data have been reviewed and locations have been selected for laboratory toxicity testing. Surficial porewater will be analyzed from the same locations selected for toxicity testing (i.e., 7 to 10 samples from at the Site and 3 reference locations). Porewater analysis will include phenolics, PAHs, alkyl PAHs, dissolved inorganic COPEC, dissolved SEM metals (copper, nickel and zinc), and cyanide. Surficial porewater provides a direct measure of the bioavailable fraction of COPECs in sediment. The surficial porewater data will be used in conjunction with the whole sediment concentration data to evaluate potential COPEC risk drivers

The theory of equilibrium partitioning (EqP) has been the basis for the study of toxicity of sediment for decades, and has been the basis for sediment guidelines since the early 1990s (USEPA, 1993; 2005). EqP theory states that certain chemicals, such as those associated with MG wastes, may be present in sediment but partitioned to binding factors, such as organic carbon. As the science has developed for organic chemicals, binding factors other than a direct measure of total organic carbon have been identified. These other binding factors, such as black carbon, are often found in urban environments such as the Anacostia River, and may produce site-specific partitioning factors much higher than levels commonly used in EqP theory. The surficial porewater samples collected will be used with sediment chemistry to estimate site-specific partitioning factors, allowing an estimation of surficial porewater concentrations throughout the study area.

Methods outlined by USEPA in the 2009 White Paper "*Evaluating Ecological Risk to Invertebrate Receptors from PAHs in Sediments at Hazardous Waste Sites*" (USEPA, 2009) will be used in the BERA evaluation to assess the potential for risks to benthic invertebrates associated with PAHs. This USEPA publication provides a conceptual model for applying various sediment approaches in a tiered system to determine potential risks from sediment PAH exposure. These include evaluating bulk sediment PAH concentrations against an appropriate sediment screening value, comparing EqP derived surficial porewater concentrations to ambient water quality criteria, and comparing directly-analyzed surficial porewater data against ambient water quality criteria. This evaluation will include, as appropriate, parent and alkyl PAHs.

The surficial porewater data, sediment data and estimated site-specific partitioning factors, will be used to estimate toxic units (TUs) in a PAH narcosis model (USEPA, 2003b). PAHs are generally considered to be Type I narcotic chemicals (i.e., those chemicals exhibiting narcosis as a mode of action; a non-specific mode of action whereby the organisms exhibit a state of arrested activity [Bradbury, et al., 1989]). The narcosis theory relies on the additivity of the toxicity of the group of chemicals. The bioavailable concentration of each of the PAH compounds, either measured in surficial porewater or predicted using EqP, from each sample is converted to a toxic unit by dividing the concentration by the effects threshold. The sum of the toxic units is then used to predict toxicity. For the benthic invertebrate assessment, the effects threshold is the final chronic value (FCV) presented in USEPA (2003b). If the sum of toxic units exceeds one, benthic toxicity may occur (USEPA, 2003b).

5.1.2.5 SEM/AVS Evaluation

To account for the potential for divalent metals bioavailability to be limited in the sediment of the River at the Site, SEM, AVS, and TOC will be measured in sediments collected as part of the proposed field effort. SEM metals include three metals (copper, nickel, and zinc) that are not on the list of preliminary COPECs. To evaluate the potential toxicity of the preliminary COPECs cadmium, lead, and silver in the sediments of the toxicity tests, all SEM metals need to be included in the analysis.

The SEM/AVS analysis will be conducted on sub-samples collected from the toxicity testing locations (i.e., 7 to 10 samples from at the Site and 3 reference locations). USEPA (2005) guidance on metals bioavailability evaluates possible binding of metals by both AVS and organic matter. Therefore, data collected as part of the proposed field program will be evaluated on a sample-by-sample basis using the following scale to evaluate whether or not the organic carbon binding phase (represented as fraction organic carbon or f_{oc}), in conjunction with the AVS, is affecting the bioavailability of divalent metals in sediments:

- If the (∑SEM-AVS)/f_{oc} excess exceeds 3,000 µmol/gram of organic carbon (g_{oc}), the sediments are presumed to be "likely to be toxic";
- If the (∑SEM-AVS)/f_{oc} excess is between 130 and 3,000 µmol/g_{oc}, predictions of effects are uncertain; and
- If the (∑SEM-AVS)/f_{oc} excess is less than 130 µmol/g_{oc}, the sediments are presumed to "not likely" be toxic.

5.1.2.6 Surface Water Benchmark Screening

Ten surface water samples from the River at the Site and three reference samples will be collected and analyzed, as described in the body of the RI/FS Work Plan, for phenolics, PAHs, arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, cyanide, and BTEX. Potential risks to all invertebrates (benthic invertebrates and aquatic invertebrates) from exposure to potential COPECs in surface water will first be evaluated by comparing maximum concentrations to screening benchmarks for water, as provided by *The NPS Protocol for the Selection and Use of Ecological Screening Values for Non-Radiological Analytes* (NPS 2014). The outcome of this screening will be a refined list of COPECs for inverterates.

5.1.2.7 Surface Water COPEC HQ Evaluation

COPECs that have been selected as a result of the benchmark screening described above will then be evaluated as follows:

For each surface water sample, concentrations of COPECs will be compared to acute and chronic toxicity values (NPS 2014). Evaluating the distribution of values allows an assessment of the frequency and magnitude of HQ values above 1, as well as a comparison of the distribution of HQ values in Site areas to appropriate background or reference areas.

For those COPECs where the distribution of HQs indicates potentially unacceptable risks for invertebrates, the BERA may include a refined HQ assessment, in which the toxicity values are refined to be protective of benthic invertebrates and specific to Site invertebrates to the extent possible. At a minimum, the following surface water screening level sources (Table 5-2) will be used to evaluate exposure to surface water:

- DOEE Water Quality Standards (WQS) for the protection of freshwater aquatic life (DDOE, 2013);
- USEPA Region 3 Freshwater Screening Benchmarks (USEPA, 2006a); and
- Literature-based toxicological benchmarks (Suter and Tsao, 1996 and Buchman, 2008).

5.1.2.8 Benthic Invertebrate Community Evaluation

The benthic invertebrate community data will be interpreted by combining a number of alternative metrics of the benthic community status to yield a biological condition score (BCS) (Plafkin et al. 1989, Barbour et al. 1999). The BCS values from Site locations will be compared to BCS values for reference stations and a biological condition category will be assigned to each sampling location.

5.1.3 Aquatic Invertebrate Community Risk Analysis

The protection and maintenance of the aquatic invertebrate community in the River at the Site is one of the assessment endpoints identified in Section 2.4. As indicated in Section 3.1, one measure of effect will be used to evaluate the assessment endpoint developed for the aquatic invertebrate community. To assess potential risks to these receptors, surface water will be evaluated as described in the following subsections.

5.1.3.1 Surface Water Benchmark Screening

As described above, ten surface water samples from the River at the Site and three reference samples will be collected and analyzed, as described in the body of the RI/FS Work Plan, for phenolics, PAHs, arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, cyanide, and BTEX. Potential risks to all invertebrates from exposure to potential COPECs in surface water will first be evaluated by comparing maximum concentrations to screening benchmarks for water, as provided by *The NPS Protocol for the Selection and Use of Ecological Screening Values for Non-Radiological Analytes* (NPS 2014). The outcome of this screening will be a refined list of COPECs for invertebrates.

5.1.3.2 Surface Water COPEC HQ Evaluation

COPECs that have been selected as a result of the benchmark screening described above will then be evaluated as follows:

For each surface water sample, concentrations of COPECs will be compared to acute and chronic toxicity values (NPS 2014). Evaluating the distribution of values allows an assessment of the frequency and magnitude of HQ values above 1, as well as a comparison of the distribution of HQ values in Site areas to appropriate background or reference areas.

For those COPECs where the distribution of HQs indicates potentially unacceptable risks, the BERA may include a refined HQ assessment, in which the toxicity values are refined to be protective of aquatic invertebrates and specific to Site invertebrates to the extent possible. At a minimum, the following surface water screening level sources (Table 5-2) will be used to evaluate exposure to surface water:

- DOEE Water Quality Standards (WQS) for the protection of freshwater aquatic life (DDOE, 2013);
- USEPA Region 3 Freshwater Screening Benchmarks (USEPA, 2006a); and
- Literature-based toxicological benchmarks (Suter and Tsao, 1996 and Buchman, 2008).

5.1.4 Fish Community Risk Analysis

The protection and maintenance of the fish community in the River impacted by the Site is one of the assessment endpoints identified in Section 2.4. As indicated in Section 3.1, several measures of effect will be used to evaluate the assessment endpoint developed for the fish community. To assess potential risks to these receptors, surface water and surficial porewater will be evaluated as described in the following subsections.

5.1.4.1 Surface Water Benchmark Screening

Ten surface water samples from the River at the Site and three reference samples will be collected and analyzed, as described in the body of the RI/FS Work Plan, for phenolics, PAHs, arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, cyanide, and BTEX. Potential risks to fish from exposure to potential COPECs in surface water will first be evaluated by comparing maximum concentrations to screening benchmarks for water, as provided by *The NPS Protocol for the Selection and Use of Ecological Screening Values for Non-Radiological Analytes* (NPS 2014). The outcome of this screening will be a refined list of COPECs.

5.1.4.2 Surface Water COPEC HQ Evaluation

COPECs that have been selected as a result of the benchmark screening described above will then be evaluated as follows:

For each surface water sample, concentrations of COPECs will be compared to acute and chronic toxicity values (NPS 2014) . Evaluating the distribution of values allows an assessment of the frequency and magnitude of HQ values above 1, as well as a comparison of the distribution of HQ values in Site areas to appropriate background or reference areas.

For those COPECs where the distribution of HQs indicates potentially unacceptable risks, the BERA may include a refined HQ assessment, in which the toxicity values are refined to be protective of finfish (and aquatic and benthic invertebrates) and specific to Site fish and invertebrates to the extent possible. At a minimum, the following surface water screening level sources (Table 5-2) will be used to evaluate exposure to surface water:

- DOEE Water Quality Standards (WQS) for the protection of freshwater aquatic life (DDOE, 2013);
- USEPA Region 3 Freshwater Screening Benchmarks (USEPA, 2006a); and
- Literature-based toxicological benchmarks (Suter and Tsao, 1996 and Buchman, 2008).

Surface water PAH concentrations will also be considered relative to the fish tissue narcosis model (DiToro et al., 2000) described below for surficial porewater.

5.1.4.3 Surficial Sediment Porewater

As described in Section 4.1.2.3, surficial sediment porewater samples will be analyzed for phenolics, PAHs, alkyl PAHs, dissolved inorganic COPEC, dissolved SEM metals (copper, nickel and zinc), BTEX, and cyanide at up to 10 locations in the River at the Site and 3 reference locations. For bottom-dwelling finfish, such as brown bullhead, there is a potential for indirect exposure to COPECs in surficial porewater, which, as described above, represents the bioavailable fraction of COPECs in surficial sediment. The surficial porewater data will be used to help decipher linkages between any observed toxicity in the laboratory toxicity testing program and the Site-related COPECs. The surficial porewater represents the bioavailable fraction of these COPECs and is a better estimate of exposure than bulk sediment to establish any causal link between Site-related COPECs and any toxicity.

Surficial porewater preliminary COPECs will be evaluated relative to surface water screening levels in a similar fashion as described in Section 5.1.3.1 and 5.1.3.2. While this evaluation is overly-conservative (fish do not dwell in interstitial pore water and surface water dilution ultimately needs to be considered), it can be used to help identify areas where further evaluation may be warranted.

For further evaluation of potential PAH toxicity to bottom-dwelling fish, surficial porewater PAH data will be compared against specific water quality benchmarks developed using the narcosis model. The methods for development of a water quality criterion for PAHs presented by DiToro et al. (2000) will be followed. This method uses median lethal concentration (LC_{50}) values for body burden to determine a final acute value (FAV) with 95^{th} percentile level of protection. LC50 values will be obtained from the narcosis database (USEPA, 2003) or calculated per DiToro et al. (2000) using Site-specific partitioning coefficients. This method is similar to the narcosis model or target lipid model for evaluation of narcotic chemicals in sediments. The endpoint of the screening benchmark will based on the toxicity of fish due to accumulation of PAHs in the lipid, here assumed to be the liver, the site of PAH accumulation in fish and most common site of tumors linked to PAH exposure.

In addition, the literature will be reviewed to determine if any sources can be identified establishing linkage between surficial porewater PAH concentrations and development of internal and external tumors and lesions in finfish. This endpoint is specific to address studies that have been conducted on the Anacostia River and adjacent waterways by the USFWS (Pinkney et al., 2002; Pinkney et al., 2004).

5.2 BERA Risk Characterization

The results of the ecological risk analysis will be analyzed and interpreted to determine the likelihood of adverse environmental effects, and to determine whether a conclusion of no significant risk can be reached for each assessment endpoint evaluated. The ecological risk characterization will summarize the results of the risk analysis phase of work and will provide interpretation of the ecologically significant findings. Aspects of ecological significance that will be considered to help place the Site impacts to the River into a broader ecological context include the nature and magnitude of effects, the spatial and temporal patterns of effects, and the potential for recovery once a stressor has been removed.

Several lines of evidence will be used to determine Site-related risks. The levels of COPECs measured in media collected from the Site will be put into the context of bioavailability, linkage to the Site, and potential upgradient or background sources of contamination that may be impacting the River or contributing to overall risk.

An evaluation of available literature data on the occurrence of tumors in bottom-dwelling fish throughout the Chesapeake Bay region will be further conducted. Studies have been conducted that indicate high occurrence of liver and skin tumors in catfish in the Anacostia and other rivers in the area. The home range of catfish is relatively small, and comparing literature-reported rates of tumors in fish from the River at the Site to those from upstream areas or other regional reference areas may provide an indication of any linkage of Site contamination to fish tumors.

The estimation of ecological risks involves a number of assumptions. A primary component of any risk assessment is an estimate or discussion of the uncertainty associated with these assumptions. The BERA for the River at the Site will include examination of uncertainty related to the site-specific risk evaluations, and an analysis of uncertainties.

5.2.1 Weight-Of-Evidence

The documentation of the risk characterization will include a summary of assumptions, uncertainties (both generic and site-specific), strengths and weaknesses of the analysis phase of work, and justification of conclusions regarding the ecological significance of the estimated (i.e., risk of harm) or actual (i.e., evidence of harm) risks.

Results from each measure of effect will be evaluated to determine whether or not they support a finding of no significant risk for each assessment endpoint. A useful tool for this sort of evaluation was developed by Menzie et al. (1996). This publication recommends the use of 10 qualitative criteria for weighting ERA measurement endpoints. These criteria, which are summarized below, can be grouped into three broad categories and will be considered in the risk characterization. The weight-of-evidence evaluation will be qualitative in nature; numeric values will not be assigned to each of the criteria listed below. Rather, these criteria will be used to help frame the considerations of the weight-of-evidence.

1) Strength of Association between Assessment and Measurement Endpoint

- "Biological relationship between the measurement and assessment endpoint refers to the correlation/applicability of the measurement endpoint with respect to the assessment endpoint."
- "Correlation of stressor to response relates to the ability of the endpoint to demonstrate effects from exposure to the stressor, and the ability to correlate the magnitude of the effect(s) with the degree of exposure."
- "Sensitivity of the measurement endpoint for detecting changes in the assessment endpoint means the ability of the measurement endpoint to detect changes in the assessment endpoint caused by the stressor."
- "Utility of the measure for judging environmental harm is the ability to judge results of the study against well-accepted standards, criteria, or objective measures."

2) Data Quality

- "Extent to which data quality objectives are met refers to the degree to which data quality objectives are designated that are comprehensive and rigorous, as well as to the extent that they are met."

3) Study Design and Execution

- "Site specificity refers to the representativeness of the data, media, species, environmental conditions, and habitat types that are used in the measurement endpoint relative to those present at the site"
- "Temporal and spatial representativeness are important factors in evaluating the appropriateness of the study design"
- "Use of a standard method refers to the extent to which the study follows specific protocols recommended by a recognized scientific authority for conducting the method correctly"
- "Sensitivity of the measurement refers to the ability to detect a response in the measurement endpoint"
- "Quantitativeness relates to the degree to which numbers can be used to describe the magnitude of the response of the measurement endpoint to the stressor."

5.2.2 Evaluation of Urban Condition

The BERA risk characterization will help place the Site impacts to the River into context within the urbanized Anacostia River environment, and the potential risks associated with Site-related contaminants will be evaluated in the context of other sources of contamination in the River. Consistent with the USEPA (2002c) policy statement on the use and definition of background at CERCLA sites, the naturally-occurring and anthropogenic background levels of COPECs will not be eliminated from the BERA. Background concentrations will be introduced in the risk characterization section of the BERA to provide information on the contribution of background to concentrations in the River at the Site.

To accomplish this, the risk characterization will include an estimation of incremental risk (IR) by comparing the potential Site risks to regional and Site-specific reference locations in this highly impacted system. IRs are the difference between risk from the River at the Site (as an HQ) and River reference risk. IRs greater than 0 may be considered directly related to the Site, and not attributable to background conditions. This will allow clear communication of overall risk, and the potential risks from the Site versus background risk, to the risk managers and the public for consideration in risk management decisions.

The data from reference locations will be evaluated in this same context. Data for sediments, surface water, surficial sediment porewater, and benthic invertebrate communities from Site locations will be evaluated by comparing the results of these samples to the upstream reference data. Using upstream reference conditions allows the Site results to be put into context of stressors that may be present throughout the River, and not linked specifically to Site-related impacts to the River.

5.2.3 BERA Uncertainty

The estimation of ecological risks involves a number of assumptions. A primary component of any risk assessment is an estimate or discussion of the uncertainty associated with these assumptions. The BERA for the Site will include examination of uncertainty related to the site-specific risk evaluations, and an analysis of the uncertainties that potentially affect all sites.

All discussions of uncertainty will include examination and review of several aspects of the BERA including, but not limited to, sampling, data quality, study design, selection of indicator species, estimates of exposure, selection of ecological benchmarks and screening values, pathways not evaluated, and the combined effects of multiple chemicals. The sampling scheme, ecological endpoints, and study design have been developed to conduct the BERA. However, a number of assumptions will still be made. The uncertainty section of the BERA will identify these assumptions and will relate them to the potential effects these uncertainties may have on the overall conclusions of the BERA.

As part of the uncertainty evaluation, potential future risks from exposure to sediments that are currently deeper than current exposure depth (i.e., deeper than 0.5 ft) will be conducted. Deeper sediments may be exposed from dredging activities, propeller wash, or storms. The concentrations of Site-related COPECs in deeper sediments will be compared to those in the surficial sediments.

Although it is not practical to account for all sources of uncertainty, it is important to identify and address the major elements of uncertainty in the risk evaluation and assessment. Some uncertainties bias the results of the risk assessment towards excessive risk, while others bias towards no significant risk. Once identified, the uncertainties will be classified by this bias, and the overall effects on the risk assessment will be reflected in the conclusions.

Table 5-1

Sediment Screening Values

Operable Unit 2 - Remedial Investigation and Feasibility Study Work Plan

Washington Gas East Station Site

Chemical	NPS ESV for COPEC Selection (a)	NPS Threshold Effects ESV		NPS Probable Effects ESV	
PAHs					
Acenaphthene	4.91	4.91		NA	
Acenaphthylene	4.52	4.52		NA	
Anthracene	0.01	0.0572		0.845	
Benz(a)anthracene	0.015	0.108		1.05	
Benzo(a)pyrene	0.032	0.15		1.45	
Benzo(b)fluoranthene	9.79	9.79		NA	
Benzo(k)fluoranthene	9.81	9.81		NA	
Chrysene	0.026	0.166		1.29	
Dibenz(a,h)anthracene	NA	0.033		NA	
Benzo(g,h,i)perylene	0.016	0.016		0.252	
Fluoranthene	0.031	0.423		2.23	
Fluorene	0.01	0.0774		0.536	
Indeno(1,2,3-cd)pyrene	0.017	0.017		0.24	
Naphthalene	0.014	0.176		0.561	
Phenanthrene	0.019	0.204		1.17	
Pyrene	0.044	0.195		1.52	
2-Methylnapththalene	4.47	4.47		NA	
Total HMW PAHs	0.193	0.193		2.34	
Total LMW PAHs	0.076	0.076		1.18	
Total PAHs	NA	NA		NA	
Phenolics					
Phenol	0.0012	0.0012		NA	
2-Methylphenol	0.012	0.012		NA	
4-Methylphenol	NA	NA		NA	
2,4-Dimethylphenol	NA	NA		NA	
Coal-tar Related VOCs					
Benzene	0.08	0.08	(b)	NA	
Ethylbenzene	0.026	0.026	(b)	NA	
Toluene	0.0036	0.0036	(b)	NA	
Total Xylenes	226	226	(b)	NA	
Cyanide					
Total	NA	NA		NA	
Free	NA	NA		NA	
RCRA Metals					
Arsenic	9.79	9.79		33	
Barium	NA	NA		NA	
Cadmium	0.583	0.99		4.98	
Chromium	36.2	43.4	(c)	111	(c)
Lead	35.8	35.8		128	
Mercury	0.18	0.18		1.06	
Selenium	NA	NA		NA	
Silver	NA	0.73	(d)	1.77	(d)

Table 5-1

Sediment Screening Values

Operable Unit 2 - Remedial Investigation and Feasibility Study Work Plan

Washington Gas East Station Site

Table 5-1 Notes:

All screening values reported in milligrams per kilogram (mg/kg) unless otherwise indicated.

FW - Freshwater.

HMW - High Molecular Weight.

LMW - Low Molecular Weight.

NA - Not available/applicable.

PAH - Polycyclic Aromatic Hydrocarbon.

TOC - Total Organic Carbon

COPEC - Contaminant of potential ecological concern.

(a) NPS ESVs are provided to support the risk assessment effort. It is understood that they may or may not be used for COPC selection, depending on the assumptions the risk assessors make with respect to the Screening Level Ecological Risk Assessment

(b) Derived using equilibrium partitioning assuming 1% TOC

(c) Total chromium

(d) Marine value used; no freshwater ESV available.

SOURCES

NPS ESV = National Park Service Ecological Screening Values (NPS, 2014)

Table 5-2
Surface Water Screening Values
Operable Unit 2 - Remedial Investigation and Feasibility Study Work Plan
Washington Gas East Station Site

Chemical	NPS ESV for COPEC Selection (a)	Chronic				Acute			
		DDOE WQS		NPS ESV		DDOE WQS		NPS ESV	
PAHs									
Acenaphthene	5.8	50		5.8	(b)	NA		NA	
Acenaphthylene	NA	NA		NA		NA		NA	
Anthracene	0.012	NA		0.73	(b)	NA		13	(b)
Benz(a)anthracene	0.018	NA		0.027	(b)	NA		0.49	(b)
Benzo(a)pyrene	0.014	NA		0.014	(b)	NA		0.24	(b)
Benzo(b)fluoranthene	NA	NA		NA		NA		NA	
Benzo(k)fluoranthene	NA	NA		NA		NA		NA	
Chrysene	NA	NA		NA		NA		NA	
Dibenz(a,h)anthracene	NA	NA		NA		NA		NA	
Benzo(g,h,i)perylene	NA	NA		NA		NA		NA	
Fluoranthene	0.04	400		0.04	(b)	NA		NA	
Fluorene	3	NA		3.9	(b)	NA		70	(b)
Indeno(1,2,3-cd)pyrene	NA	NA		NA		NA		NA	
Naphthalene	1.1	600		12		NA		190	(b)
Phenanthrene	0.4	NA		0.4	(b)	NA		NA	
Pyrene	0.025	NA		0.025	(b)	NA		NA	
2-Methylnapththalene	NA	NA		NA		NA		NA	
Total HMW PAHs	NA	NA		NA		NA		NA	
Total LMW PAHs	NA	NA		NA		NA		NA	
Total PAHs	NA	NA		NA		NA		NA	
Phenolics									
Phenol	4	NA		4	(b)	NA		NA	
2-Methylphenol	13	NA		13	(b)	NA		230	(b)
4-Methylphenol	NA	NA		NA		NA		NA	
2,4-Dimethylphenol	NA	200		NA		NA		NA	
Coal-tar Related VOCs									
Benzene	130	1000		130	(b)	NA		2300	(b)
Ethylbenzene	7.3	40		7.3	(b)	NA		130	(b)
Toluene	2	600		9.8	(b)	NA		120	(b)
Total Xylenes	62308	NA		62308	(b)	NA		NA	
Cyanide									
Total	NA	NA		NA		NA		NA	
Free	5	5.2		5.2		22		22	
RCRA Metals									
Arsenic	3.1	150		150		340		340	
Barium	4	NA		4		NA		110	
Cadmium	0.018	0.25	(c)	0.13	(d)	2.01	(c)	0.83	(d)
Chromium, trivalent	8.9	74	(c)	35	(d)	570	(c)	269	(d)
Chromium, hexavalent	1	11		11		16		16	
Lead	0.92	2.5	(c)	0.9	(d)	64.6	(c)	24	(d)
Mercury	0.026	0.77	(b)	0.65		1.4	(b)	1.19	
Selenium	1	5	(b)	5	(b)	20	(b)	NA	
Silver	0.067	NA		0.067	(d)	3.22	(c)	0.67	(d)

Table 5-2
Surface Water Screening Values
Operable Unit 2 - Remedial Investigation and Feasibility Study Work Plan
Washington Gas East Station Site

Table 5-2 Notes:
All screening values reported in micrograms per liter (ug/L). All values are for dissolved phase unless otherwise indicated.
DDOE WQS - District of Columbia Department of Environment Water Quality Standards
HMW - High Molecular Weight.
LMW - Low Molecular Weight.
NA - Not available/applicable.
PAH - Polycyclic Aromatic Hydrocarbon.
VOCs - Volatile Organic Compounds.
COPEC - Contaminant of potential ecological concern.

(a) NPS ESVs are provided to support the risk assessment effort. It is understood that they may or may not be used for COPC selection, depending on the assumptions the risk assessors make with respect to the Screening Level Ecological Risk Assessment
(b) Value is total concentration.
(c) Value is hardness dependent; a value of 100 mg/L is $CaCO_3$ assumed.
(d) Value assumes 40 mg/L hardness (default in ESVs)

SOURCES
DDOE WQS = District of Columbia Department of Environment Water Quality Standards for the protection of freshwater aquatic life (DDOE, 2013)
NPS ESV = National Park Service Ecological Screening Values (NPS, 2014)

6.0 References

AECOM Environment. 2011 - Draft Five-Year Review of Remedial Action, Washington Gas East Station Site. April 2011.

Albers, P. H., 1995. Petroleum and individual polycyclic aromatic hydrocarbons, p. 330-355. In D. J. Hoffman, B. A. Rattner, G. A. Burton Jr. and J. Cairns Jr. [eds.], Handbook of Ecotoxicology. Lewis Publishers.

AWRP. 2010. Anacostia River Watershed Restoration Plan and Report. Final Draft. Anacostia River Watershed Restoration Partnership. February 2010.

AWTA. 2002. Charting a Course Toward Restoration: A Toxic Chemical Management Strategy for the Anacostia River.

Barbour M.T., Gerritsen J., Snyder B.D., Stribling J.B. 1999. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish. Second Edition.* EPA/841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Baumann, P.C., and J.C. Harshbarger. 1998. Long term trends in liver neoplasm epizootics of brown bullhead in the Black River, Ohio. Environmental Monitoring and Assessment. 53:213-223.

Bradbury, S., R. Carlson, T. Henry. 1989. Polar narcosis in aquatic organisms. Aquat Toxicol Hazard Assess 12: 59-73.

Breton, R.L., R.S. Teed and D.R.J. Moore. An Ecological Risk Assessment of Phenol in the Aquatic Environment. Human and Ecological Risk Assessment: An International Journal. 9(2): 549-568.

Buchman, M.F., 2008. NOAA Screening Quick Reference Tables (SQuiRTs). NOAA OR&R Report 08-1. Seattle WA. Office of Response and Restoration Division National Oceanic and Atmospheric Administration, 34 pages.

Clements, W. H., J. T. Oris, and T. E. Wissing, 1994. Accumulation and food chain transfer of fluoranthene and benzo[a]pyrene in *Chironomus riparius* and *Lepomis macrochirus*. Arch. Environm. Contam. Toxicol. 26: 261-266.

District Department of the Environment (DDOE), now called District Department of Energy and Environment. 2013. Water Quality Standards. Title 21, Chapter 1104.

DDOE. 2011. District of Columbia Risk-Based Corrective Action Technical Guidance (Risk-Based Decision Making). District Department of the Environment. Toxic Substances Division. Underground Storage Tanks Branch. June 2011.

DiToro, D.M. and J.A. McGrath, 2000. Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. II. Mixtures and Sediments. Environ. Toxicol. Chem. 19, 1971–1982.

DiToro, D.M., McGrath, J.A., Hansen, D.J., 2000. Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. I. Water and tissue. Environ. Toxicol. Chem. 19, 1951–1970.

Eisler, R. 2000. Handbook of Chemical Risk Assessment, Health Hazards to Humans, Plants, and Animals – Volume 2: Organics. Lewis Publishers, Boca Raton, FL.

Elder, J.F., and P. V. Dresler. 1988. Accumulation and bioconcentration of polycyclic aromatic hydrocarbons in a nearshore estuarine environment near a Pensacola (Florida) creosote contamination site. Environm. Poll. 49: 117-132.

Environment Canada. 1999. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Phenols. Canadian Council of Ministers of the Environment. 1999.

Foster, G.D. 2008. PCBs and PAHs in the Anacostia River. Presentation at the Anacostia Watershed Toxics Alliance (AWTA) meeting, Washington, DC. October 28, 2008.

Hawkins, W.E., W.W. Walker, R.M. Overstreet, J.C. Lyttle, and T.F. Lyttle. 1990. Carcinogenic Effects of Some Polycyclic Aromatic Hydrocarbons on the Japanese Medaka and Guppy in Waterborne Exposures, Sci. Total Environ., 94: 155-167.

Horness B.H., D.P. Lomax, L.L. Johnson, M.S. Myers, S.M. Pierce, and T.K. Collier. 1998. Sediment quality thresholds: Estimates from hockey stick regression of liver lesion prevalence in English sole (Pleuronectes vetulus). Environ Toxicol Chem 17:872–882

Irwin, R.J., M. VanMouwerik, L. Stevens, M.D. Seese, and W. Basham. 1998. Environmental Contaminants Encyclopedia. National Park Service, Water Resources Division, Fort Collins, Colorado. Available at: http://www.nature.nps.gov/hazardssafety/toxic/list.cfm

Krantzberg, G and D. Boyd, 1992. The Biological Significance of Contaminants in Sediment from Hamilton Harbour, Lake Ontario, Environ. Toxicol. Chem., 11: 1527-1540.

Larsen, P.F., D.F. Gadbois, and A.C. Johnson, 1986. Polycyclic Aromatic Hydrocarbons in the Gulf of Maine Sediments: Distribution and Mode of Transport. Mar. Environ. Res., 4: 231-244.

MacDonald, D.D., C.G. Ingersoll and T.A. Berger. 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ. Contam. Toxicol. 39. 20-31.

McCarty, L. S., and Mackay, D., 1991. Enhancing ecotoxicological modeling and assessment. Environ. Sci. Technol. 27, 1719-1728.

McGee, B.L., A.E. Pinkney, D.J. Velinsky, J.T.F. Ashley, D.J. Fisher, L.C. Ferrington, and T.J. Norbert-King. 2009. Using the Sediment Quality Triad to characterize baseline condition in the Anacostia River, Washington, DC, USA. Environ Monit Assess.156: 51-67.

Menzie, C.A., M. Hope-Henning, J.J. Cura, K. Finklestein, J. Gentile, J. Maughan, D.F. Mitchell, S. Petron, B. Potocki, S. Svirsky, P. Tyler, 1996. Special report of the Massachusetts Weight-of-Evidence Workgroup: A weight-of-evidence approach for evaluating ecological risks. Human and Ecological Risk Assessment 2:277-304.

Metcalfe, C.D., V.W. Cairns, and J.D. Fitzsimons. 1988. Experimental induction of liver tumours in rainbow trout (Salmo gairdneri) by contaminated sediment from Hamilton Harbour, Ontario. Can.J. Fish. Aquat 45:2161-2167.

Metropolitan Washington Council of Governments. 2007. Anacostia River Watershed. Environmental Condition and Restoration Overview. Draft. March 2007.

Murphy, T.P., H. Brouwer, M.E. Fox, E.Nagy, L. McArdle, and A. Moller, 1993. Assessment of the Coal Tar Contamination near Randle Reef, Hamilton Harbour. Lakes Research Branch, National Water Research Institute, Burlington, Ont.

Neff, J.M., 1979. Polycyclic Aromatic Hydrocarbons in the Aquatic Environment. Sources, Fates and Biological Effects. Applied Science Publishers Ltd., Essex, England, 262 p.

NPS, 1997a. Environmental Contaminants Encyclopedia PAHs Entry. National Park Service Water Resources Division, Water Operations Branch. July 1, 1997.

NPS, 1997b. Environmental Contaminants Encyclopedia Entry for BTEX and BTEX Compounds. National Park Service Water Resources Division, Water Operations Branch. July 1, 1997.

NPS, 2014. NPS Protocol for the Selection and Use of Ecological Screening Values for Non-Radiological Analytes – Revision 1. Prepared by National Park Service Environmental Compliance and Response Branch Contaminated Sites Program with technical support from CDM Smith. January 13, 2104.

NRCC (National Research Council of Canada), 1983. Polycyclic Aromatic Hydrocarbons in the Aquatic Environment: Formation, Sources, Fate and Effects on Aquatic Biota. NRC Associate Committee on Scientific Criteria for Environmental Quality, Publication No. NRCC 18981, Ottawa, Ont., 209 p.

Payne, J.F., J. Kiceniuk, L.L. Fancey, U. Williams, G.L. Fletcher, A. Rahimtula, and B. Fowler, 1988. What Is a Safe Level of Polycyclic Aromatic Hydrocarbons for Fish: Subchronic Toxicity Study on Winter Flounder (*Pseudopleuronectes americanus*). Can.J. Fish. Aquat. Sci., 45: 1983-1993.

Persaud, D., R. Jaagumagi, and A. Hayton, 1993. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, Ontario Ministry of the Environment, Queen's Printer for Ontario; 23 pp.

Pinkney, A.E., J.C. Harshbarger, E.B. May, and M.J Melancon. 2001. Tumor prevalence and biomarkers of exposure in Brown Bullheads (*Ameiurus nebulosus*) from the tidal Potomac river, USA, Watershed. Environ Toxicol Chem (20)1196-1205.

Pinkney, A.E., J.C. Harshbarger, E.B. May, and W.L. Reichert. 2002. Tumor prevalence and biomarkers of exposure and response in brown bullheads (*Ameiurus nebulosus*) from the Anacostia River, Washington, D.C. and Tuckahoe River, Maryland. CBFO-C02-07.

Pinkney, A.E., J.C. Harshbarger, E.B. May, and M.J Melancon. 2004. Tumor prevalence and biomarkers of exposure and response in Brown Bullheads (*Ameiurus nebulosus*) from the Anacostia River, Washington, DC and Tuckahoe River, Maryland, USA. Watershed. Environ Toxicol Chem (23)638-647.

Pinkney, A.E., J.C. Harshbarger, and M.A. Rutter. 2013. Temporal and Spatial Patterns in Tumor Prevalence in Brown Bullhead (*Ameiurus nebulosus*) in the Tidal Potomac River Watershed. U.S. Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD. CBFO-C13-02.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C. EPA 440-4-89-001.

Rand, G.M. and S.R. Petrocelli (eds.), 1985. Fundamentals of aquatic toxicology. Hemisphere Publ. Corp., New York.

Stein, John. 2010. Metabolism of PAHs by Teleost Fish - Scientific Findings. Memorandum to Eric Schwaab, Assistant Administrator for Fisheries, National Marine Fisheries Service and John Oliver, Deputy Assistant Administrator for Operations, National Marine Fisheries Service, from John E. Stein, Deputy Director, Northwest Fisheries Science Center, NMFS. [http://noaa.ntis.gov/view.php?pid=NOAA:ocn747099574]

Slooff, W., J.A. Janus, A.J.C.M. Matthijsen, G.K. Montizaan, and J.P.M. Ros (eds.), 1989. Integrated Criteria Document PAHs. National Institute of Public Health and Environmental Protection (RIVM), Buthoven, Netherlands, Report No. 758474011, 199 p.

Suter, G.W. and C.L. Tsao, 1996. Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN ES/ER/TM-96/R2.

Swartz, R.C., Schults, D.W., Ozretich, R.J., Lamberson, J.O., Cole, F.A., DeWhitt, T.H., Redmond, M.S., Ferraro, S.P., 1995. PPAH: A model to predict the toxicity of polynuclear aromatic hydrocarbon mixtures in field-collected sediments. Environ. Toxicol. Chem. 14: 1977–1987.

Syracuse Research Corporation (SRC). 2000. Interpretive summary of existing data relevant to potential contaminants of concern within the Anacostia River watershed. North Syracuse, NY: SRC.

Tannenbaum, L.V., Johnson, M.S., and Bazar, M., 2003. Application of the Hazard Quotient Method in Remedial Decisions: A Comparison of Human and Ecological Risk Assessments. Human and Ecological Risk Assessment, Volume 9 (1): 387-401.

USACE, 2007. Washington Harbor, Washington, DC, Operations and Maintenance Fact Sheet.

USEPA, 1991. Ecological Assessment of Superfund Sites: An Overview. ECO UPDATE. Interim Bulletin Volume 1 Number 2. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9345.0-05I. December 1991.

USEPA, 1992. Developing a Work Scope for Ecological Assessments. ECO UPDATE. Interim Bulletin Volume 1 Number 4. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9345.0-05I. May 1992.

USEPA, 1993. Technical basis for deriving sediment quality criteria for nonionic organic contaminants for the protection of benthic organisms by using equilibrium partitioning. Office of Water; Washington, D.C. EPA/822/R-93/011.

USEPA, 1994a. Using Toxicity Tests in Ecological Risk Assessment. ECO UPDATE. Interim Bulletin Volume 2 Number 1. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9345.0-05I. March 1994.

USEPA, 1994b. Catalogue of Standard Toxicity Tests in Ecological Risk Assessment. ECO UPDATE. Interim Bulletin Volume 2 Number 2. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9345.0-05I. March 1994.

USEPA, 1994c. Field Studies for Ecological Risk Assessment. ECO UPDATE. Interim Bulletin Volume 2 Number 3. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9345.0-05I. March 1994.

USEPA, 1994d. Selecting and Using Reference Information in Superfund Ecological Risk Assessments. ECO UPDATE. Interim Bulletin Volume 2 Number 4. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9345.0-05I. EPA 540-F-94-050. September 1994.

USEPA, 1996a. Ecological Significance and Selection of Candidate Assessment Endpoints. ECO UPDATE. Interim Bulletin Volume 3 Number 1. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9345.0-05I. EPA 540/F-95-037. January 1996.

USEPA, 1996b. Ecotox Thresholds. ECO UPDATE. Interim Bulletin Volume 3 Number 2. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9345.0-05I. EPA 540/F-95-038. January 1996.

USEPA, 1997. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (Interim Final). U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Office of Emergency and Remedial Response. EPA 540/R-97/006. June 1997.

USEPA, 1998. Guidelines for Ecological Risk Assessment. Risk Assessment Forum. U.S. Environmental Protection Agency; Washington, D.C. EPA/630/R-95/002F. April 1998.

USEPA. 2000. Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Freshwater Invertebrates Second Edition. U.S. Environmental Protection Agency, Office of Research and Development, Office of Science and Technology. EPA 600/R-99-064. March 2000.

USEPA, 2001. The Role of Screening-Level Risk Assessments and Refining Contaminants of Concern in Baseline Ecological Risk Assessments. ECO UPDATE. Intermittent Bulletin. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9245.0-14. EPA 540/F-01-014. June 2001.

USEPA. 2002a. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Office of Solid Waste and Emergency Response. OSWER 9355.4-24. December 2002.

USEPA. 2002b. Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites. OSWER Directive 9285.6-10. December 2002.

USEPA. 2002c. Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites. Office of Emergency and Remedial Response. EPA 540-R-01-003. OSWER 9285.7-41. September 2002.

USEPA, 2003a. USEPA Region 5 Ecological Screening Levels. Revision August 2003. Available at: http://www.epa.gov/reg5rcra/ca/edql.htm

USEPA. 2003b. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA/600/R-02/013. Office of Research and Development, US Environmental Protection Agency, Washington, DC. November 2003.

USEPA, 2005. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metals Mixtures (Cadmium, Copper, Lead, Nickel, Silver and Zinc). EPA/600/R-02/011. January 2005.

USEPA, 2006a. EPA Region III BTAG Freshwater Screening Benchmarks. July 2006. http://www.epa.gov/reg3hwmd/risk/eco/btag/sbv/fw/R3_BTAG_FW_Benchmarks_07-06.pdf

USEPA, 2006b. EPA Region III BTAG Freshwater Sediment Screening Benchmarks. August 2006. http://www.epa.gov/reg3hwmd/risk/eco/btag/sbv/fwsed/R3_BTAG_FW_Sediment_Benchmarks_8-06.pdf

USEPA, 2008. ECO Update/Ground Water Forum Issue Paper. Intermittent Bulletin. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Publication 9285.6-17. EPA-540-R-06-072. July 2008.

USEPA 2009. Evaluating Ecological Risk to Invertebrate Receptors from PAHs in Sediments at Hazardous Waste Sites. EPA/600/R-06/162F. ERASC-011F. October 2009

USEPA. 2013a. Manufactured Gas Plants/Coal Tar Sites. Mid-Atlantic Brownfields and Land Revitalization website. http://www.epa.gov/reg3hwmd/bf-lr/regional/industry/manufactured.htm, September 25, 2013.

USEPA. 2013b. ProUCL Version 5.0.00 User Guide. Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations. EPA/600/R-07/041. Office of Research and Development, US Environmental Protection Agency, Washington, DC. September 2013. Available from: http://www.epa.gov/osp/hstl/tsc/ProUCL_v5.0_user.pdf

USEPA. 2013c. ProUCL Version 5.0.00 Technical Guide. Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations. EPA/600/R-07/041. Office of Research and Development, US Environmental Protection Agency, Washington, DC. September 2013. Available from: http://www.epa.gov/osp/hstl/tsc/ProUCL_v5.0_tech.pdf

USGS. 1997. Summary of Published Aquatic-Toxicity Information and Water-Quality Criteria for Selected Volatile Organic Compounds. Open-File Report 97-563.

Vaccaro, C. 2014. Email to Kristen Durocher, AECOM. Request for Information – OU2 Remedial Investigation Work Plan. April 7, 2014.

Van Wezel, A. P., and Opperhuizen, A., 1995. Narcosis due to environmental pollutants in aquatic organisms: Residue-based toxicity, mechanisms, and membrane burdens. Crit. Rev. Toxicol. 25: 255-279.

Vandermeulen, J.H., 1989. PAH and Heavy Metal Pollution of the Sydney Estuary: Summary and Review of Studies to 1987. Canadian Technical Report of Hydrography and Ocean Sciences, No. 108.

Velinsky, D.J. G.F. Riedel, J.T.F. Ashley, J.C. Cornwell, 2011. Historical Contamination of the Anacostia River, Washington DC. Environ. Monit. Assess. 183:307-328.

Windsor, J.G. and R.A. Hites, 1979. Polycyclic Aromatic Hydrocarbons in the Gulf of Maine Sediments and Nova Scotia Soils. Geochem. Cosmochim. Acta., 43:27-33.

Wolska, L., K. Galer, and J. Namiesnik, 2003. Transport and Speciation of PAHs and PCBs in a River Ecosystem. Polish Journal of Environmental Studies, 12(2):105-110.

Zogorski, J.S., Carter, J.M., Ivahnenko, T., Lapham, W.W., Moran, M.J., Rowe, B.L., Squillace, P.J., and Toccalino, P.L., 2006, The quality of our nation's waters--Volatile organic compounds in the nation's ground water and drinking-water supply wells: U.S. Geological Survey Circular 1292, 101 p.