N00174.AR.000538
NSWC INDIAN HEAD
5090.3a

Final

Baseline Ecological Risk Assessment Work Plan
Site 6 (Outside the Fenced Area)

Naval Support Facility, Indian Head
Indian Head, Maryland

Contract Task Order 0094

March 2007

Prepared for

Department of the Navy
Naval Facilities Engineering Command Washington

Under the

LANTDIV CLEAN III Program
Contract N62470-02-D-3052

Prepared by

CH2MHILL

Chantilly, Virginia

Contents

Abbreviations and Acronyms ..... **v**

1 Introduction **1-1**
1.1 Site Background 1-1
1.2 Rationale for a BERA 1-2
1.3 Objective 1-4
1.4 Spatial Distribution of Silver 1-4
1.5 Document Organization 1-5

2 Problem Formulation **2-1**
2.1 Ecotoxicity Profile for Silver 2-1
2.1.1 Terrestrial Toxicity 2-2
2.1.2 Aquatic Toxicity 2-2
2.2 Conceptual Site Model 2-4
2.2.1 Transport and Exposure Pathways 2-4
2.2.2 Assessment Endpoints 2-5
2.2.3 Risk Hypotheses 2-5

3 Step 4—Study Design and Data Quality Objectives **3-1**
3.1 Measurement Endpoints 3-1
3.2 Study Design 3-2
3.2.1 Toxicity Testing 3-2
3.2.2 Site-Specific Bioaccumulation Data 3-4
3.3 Data Quality Objectives 3-4

4 Sampling and Analysis Plan **4-1**
4.1 Field Sampling Plan 4-1
4.1.1 Soil Samples 4-1
4.1.2 Sediment Samples 4-1
4.1.3 Tissue Samples 4-2
4.1.4 Reference Samples 4-2
4.1.5 Sampling Frequency, Quality Assurance/Quailty Control Samples, and Sample Handling 4-2
4.1.6 Survey of Sample Locations 4-3
4.1.7 Decontamination of Sampling Equipment 4-3
4.1.8 Investigation-Derived Waste Handling 4-3
4.1.9 Sample Identification System 4-3
4.2 Quality Assurance Project Plan 4-4
4.3 Health and Safety 4-4
4.4 Data Evaluation and Reporting 4-5

5 References **5-1**

Tables

2-1 Toxicity of Silver Compounds for Representative Aquatic Species

3-1 Measurement Endpoints at Site 6
3-2 Soil Sample Locations for Toxicity Testing
3-3 Sediment Sample Locations for Toxicity Testing

4-1 Sampling and Analyses Summary
4-2 Summary of Required Containers, Preservatives, and Holding Times for Solid Samples
4-3 Summary of Required Containers, Preservatives, and Holding Times for Aqueous (QC) Samples

Figures

1-1 Facility Map
1-2 Silver Detection Within the Fenced Area
1-3 Silver Detection Outside the Fenced Area

2-1 Conceptual Site Model

4-1 Proposed Soil and Sediment Sample Locations

Photographs

Photograph 1-1: View of the forested wetland and pool downstream of the steam line. View is from northwest to southeast.

Photograph 1-2: View of standing water within the forested wetland. View is from north to south.

Photograph 1-3: View of the tidal emergent wetland downstream of the forested wetland. View is from north to south.

Photograph 1-4: View of the tidal emergent wetland at the discharge point into Mattawoman Creek. View is from northwest to southeast.

Abbreviations and Acronyms

ATSDR	Agency for Toxic Substances and Disease Registry
AVS	acid-volatile sulfide
BERA	Baseline Ecological Risk Assessment
CEC	cation exchange capacity
CLEAN	Comprehensive Long-term Environmental Action Navy
CSM	conceptual site model
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
ERA	Ecological Risk Assessment
FSP	Field Sampling Plan
HGL	HydroGeologic
HQ	hazard quotient
IDW	investigation-derived waste
IHIRT	Indian Head Installation Restoration Team
LANTDIV	Naval Facilities Engineering Command, Atlantic Division
LC_{50}	median lethal concentration
LOAEL	lowest observed adverse effect level
MATC	maximum acceptable toxicant concentration
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
µg/L	micrograms per liter
NEESA	Naval Energy and Environmental Support Activities
NOAEL	no observed adverse effect level
NSF-IH	Naval Support Facility, Indian Head
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
QC	quality control
RI	Remedial Investigation
SEM	simultaneously extracted metal
SERA	Screening Ecological Risk Assessment
TAL	target analyte list
TOC	total organic carbon
WHO	World Health Organization

SECTION 1

Introduction

This Baseline Ecological Risk Assessment (BERA) Work Plan for Site 6 (Outside the Fenced Area), located at the Naval Support Facility, Indian Head (NSF-IH), Indian Head, Maryland was prepared under the U.S. Department of the Navy (Navy), Naval Facilities Engineering Command, Atlantic Division (LANTDIV), Comprehensive Long-Term Environmental Action Navy (CLEAN) III Contract N62470-02-D-3052, Contract Task Order 0094.

1.1 Site Background

This section provides a summary of the background information for Site 6. Detailed site background information is provided in Section 1.5.1 of the *Final Remedial Investigation Report for Sites 6, 39, and 45, Naval District Washington, Indian Head, Indian Head, Maryland* [herein referred to as Remedial Investigation (RI) report] (HydroGeoLogic [HGL], 2004).

NSF-IH is located in northwestern Charles County, Maryland, approximately 25 miles southwest of Washington, DC. NSF-IH is a Navy facility consisting of the main installation on Cornwallis Neck Peninsula and the Stump Neck Annex on Stump Neck Peninsula. The main installation covers approximately 2,500 acres and is bounded by the Potomac River to the northwest, west, and south; Mattawoman Creek to the south and east; and the town of Indian Head to the northeast (Figure 1-1). Included as part of the main installation are Marsh Island and Thoroughfare Island, both located in Mattawoman Creek.

Site 6—Radiographic Facility, Building 1349, consists of the area around Building 1349 (the former control building, currently used for storage), Building 1718 (the current control building), and Building 1140 (the radiographic accelerator building) (Figure 1-2). Buildings 1349 and 1140 were built in 1965, and Building 1718 was built in 1985. X-ray photographs of explosives are taken in Building 1140. The x-ray photographs are developed in the control building (Building 1349) using silver-containing fixer and developer solutions.

The area surrounding the Site 6 buildings is maintained and mowed grass. A drainage ditch beginning just south of Building 1718 conveys surface runoff south, then east (Figure 1-2). The ditch has an approximate maximum width of 2 to 3 feet and depth of 3 to 6 inches upgradient of the fence line; it becomes deeper downgradient towards the fence line. The widest section of the drainage ditch is located near Building 1718 in a low-lying area of the site. Even though this area drains relatively poorly and collects storm water runoff, this section of the ditch is almost entirely covered with grass, indicating infrequent water retention. The eastern portion of the ditch is partially lined with concrete, which ends at the fence line. Outside the fence line, the ditch meanders through a wooded area, eventually forming a small intermittent headwater stream before entering a forested wetland (Photograph 1-1). Standing water is present within the forested wetland (Photograph 1-2). Farther downstream, the wetland transitions to a tidal emergent wetland (Photograph 1-3), where the stream discharges to Mattawoman Creek (Photograph 1-4).

The historical use of Site 6 has been documented in "Site #6: Radiographic Facility Accelerator Summary of Use Paper" (Dolph, 2001). According to this paper, the first building at the site, a radiographic accelerator facility, was constructed in 1965. During that same year, a control building and equipment building were constructed at Site 6. Within the control building was a darkroom for processing the x-ray photographs taken at the radiographic accelerator facility. In 1969, a trailer, which is no longer present, was moved to the site. The trailer contained a darkroom and a silver recovery unit. In 1985, three additional structures were constructed at Site 6: a control and silver recovery building, a transformer pad, and a tool shelter. As documented in Dolph (2001), the only industrial process that has been performed at Site 6 is the development of x-ray photographs.

In the early 1980s, approximately 2,000 x-ray sheets were being developed per month (Naval Energy and Environmental Support Activities [NEESA], 1983). In this development process, some of the silver from the solution is "fixed" to the x-ray film and the remainder of the silver is washed off. Before 1977, it is possible that some of the photographic process liquid wastes, including spent fixer and developer, were directly discharged into a nearby open ditch. According to one interviewee during the Initial Assessment Study (NEESA, 1983), before 1977 all photographic process liquid wastes, including spent fixer, were discharged to the open ditch.

Ten gallons of fixer were reportedly spilled onto the ground adjacent to and south of Building 1349 in 1973, when the contents of an old tank were transferred to a new storage facility. Subsequent spills may also have occurred south of Building 1349 (NEESA, 1983). Anecdotal information suggests that liquid wastes have not been discharged to the ditch since 1977.

1.2 Rationale for a BERA

As part of the RI for Site 6 (HGL, 2004), samples of surface soil, subsurface soil, surface water, and groundwater were collected and analyzed for various parameters. All of the initial RI samples were collected from within the fenced area of Site 6 (Figure 1-2). Based on the findings and conclusions of the RI report, a BERA technical memorandum (CH2M HILL, 2004) was prepared to present an approach to address data gaps identified in the RI. However, the only portion of the BERA technical memorandum that was executed was the collection, in 2004, of three collocated sediment and surface water samples along the drainage ditch outside the fenced area to evaluate potential offsite migration of silver (Figure 1-3). The sediment samples were analyzed for silver, and the surface water samples were analyzed for total and dissolved silver. A comparison of the silver results to background levels and ecological screening values indicated that silver had potentially migrated offsite. The results were presented to the Indian Head Installation Restoration Team (IHIRT) at the January 2005 partnering meeting.

Based on the outcome of the IHIRT's decision for the path forward for Site 6, an additional investigation was conducted in October 2005 to: (1) identify the lateral extent of silver contamination (on both sides of the ditch) to support either a removal action or a finding of no further action inside the fenced area, and (2) assess the need for a BERA and/or remediation outside the fenced area. The results are presented in the technical memorandum entitled *Site 6 Additional Investigation Results, NSF-IH, Indian Head, Maryland*

(CH2M HILL, 2006a). The results of the additional investigation were presented to the IHIRT at the December 2005 partnering meeting. The IHIRT agreed that a BERA should be performed for the area outside the fence line and that a soil removal action would be conducted inside the fenced area.

Before preparation of this BERA work plan, a streamlined screening ecological risk assessment (SERA) was completed for Site 6 (CH2M HILL, 2006b). The streamlined SERA used data from the 2004 sampling effort outside the fenced area and data collected during the 2005 additional investigation. The SERA compared the results from these investigations to ecological benchmarks to develop a screening-level estimate of ecological risk for the area outside the fence line. Because the SERA indicated that there are potential risks, Step 3A of the ERA process was also performed. Direct exposure and upper-trophic-level evaluations were performed as part of the SERA/Step 3A process, and the results are summarized below.

Direct Contact Receptors

For surface soil, the hazard quotients (HQs) for the maximum and mean concentrations were 228 and 60, respectively, indicating that silver poses a potential risk to soil invertebrates and terrestrial plants. For sediment, the HQs for the maximum and mean concentrations were 234 and 42, respectively, indicating that silver poses a potential risk to benthic invertebrates and aquatic plants. For total silver in surface water, the HQs for the maximum and mean concentrations were 9.4 and 2.5, respectively. For dissolved silver, the HQs for the maximum and mean concentrations were 6.0 and 1.3, respectively, indicating that silver poses a potential risk to water column receptors.

Upper–Trophic-Level Receptors

Based on the ingestion-based screening for terrestrial upper–trophic-level receptors, exposure to the maximum concentrations of silver poses potential risk to all the surrogate terrestrial receptors. Although the no observed adverse effect level (NOAEL)-based HQs for shrew, woodcock, and owl all exceeded 1, the lowest observed adverse effect level (LOAEL)-based HQs for these receptors were below 1, and the maximum acceptable toxicant concentration (MATC) HQ, which is based on the average of the NOAEL and LOAEL toxicity values, was below 1 for all receptors, except woodcock (1.7). This indicates that while there may be potential risk at certain locations, sitewide risk to terrestrial receptors is unlikely.

Based on the maximum concentration ingestion-based screening for aquatic upper–trophic-level receptors, only the green heron had an HQ greater than 1 (1.45). However, based on mean concentrations, none of the receptors had an NOAEL-based HQ greater than 1. Therefore, potential risk to aquatic upper-trophic-level receptors from silver in the wetland sediments is unlikely.

In summary, the Step 3A results indicate that silver poses a potential risk to soil invertebrates and/or terrestrial plants, benthic invertebrates and/or aquatic plants, and water column receptors. The Step 3A food web modeling results suggest that there may be potential risk to upper-trophic-level terrestrial receptors at certain locations, but that sitewide risk is unlikely. The results of the SERA and Step 3A are presented in a technical memorandum entitled *Streamlined Screening Ecological Risk Assessment for Site 6 (Outside the*

*Fenced Area), Naval Support Facility, Indian Head, Indian Head, Maryland (*herein referred to as SERA Technical Memorandum; CH2M HILL, 2006b).

1.3 Objective

This BERA investigation is being conducted because the results of the SERA (Steps 1 and 2) and Step 3A suggest that potentially unacceptable ecological risks exist outside the fenced area at Site 6. Therefore, the objective of this BERA investigation is to refine the risk estimates from the SERA and Step 3A. The area of focus for this investigation is the soil and sediment along the ditch from the fence line to the forested wetland downgradient of the site. Section 3 presents the study design and data quality objectives (DQOs), and Section 4 presents the sampling approach for collecting chemical and biological data to accomplish the objective. The sampling approach was discussed and agreed to by the IHIRT during the November 2006 partnering meeting.

1.4 Spatial Distribution of Silver

Discussion of the spatial distribution of silver in surface soil, sediment, and surface water used data from the 2004 sampling effort outside the fenced area and data collected during the 2005 additional investigation. The data are shown on Figure 1-3.

Surface Soil

The data do not show a spatial trend in surface soil surrounding the drainage ditch outside the fenced area. Elevated concentrations of silver are present along the ditch from the fence to the wetland area. The highest silver concentrations were found at the confluence of the drainage ditch and a small stream that flows from the northwest into the wetland, at sample locations IS06SO68 (456 milligrams per kilogram [mg/kg]) and IS06SO69 (274 mg/kg), which were near a culvert under the steam line that runs through the area (Figure 1-3).

Sediment

In 2005, 18 sediment samples were collected from locations IS06SO75 through IS06SO92 (Figure 1-3). Though the station identifications have a soil (SO) nomenclature, sediment samples were collected because water was present at these stations. Silver was detected above the U.S. Environmental Protection Agency (EPA) Region III's ecological screening criterion of 1 mg/kg in all 18 sediment samples, with concentrations ranging from 3.5J mg/kg (location IS06SO89) to 234 mg/kg (location IS06SO77).

Silver concentrations in the wetland sediments (locations IS06SO70 through IS06SO92) were generally lower than the concentrations found in the soil of the drainage ditch, with the exception of location IS06SO77 (234 mg/kg). Silver concentrations in the wetland sediments were generally higher near the terminus of the drainage ditch and decreased in the downgradient direction toward Mattawoman Creek.

The wetland system downgradient of the site transitions from a forested freshwater wetland to an emergent, tidally influenced wetland in the vicinity of locations IS06SO85 and IS06SO86 (Figure 1-3). This transition zone is also marked by a decrease in silver concentrations downstream of this area.

Surface Water

A total of seven surface water samples have been collected from Site 6 outside the fence line – three were collected in 2004 and four in 2005. Silver was detected in the three surface water samples collected from locations IS06SD13 through IS06SD15 in 2004 from the drainage ditch between the fence line and the wetland. The other four samples were collected in 2005 in the wetland from locations IS06SW17, IS06SO84, IS06SO87, and IS06SO92. Total silver was not detected in any of the four samples. Dissolved silver was analyzed in three of the four samples, and the results were nondetect in all three.

The ditch only conveys water during runoff events; therefore, these data represent temporary exposure during storm events. Because the samples were collected at different times, there could be a potential effect of storm events on silver concentrations in the surface water of the wetland.

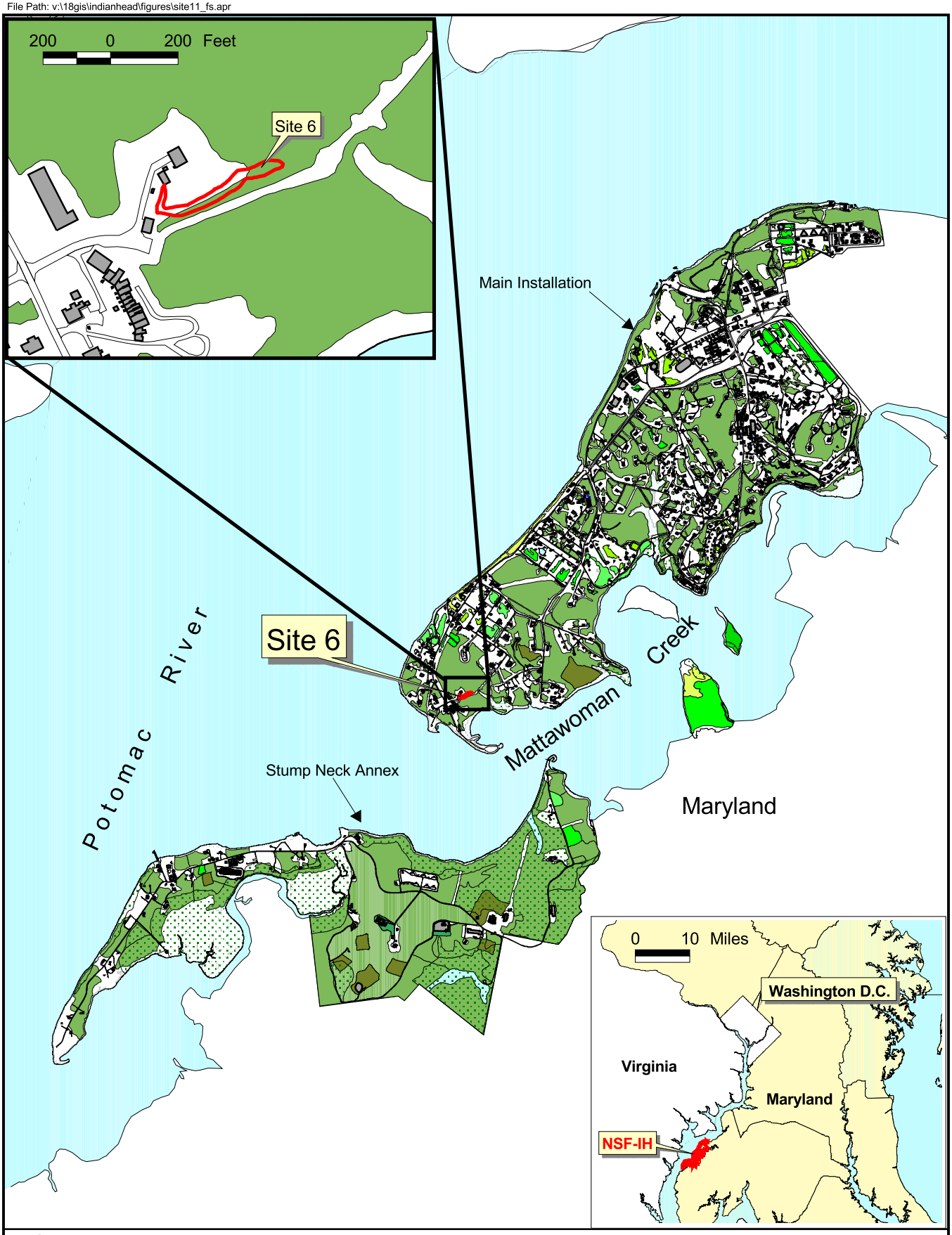
1.5 Document Organization

This work plan is organized as follows:

- Section 1: Introduction
- Section 2: Problem Formulation
- Section 3: Step 4—Study Design and Data Quality Objectives
- Section 4: Sampling and Analysis Plan
- Section 5: References

Tables and figures are provided at the end of the sections.

File Path: v:\18gis\indianhead\figures\site11_fs.apr



LEGEND

- Approximate Site Boundary
- Buildings
- Road
- Wooded Area
- Dense Wooded Area

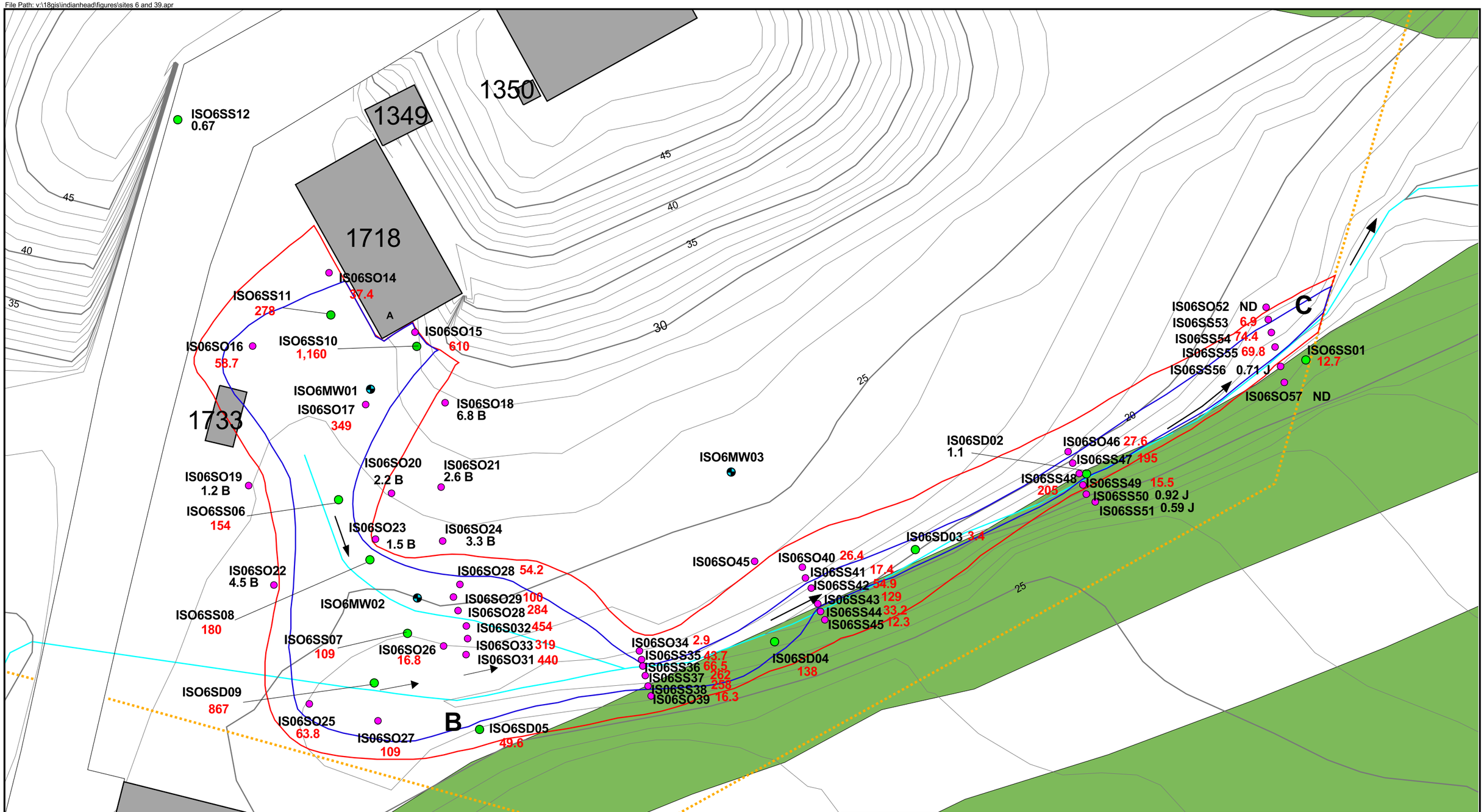
N

2000 0 2000 4000 Feet

Figure 1-1
Facility Map
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

CH2MHILL

File Path: v:\18gis\indianhead\figures\sites 6 and 39.apr



LEGEND

- Sample Location
- 2.2 Silver Concentration in mg/kg
- Previously Sampled Location (HGL, 2004)
- Monitoring Well Location
- Surface Water Drainage
- Fence
- Flow of Water in Ditch
- Isoconcentration Line - 2 mg/kg
- Isoconcentration Line - 50 mg/kg
- ND - Not Detected
- J - Estimated
- B - Possible Blank Contamination

Notes:
1. Concentrations in red indicate detection above the minimum ecologically based screening criteria of 2 mg/kg.
2. Isoconcentration lines are drawn using the October 2005 analytical data.
3. HGL, 2004 - Final Remedial Investigation for Sites 6,39, and 45.
4. Figure is from "Results for Site 6 Additional Investigation" (CH2M Hill, 2006)

N

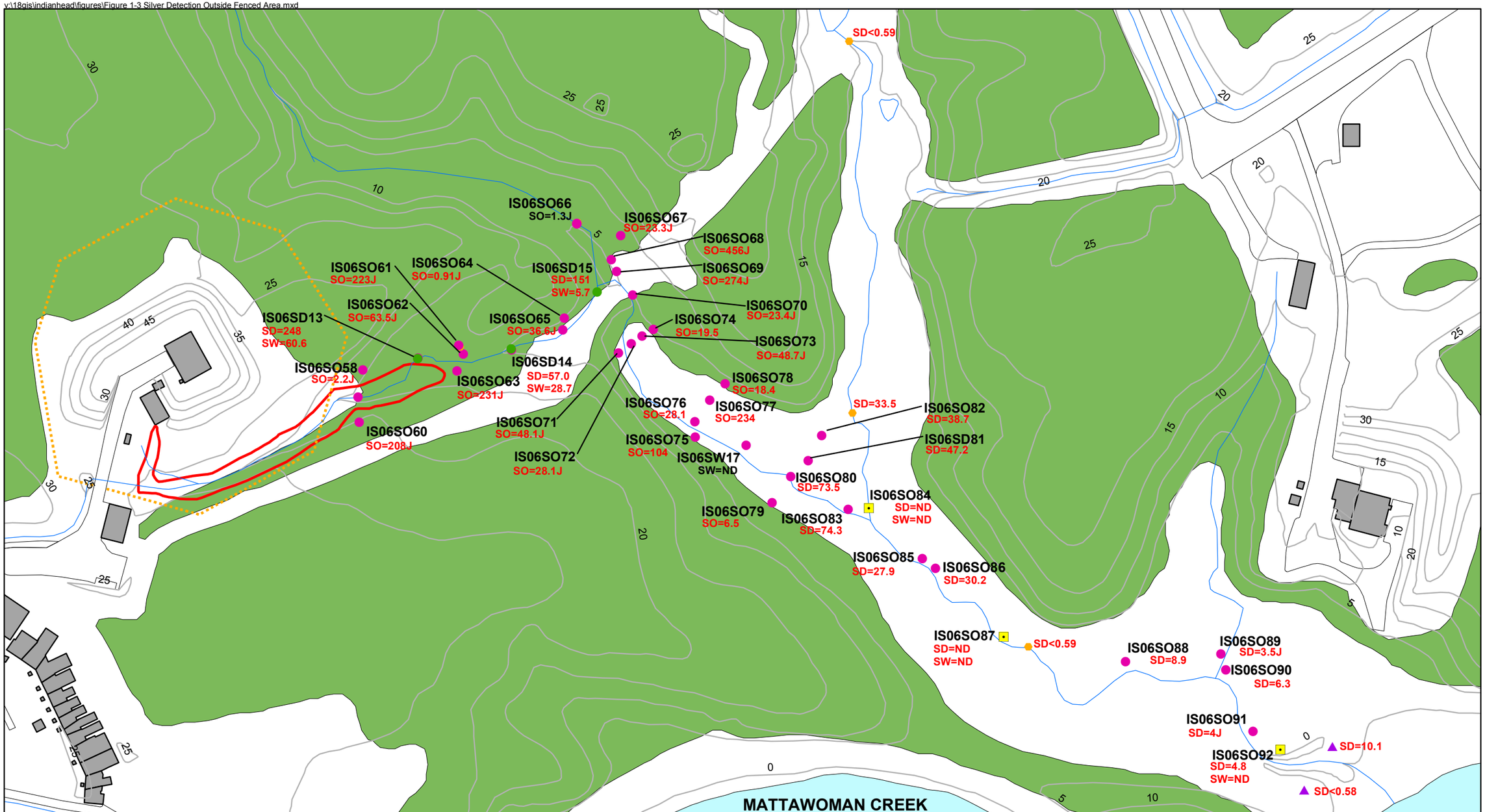
0 20 40 Feet

1 inch = 20 feet

Figure 1-2
Silver Detection Within the Fenced Area
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

CH2MHILL

v:\18gis\indianhead\figures\Figure 1-3 Silver Detection Outside Fenced Area.mxd



Legend

- Sample Location
- Surface Water and Sediment Sample Location
- Previously Sampled Location (by SIAC in 2001)
- Previously Sampled Location (by TTNUS in 2003)
- Previously Sampled Location (by CH2M HILL in 2004)
- Surface Water Drainage
- Fence

2.2 Silver Concentration
(unit for soil and sediemtn is mg/kg; unit for surface water is ug/L)
SD - Sediment Analytical Result
SO - Surface Soil Analytical Result
SW - Surface Water Analytical Result
J - Estimated

Note:
1. Concentrations in red indicate detection above the minimum ecologically based screening criteria of 2 mg/kg.
2. SAIC, 2001, Site Report for Sediment Toxicity Identification Evaluation Demonstration.
3. Figure is from "Results for Site 6 Additional Investigation (CH2M Hill, 2006)

N

0 60 120 240 Feet

Figure 1-3
Silver Detection Outside the Fenced Area
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

CH2MHILL

Photograph 1-1: View of the forested wetland and pool downstream of the steam line. View is from northwest to southeast.

Photograph 1-2: View of standing water within the forested wetland. View is from north to south.

Photograph 1-3: View of the tidal emergent wetland downstream of the forested wetland. View is from north to south.

Photograph 1-4: View of the tidal emergent wetland at the discharge point into Mattawoman Creek. View is from northwest to southeast.

SECTION 2

Problem Formulation

The BERA problem formulation is a revision of the previous problem formulation from the SERA and is focused on defining the issues associated with exposure to silver. This revised problem formulation consists of an evaluation of the toxicity of silver and a refined conceptual model. The conceptual model includes a discussion of exposure pathways, assessment endpoints, and risk hypotheses.

2.1 Ecotoxicity Profile for Silver

Based on the Step 3A results, silver poses a potential unacceptable risk to soil invertebrates and/or terrestrial plants, benthic invertebrates and/or aquatic plants, and water column receptors. The Step 3A food web modeling results suggest that there may be potential unacceptable risk to upper-trophic-level terrestrial receptors at certain locations, but that sitewide risk is unlikely.

Silver can exist as silver nitrate, chloride, sulfide or oxide, but it primarily exists in the sulfide form (Agency for Toxic Substances and Disease Registry [ATSDR], 1990). The transport of silver in the environment depends on the particular compound form. Silver adheres strongly to clay particles found in suspended particulates and sediments. In aquatic environments, the most commonly occurring forms of silver are silver (I) (soluble form), bicarbonate and sulfate salts, or complexes with particulates (ATSDR, 1990). In soil, silver tends to form complexes with inorganic chemicals and humic substances. In fresh water and soils, the primary silver compounds under oxidizing conditions are bromides, chlorides, and iodides; under reducing conditions, the free metal and silver sulfide predominate (ATSDR, 1990). Sorption is the dominant process that controls the partitioning of silver in water and its movement in soil and sediment (EPA, 1980; ATSDR, 1990). Silver adsorbs to manganese dioxide, ferric compounds, and clay minerals, and these compounds are involved in silver deposition into sediments; sorption by manganese dioxide and precipitation with halides reduce the concentration of dissolved silver, resulting in higher concentrations in sediments than in the water column (EPA, 1980).

Silver can bioaccumulate in plants and animals, but is not expected to biomagnify, and food chain transfer is not expected to be significant (Luoma and Jenne, 1977). Silver ions are very toxic to microorganisms. The use of silver in medicine for sterilizing water is based on the sensitivity of bacterial metabolism to silver ions. In photographic wastewater, silver is present as a thiosulfate complex, which in sludge is transformed to insoluble silver sulfide. Neither silver thiosulfate nor silver sulfide shows the same toxic effects observed when microorganisms are exposed to free silver ions (Ratte, 1999).

Silver thiosulfate, the principal component of photographic wastewater, is highly soluble, but has a very low toxicity (15,000 to 17,000 times less toxic than silver nitrate). The low toxicity of this compound is attributed to the complexation of silver by thiosulfate, which reduces the bioavailability of free silver ions (Ratte, 1999).

2.1.1 Terrestrial Toxicity

There is no substantial potential for silver to bioaccumulate in mammals, as evidenced by studies with laboratory rats and mice (Ratte, 1999). Terrestrial plants accumulate silver in the roots to a much greater extent than other parts of the plant (Ratte, 1999). In a study of a variety of agricultural crops, elevated silver concentrations in plant tissue relative to controls were found only in lettuce (Hirsch, 1998a). In general, accumulation of silver by terrestrial plants from soils is low, even if the soil is amended with silver-containing sewage sludge or the plants are grown on tailings from silver mines, where silver accumulates primarily in the root systems (Ratte, 1999). Germination was the most sensitive stage for plants grown in solutions containing various concentrations of silver nitrate. Adverse effects on germination were observed at silver concentrations greater than 0.75 milligrams per liter (mg /L, as silver nitrate) for lettuce and 7.5 mg/L for ryegrass (*Lolium perenne*) and other plants tested (Ratte, 1999).

Silver toxicity to terrestrial animals has been investigated primarily through laboratory bioassays (Ratte, 1999). The survival, growth, and bioaccumulation of silver in the earthworm (*L. terrestris*) were tested in artificial soil containing silver sulfide for 28 days (Ewell et al., 1993; cited in Ratte, 1999). No bioaccumulation or adverse effects on survival were observed, but reduced growth was noted and a no observed effect concentration of 62 mg/kg was reported. In another study, *L. terrestris* was exposed to 2,000 mg/kg silver sulfide in soil for 14 days, with no adverse effects to survival or growth (Beglinger and Ruffing, 1997; cited in Ratte, 1999).

No data were found on the toxicity of silver to wild animals. However, young domesticated turkeys fed diets containing 900 mg silver/kg feed for 4 weeks had enlarged hearts and reduced growth, hemoglobin, and hematocrit (EPA, 1980). Adverse effects on growth were reported in chicks fed diets containing 200 mg silver nitrate/kg ration (Smith and Carson, 1977; as cited in World Health Organization [WHO], 2002). Sublethal effects were reported in rabbits given silver nitrate via drinking water at concentrations of 250 micrograms per liter (µg/L) (brain histopathology; Smith and Carson, 1977), in rats given 400 µg/L drinking water for 100 days (kidney damage; EPA, 1980), in mice given 95 mg/L drinking water for 125 days (sluggishness; ATSDR, 1990), and in rats fed a diet containing 6 mg/kg silver nitrate for 3 months (high accumulations in kidneys and liver; Smith and Carson, 1977; cited in WHO, 2002).

2.1.2 Aquatic Toxicity

The bioavailability and toxicity of silver to aquatic organisms depends on the form of silver and on the chemical and physical properties of sediment. In solution, silver can be very toxic to aquatic organisms when present as free silver ions. At water concentrations of 0.5 to 4.5 µg/L, adverse effects on the growth of clams, oysters, snails, daphnids, amphipods, and fish are expected (Eisler, 1997), and sensitive aquatic plants die at silver concentrations greater than 130 µg/L (WHO, 2002). The acute toxicity of silver to aquatic species varies drastically by the chemical form and correlates with the availability of free ionic silver (Wood et al., 1994). In natural aquatic systems, ionic silver is rapidly complexed and sorbed by dissolved and suspended materials that are usually present. Complexed and sorbed silver species in natural waters are at least one order of magnitude less toxic to aquatic organisms than the free silver ion (Rodgers et al., 1994; Ratte, 1999). In general, silver ion is less toxic to

freshwater aquatic organisms under conditions of increasing water pH, hardness, sulfides, and dissolved and particulate organic matter (WHO, 2002; Ratte, 1999).

Silver toxicity is modified by pH, organic carbon, cation exchange capacity (CEC), and the amount of silt and clay in the sediments. These factors influence the concentrations of free silver in the pore water and at the sediment-water interface, which is the main exposure route for epifauna and infauna (Ratte, 1999). In experiments with the amphipod *Hyalella azteca*, Hirsch (1998b) found that 10-day median lethal concentration (LC_{50}) values ranged from 1.6 to 397.7 mg/kg in sediments spiked with silver nitrate (Table 2-1), but varying in the physical and chemical parameters described above, indicating that toxicity differed because bioavailability was affected by these properties of the sediment. In the same experiments, *H. azteca* was not affected by any of the test concentrations of silver chloride and was relatively insensitive to silver thiosulfate complex and silver sulfide, with 10-day LC_{50} values of >569 mg/kg and >753.3 mg/kg, respectively.

Currently, there are no established sediment quality guidelines for silver in freshwater sediments except for the upper effects threshold of 4.5 mg/kg that is based on the results of *Hyalella azteca* bioassays (Buchman, 1999). The screening value used in the SERA of 1.0 mg/kg is based on an effects range low value from Long et al. (1995), which is a conservative value based on results from marine sediments.

Sediments contaminated with silver sulfide do not seem to pose a major route of entry into the aquatic food web. Aquatic oligochaetes (*Lumbriculus variegatus*) held on sediments containing 444 mg silver/kg dry weight, as silver sulfide, for 28 days had a low bioconcentration factor of 0.18 (Hirsch, 1998c). In general, sediments contaminated with certain metals that contain an excess of acid-volatile sulfide (AVS) relative to simultaneously extracted metal (SEM) are generally not toxic. Sediments with an excess of SEM relative to AVS, and no measurable AVS, are generally toxic (Berry et al., 1999). Of the SEM metals, silver has the greatest affinity for sulfide; therefore, if AVS is present, silver should not cause adverse biological effects (EPA, 2005).

Silver ion is the most toxic chemical form of silver to fish. For fathead minnows (*Pimephales promelas*), silver ion was 300 times more toxic than silver chloride, 15,000 times more toxic than silver sulfide, and more than 17,500 times more toxic than silver thiosulfate complex. In all cases, toxicity reflected the free silver ion content of tested compounds (LeBlanc et al., 1984; cited in WHO, 2002), and a similar pattern was noted in rainbow trout (Hogstrand et al., 1996; cited in WHO, 2002). For example, silver nitrate, which is strongly dissociated, was shown to be very toxic to rainbow trout, with a 7-day LC_{50} value of 9.1 µg/L. In contrast, silver thiosulfate, silver chloride, and silver sulfide were much less toxic (7-day LC_{50} values >100 000 µg/L), presumably attributable to the abilities of the anions to remove ionic silver from solution (Wood et al., 1994, 1996; Hogstrand et al., 1996). Silver was less toxic to fathead minnows under conditions of increasing water hardness between 50 and 250 mg calcium carbonate/L, increasing pH between 7.2 and 8.6, and increasing concentrations of humic acid (Brooke et al., 1994; cited in WHO, 2002).

For freshwater fish, the acute toxicity of silver is caused solely by silver ion interacting with the gills, inhibiting the active uptake of sodium and chloride ions by the gills, and therefore disrupting osmoregulation by the fish. This effect is not from bioaccumulation of silver, but

rather from a surface interaction with negatively charged binding sites on the gills, where metals and other cations are attracted and competitively bound (Ratte, 1999).

Freshwater fish and amphibians are the most sensitive vertebrates to dissolved silver, with the greatest toxicity reported from studies with silver nitrate (Ratte, 1999). The leopard frog (*Rana pipiens*) is among the most sensitive amphibians, with a reported LC_{50} of 10 µg/L, while the most sensitive fish are even less tolerant, with LC_{50}s between 2.5 and 10 µg/L. (Ratte, 1999). Chronic toxicity values have been reported for fathead minnow that are even lower than these acute LC_{50} values, with MATC values for silver nitrate ranging from 0.4 to 0.7 µg/L (Ewell et al., 1993; cited in Ratte, 1999). Table 2-1 presents a compilation of silver concentrations that would cause toxicity to various aquatic species.

2.2 Conceptual Site Model

The conceptual site model (CSM) describes the habitat features of the site, transport and exposure routes, and ecological receptors associated with the site (Figure 2-1). The CSM serves as the basis for selecting assessment and measurement endpoints and for developing a sampling and analysis plan to evaluate those endpoints. The CSM has been revised to reflect the results of the SERA and Step 3A.

2.2.1 Transport and Exposure Pathways

Releases and/or disposal activities at the site have caused the release of silver into areas around the buildings. Through surface runoff, silver has been transported from the vicinity of Building 1349 into the drainage ditch and ultimately to the wetland system outside the fenced area.

Groundwater is not expected to be a source of water to the ditch because the water table was encountered at depths ranging from approximately 8 feet to 11 feet below ground surface (HGL, 2004). Based on water-level measurements taken in monitoring wells at the site during the RI, it was determined that the water table slopes gently to the east under the site. Dissolved silver would be transported with the shallow groundwater flow and may discharge into Mattawoman Creek. During transport, advection and dispersion would attenuate the silver concentration. In addition, silver may precipitate or bind with the subsurface media, further decreasing its concentration. Because silver was detected in only one well and at a relatively low concentration, 4.8 µg/L, it is unlikely that the Site 6 shallow groundwater poses a threat to Mattawoman Creek (HGL, 2004).

The data gathered to date suggest that some contaminant transport has occurred through soil erosion and surface runoff along the drainage ditch and into the wetland downgradient of the site, as evidenced by the elevated silver concentrations in the drainage ditch and wetland sediments. Additional evidence of possible contaminant migration is the silver concentrations measured in surface water from the drainage ditch. The presence of silver in the surface water likely results from surface runoff from the site and suspension of particulates to which silver is sorbed. The planned soil removal action within the fenced area to remediate the contamination source area will mitigate the bulk of surface water exposures during storm events. The primary processes by which silver could migrate from sediments into the water column are through desorption from sediment particles and

resuspension through physical disturbance of the sediments, such as from high flow during storm events.

Ecological receptors include soil invertebrates, terrestrial plants, benthic invertebrates, aquatic plants, water column invertebrates, amphibians, reptiles, fish, birds, and mammals. Receptors may be exposed to chemicals via direct contact with soil, sediments, and surface water; root uptake; ingestion of soil, sediment, and surface water; and/or trophic transfer through the food web.

2.2.2 Assessment Endpoints

Assessment endpoints for the BERA are summarized below.

Survival and growth of the soil invertebrate community—Soil invertebrates serve as a forage base for many terrestrial species. The soils at the site will support fewer birds and mammals if chemical concentrations are limiting the survival, growth, and reproduction of soil invertebrates. This assessment endpoint is considered to also be protective of the terrestrial plant community because no visible impacts to the plant community were observed at the site.

Survival, growth, and reproduction of insectivorous birds—These receptors are third-order consumers and are thus more susceptible to bioaccumulative chemicals. American woodcock (*Scolopax minor*) was chosen to represent this endpoint because the habitat at the site is favorable for this species.

Survival and growth of the benthic invertebrate community—Healthy, viable benthic invertebrate communities are necessary for a well-developed and balanced aquatic ecosystem. Benthic invertebrates influence nutrient cycling and availability and sediment condition. By serving as prey species for many upper-trophic predators, they are critical to the sustenance of the communities of upper-trophic-level species. This assessment endpoint is considered to also be protective of the aquatic plant community because benthic invertebrates are generally more sensitive to silver than aquatic plants, as described in Section 2.1.2.

Survival and growth of the fish and amphibians—Fish and amphibians are susceptible to direct chemical exposure from site sediment and through food chain transfer of bioaccumulative chemicals. Fish and amphibians provide an important link between the lower and upper-trophic levels of the aquatic food web.

2.2.3 Risk Hypotheses

Risk hypotheses are questions about how assessment endpoints could be affected. Risk hypotheses clarify and articulate relationships that are possible through consideration of available data, information from the scientific literature, and the best professional judgment of risk assessors. The risk hypotheses/questions associated with the assessment endpoints are:

1. Is silver in the surface soil outside the fenced area at Site 6 impairing the survival and growth of soil invertebrate communities to the extent that the prey base to support vermivorous wildlife has been adversely affected?

2. Is silver in the surface soil outside the fenced area at Site 6 bioaccumulating in soil invertebrates to the extent that the growth, survival, or reproduction of insectivorous birds that forage at the site may be impaired?
3. Are the concentrations of silver in the wetland sediments impairing the survival or growth of benthic invertebrates to the extent that the prey base to support finfish has been adversely affected?
4. Are the concentrations of silver in the wetland sediments impairing the survival or growth of finfish?

TABLE 2-1
Toxicity of Silver Compounds for Representative Aquatic Species
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

Species	Test Condition / End-point[a]	Silver concentration (µg/L)[b]	Reference
Invertebrates			
Flatworm (*Dugesia dorotocephala*)	96-h LC_{50}	30	Ratte (1999)
	96-h LC_{50}	>1,000,000[d]	Ratte (1999)
	96-h EC_{50}	>1,300[c]	Ratte (1999)
Oligochaete (*Lumbriculus variegatus*)	96-h LC_{50}	>1,000,000[d]	Ratte (1999)
Snail (*Planorbella trivolis*)	96-h LC_{50}	300	Ratte (1999)
	96-h LC_{50}	>1,000,000[d]	Ratte (1999)
	96-h LC_{50}	>1,300[c]	Ratte (1999)
Amphipod (*Hyalella azteca*)	96-h LC_{50}	1.9 (1.4–2.3)	Diamond et al. (1990); cited in WHO (2002)
	21-day NOEC (survival)	0.95	Diamond et al. (1990); cited in WHO (2002)
	21-day LOEC (survival)	1.9	Diamond et al. (1990); cited in WHO (2002)
	10-d LC_{50} (Ag_2S-spiked sediment)	753.3 (mg/kg)	Hirsch (1998b)
	10-d LC_{50} ($AgNO_3$-spiked sediment)	1.6 – 397.7 (mg/kg)	Hirsch (1998b)
Daphnid (*Daphnia magna*)	96-h LC_{50}	5	Ratte (1999)
	96-h LC_{50}	20[e]	Ratte (1999)
	96-h EC_{50}	>1,000,000[d]	Ratte (1999)
	96-h LC_{50}	>1,330[c]	Ratte (1999)
Chironomid (*Chironomus tentans*)	10-day LC_{50}	57	Call et al. (1999); cited in WHO (2002)
	10-d LC_{50} ($AgNO_3$-spiked sediment)	1,170–2,750 (mg/kg)	Call et al. (1999); cited in WHO (2002)
Fish			
Rainbow trout (*Oncorhynchus mykiss*)	96-h LC_{50}	11.8	Hogstrand et al. (1996); cited in WHO (2002)
	96-h LC_{50}	161,000[c]	Hogstrand et al. (1996); cited in WHO (2002)
	168-h LC_{50}	9.1	Hogstrand et al. (1996); cited in WHO (2002)

TABLE 2-1
Toxicity of Silver Compounds for Representative Aquatic Species
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

Species	Test Condition / End-point[a]	Silver concentration (µg/L)[b]	Reference
	168-h LC_{50}	137,000[c]	Hogstrand et al. (1996); cited in WHO (2002)
	168-h LC_{50}	>100,000[f]	Hogstrand et al. (1996); cited in WHO (2002)
	4-days post hatch, 28-day total exposure, LC_{50}	10	Birge & Zuiderveen (1996)
Fathead minnow (*Pimephales promelas*)	96-h LC_{50} at 50 mg $CaCO_3$/litre	5	Ratte (1999)
	96-h LC_{50} at 250 mg $CaCO_3$/litre	13	Ratte (1999)
	96-h LC_{50} at pH 7.2	2.5	Ratte (1999)
	96-h LC_{50} at pH 8.6	8	Ratte (1999)
	30-day, MATC	0.4<MATC<0.7	Ratte (1999)
	30-day, NOEC	>11,000[d]	Ratte (1999)
	10-week, NOEC	>5,000[c]	Ratte (1999)
Amphibians			
Leopard frog (*Rana pipiens*)	4-days post hatch, 6-8 day total exposure, LC_{50}	10	Birge & Zuiderveen (1996)
Pickerel frog (*Rana palustris*)	4-days post hatch, 6-8 day total exposure, LC_{50}	10	Birge & Zuiderveen (1996)
Narrow-mouthed toad (*Gastrophryne carolinensis*)	4-days post hatch, 6-8 day total exposure, LC_{50}	10	Birge & Zuiderveen (1996)
American bullfrog (*Rana catesbeiana*)	4-days post hatch, 6-8 day total exposure, LC_{50}	20	Birge & Zuiderveen (1996)
Fowler's toad (*Bufo fowleri*)	4-days post hatch, 6-8 day total exposure, LC_{50}	230	Birge & Zuiderveen (1996)
Marbled Salamander (*Ambystoma opacum*)	4-days post hatch, 6-8 day total exposure, LC_{50}	240	Birge & Zuiderveen (1996)

[a] EC_{50} = median effective concentration; EC_{100} = effective concentration for 100% of the population; LC_{50} = median lethal concentration; NOEC = no-observed-effect concentration; LOEC = lowest-observed-effect concentration; $CaCO_3$ = calcium carbonate.
[b] Tests performed using silver nitrate, unless stated otherwise.
[c] Silver thiosulfate.
[d] Silver sulfide.
[e] Silver sulfate.
[f] Silver chloride.

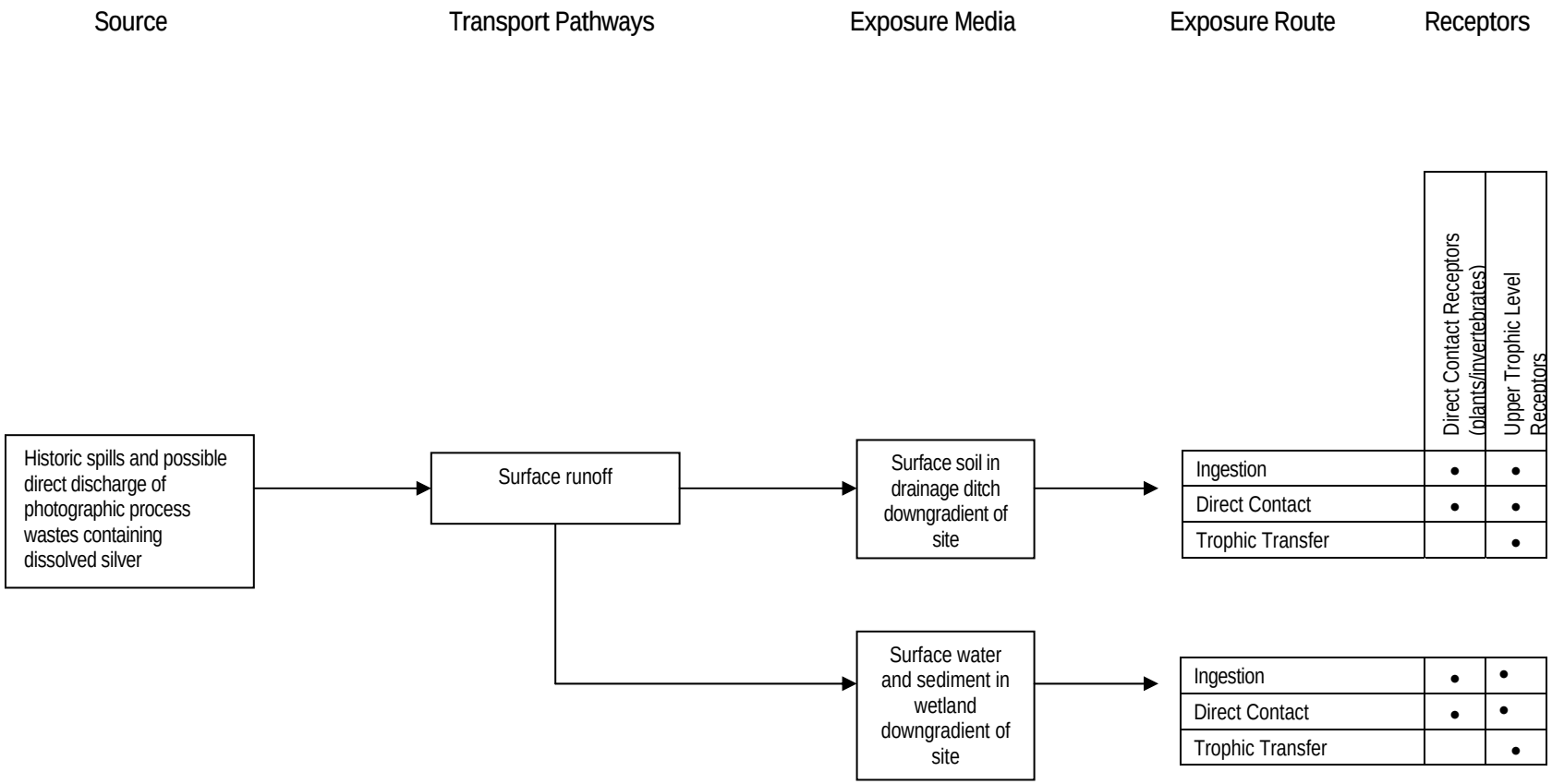


Figure 2-1
Conceptual Site Model
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

SECTION 3

Step 4—Study Design and Data Quality Objectives

Step 4 of the ERA process establishes the measurement endpoints, the study design, and DQOs for the investigations necessary to complete the ERA (EPA, 1997). Another element of Step 4 is the Sampling and Analysis Plan, which is provided in Section 4 of this document. The field sampling is designed to focus on areas identified as having the greatest potential risk and/or degree of uncertainty in earlier steps of the ERA process.

3.1 Measurement Endpoints

Measurement endpoints are measures of biological effects (e.g., laboratory toxicity test results) that are related to each respective assessment endpoint (EPA, 1997). Table 3-1 shows the measurement endpoints associated with each assessment endpoint for the areas of concern outside the fenced area at Site 6.

3.2 Study Design

This section presents the scope and rationale for the sampling planned for Site 6 to address potential risks and uncertainties in the ERA. A detailed description of the proposed sampling activities and analyses is presented in Section 4 (Sampling and Analysis Plan).

3.2.1 Toxicity Testing

Toxicity tests will be performed with earthworms, benthic invertebrates, and finfish to evaluate the potential risk posed by silver in site media to ecological receptors. Chemical analyses of soil and sediment will support the toxicological analyses. A control will be run for each test organism to ensure that representatives of the population used in the toxicity testing are healthy. Good health is demonstrated when the organism's performance meets or exceeds the criteria specified for each test protocol (e.g., 80 percent survival is the typical requirement for a 28-day test). The toxicity testing laboratory will select the appropriate substrate for control testing.

Soil Samples

The ability of the soil to potentially support a viable soil invertebrate community will be assessed by evaluating growth and survival data from bioassays conducted on split samples from soil sampling locations. At each location, sufficient sample volume to conduct the tests will be homogenized in the field before filling containers for chemical and toxicological analysis. *Eisenia foetida* (*E. foetida*) (earthworm) will be the test organism used for the soil toxicity tests.

The spatial distribution of silver in soil was discussed in Section 1.4. The spatial distribution of silver concentrations was evaluated to select the locations from which soil samples will be

collected for laboratory toxicity tests. Based on this evaluation, eight surface soil sampling locations were identified for soil toxicity testing to characterize the potential risk to the soil invertebrate community (Figure 4-1).

The eight locations (Table 3-2) for soil toxicity testing were chosen to develop an exposure-response gradient, as well as provide good spatial coverage of both the drainage ditch and the surrounding floodplain. The locations were selected to cover a range of silver concentrations, from the areas with the highest concentrations to areas with minimal screening value exceedances. The intent is to identify: (1) a significant difference in survival or growth in site soils relative to reference and control soils, and (2) if a significant difference is identified, a toxic threshold concentration for silver that can be used in future risk management decisions for the site.

Sediment Samples

The ability of the sediment to potentially support viable benthic invertebrate and finfish communities will be assessed by evaluating growth and survival data from bioassays conducted on surface sediment collected at the site. *Hyalella azteca* (amphipod) and fathead minnow (*P. promelas*) will be the test organisms used for the sediment toxicity tests. *Hyalella azteca* was selected because its use is widely accepted for sediment bioassays and it is tolerant of a wide range of grain sizes. Fathead minnow was selected because its use is widely accepted in aquatic toxicology studies and appears to be generally more sensitive than other finfish species to silver, based on toxicity data presented in Ratte (1999).

After a site visit on November 7, 2006, with EPA Region III's Biological Technical Assistance Group representative, CH2M HILL focused the wetland sampling approach on the forested wetland portion of the site (Section 1, Photographs 1-1 and 1-2) because the silver concentrations are much higher in this portion of the wetland than they are downstream of this area. In addition, the high quality tidal wetland habitat downstream of this area (Section 1, Photographs 1-3 and 1-4) would likely discourage the use of any remedial measures that might damage the habitat.

Silver concentrations in the forested wetland area range from 6.5 mg/kg to 234 mg/kg, while the silver concentrations in the tidal emergent wetland range from not detected (<0.6 mg/kg) to 10 mg/kg. The silver concentrations in the lower tidal portion of the wetland are similar or lower than concentrations in the bioassay samples used in the Toxicity Identification Evaluation Study (Science Applications International Corporation, 2001). In that study, at concentrations ranging from 3.7 mg/kg to 99 mg/kg, silver was not attributed to causing adverse effects to amphipods and fish. Similar results were found in the Mattawoman Creek Study (TetraTech NUS, Inc., 2002), in which silver concentrations in bioassay samples ranging up to approximately 6 mg/kg were not attributed to causing adverse effects on test organisms (amphipods). Therefore, it is likely that the silver in the sediments of the lower tidal portion of the wetland does not pose a significant risk to ecological receptors.

The spatial distribution of silver concentrations in the forested wetland area was evaluated to select the locations from which sediment samples will be collected for conducting sediment toxicity tests. Based on this evaluation, six sediment sample locations were identified for toxicity testing (Table 3-3). The locations were chosen to develop an exposure-

response gradient, as well as to provide good spatial coverage of the forested wetland portion of the site that would include a range of silver concentrations, from the areas with the highest concentrations to areas with minimal screening value exceedances. The intent is to identify: (1) a significant difference in survival or growth in site sediments relative to reference and control sediment, and (2) if a significant difference is identified, a toxic threshold concentration for silver that can be used to aid in future risk management decisions for the site.

Reference Samples

The response of organisms to reference and control soil and sediment will be compared statistically to the response of organisms exposed to site soil and sediment. The response of organisms exposed to reference media will be used to evaluate whether any observed toxicity may be site-related or reflect ambient conditions in the area. The health of the test organisms used for the bioassays will be evaluated by control performance criteria for each test. Care will be taken to collect appropriate reference media samples (i.e., having similar physical characteristics as the site medium). The similarities and differences between each reference area and the group of samples it is used for will be described and presented in the BERA report. Section 4.1.4 presents a discussion of where the reference samples will be collected.

3.2.2 Site-Specific Bioaccumulation Data

The potential risk to birds that feed on soil invertebrates at the site will be assessed by collecting earthworms from the site and analyzing their tissue for silver. Three composite samples of earthworms will be collected from the drainage ditch and floodplain area, and one from the reference soil location. The three composite samples will be collected from the upper ditch area (near location IS06SD13), the middle ditch area (near location IS06SD14), and the lower ditch near location IS06SD15 (Figure 4-1). The earthworm tissue will be analyzed for silver and percent moisture. The silver data will be used to refine the food chain model described in the SERA (CH2M HILL, 2006b), and HQs will be calculated.

3.3 Data Quality Objectives

The DQO process provides a procedure for defining the criteria that a study design should satisfy. The steps of the DQO process are: Step 1, State the Problem; Step 2, Identify the Decision; Step 3, Identify Inputs to the Decision; Step 4, Define the Study Boundaries; Step 5, Develop Decision Rules; Step 6, Specify Limits on Decision Errors; and Step 7, Optimize the Design for Obtaining Data. Because ERAs are weight-of-evidence-based, the last three steps of the DQO process cannot be applied fully to ERAs. Weight-of-evidence evaluations often involve different types of measurements, ranging from contaminant concentrations to toxicity test results, where probabilistic hypotheses with confidence limits cannot be formulated; therefore, simple optimization rules cannot be followed (Barnthouse and Suter, 1996). The steps of the DQO process for this investigation are described below.

Step 1. State the Problem

The data gathered to date suggest that concentrations of silver are elevated in surface soils and sediment outside the fenced area at the site, likely because of past activities. Evaluation

of the available data collected to date indicates that potential risks exist to soil invertebrates, vermivorous wildlife, benthic invertebrates, amphibians, and finfish from silver in site media.

Step 2. Identify the Decisions

Primary Question:

What are the ecological risks related to silver in soil and sediment outside the fenced area at Site 6?

Secondary Questions:

- Is silver in soil outside the fenced area impairing the survival or growth of soil invertebrates to the extent that the prey base to support vermivorous wildlife has been adversely affected?
- Is silver in soil outside the fenced area accumulating in the food web and impairing the survival, growth, or reproduction of upper-trophic-level receptors?
- Is silver in sediment outside the fenced area impairing the survival or growth of benthic invertebrates to the extent that the prey base to support finfish has been adversely affected?
- Is silver in sediment outside the fenced area impairing the survival or growth of finfish?

Step 3. Identify Inputs to the Decision

1. Results of previous sampling events
   - In surface soil and sediment, concentrations of silver are elevated relative to background, posing a potentially unacceptable ecological risk.
   - Silver poses a potentially unacceptable risk to terrestrial upper–trophic-level receptors.
2. Toxicity testing (risk to soil invertebrates, benthic invertebrates, and finfish)
   - Bulk soil and sediment toxicity.
   - Soil and sediment chemistry to support interpretation of the toxicity testing.
3. Tissue Analysis
   - Silver residues in earthworm tissue.
   - Silver residues measured in earthworm tissue will be used to replace modeled values used in Step 3A to estimate risk to upper-trophic-level receptors.

Step 4. Define the Study Boundaries

1. Silver is the constituent of potential concern for direct-contact ecological receptors in soil and sediment, and for terrestrial upper-trophic-level receptors. The study area has been delineated based on the previous sampling efforts outside the fenced area and includes the drainage ditch and its associated floodplain area and the forested wetland downgradient of the drainage ditch.

2. Sampling depth for soil and sediment will be 0 to 6 inches, an estimate of the biologically active zone. Consumption of soil invertebrates by higher-trophic-level consumers can facilitate movement of contamination through the food chain.

3. The soil reference location will be in the wooded area north of the drainage ditch at an elevation likely to be unaffected by contaminant transport mechanisms (Figure 4-1), unless the soil in this area does not physically resemble the soil in the drainage ditch area.

4. The sediment reference location will be located upstream of the confluence of the drainage ditch and the stream north of the site (Figure 4-1), unless the sediment in this area does not physically resemble the forested wetland sediment.

Step 5. Develop Decision Rules

Soil Invertebrate Community. The following criteria will be used to weigh the results of the assessment of potential risk to the soil invertebrate community:

- **Bulk Soil Toxicity**. The growth and survival of test organisms (earthworms) in site soil will be statistically compared with the results of these parameters from reference and control soil. If significant (alpha level of 0.05) adverse effects are found relative to the response of test organisms in reference soil, the soil will be considered toxic at a given station. If no significant adverse effects are found in a given sample, then the soil at that station will be considered nontoxic to soil invertebrates.

- **Soil Chemistry.** If significant adverse effects are found in the site tests, then associations between biological and physical/chemical data will be evaluated by examining the relationship between effects and silver concentrations to identify the potential threshold concentration driving the toxicity. If the data suggest that there is toxicity, but it is not caused by silver, the IHIRT will make a risk management decision based on the lines of evidence that will be presented.

Benthic Invertebrate Community. The following criteria will be used to weigh the results of the assessment of potential risk to the benthic invertebrate community:

- **Bulk Sediment Toxicity**. The growth and survival of test organisms (benthic invertebrates) in site sediment will be statistically compared with the results of these parameters from reference and control sediment. If significant (alpha level of 0.05) adverse effects are found relative to the response of test organisms in reference sediment, the sediments will be considered toxic at a given station. If no significant adverse effects are found in a given sample, then the sediment at that station will be considered nontoxic to the benthic invertebrate community.

- **Sediment Chemistry.** If significant adverse effects are found in the site tests, then associations between biological and physical/chemical data will be evaluated by examining the relationship between effects and silver concentrations to identify the potential threshold concentration driving the toxicity. If the data suggest that there is toxicity, but it is not caused by silver, the IHIRT will make a risk management decision based on the lines of evidence that will be presented.

Fish and Amphibian Communities. The following criteria will be used to weigh the results of the sampling effort to assess potential risk to fish and amphibians:

- **Bulk Sediment Toxicity**. The growth and survival of test organisms (fathead minnow) in site sediment will be statistically compared with the results of these parameters from reference and control sediment. If significant (alpha level of 0.05) adverse effects are found relative to the response of test organisms in reference sediment, the sediments will be considered toxic at a given station. If no significant adverse effects are found in a given sample, then the sediment at that station will be considered nontoxic to fish and amphibians.
- **Sediment Chemistry.** If significant adverse effects are found in the site tests, then associations between biological and physical/chemical data will be evaluated by examining the relationship between effects and silver concentrations to identify the potential threshold concentration driving the toxicity. If the data suggest that there is toxicity, but it is not caused by silver, the IHIRT will make a risk management decision based on the lines of evidence that will be presented.

Upper-Trophic-Level Receptors. The following criteria will be used to weigh the results of the sampling effort to assess potential risk to upper-trophic-level receptors that may forage at Site 6:

- **Earthworm Tissue.** Silver measured in the composite earthworm samples will be used to model exposure to vermivorous wildlife. Unacceptable risk will be constituted by exceedance of LOAEL-based reference toxicity values for these receptors. If unacceptable risks are identified for receptors, attempts will be made to use the site-specific bioaccumulation data derived from the chemical analyses in conjunction with the toxicity data to obtain a toxicity threshold to support any remedial cleanup goals for the site, if warranted.
- **Reference Earthworm Tissue.** Silver measured in the reference earthworm tissue will also be used to model exposure to vermivorous wildlife so that a comparison to background risk levels can be made. If silver concentrations in earthworm tissue samples from the site are similar to silver concentrations in the reference earthworm tissue, then the level of bioaccumulation will be considered equivalent to background risk levels.

Step 6. Evaluate Decision Errors

The intent of this data collection effort is to reduce uncertainty in the risk estimates arrived at after the conclusion of Step 3A. The results of this effort will establish the baseline ecological risk posed by silver in the soil and sediment outside the fenced area at Site 6.

Baseline Decision Rule Errors:

- Deciding that silver in the media outside the fenced area at Site 6 is not toxic to ecological receptor when, in fact, it is toxic and is potentially causing harm to ecological receptors. The consequence of making this error is failing to proceed with an evaluation of remedial alternatives when an unacceptable risk is present.

- Deciding that the silver in the media outside the fenced area at Site 6 is toxic to ecological receptors and potentially causing harm when, in fact, it is not toxic to ecological receptors. The consequence of making this error is deciding to proceed with an evaluation of remedial alternatives when there is no unacceptable risk. The level of significance that will be used to evaluate the data (i.e., the probability of making this error) is $\alpha = 0.05$.

In addition, at each point in which analyses are based on assumptions, conservative, non-compensating assumptions will be used to minimize the possibility of decision errors.

Step 7. Optimize the Design for Obtaining Data

The study design for obtaining the data to reduce the uncertainties surrounding the risk conclusions at Site 6 is described in Section 4.3. The uncertainty in the risk estimates for the soil invertebrate community, the benthic invertebrate community, the finfish community, and vermivorous wildlife will be reduced through the results of the data collection.

The uncertainty in the risk estimates for upper-trophic-level receptors will be greatly reduced by developing site-specific bioaccumulation data from silver residues measured in earthworms collected from the site. These data will provide more accurate estimates of the bioavailability and bioaccumulation potential of silver in site soils, rather than relying on bioaccumulation factors from the literature. Therefore, the outcome of this effort should provide a refined baseline estimate of ecological risk to upper-trophic-level receptors that forage at the site.

The existing data were used to optimize the design in terms of sample placement and number of samples. The stepwise ERA process also results in optimization of data collection.

TABLE 3-1
Measurement Endpoints at Site 6
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

Assessment Endpoints	Measurement Endpoints
Evaluate the survival and growth of the soil invertebrate community and its ability to function as a prey base for vermivorous wildlife**.**	Results of 28-day soil toxicity tests (survival and growth) with the earthworm *Eisenia foetida*, using site, reference, and control soils to evaluate potential adverse effects to the soil invertebrate community and its ability to function as a prey base for vermivorous wildlife. Adverse effects in the site and reference samples will be identified by statistically significant effects relative to the control.
Evaluate the survival, growth, and reproduction of birds that feed on soil invertebrates at the site.	Comparison of estimated exposure dose to toxicity reference value using site-specific bioaccumulation data obtained from silver concentrations in earthworm tissue to a reference HQ of 1.0.
Evaluate the survival and growth of the benthic invertebrate community and its ability to function as a prey base for upper-trophic-level receptors**.**	Results of 28-day sediment toxicity tests (survival and growth) with the amphipod *Hyalella azeteca*, using site, reference, and control sediment to evaluate potential adverse effects to the benthic invertebrate community and its ability to function as a prey base for upper-trophic-level receptors. Adverse effects in the site and reference samples will be identified by statistically significant effects relative to the control.
Evaluate the survival and growth of the fish community and amphibians	Results of 28-day sediment toxicity tests (survival and growth) with fathead minnow, using site, reference, and control sediment to evaluate potential adverse effects to the fish and amphibians. Adverse effects in the site and reference samples will be identified by statistically significant effects relative to the control. This measurement endpoint is considered to also be protective of amphibians because fathead minnow is generally more sensitive to silver than amphibians, as described in Section 2.1.2.

TABLE 3-2
Soil Sample Locations for Toxicity Testing
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

RI Sample Location	Silver Concentration (mg/kg)
IS06SO68	456
IS06SD13	248
IS06SO63	231
IS06SO61	223
IS06SO59	145
IS06SD14	57
IS06SO67	23.3
IS06SO58	2.2

TABLE 3-3
Sediment Sample Locations for Toxicity Testing
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

RI Sample Location	Silver Concentration (mg/kg)
IS06SO77	234
IS06SO75	104
IS06SO80	73.5
IS06SO86	30.2
IS06SO70	23.4
IS06SO79	6.5

SECTION 4

Sampling and Analysis Plan

The Sampling and Analysis Plan has two components: the Field Sampling Plan (FSP) and the Quality Assurance Project Plan (QAPP). The FSP provides detailed descriptions of the sampling activities and procedures that will be used to meet the objective of this work plan. The QAPP provides a description of the quality control (QC) procedures that will be used ensure that the data collected meet the DQOs of this work plan. This Work Plan incorporates by reference the *Master Plans for Installation Restoration Program Environmental Investigation*s (Tetra Tech NUS, Inc., 2004; hereafter referred to as the Master Plans).

4.1 Field Sampling Plan

Fieldwork will follow the standard operating procedures provided in the Master Plans and will be consistent with work performed during the RI and subsequent additional investigations. All sampling and field information will be documented in a field log book.

4.1.1 Soil Samples

Surface soil will be collected from the eight sample locations shown on Figure 4-1. At each location, the sample will be collected from 0 to 6 inches below ground surface with a disposal trowel or decontaminated stainless steel trowel. The sample will be placed in a decontaminated stainless steel bowl and homogenized (i.e., mixed for consistency) with the trowel. Approximately 8 liters of soil will be placed in a sample jar for offsite laboratory analysis. To prevent cross-contamination, sampling equipment (i.e., trowel and mixing bowl) will be decontaminated between sampling locations.

At each location, following homogenization, the soil sample will be placed into two jars—one for toxicity testing and one for chemical analysis. A 28-day soil toxicity test with the earthworm *E. foetida* will be conducted on each sample. Samples for chemical analyses will be sent to an offsite laboratory for target analyte list (TAL) metals, cyanide, pH, total organic carbon (TOC), CEC, and grain size (by sieve analysis).

4.1.2 Sediment Samples

Sediment will be collected from the six sample locations shown on Figure 4-1, as close as possible to the original sampling locations. The samples will be collected from 0 to 6 inches below the sediment/water interface with a disposal trowel or decontaminated stainless steel trowel, or an auger. If standing water is present at a sample location, an Ekman dredge will be used to collect the sediment to minimize the loss of the finer material. Approximately 8 liters of sample will be collected and mixed to a consistent color and texture in a decontaminated stainless steel bowl. Before mixing, however, the AVS/SEM sample will be collected to ensure that this parameter is measured correctly.

At each location, following collection of the AVS/SEM samples and homogenization, the sediment sample will be placed into two jars—one for bulk sediment toxicity testing and

one for chemical analysis. A 28-day bulk sediment toxicity test (growth and survival endpoints) with the amphipod *H. azteca* will be conducted for each sample. Ammonia concentrations will be monitored in the overlying water during the toxicity tests to ensure that ammonia buildup does not confound the test results. Samples for chemical analyses will be sent to an offsite laboratory for TAL metals, cyanide, pH, TOC, sulfide, AVS/SEM, CEC, and grain size (by sieve analysis).

4.1.3 Tissue Samples

Three composite earthworm tissue samples will be collected from the drainage ditch and floodplain area, and one from the reference soil location for site-specific bioaccumulation data. The three composite samples will be collected from the upper ditch and floodplain area (near location IS06SD13), the middle ditch area (near location IS06SD14), and the lower ditch near location IS06SD15 (Figure 4-1). Each composite sample will consist of at least 10 individual earthworms, which will be collected by digging in surface soil with a decontaminated shovel in the vicinity of each sample location. The earthworms will be homogenized in the laboratory, and a subsample of each composite sample will be analyzed for silver and percent moisture. The tissue residue data will be used to refine the food chain model described in the SERA Technical Memorandum, and HQs will be calculated. As a contingency, if enough worms are not found at the site for tissue analysis, the worms used in the toxicity tests will be analyzed for silver at the conclusion of the 28-day tests.

4.1.4 Reference Samples

One soil sample and one sediment sample will be collected from reference locations. The reference soil location is planned to be in the wooded area immediately north of the drainage ditch in an area that is 10 to 15 feet higher in elevation to minimize the chance of silver being present. The reference sediment location will be upstream of the confluence of the drainage ditch and the stream north of the site (Figure 4-1). This location should represent forested wetland environment and should not be impacted by site contamination.

Care will be taken to ensure that the reference soil and sediment falls within the range of the physical characteristics (i.e., similar grain size and amount of organic material) of the site soil and sediment. Based on field observations, if either of the proposed reference locations do not match the site soil or sediment characteristics, an alternate location will be selected in the local area that more closely matches the medium, but is unlikely to be affected by site contamination.

4.1.5 Sampling Frequency, Quality Assurance/Quality Control Samples, and Sample Handling

Table 4-1 presents a summary of the proposed soil and sediment samples with the analytical procedures and the frequency at which field quality assurance/quality control (QA/QC) samples will be collected. Tables 4-2 and 4-3 list the sample containers, preservatives, and holding times required for the intended analyses for solid and aqueous samples. Samples will be labeled, handled, documented, packaged, and shipped as detailed in the Master Plans and utilizing the protocol from the RI and subsequent additional investigations.

4.1.6 Survey of Sample Locations

The horizontal locations (northing and easting coordinates) of the soil and sediment samples will be surveyed with a portable global positioning system unit. The horizontal locations will be referenced to the 1983 North American datum.

4.1.7 Decontamination of Sampling Equipment

All non-dedicated sampling equipment will be decontaminated before beginning sampling activities and after each use. To minimize the amount of liquid investigation-derived waste (IDW), disposable hand trowels will be used for sampling activities. Decontamination procedures are presented in the standard operating procedure provided in the Master Plans.

4.1.8 Investigation-Derived Waste Handling

All handling and disposal of IDW will be performed in accordance with the Master Plans. A minimal amount of IDW will be generated during the sampling program. Paper towels used to wipe down equipment, personal protective equipment, and disposable trowels used during sampling will be disposed in the facility dumpsters.

4.1.9 Sample Identification System

Each sample will be designated by an alphanumeric code that identifies the site and matrix sampled and contains a sequential sample number. Site-specific procedures are elaborated below. The following is a general guide for sample identification:

First Segment of Sample Number:	Second Segment of Sample Number:	Third Segment of Sample Number		
Naval Installation Abbreviation	Site Number	Sample Type	Sample Location	Additional Qualifiers (sample depth, date)
A	ANN	AA	NN	NNNN

Symbol Definition:

A = Alphabetic
N = Numeric

Naval Installation Abbreviation:

A = One-letter abbreviation identifying the Naval Installation where the sample was collected (for example, Indian Head = I)

Site Number:

ANN = One letter and two numbers identifying the site on the facility where the sample was collected (i.e., S06 = Site 6)

Sample Type:

SS = Surface Soil
SD = Sediment Sample
TI = Tissue Sample
EB = Equipment Blank

FB = Field Blank

Sample Location:

MM = QC Samples—two-digit month of sampling event
NN = Primary Samples—two-digit number indicating sample location

Additional Qualifiers:

BDED = Surface Soil and Sediment Samples—2-digit beginning depth and 2-digit end depth rounded up to nearest foot (i.e., 2 feet to 2 feet 6 inches = 0203)

DDYY = QA/QC Samples—2-digit day and 2-digit year of sampling event

Example of this numbering approach is:

IS06SD040001 4th sediment sample collected from 0 foot to 1 foot below ground surface

Example of this numbering approach for a QA/QC sample is:

IS06EB061507 Equipment blank collected at Site 6 on June 15, 2007

Field duplicates will be "blind duplicates," and thus labeled in the same manner as regular samples. Their locations and corresponding sample numbers will be recorded in the logbook.

4.2 Quality Assurance Project Plan

Data will be collected to meet analytical DQOs. The appropriate number of field QA/QC samples, including field blanks and equipment blanks, will be analyzed in addition to laboratory QA/QC samples, including matrix spike/matrix spike duplicate samples. This will be done as outlined in the *Master Quality Assurance Project Plan* of the Master Plans.

Data collected during the BERA investigation fieldwork will be validated before interpretation. Data validation will be performed by an independent subcontractor, and will conform to *Region III Modifications to the Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses* (EPA, 1993) and *Region III Modifications to National Functional Guidelines for Organic Data Review Multi-media, Multi-concentration,* (OLM01.0-OLM01.9; EPA, 1994). Field QC samples will not be collected for laboratory toxicity tests; QC procedures for these tests will be specified in the test-specific standard operating procedure documents to be provided by the toxicity test laboratory.

4.3 Health and Safety

Health and safety procedures will follow those described in the Master Plans and CH2M HILL's site-specific health and safety plan.

4.4 Data Evaluation and Reporting

Following laboratory analysis and data validation of the samples, risk assessment will be performed on the data as outlined in this work plan. Field activities conducted, analytical results, and interpretation will be presented in a BERA report and discussed with the IHIRT.

TABLE 4-1
Sampling and Analyses Summary
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

Matrix	Laboratory Parameter (Method)	Samples	Field Duplicates[a]	Field Blanks[b]	Equipment Blanks[c]	Trip Blanks	Solids Total[e]	Aqueous Total[f]	MS/ MSDs[d]
Surface Soil	TAL metals and cyanide by EPA CLP ILM04	9	1	1	2		10	3	1/1
	Total organic carbon by Lloyd Kahn	9	1	1	2		10	3	1/1
	pH by SW-846 9045	9	1				10		
	Cation exchange capacity by SW-846 9081	9	1				10		
	Grain size by ASTM D-422	9					9		
	Toxicity Tests	9					9		
Sediment	TAL metals and cyanide by EPA CLP ILM04	7	1		2		8	2	1/1
	Total organic carbon by Lloyd Kahn	7	1		2		8	2	1/1
	pH by SW-846 9045	7	1				8		
	Sulfide by SW-846 9030	7	1	1	2		8	3	1/1
	Cation exchange capacity by SW-846 9081	7	1				8		
	Grain size by ASTM D-422	7					7		
	AVS/SEM by EPA 821-R-91-100	7	1				8		1/1
	Toxicity Tests	7					7		
Tissue (Earthworm)	Silver by EPA CLP ILM04	4					4		
	Percent moisture	4					4		

Notes:

[a] Field duplicates are collected at a rate of 1 per 10 samples per matrix.

[b] Field Blanks are collected at a rate of 1 per week.

[c] Equipment Blanks are collected at a rate of 1 per day per decontaminated equipment (i.e., if dedicated disposable equipment is not used) or one per event per disposable equipment is used.

[d] Matrix Spike/Matrix Spike Duplicates (MS/MSDs) are collected at a frequency of 1 per 20 per matrix.

[e] Solids total consists of the samples and their field duplicates. MS/MSDs are not billable and are not included.

[f] Aqueous total consists of equipment blank, field blanks, and trip blanks. Samples for toxicity testing and tissue samples do not require QC samples.

TAL = Target Analyte List
SW-846 = Test Methods for Evaluating Solid Waste
ASTM = American Society for Testing and Materials

Toxicity testing will be conducted as follows:
28-day Soil Toxicity Test (*E. foetida*) by ASTM E1676-97 (ASTM, 2000) and EPA/600/3-88/029 (EPA, 1989)
28-day Sediment Toxicity Test (H. azteca) by ASTM E1706-00 (ASTM, 2001) and EPA/600/R-99/064 (EPA, 2000)
28-day Toxicity Test (*Pimephales promelas*) by EPA/R-99/064 (EPA, 2000)

TABLE 4-2
Summary of Required Containers, Preservatives, and Holding Times for Solid Samples
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

Parameter	Container Type[1]	Preservation[a]	Holding Time	Notes
TAL metals and cyanide	One 8oz jar	Cool to 4°C	6 months, 28 days for Hg, 14 days for CN	Fill completely
Silver	One 8oz jar	Cool to 4°C	6 months	Tissue only
Sulfide	One 8oz jar	Cool to 4°C	7 days	Fill completely
AVS/SEM	One 8oz jar	Cool to 4°C	14 days	Fill completely
TOC	One 4oz jar	Cool to 4°C	ASAP	Fill completely
pH	One 4oz jar	Cool to 4°C	ASAP	Fill completely
CEC	One 4oz jar	Cool to 4°C	ASAP	Fill completely
Grain size	One 16oz jar	N/A	N/A	Fill completely
Toxicity Tests	One 8L tub	Cool to 4°C	ASAP	Fill completely

Notes:

[a]Container type and preservation are laboratory-specific and subject to change upon selection of laboratory.

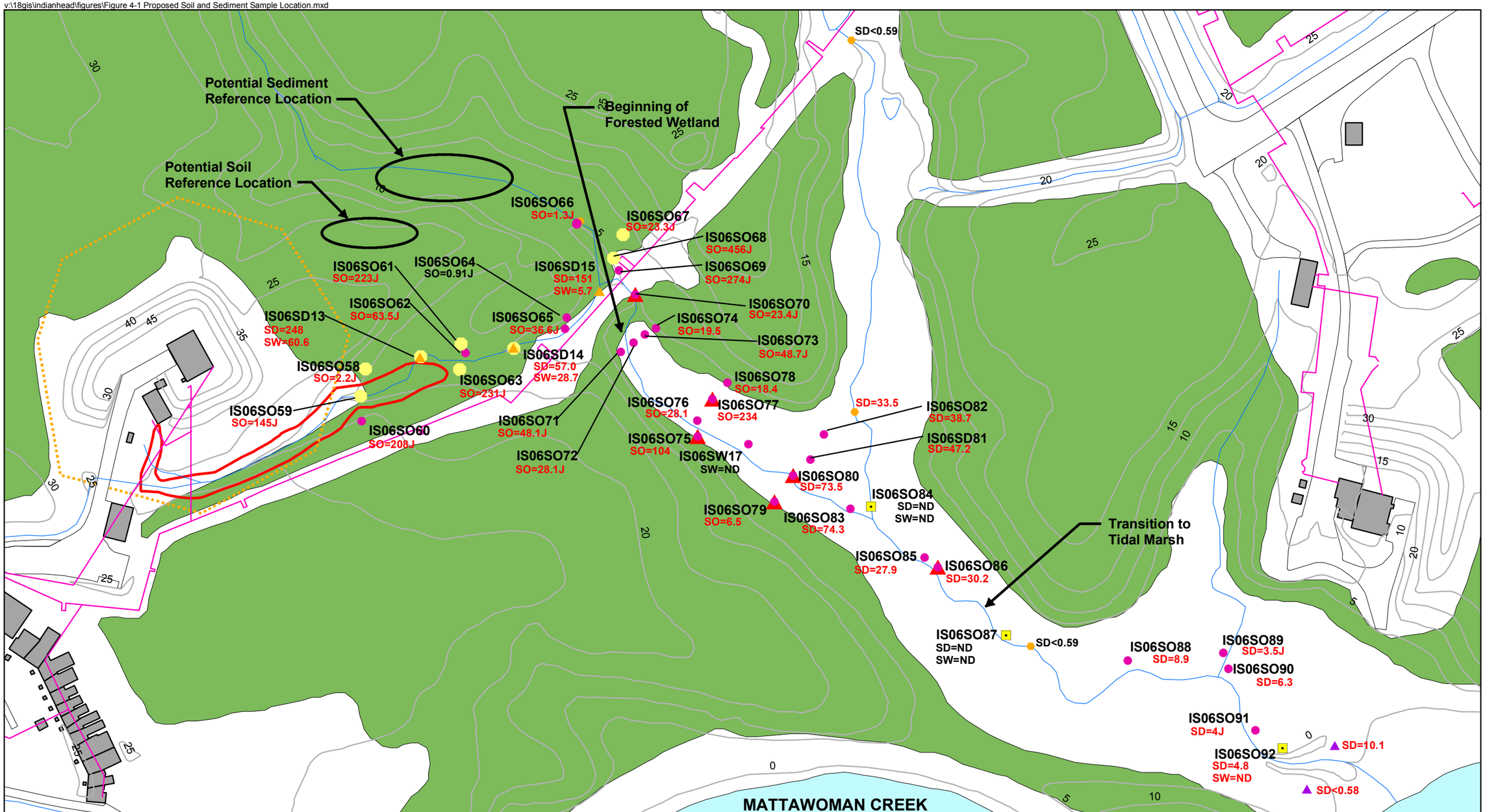
TABLE 4-3
Summary of Required Containers, Preservatives, and Holding Times for Aqueous (QC) Samples
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

Parameter	Container Type[1]	Preservation[a]	Holding Time	Notes
TAL metals	One 500mL poly	HNO_3 to pH < 2; Cool to 4°C	6 months, 28 days for Hg	Fill completely
Cyanide	One 250mL poly	NaOH to pH > 12; Cool to 4°C	14 days	Fill completely
Sulfide	One 250mL poly	NaOH to pH > 9; ZnAce; Cool to 4°C	7 days	Fill completely
TOC	3X 40mL amber vial	H_2SO_4 to pH < 2; Cool to 4°C	ASAP	Fill completely

Notes:

[a]Container type and preservation are laboratory-specific and subject to change upon selection of laboratory.

v:\18gis\indianhead\figures\Figure 4-1 Proposed Soil and Sediment Sample Location.mxd



Legend

- Sample Location (CH2M HILL, 2006)
- Surface Water and Sediment Sample Location (CH2M HILL, 2006)
- Previously Sampled Location (by SIAC in 2001)
- Previously Sampled Location (by TTNUS in 2003)
- Proposed Sediment Sample Locations for BERA
- Proposed Soil Sample for BERA
- Previously Sampled Location (by CH2M HILL in 2004)
- Surface Water Drainage
- Fence
- Steam Line

2.2 Silver Concentration
(unit for soil and sediemtn is mg/kg; unit for surface water is ug/L)
SD - Sediment Analytical Result
SO - Surface Soil Analytical Result
SW - Surface Water Analytical Result
J - Estimated

Note:
1. Concentrations in red indicate detection above the minimum ecologically based screening value of 2 mg/kg for soil and 1 mg/kg for sediment.
2. SAIC, 2001, Site Report for Sediment Toxicity Identification Evaluation Demonstration.
3. Figure is from "Results for Site 6 Additional Investigation (CH2M Hill, 2006)

N

0 60 120 240 Feet

Figure 4-1
Proposed Soil and Sediment Sample Locations
BERA Work Plan, Site 6 (Outside the Fenced Area)
NSF-IH, Indian Head, Maryland

CH2MHILL

SECTION 5

References

Agency for Toxic Substances and Disease Registry (ATSDR). 1990. *Toxicological Profile for Silver*. Public Health Service, U.S. Department of Health and Human Services. Atlanta, GA.

Barnthouse, L. W., and G.W. Suter II. 1996. *Guide for Developing Data Quality Objectives for Ecological Risk Assessment at DOE Oak Ridge Operations Facilities.* Oak Ridge National Laboratory, Oak Ridge, TN.

Berry, W., M. Cantwell, P. Edwards, J. Serbst, D. Hansen. 1999. "Predicting toxicity of sediments spiked with silver." *Environmental Toxicology and Chemistry*, 18(1):40–48.

Beglinger, J.M., and C.J. Ruffing. 1997. Effects of silver sulfide on the terrestrial earthworm. In: Andren, A., and T. Bober, eds. *Transport, fate, and effects of silver in the environment. Proceedings of the 5th international conference.* 28 September – 1 October 1997, Hamilton, Ontario. Madison, WI, University of Wisconsin Sea Grant Institute, pp. 313–314.

Brooke, L., R. Erickson, M. Kahl, F. Vande-Venter, S. Harting, T. Markee, C. Stephan, R. Spehar. 1994. Effects of laboratory test conditions on the toxicity of silver to aquatic organisms. In: Andren A., and T. Bober, eds. *Transport, fate, and effects of silver in the environment. Proceedings of the 2nd international conference*. 11–14 September 1994. Madison, WI, University of Wisconsin Sea Grant Institute, pp. 119–122.

Buchman, M.F. 1999. "NOAA Screening Quick Reference Tables." *NOAA HAZMAT Report 99-1*, Seattle, Wash. 12 pp.

CH2M HILL. 2006a. *Site 6 Additional Investigation Results, NSF-IH, Indian Head, Maryland.*

CH2M HILL. 2006b. *Streamlined Screening Ecological Risk Assessment for Site 6 (Outside the Fenced Area), Naval Support Facility, Indian Head, Indian Head, Maryland.*

CH2M HILL. 2004. *Sampling Design and Rationale for Baseline Ecological Risk Assessment at Site 6, Naval District Washington, Indian Head, Maryland.*

Dolph, J. 2001. *Literature Search Summary for NDWIH Site 6*.

Eisler, R. 1997. *Silver Hazards to Fish, Wildlife and Invertebrates: A Synoptic Review*. Patuxent Wildlife Research Center, U.S. Geological Survey. Contaminant Hazard Reviews, Report No. 32.

U.S. Environmental Protection Agency (EPA). 2005. *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metal Mixtures (Cadmium, Copper, Lead, Nickel, Silver, and Zinc).* Office of Research and Development, Washington, DC. EPA-600-R-02-011.

EPA. 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. Interim Final*. EPA/540/R-97/006.

EPA. 1994. *Region III Modifications to National Functional Guidelines for Organic Data Review Multi-media, Multi-concentration*. OLM01.0-OLM01.9.

EPA. 1993. *Region III Modifications to the Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses.*

EPA. 1980. *Ambient Water Quality Criteria for Silver*. Office of Water. EPA, Washington D.C.

Ewell, W.S., J.W. Gorsuch,, M. Ritter, C.J. Ruffing. 1993. Ecotoxicological effects of silver compounds. Proceedings, 1st Argentum International Conference on the Transport, Fate, and Effects of Silver in the Environment, Madison, WI, USA, August 8–10, p 9. 40.

HydroGeoLogic, Inc. (HGL). 2004. *Final Remedial Investigation Report, Sites 6, 39 and 45, Naval District Washington, Indian Head, Indian Head, Maryland*.

Hirsch, M. 1998a. "Availability of sludge-borne silver to agricultural crops." *Environmental Toxicology and Chemistry*, 17(4):610–616.

Hirsch, M. 1998b. "Toxicity of silver sulfide-spiked sediments to the freshwater amphipod (*Hyalella azteca*)." *Environmental Toxicology and Chemistry*, 17(4):601–604.

Hirsch, M. 1998c. "Bioaccumulation of silver from laboratory-spiked sediments in the oligochaete (*Lumbriculus variegatus*)." *Environmental Toxicology and Chemistry*, 17(4):605–609.

Hogstrand, C., F. Galvez, C. Wood.1996. "Toxicity, silver accumulation and metallothionein induction in freshwater rainbow trout during exposure to different silver salts." *Environmental Toxicology and Chemistry*, 15:1102–1108.

LeBlanc, G., J. Mastone, A. Paradice, B. Wilson, H. Lockhart, K. Robillard. 1984. "The influence of speciation on the toxicity of silver to fathead minnow (*Pimephales promelas*)." *Environmental Toxicology and Chemistry*, 3:37–46.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management.* 19:81-97.

Luoma, S.N. and E.A. Jenne. 1977. "The availability of sediment-bound cobalt, silver and zinc to a deposit-feeding clam." In: *Biological Implications of Metals in the Environment*. H. Drucker and R.E. Wildung, eds. U.S.N.T.I.S. Springfield (Conf. 750929), pp. 213-231.

Naval Energy and Environmental Support Activities (NEESA). 1983. *Initial Assessment Study of Naval Ordnance Station, Indian Head, Maryland*.

Ratte, H. 1999. "Bioaccumulation and toxicity of silver compounds: A review." *Environmental Toxicology and Chemistry*, 18(1):89–108.

Rodgers, J., E. Deaver, P. Rogers. 1994. Evaluations of the bioavailability and toxicity of silver in sediment. In: Andren A., and T. Bober, eds. *Transport, fate, and effects of silver in the environment. Proceedings of the 2nd international conference*. 11–14 September 1994. Madison, WI, University of Wisconsin Sea Grant Institute, pp. 131–137.

Science Applications International Corporation. 2001. *Site Report for Sediment Toxicity Identification Evaluation Demonstration: Indian Head Naval Surface Warfare Center*.

Smith, I.C. and B.L. Carson. 1977. *Trace Metals in the Environment, Vol. 2 – Silver*. Ann Arbor Science, Ann Arbor, MI.

TetraTech NUS. 2002. *Mattawoman Creek Study. Indian Head Division, Naval Surface Warfare Center, Indian Head, Maryland. Vols. I and II.* Engineering Field Activity, Chesapeake, Naval Facilities Engineering Command.

TetraTech NUS. 2004. *Master Plans for Installation Restoration Program Environmental Investigations at Naval District Washington, Indian Head, Indian Head, Maryland*.

World Health Organization. 2002. *Silver and Silver Compounds: Environmental Aspects.* (Concise international chemical assessment document; 44). Geneva.

Wood, C., S. Munger, F. Galvez, C. Hogstrand. 1994. The physiology of silver toxicity in freshwater fish. In: Andren, A., and T. Bober, eds. *Transport, fate, and effects of silver in the environment. Proceedings of the 2nd international conference*. 11–14 September 1994. Madison, WI, University of Wisconsin Sea Grant Institute, pp. 109–114.

Wood C., Hogstrand C., Galvez F., Munger R. 1996. The physiology of waterborne silver toxicity in freshwater rainbow trout (Oncorhynchus mykiss): 2. The effects of silver thiosulfate. Aquatic Toxicology, 35:111–125.