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Final

Remedial Investigation/Human Health Risk Assessment/Ecological Risk Assessment Report for Sites 3, 4, 5, and 6

St. Juliens Creek Annex
Chesapeake, Virginia

Volume I - Text

Prepared for

Department of the Navy
Atlantic Division
Naval Facilities Engineering Command
Norfolk, Virginia

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March 2003

Prepared by

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CDM
Federal Programs Corp.

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Executive Summary

A Remedial Investigation (RI), including human health and ecological risk assessments, was conducted for Site 3 (Waste Disposal Area), Site 4 (Landfill D), Site 5 (Burning Grounds), and Site 6 (Small Arms Pit) at the St. Juliens Creek Annex (SJCA) of the Norfolk Naval Base, in Chesapeake, Virginia. This investigation was performed under Navy Contract No. N62470-95-D-6007 by CDM Federal Programs Corporation (CDM Federal) and CH2M HILL.

This report describes the procedures and results of all investigations conducted at the four sites. The RI's objectives were to delineate Sites 3, 4, 5, and 6 boundaries, define the geologic and hydrogeologic site conditions, define the nature and extent of contamination, define the fate and transport of contaminants, and assess human health and ecological risks to current and potential future receptors from site contamination.

Site Descriptions

Site 3 (Waste Disposal Area) is an unlined waste disposal area that covers approximately 2.1 acre, which operated from 1940 to 1970. Solvents, acids, bases, and mixed municipal waste were burned and the ash was disposed of at the site. Two pits identified along the north side of the road were reportedly used for oil and oily sludge disposal, as well as for periodic burning.

Site 4 (Landfill D), approximately 12.5 acres, is an unlined trench-and-fill landfill that reportedly operated from 1970 to 1981. Refuse included solvents, acids, bases, polychlorinated biphenyls (PCBs), and drums of unknown wastes.

Site 5 (Burning Grounds) is approximately 3 acres. Waste ordnance materials were reportedly disposed by open burning between the 1930s and 1970s. Wastes disposed at the site include black powder, smokeless powder, Explosive D, Composition A-3, tetryl, TNT, fuzes, carbon tetrachloride, trichloroethylene (TCE), paint sludge, pesticides, and various types of refuse.

Site 6 (Small Arms Pit or Caged Pit) is located southeast of Site 5 (Burning Grounds) and consisted of a pit with a cage over it where small items, such as igniters and fuzes, were burned in the pit. A review of historical aerial photographs during Phase III of the RI investigation indicated that activities began around 1949 and continued to the early 1980s. Due to proximity to Site 5, Site 6 has been investigated as part of Site 5.

Remedial Investigation Activities

RI field activities were conducted in three phases. CDM Federal conducted the first and second from June to November 1997 and from April to October 1999, respectively. CH2M HILL conducted the third from June to August 2001. The following field activities were implemented to accomplish the RI objectives:

- Sampled and analyzed surface and subsurface soil to determine stratigraphic profile as well as the nature and extent of soil contamination.
- Sampled and analyzed shallow (Columbia Aquifer) and deep (Yorktown Aquifer) monitoring wells to determine the nature and extent of potential groundwater contamination.
- Measured water levels in wells to determine groundwater elevation, gradient, and flow direction to evaluate potential groundwater contaminant migration to surface water.
- Sampled and analyzed sediment and surface water to determine the nature and extent of contamination and to evaluate potential contaminant migration and impacts to drainage ditches and Blows Creek.
- Geophysical surveys to determine the horizontal extent of waste at Sites 3, 4, and 5, and the location of the caged pit at Site 6.
- Trenching to delineate the horizontal and vertical extent of waste at Sites 3 and 5, and confirm the location of the caged pit at Site 6.
- Tidal surveys to assess tidal influences of Blows Creek on the Columbia and Yorktown Aquifers at Sites 3, 4, and 5.

Hydrogeologic Characteristics

The area's hydrogeologic characteristics were determined by soil boring data, groundwater level measurements, aquifer tests, and tidal surveys. A review of historic aerial photographs confirms the placement of dredge fill, reportedly from the Southern Branch of the Elizabeth River and possibly Blows Creek, prior to 1937, over the entire area of Sites 3, 4, 6, and all but the western limits of Site 5. In addition to dredge fill, Bohicket surface soil exists along the banks of Blows Creek south of Site 5.

The hydrostratigraphic units relevant to the RI are the Columbia Aquifer (water table aquifer), the underlying Yorktown Confining Unit, and the Upper Yorktown Aquifer. The Columbia Aquifer occurs in dredge fill and the underlying native clay and silty sand sediment. Dredge fill consists of poorly sorted silt and clay with thin lenses of fine sand. The underlying Yorktown Confining Unit is a continuous clay layer, about 20 ft bgs and between 9and 36 ft thick, that separates the overlying Columbia Aquifer from the sand and silty sand of the underlying Upper Yorktown Aquifer. The Upper Yorktown aquifer is a predominately sandy unit typically encountered at a depth of 45 ft below ground surface (bgs).

Data collected during the RI indicate the following hydrogeologic characteristics of the sites:

- Depth to groundwater (Columbia Aquifer) in the upland areas is expected to range seasonally between 2 and 6 ft bgs. The water table gradient is flat (.006 to 0.01 ft/ft) with groundwater flow from the northeast (Site 3) to the south (Site 4) and southwest (Site 5), toward Blows Creek. The average horizontal groundwater flow rate for the Columbia Aquifer was estimated to be about 16 ft/day.

- Discharge from the shallow groundwater system is to low-lying marsh areas and Blows Creek. Groundwater discharge to the upland drainage ditches is expected to occur during extremely high water-table conditions.
- Hydraulic head differences between the Columbia Aquifer and Upper Yorktown Aquifer indicate vertical groundwater flow potential is downward from the Columbia Aquifer to the Upper Yorktown Aquifer under a gradient of approximately 0.17 ft/ft. The rate of vertical seepage across the Yorktown Confining Unit was not estimated.
- Horizontal groundwater flow gradient in the Upper Yorktown Aquifer is very flat (0.0003 to 0.0002 ft/ft) with groundwater flow from the west-northwest to the east-southeast towards, and discharging to the Southern Branch of the Elizabeth River. The average horizontal groundwater flow rate for the Upper Yorktown Aquifer was estimated to be about 0.005 ft/day.
- Tidal influences on the Columbia Aquifer are limited to the area adjacent to Blows Creek and the Southern Branch of the Elizabeth River. Tidal influences on the Upper Yorktown Aquifer are limited to the area near the Southern Branch of the Elizabeth River.

Nature and Extent of Contamination

Extent of Waste

Site 3

An electromagnetic geophysical survey at Site 3 showed no anomalies in the waste disposal area. The results of the trenching activities indicated visual signs of potentially burnt/stained soils, debris (wires, tin cans, metal strapping, and wood), and spent ordnance (dummy fuze, a distress flare, and a 40-mm shell). The burnt/stained soil extended to a maximum depth of 2.5 ft bgs, and debris was generally located within the first 2 ft of the test pit. Trenching activities indicated that Site 3 is approximately 2.1 acres, significantly smaller than the previously estimated 10.

Site 4

Electromagnetic and ground penetrating radar geophysical surveys at Site 4 showed anomalies typical of landfill materials and numerous buried objects suspected to be concrete blocks, metal pipes, drums, or other reflective materials. Similar materials were also visually observed on the ground surface during the geophysical survey. Trenching activities were not conducted at Site 4.

Site 5

The electromagnetic geophysical survey at Site 5 showed anomalies associated with metallic and other objects on the ground surface. Trenching activities indicated visual signs of burnt/stained soils, construction debris (wires, ceramics, brass, glass, and wood), and spent ordnance material (spent percussion primer and a Mark 7 cartridge case). The burnt/stained soils were identified to a depth of no more than 26 inches (in.) bgs, and debris was generally located within the first 16 in. of the test pit. Based on the results of the trenching activities,

the extent of the Site 5 boundaries was expanded to the north; the burning grounds waste disposal area is approximately 3 acres.

Site 6

An electromagnetic survey at Site 6 identified conductivity and magnetic anomalies in the area considered to be the former caged pit. Trenching activities indicated concrete within 6 in. of ground surface and an M3 initiator switch; no signs of burnt/stained soils were encountered.

Summary of Site 3 Analytical Results

Constituents in surface and subsurface soils reflective of potential impacts from Site 3 were metals, PAHs, and dioxin. The highest concentrations of metals exceeding background upper tolerance limits (UTL) are limited to the waste area and one surface soil location outside the waste. Central-tendency comparisons to dredge fill background show metals concentrations in Site 3 soils were similar to background. Statistically elevated over background, the PAHs anthracene and phenanthrene in surface soil were limited to the waste area and below risk screening criteria in subsurface soil.

Iron and manganese were consistently detected in the Columbia Aquifer in samples at levels above screening criteria and maximum background. There were no MCL exceedances in deep groundwater in the 1999 samples. In the Upper Yorktown Aquifer, only manganese exceeded screening criteria and maximum background. The Upper Yorktown Aquifer does not appear to have been impacted at Site 3.

Several metals and pesticides exceed the background UTL in sediment, and pose a potential risk based on human health and ecological screening. The greatest metals concentrations in sediment were near the Site 3 southeastern waste boundary. The pesticide 4,4'-DDE was present in sediment in both the eastern and western drainage ditches. PCB aroclor-1260 was present near the waste at levels above ecological screening criteria. Although exceeding ecological screening values, PAHs in sediment were below background and reported at estimated concentrations below quantitation limits.

In surface water, several metals and pesticides pose a potential risk based on human health and ecological screening. The greatest metals concentrations in surface water were in the eastern drainage ditch near the southeastern waste boundary, and the greatest pesticides concentrations in surface water were in the western drainage ditch. Significantly elevated metals levels were reported in a sample collected from the north side of the perimeter road northeast of Site 3. This location (SJS03-SW01) is not connected to the drainage ditch near the southeastern waste boundary and would not receive runoff from Site 3 except during significant storms or floods.

Summary of Site 4 Analytical Results

Surface and subsurface soils contained metals elevated above background (UTL and population central-tendency). These were antimony, copper, lead, nickel, and zinc in surface soil and antimony, arsenic, barium, beryllium, copper, iron, lead, manganese, mercury, vanadium, and zinc in subsurface soil. The surface soils also contained PAHs, pesticides, and PCBs. None of the pesticides indicated a statistical difference from background, based

on central-tendency population comparisons, and all pesticide exceedances of background UTLs occurred within the limits of waste. The most significant PCB detection was aroclor-1260 at 6,300 µg/kg within the waste. Soils along the north-southwestern perimeter, adjacent to the waste, contained elevated concentrations of metals in surface and subsurface soils.

In the Columbia and Upper Yorktown Aquifers, several total and dissolved metals were detected in groundwater above tap water RBCs and maximum background value. Of these, only iron and manganese were consistently detected in samples from both shallow and deep wells above screening criteria and background, and the highest concentrations were upgradient of the site, which is downgradient of Site 3.

Several metals and PAHs in sediment pose a potential risk based on human health and ecological screening. Of significance is mercury in sediment in the eastern drainage ditch at 6.4 mg/kg. Although exceeding ecological screening criteria, most PAHs were reported at estimated concentrations below quantitation limits.

In surface water, several metals and carbon disulfide exceeded screening criteria. Of significance is the elevated concentration of metals in surface water at the southwestern boundary of the waste, including a total lead concentration of 746 µg/l.

In general, similar concentrations of constituents found in Site 4 groundwater, surface water and sediment were found in the upgradient Site 3 groundwater, surface water, and sediment.

Summary of Site 5 Analytical Results

Metals, explosives, and dioxins reflect potential contamination in soils within the limits of the waste area. The metals in soil most indicative of site-related activities were characterized by samples within the northern portion and included barium, copper, lead, and zinc. Outside the waste boundary arsenic, barium, lead, chromium, and zinc were elevated in surface soil in localized areas: arsenic to the northeast and southwest; lead in the marsh to the southeast; and antimony, barium, chromium, lead, and zinc south towards Blows Creek. There was not widespread metals contamination in subsurface soil at Site 5. Pesticides were most frequently detected in soils west of Site 5 along the perimeter road and near the drop tower to the southeast of the waste area with no definitive pattern to indicate that these compounds are related to the waste.

In the Columbia Aquifer, total and dissolved beryllium, cadmium, and lead exceeded the MCL in one downgradient groundwater sample. Total and dissolved iron and manganese were elevated in samples from all shallow wells. A few VOCs and SVOCs were infrequently detected at low estimated concentrations in groundwater below the human health and ecological screening criteria. In deep groundwater (Yorktown Aquifer) the explosive RDX was detected in the 1999 sample from MW01D located within the waste.

Metals and pesticides in sediment were elevated in localized areas of the upland drainage ditch and the low-lying marsh area east of Site 5. Although present in some sediment samples, PAH concentrations were similar to Blows Creek reference concentrations.

Metals were elevated in the surface water in the marsh area east of Site 5. One sample in this area contained arsenic, copper, iron, lead, manganese, nickel, and zinc at concentrations that

exceeded the maximum concentration of the reference samples by an order of magnitude as well as screening criteria.

Summary of Site 6 Analytical Results

Site 6 was investigated as part of Site 5, consequently, groundwater, surface water, and sediment samples were not collected there.

Constituents in surface soil reflective of potential impacts from Site 6 are the metals barium and zinc, present at an order of magnitude greater than the background UTL and with statistically elevated central-tendency over the background population. Only barium also exceeded the adjusted residential soil RBC and both compounds exceed the BTAG soil flora/fauna screening values.

Contaminant Fate and Transport

Waste materials and impacted soil, sediment, surface water, and groundwater are sources for contaminant migration and transport at the sites. The principal mechanisms for constituents transport from the waste areas is from surface water runoff and erosion resulting in potential leaching and dissolution of constituents from soil, as well as physical transport to the drainage ditches, where suspended particulates settle to sediment.

Based on the distribution of potential site-related constituents in site media, other potential (but less prominent) mechanisms for transport and migration are: (1) infiltrating precipitation and flow through the vadose zone resulting in the leaching of constituents from soil to the groundwater system, followed by groundwater discharge to low-lying marsh areas and Blows Creek, and during high water-table conditions to the upland drainage ditches; (2) infiltration of surface water in upland drainage ditches during low water-table conditions through the vadose zone resulting in the leaching of constituents from sediment to the groundwater system; (3) suspension and dissolution of constituents from sediment to surface water and transport of surface water and sediment to Blows Creek; and (4) in the southeastern portions of Site 4, it is likely that the water table intersects the waste resulting in potential transport of constituents to the groundwater. During extreme high water-table conditions, groundwater may come in contact with the waste at Sites 3, 5, and 6 and discharge to the upland drainage ditches. Because the sites are vegetated and volatile compounds are not prevalent in site media, wind erosion and volatilization to the atmosphere are not pathways of concern at the sites.

The following summarizes the key elements for the fate and transport of potential site-related constituents at Sites 3, 4, 5, and 6:

Site 3

Surface water runoff and erosion can potentially transport metals, SVOCs, pesticides, and PCBs present in soil to the upland drainage ditches at Site 3. Their presence in sediment suggests physical transport from runoff at the southeast extent of the waste area. Although present, SVOCs, pesticides, and PCBs are not prevalent at high concentrations in site soils, and do not readily dissolve in water but adsorb very strongly to soil and sediment. Thus, these compounds have little or impact on surface water or groundwater. Dioxins in

subsurface soil within the waste have little potential to migrate, as they are relatively insoluble and adsorb strongly to subsurface soil. Metals, either suspended or dissolved in surface water, may migrate to the south within the drainage ditches to Blows Creek. It is also possible that metals, PAHs, pesticides, and the PCB arcolor-1254 in sediment may migrate within the eastern drainage ditch to the south, adjacent to (and merging with) runoff from Site 4, to discharge at Blows Creek.

The presence of some metals, particularly iron and manganese, in the Columbia Aquifer above screening criteria and/or maximum background suggests potential infiltration of precipitation through the vadose zone and leaching from soil to the groundwater system. Although the waste and site soils may contribute to the concentrations of iron and manganese in shallow groundwater, elevated iron and manganese in groundwater upgradient of Site 3 indicate contributions from offsite. The Columbia Aquifer may be a source of dissolved iron and manganese to the Upper Yorktown Aquifer. Metals in shallow groundwater may also be transported through groundwater discharge to Blows Creek and its low-lying marsh areas.

Site 4

Surface water runoff and erosion can potentially transport metals, SVOCs, pesticides, and PCBs present in soil to the upland drainage ditch at Site 4 and the wetland marsh area in the southwest portion of the site. Their presence in sediment suggests physical transport from runoff across the waste area. SVOCs and pesticides, although present, are not prevalent in site soil at significantly high concentrations above background levels, and do not readily dissolve in water but adsorb very strongly to soil and sediment. Thus, there is little to no impact on surface water or groundwater from these compounds. Additionally, PCBs do not readily dissolve in water but adsorb very strongly to soil and sediment. Thus, there is no impact on surface water or groundwater from PCBs present in soil.

PCBs were detected in a surface soil sample at high concentrations within the waste. Low concentrations of arcolor-1260 in the eastern drainage ditch sediment likely reflect the transport of adsorbed PCBs to soil by surface runoff. Metals, either suspended or dissolved in surface water, may migrate to the south in surface water and sediment within the drainage ditch and to the southwestern marsh area of Blows Creek. Significantly elevated mercury levels found in one sediment sample from the eastern drainage ditch may have resulted from transport by surface runoff; however, mercury concentrations in all surface soil samples are low and below background concentrations.

The presence of some metals, in particular iron and manganese, in the Columbia Aquifer above screening criteria and/or maximum background levels, suggests potential infiltration of precipitation through the vadose zone and leaching from soil to the groundwater system. Direct transport to groundwater is possible in the site's southeastern portions, where buried waste may be in contact with shallow groundwater. Although the waste and site soils may contribute to the concentrations of iron and manganese in shallow groundwater, elevated iron and manganese in groundwater upgradient of Site 4 (Site 3 and offsite) indicate contributions to groundwater other than Site 4. The Columbia Aquifer may be a source of dissolved iron and manganese to the Upper Yorktown Aquifer. Metals in shallow groundwater may also be transported through groundwater discharge to Blows Creek and its low-lying marsh areas. The southern extent of Site 4 is expected to be affected by tidal

influx from Blows Creek and the Southern Branch of the Elizabeth River resulting in an exchange of constituents (surface water, sediment, and groundwater) migrating between the southern extent of Site 4 and Blows Creek.

Site 5

Surface water runoff and erosion can potentially transport metals, SVOCs, pesticides, and explosives (2,4-dinitrotoluene) present in soil to the upland drainage swale at Site 5 and to the phragmites marsh area east and southeast of the site. The presence of metals, SVOCs, and pesticides in sediment suggest physical transport from runoff across the waste area. Explosives adsorbed to surface soil do not appear to have migrated from the site as evidenced by the absence of explosive compounds in subsurface soil, sediment, surface water, or shallow groundwater. Dioxins in subsurface soil within the waste also have little potential to migrate, as they are relatively insoluble and adsorb strongly to soil.

Although present, SVOCs and pesticides, are not prevalent at significantly high concentrations above background in site soils, and do not readily dissolve in water but adsorb very strongly to soil and sediment. Thus, these compounds have little impact on surface water or groundwater.

Metals ether suspended or dissolved in surface water runoff may migrate in surface water and sediment to the south within the upland drainage swale and east-southeast to the phragmites marsh area and subsequently to Blows Creek. Significantly elevated metals levels were present in one surface water sample from the phragmites marsh area east of Site 5 that may have resulted from dissolution and suspended soil transport by surface runoff, or analysis of an extremely turbid sample. Metals in surface water downstream of this location were much lower as were metals in the co-located sediment sample at this location.

The presence of some metals, particularly iron and manganese, in the Columbia Aquifer above screening criteria and/or maximum background levels suggests potential infiltration of precipitation through the vadose zone and leaching from soil to the groundwater system. Although the waste and site soils may contribute to the concentrations of iron and manganese in shallow groundwater, elevated iron and manganese in groundwater upgradient of Site 5 (Site 3 and offsite) indicate contributions to groundwater from sources other than Site 5. The Columbia Aquifer may be a source of dissolved iron and manganese to the Upper Yorktown Aquifer. Metals in shallow groundwater may also be transported through groundwater discharge to Blows Creek and low-lying phragmites marsh areas east of the site, and to upland drainage swales during extreme high water-table conditions. The explosive RDX was detected in the Upper Yorktown Aquifer in the 1999 sample from MW01D collected within the waste. The absence of RDX in any other media sampled, including shallow groundwater, suggests the transport mechanism may have been from well installation through the waste. Further evaluation of Site 5 groundwater may be considered to confirm possible RDX contamination.

Site 6

Surface water runoff and erosion can potentially transport metals, and pesticides present in soil at Site 6 to the phragmites marsh area southwest of the site. The area consists of grasses with mixed forest between the site and the marsh area and metals concentrations in soil

were not significantly elevated. Transport of metals through surface runoff and erosion is expected to be minimal.

Baseline Human Health Risk Assessment

A baseline Human Health Risk Assessment (HHRA) was conducted to evaluate the potential human health risks associated with the presence of site-related soil, (surface and subsurface soil combined), surface water, sediment, deep groundwater, and shallow groundwater contamination at Sites 3, 4, 5 and 6 at the SJCA. The baseline risk assessment was conducted to characterize the current and potential future human health risks at each if no additional remediation is implemented. Total potential risks are summarized below for current/future adult and adolescent trespassers, current adult, child, and lifetime residents, future adult, child, and lifetime residents; future adult construction workers; and future adult other workers for each site.

All Sites

- Shallow groundwater (Columbia Aquifer) is not considered a regional potable water source; therefore, human health risks were evaluated based on dermal contact and incidental ingestion under a construction worker scenario, for which results were within acceptable risk ranges.
- No hazards or risks above USEPA target levels (noncarcinogenic hazard of 1 and carcinogenic risk range of 10^{-6} to 10^{-4}) based on industrial use of any of the sites.
- Hazards and risks above USEPA target levels exist if deep groundwater beneath the sites is used as a residential potable water supply and/or the sites are used for future residential development.
- Concentrations of site-related constituents in deep groundwater downgradient of the sites are expected to be less than onsite. Therefore, downgradient uses of groundwater would result in much lower risks than calculated at the sites.

Site 3

- The noncarcinogenic hazards to current and future adult and child residents who use the deep groundwater beneath Site 3 as a potable water supply exceed USEPA's target, primarily based on ingestion of manganese and arsenic in deep groundwater.
- The noncarcinogenic hazards associated with potable use of the deep groundwater also exceed USEPA's target, associated with ingestion of thallium. However, thallium was only detected in a 1997 sample from the upgradient well and not detected in the subsequent sampling rounds.
- Future use for residential development would also result in a carcinogenic risk above USEPA's target based on contact with arsenic in the deep groundwater, soil, and sediment.
- The noncarcinogenic hazard to the future child resident based on arsenic and iron in the soil, and antimony and iron in the sediment also exceeds USEPA's target hazard.

Site 4

- The carcinogenic risk associated with use of the deep groundwater as a potable residential water supply exceeds USEPA's target risk range, mainly associated with arsenic and a smaller contribution from bis(2-ethylhexyl)phthalate and chloroform. Bis(2-ethylhexyl)phthalate and chloroform were only detected in deep groundwater in 1997 and not in subsequent sampling events, and these common lab contaminants may reflect artifacts of the analysis process.
- The noncarcinogenic hazards associated with potable use of the groundwater also exceed USEPA's target hazard, associated with the ingestion of arsenic, iron, and manganese.
- Future residential development would result in a carcinogenic risk slightly above USEPA's target risk range due to arsenic in the soil and the use of groundwater as a potable water supply.
- The noncarcinogenic hazard to a child resident exposed to the arsenic and iron in the soil (and iron in the sediment) exceeds USEPA's target hazard level.

Sites 5 and 6

- Current carcinogenic risks are within or below USEPA's target risk range for all media for all exposure scenarios.
- The site's future residential may result in a carcinogenic risk slightly above USEPA's target risk range associated with the combined exposure to arsenic in the deep groundwater, the soil, and the sediment.
- Although chloroform was also identified as a combined exposure carcinogenic risk in deep groundwater for future residential use, chloroform was only detected in 1997 and not detected in the subsequent sampling rounds. Additionally, chloroform is a common potential lab contaminant and it is suspected that the 1997 sample results reflect artifacts of the sampling and analysis process.
- Potable use of deep groundwater would result in noncarcinogenic hazards in exceedance of USEPA's target HI for adult and child residents. The HI exceedances are primarily attributable to the ingestion pathway due to the presence of antimony, arsenic, iron, and manganese in deep groundwater for adult and child residents.
- Future residential development would result in exceedance of USEPA's target noncarcinogenic hazard to the child resident, primarily attributable to incidental ingestion of arsenic and iron in the soil, and incidental ingestion of (and dermal contact with) arsenic and iron in the sediment.

Screening Ecological Risk Assessment and Baseline Ecological Risk Assessment Step 3

Terrestrial Receptors

- The Ecological Risk Assessment (ERA) indicates the potential for adverse effects to:
  - Lower trophic-level receptors (plants and soil invertebrates) from the presence of chemicals (primarily inorganic chemical and PAHs) in soils at Sites 3, 4, and 5/6; and,
  - Avian and mammalian vermivores from lead and zinc in Site 3 and Site 5/6 soils.

Presumptive remedies/remedial activities currently planned for these sites will eliminate potential risks to ecological receptors by either placing a soil cover over contaminated areas, thus eliminating potential ecological exposure pathways to surface soil, and/or by removing surface soil to reduce chemical concentrations.

- Further investigation of potential risks to terrestrial receptors from the presence of COPCs in soil is not recommended.

Aquatic Receptors

- Inorganic and organic chemicals (predominantly pesticides and PAHs) were detected in site-related drainage sediments at concentrations that could potentially adversely affect aquatic life. However, the drainages above the area of tidal influence provide very little (Sites 4 and 5/6) or no (Site 3) viable habitat for aquatic species based on the limited surface water present. A much greater diversity of aquatic species is expected to occur in Blows Creek and in the tidally influenced lower reaches of the site drainages (immediately adjacent to Blows Creek) and chemicals originating from the site sediments may have been transported to Blows Creek sediment. Further evaluation of the potential for adverse effects to aquatic life in Blows Creek sediment (as a result of chemical transport from Sites 3, 4, and 5/6) is accordingly recommended. This evaluation should include further consideration of the elevated mercury concentrations (more than 6 mg/kg) detected in the Site 4 drainage sediments adjacent to Blows Creek.

- Chemicals present in surface water (primarily inorganic chemicals) may also have limited potential to adversely affect aquatic life. As with sediment, there is the potential for chemical transport to Blows Creek, where a variety of aquatic species could be exposed to chemicals in surface water or following deposition to sediment. Further consideration of potential risks to aquatic life resulting from chemicals in surface water may be warranted. It is, however, recommended that any additional site investigations focus on Blows Creek sediment. This conclusion is based on the transient nature of surface water and the expectation that Blows Creek sediment is the primary source of chemicals to surface water.

- Step 3A risk calculations indicated the potential for adverse effects to avian piscivores and reptiles from mercury in drainage sediments at Sites 4 and 5/6. Avian piscivores and reptiles are, however, expected to spend most of their time foraging in the higher-quality aquatic habitats provided by Blows Creek. Only limited data are currently

available for Blows Creek. The potential adverse effect to all aquatic-based wildlife considered in this ERA should, therefore, be further screened if additional data are collected from this water body. It is recommended that further evaluation focus on the characterization of chemical concentrations in Blows Creek sediment, which would be the repository for potentially bioaccumulative chemicals.

Risk Management

The findings of the RI activities, including site characterizations, extent of contamination, fate and transport of contaminants, and risks identified in the human health and ecological risk assessments, provide the basis for evaluating potential remedial alternatives for the protection of human health and the environment. Risk management is an essential consideration in assessing remedial alternatives protective of human health and the environment. This necessitates an understanding of the uncertainties inherent in the risk assessment process and identification of site-related contaminant releases with regard to naturally occurring compounds, anthropogenic compounds, and compounds typically reported in environmental media that are common artifacts of the sampling and analytical process.

Remedies under consideration by the SJCA Partnering Team include removal and/or soil cover to address potential risk from exposure to surface soil and upland ditch sediment. Mitigation of risk through remedial actions for surface soil and upland ditch sediment will also eliminate concern for continued transport of potential contaminants to Blows Creek. To identify risk associated with potential historical contributions to Blows Creek via transport in upland drainages, a Baseline Ecological Risk Assessment (BERA) for Blows Creek is scheduled for FY 2003. In partnership, the Navy, USEPA, and VDEQ is evaluating the following risk management considerations for the sites:

Site 3

Concurrent with the completion of this RI, the SJCA Partnering Team (Navy, USEPA, and VDEQ) developed an Engineering Evaluation Cost Analysis (EE/CA) for a removal action at Site 3. The selected alternative consists of the complete removal of waste and debris at Site 3, the removal of soil posing a potential risk outside the waste area (SJS03-SS15), and the removal of surface sediment in the upland drainage ditches. The SJCA Partnering Team may consider additional soil sampling at Site 3 in support of evaluating FS alternatives.

Human health risk drivers for the deeper Upper Yorktown Aquifer are arsenic, manganese, and thallium. Arsenic was only detected in one unfiltered sample in the upgradient well and the concentration was below the MCL. Total and dissolved manganese were detected in samples from both deep wells at concentrations below the tap water RBC. Total thallium exceeded the tap water RBC and MCL in a 1997 sample from the upgradient well but was not detected in the subsequent sampling rounds. The Navy, EPA, and VDEQ agreed risk management of groundwater is warranted with no further action. The SJCA Partnering Team is also considering risk management of vanadium copper, and lead in Site 3 surface soil outside the limits of waste and "hot spot" SJS03-SS15.

Site 4

A presumptive remedy consisting of a minimum 2-ft soil cover over Site 4 is currently being considered by the SJCA Partnering Team. Risks associated with constituents in site soil will be addressed in the feasibility study (FS) for Site 4. Land use restrictions and prohibitions on groundwater use are anticipated for risk management because Site 4 is a landfill and expected to remain in place.

The primary human health risk drivers for the deeper Yorktown Aquifer are arsenic, iron, and manganese. However, bis(2-ethylhexyl)phthalate and chloroform were also identified as deep groundwater risk drivers. Bis(2-ethylhexyl)phthalate was only detected at one well in 1997 but not detected in the previous or subsequent sampling rounds. Chloroform was detected in 1997 samples from both wells at concentrations below the MCL and not in the two subsequent sampling events conducted. The SJCA Partnering Team will consider addressing bis(2-ethylhexyl)phthalate and chloroform in the Yorktown Aquifer in 1997 as possible false positives.

Sites 5 and 6

Presumptive remedies currently under consideration for Site 5 by the SJCA Partnering Team consist of soil cover and/or removal of waste/soil/sediment posing potential risk. Risks associated with Site 5 will be addressed in the site's Feasibility Study (FS). Because Site 6 is a very small area where remnants of the caged pit are believed buried, the SJCA Partnering Team agreed that complete removal of the caged pit and associated potential risk to soil at Site 6 was warranted. Site 6 is included in the EE/CA with Site 3 and the removal of Site 6 was completed in the summer of 2002. The SJCA Partnering Team may consider additional soil sampling at Site 5 in support of evaluating FS alternatives.

Human health risk drivers for the deep groundwater in the Upper Yorktown Aquifer are antimony, arsenic, iron, manganese, and chloroform. Total antimony was detected in two samples collected from SJS05-MW02D at concentrations below the MCL and tap water RBC. Total arsenic was only detected, at a concentration below the MCL, in 1997 from SJS05-MW02D and not detected in the two subsequent sampling rounds. Total and dissolved iron and manganese were detected in multiple rounds of sampling from all three wells at concentrations that exceeded the respective tap water RBCs. In the most recent sampling event, all iron and manganese concentrations were below the maximum background concentration. Chloroform was also identified as a deep groundwater risk driver; however, a review of the data shows that chloroform was detected in two 1997 samples but not in the subsequent sampling rounds. The SJCA Partnering Team will consider risk management of metals and chloroform in the Yorktown Aquifer at Site 5/6 through removal of source waste and soils.

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Acronyms and Abbreviations

AEDS	American Environmental Drilling Services
AOCs	Areas of Concern
BAFs	bioaccumulation factors
BCF	bioconcentration factor
BERA	baseline ecological risk assessment
BTAG	Biological Technical Assistance Group
CDDs	polychlorinated dibenzodioxins
CDFs	polychlorinated dibenzofurans
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLEAN	Comprehensive Long-Term Environmental Action Navy
COPCs	contaminants of potential concern
CRDL	Contract Required Detection Limit
CRQL	Contract Required Quantitation Limit
CSF	Cancer slope factor
CT	central-tendency
CTO	Contract Task Order
DDD	Dichlorodiphenyldi-chloroethane
DDE	Dichlorodiphenyldichloro-ethene
DDT	Dichlorodiphenyltrichloro-ethane
DEHP	di2-ethylhexyl phthalate
DNH	Division of Natural Heritage
DO	dissolved oxygen
DOD	Department of Defense
DPT	direct-push technology
DRO	Diesel Range Organics
EE/CA	Engineering Evaluation/Cost Analysis
EOD	Explosives Ordnance Detachment
EPC	Exposure point concentration
EPIC	Environmental Photographic Interpretation Center
ERA	ecological risk assessment
ERT	Earth Resources Technology
FS	feasibility study
ft^2/day	square ft per day
gpd/ft	gallons per day per ft
gpm	gallons per minute
GPR	ground penetrating radar
GRO	Gasoline Range Organics

HEAST	Health Effects Assessment Summary Tables
HHRA	Human Health Risk Assessment
HI	The hazard index
HQ	hazard quotient
HSDB	Hazardous Substances Data Bank
IAS	initial assessment study
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
K	hydraulic conductivity
LANTDIV	U.S. Navy, Naval Facilities Engineering Command, Atlantic Division
LMS	linearized multistage
LOAELs	Lowest Observed Adverse Effect Levels
MCLs	Maximum Contaminant Levels
MFs	modifying factors
MGD	million gallons per day
MS/MSD	matrix spike/matrix spike duplicates
msl	mean sea level
NAB	Naval Amphibious Base
NACIP	Naval Assessment and Control of Installation Pollutants
NAD	Naval Ammunition Depot
NCEA	National Center for Environmental Assessment
NOAELs	No Observed Adverse Effect Levels
NPL	National Priorities List
NUS	NUS Corporation, Superfund Division
OD	outer diameter
OE	Ordnance/explosives
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
PA	Preliminary Assessment
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
psi	per square inch
PVC	polyvinyl chloride
PWC	public works center
QA/QC	quality assurance/quality control
QC	quality control
RAGS	*Risk Assessment Guidance for Superfund*
RBC	Risk-Based Concentration
RCRA	Resource Conservation and Recovery Act

RFA	RCRA Facility Assessment
RfDs	reference doses
RFIs	RCRA Facility Investigations
RI	Remedial Investigation
RME	reasonable maximum exposure
RRR	Relative Risk Ranking
RTECS	Registry of Toxic Effects of Chemical Substances
SERA	screening ecological risk assessment
SFs	slope factors
SIR	Subsurface Interface Radar
SQL	sample quantitation limit
SSA	Site Screening Assessment
SVOCs	semivolatile organic compounds
SWMU	Solid Waste Management Unit
TAL	Target Analyte List
TCDD	Tetrachlorodibenzo-p-dioxin
TCE	Trichloroethene
TCL	Target Compound List
TCLP	Toxicity Leaching Characteristic Procedure
TEFs	toxicity equivalency factors
TEQ	toxic equivalency
TICs	tentatively identified compounds
TNT	trinitrotoluene
TOC	total organic carbon
TPHs	total petroleum hydrocarbons
UCL	upper confidence limit
UFs	uncertainty factors
USEPA	United States Environmental Protection Agency
USFWS	U. S. Fish and Wildlife Service
UTLs	upper tolerance levels
VAWQS	Virginia Water Quality Standard
VDEQ	Virginia Department of Environmental Quality
VOCs	volatile organic compounds
VSI	visual site inspection

SECTION 1

Introduction

This report presents the data, results, and conclusions of the Remedial Investigation (RI) of Site 3 (Waste Disposal Area), Site 4 (Landfill D), Site 5 (Burning Grounds), and Site 6 (Small Arms Pit) at the SJCA of the Norfolk Naval Base, in Chesapeake, Virginia. The locations of St. Juliens Creek Annex (SJCA) and Sites 3, 4, 5, and 6 are shown in Figures 1-1 and 1-2, respectively. This RI report includes a baseline quantitative HHRA and an ERA (Steps 1 through 3a) for Sites 3, 4, 5, and 6.

RI activities at Sites 3, 4, 5, and 6 commenced in 1997 under the *Final Landfill B and the Burning Grounds Work Plan* and the *Final Landfill C and Landfill D Work Plan,* both dated May 1997 (CDM, 1997). Results of the RI activities were reported in a draft RI report in February 1998. CDM met with the United States Environmental Protection Agency (USEPA), Virginia Department of Environmental Quality (VDEQ), and the Biological Technical Assistance Group (BTAG) and determined that additional data collection was necessary to fully define the extent of contamination at Sites 3, 4, 5, and 6. A *Final Supplemental Field Investigation Plan for Landfill B and the Burning Grounds* and a *Final Supplemental Field Investigation Plan for Landfill C and Landfill D* were prepared in March 1999 to address the additional data needs (CDM, 1999). This RI report presents results and conclusions for data collected as part of the initial investigation as well as that collected during previous and subsequent investigations.

This RI's broad purpose was to collect sufficient data so that, supplemented by existing data, the three-dimensional nature and extent of contamination and potential risks to human health and the environment posed by the contaminants could be evaluated and characterized at each site. The data in this RI report will assist in making risk management decisions and in identifying potential remedial alternatives, if needed, during a subsequent feasibility study (FS).

This RI report was prepared by CH2M HILL under the U.S. Navy, Naval Facilities Engineering Command, Atlantic Division (LANTDIV), Comprehensive Long-Term Environmental Action Navy (CLEAN) II Contract N62470-95-D-6007, Contract Task Order (CTO) 0027, for submittal to LANTDIV, the SJCA Installation Restoration (IR) Program, USEPA, and VDEQ.

1.1 Objectives and Approach

In order to achieve the purpose of this RI, the following objectives were identified:

- Define the nature and extent of surface and subsurface soil, groundwater, sediment, and surface water contamination associated with Sites 3, 4, 5, and 6 to an extent sufficient for a FS, if needed, at the site;
- Evaluate the geologic and hydrogeologic systems at Sites 3, 4, 5, and 6 to further understand contaminant distribution and potential contaminant migration pathways; and,

- Determine if the sites pose unacceptable human and ecological risks.

Historical data, as well as data collected during this RI, were evaluated in order to achieve the above mentioned objectives.

1.2 Report Organization

This RI report comprises the following sections:

- Section 1—Introduction
- Section 2—Background Description
- Section 3—Field Investigation Activities
- Section 4—Physical Characteristics
- Section 5—Nature and Extent of Contamination
- Section 6—Contaminant Fate and Transport
- Section 7—Baseline HHRA
- Section 8—Screening ERA and Step 3
- Section 9—Conclusions

Figures and tables are provided in Volume II, and Appendixes are provided in Volume III. References are provided at the end of each section.

1.3 References

CDM Federal. *Final Landfill B and the Burning Grounds Work Plan.* St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. May 1997.

CDM Federal. *Final Landfill C and Landfill D Work Plan.* St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. May 1997.

CDM Federal. *Final Supplemental Field Investigation Plan Landfill B and the Burning Grounds.* St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. March 1999.

SECTION 2

Background Description

This section describes background information associated with SJCA and Site 3, 4, 5, and 6. Sections 2.1 through 2.3 contain information on the history, mission, operations, and land use at the SJCA facility. A history of regulatory involvement at St Juliens Creek Annex is presented in Section 2.4. Background and historical information for Sites 3, 4, 5, and 6 is provided in Sections 2.5 through 2.8, respectively. Previous investigations at St Juliens Creek Annex and at the sites addressed in this RI are provided in Section 2.9. Current IRP activities at St Juliens Creek Annex are summarized in Section 2.10.

Background information was obtained primarily from the *Phase II RCRA Facility Assessment of the St. Juliens Creek Annex Facility* (A.T. Kearney, Inc., 1989), the *Navy Assessment and Control of Installation Pollutants: Initial Assessment Study of St. Juliens Creek Annex* (NEESA, 1981), and the *Final Master Project Plan* (CDM, 2000).

2.1 St. Juliens Creek Annex History

The SJCA began operations as a naval ammunition facility in 1849. At that time, the area, known as Fort Norfolk, was transferred from the War Department to the Navy Department for use as a storage facility for ordnance and materials. The facility was renamed Magazine, Fort Norfolk. In 1896, the facility gained an additional 48 acres to accommodate additional magazines, wharves, housing, and administrative buildings. In 1898, ordnance material and equipment were moved from Craney Island to the Magazine; the facility was renamed U.S. Arsenal, St. Juliens Creek.

In 1902, the name was changed to U.S. Naval Magazine, St. Juliens Creek. The Magazine was at that time fully operational and provided critical support to the fleet during the end of the Spanish-American War.

In 1915, modernized motor-powered machines replaced manually operated machines at the facility. In 1917, the facility installed equipment for loading MARK VI mines. The facility's name was changed again, to Naval Ammunition Depot (NAD)—St. Juliens Creek, and operated under the Commandant, Fifth Naval District.

Between World War I and World War II, the facility assumed a mission of supplying ammunition to the fleet.

The facility operated at its peak level during World War II. An additional 119 acres of land were purchased and additional magazines, filling houses, and other facilities were constructed. A fence was erected to secure the facility. The mission of NAD-St. Juliens Creek during World War II included loading, assembling, issuing, and receiving naval gun ammunition. The depot also served as the principal experimental and test loading facility for new ammunition types for the Bureau of Ordnance.

The depot also supplied ammunition during the Korean War. After the war, the depot again resumed its mission of peacetime service to the fleet. In 1964, the depot was the prime source of gun ammunition for the Navy and Marine Corps operations in Southeast Asia.

In October 1969, after 50 years as an independent facility, NAD-St. Juliens Creek was disestablished under the Department of Defense (DOD) "Project 703," and was consolidated as an annex to the Naval Weapons Station, Yorktown, Virginia. On October 1, 1977, the Annex was transferred to the Norfolk Naval Shipyard.

The Norfolk Naval Shipyard transferred the Annex to Naval Base, Norfolk in July 1995. The Class II property on the Annex was transferred from Naval Base to Naval Station in April 1996.

2.2 St. Juliens Creek Annex Mission and Operations

Activity at the Annex has decreased in recent years due to current events. The current primary mission of the SJCA facility is to provide a radar testing range and various administrative and warehousing facilities for nearby Norfolk Naval Shipyard and other local Naval activities. SJCA also provides administrative offices, light industrial shops and storage facilities for tenant naval commands.

A high electric transmission line owned by Dominion Virginia Power bisects the facility (Figure 1-2). Currently, structures northwest of the power line are predominantly used for storage and warehousing, while those southeast of the power line are light industrial, manufacturing, and housing facilities; the search radar test range for the Norfolk Naval Shipyard is also located here.

In the past, operations at the SJCA facility have included general ordnance operations involving wartime transfer of ammunitions to various other U.S. Naval facilities throughout the United States and abroad. In addition, the Annex has been involved in specific ordnance operations and processes including those involving black powder operations, smokeless powder operations, projectile loading operations, mine loading, tracer mixing, testing operations, and decontamination operations.

The SJCA facility has also been involved in non-ordnance operations, including paint, machine, vehicle-and-locomotive maintenance, pest-control, battery, print, and electrical shops; degreasing operations; boiler-plant operations; wash-rack operations; potable- and saltwater fire-protection systems; and fire training operations. The locomotive maintenance, printing, and pest control operations have been discontinued.

Materials stored at the SJCA facility have included oil, ordnance materials, non-ordnance chemicals, and disaster-preparedness chemicals. Various parts of the facility are used to store small amounts of waste before transfer to accumulation points.

2.3 St. Juliens Creek Annex Location and Land Use

The SJCA Facility is situated at the confluence of St. Juliens Creek and the Elizabeth River in the City of Chesapeake, southeastern Virginia (Figure 1-1). The facility covers approximately 490 acres and includes administrative buildings, wharf areas to the Elizabeth River, a central heating plant, numerous non-operational industrial facilities, and miscellaneous structures.

The facility is bordered on the north by the Norfolk and Western Railroad, the City of Portsmouth, and residential areas; to the west by residential areas; to the south by St. Juliens Creek; and to the east by the Southern Branch of the Elizabeth River (Figure 1-1). Most of the surrounding areas are developed, and include residences, schools, recreational areas, and shipping facilities for several large industries. The Norfolk Naval Shipyard is located approximately 1.5 miles (mi.) to the north. Some undeveloped areas are located in various areas surrounding the facility.

There is a large concentration of military installations within a 25-mi. radius of the facility, including: Naval Base Norfolk, Fort Monroe, Langley Air Force Base, and Norfolk Naval Shipyard to the north; Naval Amphibious Base and Fort Story on the east; Naval Air Station Oceana on the southeast; and Naval Supply Center-Craney Island Fuel Terminal on the southwest.

There are many neighboring industrial properties located near SJCA with a large concentration located along the Southern Branch of the Elizabeth River. These facilities are located along tidally influenced water bodies, such as the Southern Branch of the Elizabeth River and its tributaries. Notable neighboring industries or other facilities include:

- Atlantic Wood Industries Inc. (approximately 1.25 mi. north)—used for the treatment and storage of wood products until 1991.
- Portsmouth School Board (approximately 1.25 mi. north)—operates a vehicle maintenance facility that has operated since 1974 and included as many as five underground storage tanks (UST) for gasoline and oil.
- British Petroleum Oil Company (approximately 1.25 mi. north)—a bulk fuel storage facility until 1992, then used to sandblast until 1996.
- The Southeastern Public Service Authority (SPSA) (approximately 1 mi. north)—currently operates a refuse-derived fuel (RDF) processing plant.
- Eppinger and Russell Company (1/2 mi. east)—has been identified as a hazardous waste site by the USEPA.

The Elizabeth River watershed receives pollutant loads from both point and non-point sources. Point sources include industrial, municipal, and federal waste treatment and management facilities discharging to surface waters, while a non-point source pertains to stormwater runoff. Metals and polycyclic aromatic hydrocarbons (PAHs) loads are of particular concern in the Elizabeth River. The estimated input of metals to the Elizabeth River watershed is estimated to exceed 100,000 pounds per year, 12 percent of which is attributable to point sources and 88 to non-point sources. The estimated input of PAHs to the Elizabeth River watershed exceeds 1.1 million pounds per year, with 99 percent of that load the result of stormwater runoff (URS Consultants, 1996).

There have been several studies done in the Elizabeth River and the watersheds surrounding SJCA. Several of these documents are provided on CD in Volume III, but are not summarized in this report. Data from these studies will be evaluated in future watershed evaluations related to CERCLA sites at SJCA.

2.4 Regulatory Background

In 1975, the DOD began a program to assess past hazardous and toxic materials storage and disposal activities at military installations. The goals of this program, now known as the Installation/Restoration Program (IRP), were to identify environmental contamination resulting from past hazardous-materials management practices, assess the impacts of the contamination on public health and the environment, and provide the required corrective measures to mitigate adverse impacts to public health and the environment.

The Resource Conservation and Recovery Act (RCRA) was passed by Congress in 1976 to address potentially adverse human health and environmental impacts of hazardous waste management and disposal practices. RCRA was legislated to manage the present and future disposal of hazardous wastes. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or "Superfund," was passed in 1980 to investigate and remediate areas resulting from past hazardous-waste management practices. These programs are administered by the USEPA or state agencies.

In 1981, the DOD's IRP was reissued, with additional responsibilities and authorities specified in CERCLA delegated to the Secretary of Defense. The Navy subsequently restructured the IRP to match the terminology and structure of the USEPA CERCLA Program. The current IRP is consistent with CERCLA and applicable state environmental laws.

SJCA was listed on the USEPA National Priorities List (NPL) in August 2000. The Navy is acting in partnership with the USEPA and VDEQ to address environmental investigations at the Base, and its environmental condition is being investigated through the IRP.

2.5 Site 3 History and Description

Site 3 (Waste Disposal Area) covers approximately 2.1 acres in the northeastern corner of the Annex and is accessible by way of Patrol Road (Figure 1-2). In earlier documents, Site 3 was referred to as "Dump C" or "Landfill C" and the extent of Site 3 was reported to be about 10 acres. Intrusive investigations conducted as part of this RI show that Site 3 is not a landfill and the extent of waste at Site 3 is substantially smaller than previously reported.

The Site 3 area was originally a mudflat where refuse was allowed to burn; the ash was then used to fill in the area. The area is unlined. Operations began in 1940 and continued until 1970. After 1970, the area was graded level and covered with grass (CDM, 1999). Review of historical aerial photographs, reviewed by USEPA's Photographic Interpretation Center, indicate that prior to use as a disposal area, the site, and much of the adjacent area, had been used for placement of dredge spoil material (USEPA, 1995).

Refuse disposed at Site 3 included solvents, acids, bases, and mixed municipal waste. Prior to burning, the total volume of solvent, waste oil, and oil sludge disposed was estimated to be about 27,778 cubic yards. Salvageable materials were removed from the site each day, and once every 2 weeks the site was bulldozed for compaction and leveling.

Two pits at Site 3 were reportedly used for disposal of oil and oily sludge, as well as for periodic burning. The locations of the waste disposal pit and waste disposal area were outlined based on historical aerial photographs taken in 1958, 1961, 1964, and 1970 that were

interpreted by USEPA (USEPA, 1995). As identified in the photographs, the disposal pits were located along the north side of the dirt road that crosses the site diagonally. USEPA also interpreted ground scarring along the road to be possible waste disposal areas (CDM, 1999).

2.6 Site 4 History and Description

Site 4 (Landfill D) covers an estimated 12.5 acres approximately 300 ft south of Site 3 (Figure 1-2). The areal extent of Site 4 was previously reported to be about 5 acres. A review of historical aerial photographs and site reconnaissance during Phase III of the RI show that the extent of Site 4 is greater than previously thought, extending west from the original site boundary. No Phase III RI trenching activities were conducted at Site 4.

Site 4 consisted of a series of unlined trenches and a landfill that reportedly operated from 1970 to 1981. The first trench was identified on a historic aerial photograph from 1961, well before the reported start date of 1970. The first trench was approximately 500 ft long and was located parallel to and about 200 ft north of Blows Creek. The original trench and others were filled with soil from subsequent trenches. The total number of trenches in use at Site 4 is not known (CDM, 1999).

Refuse disposed of at Site 4 included solvents, acids, bases, PCBs, and drums of unknown wastes. According to Base Public Works Center (PWC) personnel, the PCBs most likely came from ballast containers for fluorescent light fixtures; it is not known whether or not these were sealed units. The RCRA Facility Assessment (RFA) indicated that several tanks with undetermined wastes were also once located there. Total disposal volumes are not known (CDM, 1999), however, the *Hazard Ranking System Documentation Record for St Juliens Creek Annex,* Tetra Tech EM Inc. (January 2000) estimated that 1,500,000 cubic yards of waste were disposed at Site 4.

2.7 Site 5 History and Description

Site 5 (the Burning Grounds) consists of approximately 3 acres located off of Craddock Street in the northern portion of the facility (Figure 1-2). The site currently consists of an open field with the southwestern portion overgrown with phragmites. A significant portion of the south-central area of the site is covered with a layer of gravel. The area where burning is thought to have occurred was determined from aerial photographs and interviews with Mr. Bryant, a Navy employee present during past burning activities. It was determined during a waste delineation activity that the remaining unburned material was pushed to the north of the burning activities.

The exact start and closure dates of the Burning Grounds are unknown, although it is believed to have operated between the 1930s and 1970s where waste ordnance materials were disposed by open burning. In 1977, the ground surface at Site 5 was burned with straw, diced, and burned again in an effort to remediate the soil. One report stated that oil was mixed with the straw; however, a former Navy employee who had worked at the Burning Grounds stated that no oil was burned with the straw (CDM, 1999).

Wastes disposed at Site 5 include ordnance materials such as black powder (mixture of charcoal, nitrate, and sulfur), smokeless powder (nitrocellulose), Explosive D (ammonium

picrate), Composition A-3 (contains RDX and wax), tetryl, trinitrotoluene (TNT), and fuzes. Other wastes consisted of carbon tetrachloride, trichloroethene, paint sludge, pesticides, and various types of refuse (CDM, 1999). The amount of ordnance disposed of varied from year to year and there is insufficient information to calculate waste volume.

2.8 Site 6 History and Description

The Small Arms Pit, also called the Caged Pit, was operated as part of the ordnance disposal operations at the Annex. It was located northeast of Site 5 (the Burning Grounds) and consisted of a 100-ft^2 pit with a cage over it. Historical records do not provide dates of operation. However, a review of historical aerial photographs conducted during Phase III indicated that activities associated with Site 6 began around 1949 and continued through the early 1980s. According to the RFA report, an unknown volume of small items, such as igniters and fuzes, were burned in the pit. The 1989 RFA also reported that the Navy had filled in the pit "during recent years." Currently, there is no surface evidence of the Caged Pit at Site 6, and the area is grass covered. Due to its proximity to the Burning Grounds, this site was previously investigated as part of Site 5.

2.9 Previous Basewide and Site Investigations

Previous basewide investigations completed through the IRP include the Initial Assessment Study (IAS), August 1981; and a Relative Risk Ranking (RRR) System Data Collection Report, April 1996. In addition, USEPA Region III conducted two assessments at the Annex: a Preliminary Assessment (PA), dated 1983; and a Phase II RFA, dated March 1989.

2.9.1 Initial Assessment Study—1981

In 1981, the Navy conducted the IAS as part of the Naval Assessment and Control of Installation Pollutants (NACIP) Program. The purpose was to identify and assess sites that posed a potential threat to human health or the environment because of contamination from past handling of (and operations involving) hazardous materials. The study results revealed that low-level concentrations of ordnance materials exist throughout the facility. However, the sites identified, which included Sites 3, 4, 5, and 6, were determined not to pose a threat to human health and the environment, and no confirmation study was conducted. No sampling was conducted as part of the study.

2.9.2 Preliminary Assessment—1983

In 1983, NUS Corporation, Superfund Division (NUS), conducted a PA at seven sites at the facility:

- Cross and Mine (Solid Waste Management Unit [SWMU] 9 [renamed Site 8]);
- Building 249 (SWMU 13);
- Dump A (SWMU 1 [renamed Site 1]);
- Dump B (SWMU 2 [renamed Site 2]);
- Dump B Incinerator (SWMU #3 [included with Site 2]);
- Dump C (SWMU #5 [renamed Site 3]); and
- Dump D (SWMU #6 [renamed Site 4]).

Ambient air at each site, including Sites 3 and 4, was monitored for volatile organic compounds (VOCs) and radiation with an organic vapor meter and radiation meter, respectively. No readings above background were encountered and NUS did not observe significant signs of contamination at the sites. However, the PA report mentioned that various locations on the facility were contaminated with low-level residues of pesticide and herbicide materials.

2.9.3 Phase II RCRA Facility Assessment—1989

In 1989, A.T. Kearney, Inc. and K.W. Brown and Associates, Inc. prepared a Phase II RFA. The RFA included a preliminary review of all available relevant documents and a visual site inspection (VSI) for 34 SWMUs and Areas of Concern (AOCs). RCRA Facility Investigations (RFIs) were recommended at 11 the SWMUs and AOCs. No sampling was conducted during the RFA. Sites 3, 4, 5, and 6 were included in this 1989 Phase II RFA.

Sites 3 and 4 were recommended for further investigation and sampling due to the following:

- High potential for release to soil and groundwater due to the unlined nature of the Sites and the shallow depth to groundwater at the Annex (less than 10 ft);
- Moderate to high potential for release to surface water via groundwater discharge and due to the close proximity of Blows Creek;
- High potential for releases to air from open burning of wastes; and
- Moderate to high potential for release of subsurface gas based on the volatile nature of wastes disposed.

Sites 5 and 6 were addressed as one unit in the RFA. At the Burning Grounds, a faint hydrocarbon odor was noted emanating from the soil and several abandoned automotive vehicles were observed during the VSI. However, the unit has been inactive since 1977 and it was concluded that there was a low potential for ongoing releases to air. Site 5 was recommended for further investigation and sampling due to the following:

- High potential for release to soil and groundwater due to the waste burning on the ground surface and the shallow depth to groundwater at the Annex (less than 10 ft);
- Moderate to high potential for release to surface water via groundwater discharge and due to the close proximity of Blows Creek; and
- Moderate to high potential for release of subsurface gas based on the volatile nature of wastes disposed.

The RFA recommended that further investigation at Site 6 should be combined with any RFI activities at Site 5.

2.9.4 Relative Risk Ranking System Data Collection Report—1996

In April 1996, CH2M HILL submitted a RRR System Data Collection Report for the SJCA to the Department of the Navy. The report contained results from sampling at 21 sites where data had not previously been available. The sampling effort's goal was to gather data for the Navy to perform assessments of the sites using the Navy's RRR System.

Sites 3, 4, 5, and 6 were sampled as part of the RRR System Data Collection. Table 2-1 summarizes the number and analyses of surface soil and groundwater samples collected from Sites 3, 4, and 5. The surface soil samples were collected using stainless-steel trowels at a depth of 0 to 1 ft. Groundwater samples were collected using Geoprobe© direct-push sampling equipment. Samples were collected to characterize the sites and determine the types of contaminants associated with each site. Samples were analyzed for Target Compound List (TCL) VOCs, semivolatile organic compounds (SVOCs), pesticides, PCBs, Target Analyte List (TAL) inorganics, total phosphorus, and explosives. No background or quality control (QC) samples were collected. The analytical results from the RRR System data collection at Sites 3, 4, 5, and 6 are presented in Table 2-2.

2.9.4.1 Site 3 Results

Two surface soil (0 to 1 ft) and three groundwater samples were collected from Site 3 (Figure 2-1). The analytical results of the RRR study are shown in Table 2-2. Organic compounds, including 4,4-DDE (17 μg/kg), 4,4-DDT (7.9 μg/kg), fluoranthene (660 μg/kg), and pyrene (520 μg/kg), were detected in surface soil sample 03SS01 collected in the northeast corner of the 1996 Site 3 boundary. PCB Aroclor-1254 (44 μg/kg detected in 03SS02) and several other organic and inorganic compounds were also detected in the surface soil samples collected in the central/northeastern corner of the 1996 Site 3 boundary. No VOCs were detected in surface soil samples.

None of the pesticides or PCBs were detected in surface soil were detected in direct-push groundwater samples. Although no explosives were detected in surface soil, three explosives (1,3,5-trinitrobenzene, 2,6-dinitrotoluene, and 4-nitrotoluene) were detected in direct-push groundwater samples collected at three locations at Site 3. Several SVOCs were also detected in groundwater samples. The majority of the SVOCs detected and the highest SVOC concentrations detected were found in groundwater sample 03GW01 in the northeast corner of the 1996 Site 3 boundary. Several inorganics also were detected in the groundwater samples.

2.9.4.2 Site 4 Results

Two surface soil and three groundwater samples were collected from Site 4 (Figure 2-2). The analytical results of the RRR study are shown in Table 2-2.

Pesticides and PCBs, including 4,4-DDD (20 μg/kg), 4,4-DDE (18 μg/kg), 4,4-DDT (64 μg/kg), Aroclor-1254 (260 μg/kg), alpha-chlordane (34 μg/kg), gamma-chlordane (45 μg/kg), and dieldrin (34 μg/kg) were detected in surface soil samples at Site 4. Several polycyclic aromatic hydrocarbons (PAHs), including benzo(a)anthracene (1,300 μg/kg), benzo(a)pyrene (1,900 μg/kg), and benzo(b)fluoranthene (3,100 μg/kg), were also observed in surface soil samples.

Acetone (25 μg/l) was detected in one groundwater sample (04GW01) located in the northeastern corner of Site 4. No other organic compounds were detected in groundwater samples. Several inorganic analytes were detected in both soil and groundwater samples.

2.9.4.3 Site 5 Results

Four surface soil and four groundwater samples were collected from Site 5 (the Burning Grounds) and surrounding area (Figure 2-3). The analytical data are summarized in Table 2-2.

Pesticides, including 4,4-DDD (3.9 μg/kg), 4,4-DDE (18 μg/kg), and 4,4-DDT (6.3 μg/kg) were detected in Site 5 surface soil samples 05SS01 and 05SS02. Several other pesticides were also detected in some samples. Aroclor 1254, a PCB, was observed in soil samples 05SS02 and 05SS04 at a concentration no greater than 23 μg/kg. Several SVOCs, mostly PAHs, were detected in all four surface soil samples. The greatest number of SVOCs detected and the highest concentrations of SVOCs were generally observed in surface soil sample 05SS04.

Only three organic compounds were detected in the four groundwater samples. Di-n-butylphthalate, pentachlorophenol, and phenanthrene were detected at low concentrations of about 1 μg/l. Several inorganics were detected in both soil and groundwater samples.

2.9.4.4 Site 6 Results

One surface soil sample was collected from Site 6 (the Caged Pit) (Figure 2-4). The analytical data are summarized in Table 2-2. Three pesticides, including 4,4-DDD (5.8 μg/kg), 4,4-DDE (120 μg/kg), and 4,4-DDT (73 μg/kg), and several PAHs were observed in the Site 6 surface soil sample. Detected PAHs include benzo(a)anthracene (920 μg/kg), benzo(a)pyrene (910 μg/kg), benzo(b)fluoranthene (1,200 μg/kg), benzo(g,h,i)perylene (860 μg/kg), and pyrene (1,400 μg/kg), among other PAHs and SVOCs. Several inorganic constituents were also detected.

2.9.5 Environmental Photographic Interpretation Center (EPIC) Study and Regulatory Review– 1999

Twelve potential AOCs were identified for investigation during a joint USEPA, VDEQ, and Navy review of historical aerial photography (EPIC Study) of the facility in June 1999. In November 1999, a work-in progress/site visit with representatives of the Navy, CDM Federal, VDEQ, and the biological technical assistance group (BTAG) was conducted to evaluate the 12 "EPIC AOC" locations (EPIC AOCs 1 through 12). A review of the current and past conditions of each of the 12 "EPIC AOC" locations was also conducted using the EPIC photographs to determine if sampling was warranted at any of the locations. Further desktop review and site visits were conducted by the SJCA Partnering Team in 2001 and EPIC AOCs 2 through 12 were recommended for no further action.

The group also reviewed site conditions and historical photographs of IRP sites to be included in a Site Screening Assessment (SSA). The SSA was conducted in 2001 and included Sites 1, 7, 8, 10, 11, 18, 19, 20, and 21, in addition to the EPIC AOCs. Six of the Sites/AOCs were recommended for further site investigations to determine if a release had occurred and if a RI was warranted for the sites. CH2M HILL submitted a Final Site Screening Assessment Report in April 2002.

2.9.6 Historical Aerial Review

This section describes a review of historical aerial photographs. Historical aerial photographs reviewed were acquired from the Navy and from the USEPA EPIC Study conducted in 1995.

A total of 15 dates were reviewed from Navy photographs; May 1937, April 1949, May 1958, October 1961, March 1963, October 1964, May 1970, October 1974, January 1976, February 1976, March 1980, April 1982, February 1985, June 1986, and a 1995 photo.

Eight aerial photographs (May 1937, April 1949, May 1958, October 1964, October 1974, June 1986, March 1990, and an unidentified photograph circa 1995) were chosen to discuss conditions and changes at Sites 3, 4, 5, and 6. These photographs are shown on Figure 2-5. In addition to activities at the sites, the review included activities adjacent to the Blows Creek watershed.

2.9.6.1 May 20, 1937 EPIC Photograph

This photograph was the earliest aerial photo reviewed. Much of the area identified as hydraulic spoil (dredge fill) is highly reflective of light due to the lack of vegetation. Sites 3 through 6 do not exist at the time of this photo.

A review of the updated Sites 3 through 6 boundaries indicates that all of Sites 3 and 6 will lie within the hydraulic spoil material. Only the eastern portion of Site 5 and the extreme northern side of Site 4 will lie within the hydraulic spoil. A drainage ditch between Sites 5 and 6 is present in the same manner as it exists today. Blows Creek appears as it does today. There are no other areas of environmental concern related to the sites.

2.9.6.2 April 9, 1949 EPIC Photograph

Ground scarring at Sites 5 and 6 is evident indicating activities at these sites, which corresponds to historical information regarding the timeframe of these activities. There is no indication of activities at either Site 3 or Site 4. Site 3 and the northern portion of Site 4 remain a hydraulic spoil area and now contains a large drainage trough which trends northwest to southeast across the fill. A drainage ditch has been created on the western side of the hydraulic spoil, which leads south to Blows Creek.

Two outside storage areas are located both north and south of Blows Creek and a fill area is identified on a tributary to Blows Creek.

2.9.6.3 May 4, 1958 EPIC Photograph

Disturbed ground was identified at Site 5. Stained soil and a small trench are also identified at Site 5. A waste disposal area and pit are identified at Site 3. The pit at Site 3 corresponds to waste found at Site 3 during the waste delineation. No activities are identified at Site 4 or near Blows Creek.

2.9.6.4 October 26, 1964 EPIC Photograph

The EPIC analysis noted findings from the 1961 aerial photograph on the 1964 photograph. Activities associated with burning activities at Site 5 continue and a possible excavation area was identified on the southern part of the site. A possible fire training area is identified at Site 5. The waste disposal area and pit at Site 3 are still active. Site 3 now indicates mounded material, likely associated with the waste disposal activities at the site. Two waste disposal activities are now occurring at Site 4, one in the northeast corner and one in the southern side of the site. The date on the EPIC photograph indicates activities at Site 4 from 1961 to 1964, earlier than the 1970 date identified in the Phase II RFA report.

An open storage area, mounded material and a waste disposal area are identified south of Blows Creek. A drop tower is now present, located approximately 300 ft south of Site 6.

2.9.6.5 October 10, 1974 EPIC Photograph

Review of this photograph included information from the 1970 and 1976 aerial photography. Site 3 disposal activities continue along the northwest-southeast trending gravel roadway. Activities associated with disposal continue on the northern side of Site 4. The extent of clearing associated with Site 4 has now expanded to the west; however, there is no indication on future photographs that this area received waste, and therefore, it was not included in the current site boundary. Ground scarring associated with Site 5 burning activities is apparent on the south side of the site. There is also a wet ground/stain area adjacent to Building 272 at Site 5, possibly related to building activities. The possible fire training area still exists at Site 5.

Waste disposal areas are identified near Site 3 and northwest of Site 4. These areas do not appear in future aerial photographs. A pit containing liquid was identified north of Site 6 (just east of the Site 5 call-out box). The symbol LQ that identifies the pit is outside the October 10, 1974 photograph frame and is therefore not shown on Figure 2-5. The pit containing liquid does not appear in the 1986 aerial photograph.

2.9.6.6 June, 9, 1986 EPIC Photograph

Review of this photo included information from 1981, 1982, and 1985 photography. There appears to be no indication of disposal at Site 3. Though ground scarring is evident northeast of Site 3, the EPIC photo does not associate any activities with this ground scarring and it does not appear that there are any environmental concerns regarding the ground scarring. Debris was identified at several areas within Site 4 during several of the dates reviewed. The fire training area associated with Site 5 was reported as removed in 1981 and there is no indication of activities at the fire training area in the 1986 photo. There is outside storage reported at Building 272, located on the west side of Site 5. Possible drums were also identified near the road west of Site 5. A road leads from Site 5, through Site 6 and terminates at the drop tower area. There is no indication of activities at Site 6 and the area now appears to be vegetated.

2.9.6.7 March 4, 1990 EPIC Photograph

The photo is slightly truncated near Site 3, but does not indicate any activity associated with Site 3. Outside storage of construction material and containers is evident at Sites 4 and 5. Debris has been identified on the southwest side of Site 4, however it does not appear that the debris is recent, it is more than likely debris that was disposed of from 1982 to 1986. As in the 1986 photo, there is no indication of structures or activities at Site 6.

2.9.6.8 Unidentified Photograph Circa 1995

The photograph indicates that there are no activities of concern at Sites 3 or 6. There is ground scarring in the northeast corner at Site 4, but there is no indication that it is an open storage area. There is activity at Site 5, which may indicate some debris or open storage in the southern portion of the Site.

2.10 Current IRP Activities

Current IRP activities being conducted by the Navy at St. Juliens Creek include:

- A basewide background study of soil and groundwater was completed 2001;
- A RI/FS for Site 2;
- A SSA for nine IRP sites and three of the 12 "EPIC AOCs" was completed in 2002; and
- Site Investigations for the SSA Sites/AOCs recommended for further evaluation and a Site Investigation for Site 17.

2.11 References

A.T. Kearney, Inc. and K.W. Brown and Associates, Inc. *Phase II RCRA Facility Assessment of the St. Juliens Creek Annex Facility*. Chesapeake, Virginia. March 1989.

CDM Federal. *Final Supplemental Field Investigation Plan Landfill B and the Burning Grounds.* St. Juliens Creek Annex, Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. March 1999.

CDM Federal. *Final Master Project Plan*. St. Juliens Creek Annex. Chesapeake, Virginia. July 2000.

CH2M HILL. *Relative Risk Ranking System Data Collection Report*. St. Juliens Creek Annex to the Norfolk Naval Base. Chesapeake, Virginia. April 1996.

Navy Engineering and Environmental Support Activity. *Navy Assessment and Control of Installation Pollutants: Initial Assessment Study of St. Juliens Creek Annex*, Norfolk Naval Shipyard. Portsmouth, Virginia. NEESA 13-001. August 1981.

NUS Corporation, Superfund Division. *Preliminary Assessment*. 1983.

Tetra Tech EM Inc. *Hazard Ranking System Documentation Record for St. Juliens Creek Annex (U.S. Navy)*. Chesapeake City, Virginia. January 2000.

URS Consultants, Inc. *Technical Assessments in Support of the Elizabeth River Regional Action Plan Development*. Contract No 970500142. Revised April 1996.

USEPA. *Aerial Photographic Site Analysis, Norfolk Naval Shipyard: Annex Areas*. Norfolk, Virginia. February 1995.

SECTION 3

Field Investigation Activities

This section outlines the scope of the field investigation activities conducted as part of the RIs at Sites 3, 4, 5, and 6 at St Juliens Creek Annex. The field investigation activities described below were conducted to meet the objectives of the RIs described in Section 1.1.

The RI field activities were conducted during three phases of work. CDM Federal Programs Corp. conducted the first and second phases. The first phase (Phase I) of field activities was conducted from June to November 1997. The second phase (Phase II) of field activities was conducted between April and October 1999. CH2M HILL conducted the third phase (Phase III) from June to August 2001.

The RI field investigation activities included geophysical investigations, installation of monitoring wells, water-level monitoring, and the collection and analysis of surface and subsurface soil samples, groundwater samples, sediment samples, surface water samples, and waste delineation. The RI activities at Sites 3, 4, 5, and 6 are summarized in Table 3-1. RI activities are described in more detail in the following sections.

Sample analyses and the number of samples for each medium sampled at each site are provided in Tables 3-2 through 3-4.

Detailed field procedures for the activities conducted as part of this RI are outlined in the following RI work plans: *Final Landfill B and the Burning Grounds Work Plan*, dated May 1997; *Final Landfill C and Landfill D Work Plan*, dated May 1997, *Final Supplemental Field Investigation Plan Landfill B and the Burning Grounds*, dated March 1999, *Final Supplemental Field Investigation Plan Landfill C and Landfill D*, dated March 1999, *Technical Memorandum Work plan for Limits of Waste Delineation at Sites 2, 3, 4, 5, and 6*, September 2001.

3.1 Geophysical Investigations

Earth Resources Technology (ERT) of College Park, Maryland conducted geophysical surveys at Sites 3, 4, 5, and 6. The objectives of the investigation were to:

- Define the extent of the site boundaries at Sites 3 and 4;
- Identify geophysical anomalies to be used in delineating the Site 5 boundaries; and,
- Determine the location of the caged pit at Site 6.

At each site, an electromagnetic (EM-31) survey was performed. At Site 4, a magnetometer and a limited ground penetrating radar (GPR) survey were also performed. The GPR survey at Site 4 was conducted over a limited area to determine if GPR could be used to identify buried drums at the site. The location of the geophysical survey grids for Sites 3, 4, 5, and 6 are shown in Figures 3-1, 3-2, and 3-3.

3.1.1 Electromagnetic Survey

A Geonics EM-31 instrument was used to conduct the electromagnetic survey. The EM-31 unit permits the measurement of the specific conductivity of the underlying subsurface materials using the principle of mutual inductance. The method allows for the measurement of subsurface electrical properties without the use of probes inserted into the ground surface. Changes in conductivity (expressed as in-phase and quaderature phase) can often be correlated to subsurface geologic variation and/or zones of groundwater contamination. The instrument has an effective exploration depth of about 20 ft.

3.1.1.1 Site 3 Electromagnetic Survey

At Site 3, the electromagnetic survey was conducted on a grid measuring approximately 800 ft by 900 ft (Figure 3-1). The gridlines were established parallel to the site/Base fence lines. Grid spacing immediately adjacent to the fences was about 50 ft, but was generally about 100 ft throughout the rest of the site. The southernmost grid line was spaced at approximately 200 ft.

3.1.1.2 Site 4 Electromagnetic Survey

At Site 4, the grid was difficult to establish due to the very heavy brush cover. Over the open area in the northeast, a grid approximately 250 ft by 400 ft was laid out with grid lines every 50 to 100 ft (Figure 3-2). In addition to these grid lines, three north-south trending grid lines, spaced at about 200 ft, were established. These grid lines tie into grid lines associated with the Site 3 geophysical survey. One 850-ft-long line trending approximately east to west was cut to obtain access to the western portion of Site 4.

3.1.1.3 Site 5 Electromagnetic Survey

At Site 5, the electromagnetic survey was conducted on a grid approximately 400 ft by 300 ft referenced to Building 272 (Figure 3-3). A portion of the site was covered by very dense vegetation (marsh reeds) and was not surveyed. Most of the grid lines were spaced every 50 ft.

3.1.1.4 Site 6 Electromagnetic Survey

In the caged pit area, a 150 by 300 ft grid with 50 or 100 ft spacing was established (Figure 3-3). Following an initial survey, additional grid lines were added to create a 10-ft spacing over a 60-by-100-ft area.

3.1.2 Magnetometer Survey

The magnetometer survey was conducted using a Geometrics Portable Cesium Magnetometer, Model G858. This instrument measures the earth's total geomagnetic field at a particular location in gamma units. Local variations in the field can be attributed to metal objects located near or directly below the ground surface.

The magnetometer survey at Site 4 was conducted along the same grid and profile lines as the electromagnetic survey (Figure 3-2).

3.1.3 Ground Penetrating Radar

The GPR survey was performed using a Subsurface Interface Radar (SIR) from Geophysical Survey Systems, Inc. This instrument radiates a 500 MHz electromagnetic pulse from a transmitter antenna into the earth and receives a reflection of the pulse via a receiving antenna. The reflections are caused by interfaces at which changes in the electrical properties occur. The depth of the penetration of the radar signal is inversely proportional to the conductivity of the soil. As a result, electrically resistive earth materials such as coarse-grained, unsaturated, sediments allow deep penetration and finer-grained soils (clays and silts), reinforced concrete, and shallow groundwater attenuate the signal.

The surveyed area of Site 4 (Landfill D) consists of fill (including concrete), thereby limiting the penetration depth of the GPR to approximately 10 ft. The GPR survey at Site 4 was conducted along the grid established in the cleared area of the site (Figure 3-2). Readings were taken approximately every 10 ft along each grid line.

3.2 Surface Soil Sampling

The objectives of the surface soil sampling were to collect analytical data for evaluating the nature and extent of contamination and use in the human health and ecological risk assessments. Surface soil samples were collected at Sites 3, 4, and 5 during both Phase I and Phase II of the RI fieldwork (Table 3-1). During Phase II, a surface soil sample was also collected at Site 6. The Phase II sampling locations were based on the results of the Phase I RI activities.

Samples were analyzed for TCL VOCs, SVOCs, pesticides, and PCBs, TAL inorganics, and total phosphorus (Tables 3-2 through 3-4). Samples collected at Site 3 were also analyzed for total petroleum hydrocarbons (TPHs).

During Phase I, samples were analyzed in the field for TNT using the D TECH TNT test kit from EM Science/Strategic Diagnostics Inc. The results were used to determine which samples would be sent to the offsite laboratory for nitramine analysis. One Site 5 surface soil sample collected during Phase I was selected using the field screening technique for offsite nitramine analysis. During Phase II, all samples collected from Sites 5 and 6 were analyzed for nitramines at an offsite laboratory.

Samples were collected using a stainless-steel spoon and bowl following procedures described in the work plans. Samples collected during Phase I were from a depth of 0 to 3 in., while those collected during Phase II were from a depth of 0 to 6 in. The change in sampling-depth protocol was agreed upon during a December 1998 meeting between the Navy, VDEQ, USEPA, CH2M HILL, and CDM Federal.

3.2.1 Site 3 Surface Soil Sampling

Twenty-one surface soil samples (18 samples, 3 duplicates) were collected from 18 sample locations in and around Site 3 as shown on Figure 3-4. Seven of the samples were collected during Phase I investigations and the remaining 11 samples were collected during Phase II.

With the exception of two samples (SJS03-SS01 and SJS03-SS05), the Phase I samples were collected at locations thought to be within the site boundary. During evaluation of the data,

it was determined that the Phase I data did not clearly define the site boundary or identify a source area for contamination. The locations of Phase II samples were therefore, distributed within and outside the suspected site boundary to locate source areas.

Background surface soil samples of the hydraulic dredge material on which the site is located were collected in an area between Sites 3 and 4 as part of the basewide background investigation. These data were incorporated into the Background Investigation at SJCA, October 2001.

3.2.2 Site 4 Surface Soil Sampling

Twenty surface soil samples (18 samples, 2 duplicates) were collected from 18 sample locations at Landfill D as shown Figure 3-5.

Eleven samples (10 samples, one duplicate) were collected during Phase I from within the suspected landfill area. Samples SJS04-SS01 and SJS04-SS03 were collected north and south of the site, respectively, in areas outside the original landfill boundary.

During Phase II, nine additional samples (eight samples, one duplicate) were collected from the original landfill perimeter to define the landfill boundary. Background samples of hydraulic dredge material from the north and west side of the site were collected as part of the basewide background investigation and incorporated in a Background investigation for SJCA, October 2001.

3.2.3 Site 5 Surface Soil Sampling

Thirty-eight surface soil samples (35 samples, three duplicates) were collected from 35 locations in and around Site 5 as shown on Figure 3-6. Ten of the samples (nine samples, one duplicate) were collected during Phase I and the remaining samples were collected during Phase II (25 samples, two duplicates).

The surface of the central portion of Site 5 consists of hard-packed gravel that prohibited the collection of surface soil samples. Samples were collected to the west and north of the burning area to define the boundaries of the site. These samples include SJS05-SS16 and SJS05-SS17 collected to the north and SJS05-SS30, SJS05-SS31 and SJS05–SS18 collected to the west.

Four samples were collected in the area of the former drop tower (SJS05-SS25 through SJS05-SS28), which is located to the southeast of Site 5.

3.2.4 Site 6 Surface Soil Sampling

During Phase II, one sample, SJS05-SS29, was collected in the caged pit area. This location is shown on Figure 3-6.

3.3 Subsurface Soil Sampling

Objectives of the subsurface soil sampling were to collect analytical data for use in the Human Health Risk Assessment, to delineate site boundaries, and to characterize lithology at the sites.

Subsurface soil samples were collected at all four sites (Table 3-1). Samples were obtained using a truck-mounted, hydraulic, direct-push technology (DPT) probe or a stainless-steel hand auger. Subsurface soil samples collected from boreholes during monitoring well installation were collected with split-spoon samplers. Samples were collected according to procedures described in the work plans. Subsurface soil samples were collected from just above the water table. If additional volume was needed to meet sampling requirements, a second core was obtained adjacent to the first at the same depth. Two samples at Site 3 were collected as composite samples from ground surface to a depth of four ft.

During Phase I, Envirosurv Inc., of Fairfax, Virginia, conducted subsurface soil sampling using DPT. Soil samples were collected using a 4-ft-long by 2in.-outer-diameter (O.D.) MacroCore sample barrel equipped with dedicated acetate liners. Phase II subsurface soil samples were collected by Columbia Environmental Technologies LLC, of Columbia Maryland, using DPT, or in areas that were difficult to access, by Columbia Environmental Technologies or CDM Federal personnel using a stainless-steel hand auger.

Samples collected during Phase III as part of the waste delineation/trenching activities are discussed in Section 3.5.

3.3.1 Site 3

The subsurface soil investigations conducted at Site 3 had a dual purpose, to delineate the boundaries of the site, and during Phase II, to locate the sludge disposal pits reported to be present on the site. Both of these efforts are described below.

3.3.1.1 Site Delineation

During both Phase I and Phase II, subsurface soil samples were collected from within and outside the area of the suspected waste disposal area. Sample locations were spaced throughout the site in an attempt to locate areas of waste.

A total of 22 subsurface soil samples (20 samples, 2 duplicates) were collected from 20 locations during the Phase I and II investigations (Table 3-1, Figure 3-7). Eight (7 samples, 1 duplicate) were collected in Phase I and 14 (13 samples, 1 duplicate) were collected in Phase II. The sampling locations included one location (SJS03-SB01) to the north of the original suspected site boundary, two locations (SJS03-SB13 and -SB14) to the south of the original suspected site boundary, and two locations (SJS03-SB15 and SB-16) to the west of the site boundary. The remaining sampling locations were within the original suspected site boundary.

Samples were collected from the 2-ft interval just above the groundwater table, from approximately 3-5 ft bgs. If the water table was within 3 ft of the ground surface, the sample was collected from 1 to 3 ft bgs. Samples were analyzed for TCL organic constituents, TAL metals, and total phosphorus. Two composite samples (0 to 4 ft) collected during Phase I were also analyzed for total organic carbon (TOC) (Table 3-2).

Five subsurface soil samples were collected from five locations during Phase III as part of the waste delineation/trenching activities and will be discussed in Section 3.4.1.

3.3.1.2 Disposal Pit Investigation

Based on historical aerial photographs, the disposal pits were located along the north side of the gravel road that trends northwest to southeast across Site 3. Samples were collected from four areas, two areas on the north side and two areas on the south side of the dirt road. One of these areas was the pit identified by USEPA during review of the historical aerial photographs. The remaining three additional areas were located within the formerly scarred area and were associated with dark areas of the photograph, indicative of possible burning or moisture.

At each area, DPT borings were advanced in a line that extended generally perpendicular to the road for about 50 ft. The locations of these lines are shown on Figure 3-7. Ten borings were drilled on each line at a spacing of approximately 5 ft. The borings extended in depth from the ground surface to the water table, at approximately 3 to 5 ft bgs.

Samples from each boring were collected in the same manner as the other subsurface soil samples. Each sample was examined for visual evidence of contamination and a geologist logged the material in the borings. If there was no visual evidence of contamination, a composite of the core sample was placed in a clean jar for field headspace analysis. A sample of material was then analyzed using a field test kit (the Dexsil® PetroFlag® Test System) for the presence of TPH. Based on the results of the tests, one sample from each line of borings was selected for offsite analysis for TCL organics, TAL inorganics, and TPH.

Samples collected as part of the disposal pit investigation are shown on Figure 3-7 and include SJS03-SB17 (from Line 1), SJS03-SB18 (from Line 2), SJS03-SB19 (from Line 3) and SJS03-SB20 (from Line 4).

3.3.2 Site 4 Subsurface Soil Sampling

Subsurface soil sampling was conducted with DPT at eight locations at Site 4 (Table 3-1, Figure 3-8). Three samples were collected during the Phase I investigation and six samples (five samples, one duplicate) were collected during the Phase II investigation. Two samples were collected along the southeastern edge of the landfill adjacent to Patrol Road (SJS04-SB02 and -SB03). The remaining six samples were collected near the landfill perimeter. The sampling locations were selected to be outside of the landfill, and therefore to confirm the landfill boundary and extent of contamination.

Samples were collected from the 2 ft interval just above the groundwater table, from approximately 3 to 5 ft bgs. If the water table was within 3 ft of the ground surface, the sample was collected from 1 to 3 ft bgs.

The original work plan proposed 10 sampling locations for Site 4. However samples could not be collected on the landfill itself due to the density of concrete and other rubble, as well as the suspected presence of unexploded ordnance within the landfill. Nine subsurface soil samples (eight samples, one duplicate) collected from eight sample locations were analyzed for TCL organic constituents, TAL metals, and total phosphorus (Table 3-3).

No subsurface soil samples were collected during the waste delineation/trenching activities conducted in June and July 2001.

3.3.3 Site 5 Subsurface Soil Sampling

During the Phase I and II investigations, 24 subsurface soil samples (21 samples, three duplicates) were collected with the DPT probe or stainless-steel hand auger at three distinct areas at Site 5 (Table 3-1). Three samples were collected from the caged pit area (SJS05-SB09, SJS05-SB10, and SJS05-SB11) and four samples were collected from the former drop tower area (SJS05-SB12, SJS05-SB13, SJS05-SB14, and SJS05-SB15) (Figure 3-9). The remaining samples were collected near the reported burning grounds. All Phase II samples were collected from within the eastern portion of the burning grounds. Seventeen samples (15 samples, 2 duplicates) were collected during Phase I and seven samples (six samples, one duplicate) were collected during Phase II.

The location of the former drop tower was estimated using historical aerial photographs. The drop tower location is visible in the field as a slightly raised, square grass-covered area. One subsurface sample was collected midway along each edge of the square of the tower location.

Samples were collected from the 2-ft interval just above the groundwater table, from approximately 3 to 5 ft bgs. If the water table was within 3 ft of the ground surface, the sample was collected from 1 to 3 ft bgs. All samples were analyzed for TCL organic constituents, TAL metals, and total phosphorus (Table 3-4). During Phase I, one sample was selected using the field screening technique for TNT for offsite nitramine analysis. All five Phase II samples were analyzed for nitramine. During Phase I, five subsurface samples (SJS05-SB02, -SB03, -SB04, -SB06, and -SB07) were analyzed for dioxin.

Four subsurface soil samples were collected from four locations during the waste delineation/ trenching activities (Phase III) and are discussed in Section 3.4.2.

3.3.4 Site 6 Subsurface Soil Sampling

Three subsurface soil samples were collected near the caged pit (SJS05-SB09, SJS05-SB10, and SJS05-SB11) based on results of the geophysical investigation, but were given sample identification relating the samples to Site 5 (Table 3-1, Figure 3-9). The borings were located around a geophysical anomaly that could have been caused by metallic remains in the caged pit.

Two subsurface soil samples (one sample, one duplicate) were collected from one location during Phase III as part of the waste delineation/trenching activities, discussed in Section 3.5.3.

3.4 Waste Delineation/ Trenching Activities

A review of information, including the 1981 IAS, the 1989 Phase II RFA, and historical aerial photographs, was performed for Sites 3, 4, 5, and 6 to determine if the extent of each site was appropriately defined. Based on this review, it was concluded that the extent of Sites 3 and 5 may not be sufficiently defined and that current analytical data and geophysical data would be insufficient to delineate site boundaries. It was also determined that Site 4 and 6 were sufficiently defined based on historical aerial photographs and documentation. Based on these conclusions, a waste delineation investigation was conducted in June and July 2001.

Because historical activities at Sites 3 and 5 included the burning of waste, subsurface soil samples were collected for dioxins analysis during the investigation.

Delineation and collection of subsurface soil samples at Sites 3, 5, and 6 was conducted using a backhoe excavator. Initial trenching locations were determined based on review of the historical photographs. A review of the historical photographs is presented in Section 2.9.6. Delineation of waste focused on subsurface soils containing debris and/or that exhibited signs of burning or contamination rather than surface debris such as nails or metal strapping, which was commonly encountered during the trenching activities.

USA Environmental, Inc. of Tampa, FL provided ordnance/explosives (OE) support during the investigation. The purpose of the OE contractor was to assist in the avoidance of ordnance and the identification and safe handling of ordnance in the event they were encountered. Delineation was considered complete when evidence of waste was no longer encountered.

The sub-sections below discuss the waste delineation activities conducted at each of the sites, including the depths of test pits and samples collected. Test pit logs recorded during the activities are provided as Appendix A.

3.4.1 Site 3 Waste Delineation

Site 3 was originally a mud-flat area for the deposition of dredge spoils where refuse was reportedly disposed and burned. The 1964 EPIC aerial photograph identified a pit where material may have been disposed or burned.

A total of 49 test pits were excavated at Site 3 at locations that paralleled a gravel roadway that transects the site (Figure 3-10). Test pits ranged in depth from approximately 3 to 4.8 ft bgs. Test pit locations were designated SJS03-Trench1 through SJS03-Trench49. Results of the delineation are discussed in Section 5-2 of this report.

Six subsurface soil samples were collected from the trenches based on visual observations of the soil biased for evidence of waste/contamination. Of the six samples, five were retained and sent to Chemtech Consulting Group, Inc. located in Edison, NJ. Three samples, SJS03-SB21-001, SJS03-SB23-001 and SJS03-SB26 were analyzed for dioxins using Method 8290. Based on petroleum odors from inspection of the soils, two samples, SJS03-SB22-001 and SJS03-SB24-001, were submitted for analysis of TPH—Gasoline Range Organics (GRO) and Diesel Range Organics (DRO). Results of the subsurface soil samples are discussed in Section 5-2 of this report.

3.4.2 Site 5 Waste Delineation

The initial Site 5 boundary was determined from historical aerial photographs, and the initial trenching locations were focused on the presumed site boundary. However, results of initial trenching indicated the need to expand trenching activities to the north of the original site boundary.

A total of 42 test pits were constructed at Site 5 (Figure 3-11). Test pits ranged in depth from approximately 1.5 to 5.3 ft bgs. Test pit locations were designated SJS05-Trench1 through SJS05-Trench42.

Five subsurface soil samples were collected from the trenches based on visual observations of the soil biased for waste/contamination. Of the five samples, four were retained and sent to Chemtech Consulting Group. Four samples, SJS05-SB22-001, SJS05-SB24-001, SJS05-SB25-001, and SJS05-SB26-001 were analyzed for dioxins using Method 8290. One sample, SJS05-SB25-001 was also analyzed for Toxicity Leaching Characteristic Procedure (TCLP) organics and metals to assess the potential for the waste to be characterized as hazardous. Results of the subsurface soil samples are discussed in Section 5.4 of this report.

3.4.3 Site 6 Waste Delineation

Historical activities at Site 6, the Small Arms Pit, included burning small items and munitions. Based on historical aerial photographs, the location and size of the pit is known. Two test pits, SJS06-Trench1 and SJS06-Trench2, were advanced in order to collect a subsurface soil sample to be analyzed for dioxin (Figure 3-11).

One subsurface soil sample and a duplicate sample, SJS06-SB01-001 and SJS06-SB01-001P were collected from one of the trenches based on visual observations of the soil and sent to Chemtech Consulting Group for analysis for dioxins using Method 8290. Results of the subsurface soil samples are discussed in Section 5.5 of this report.

3.5 Monitoring Well Installation

American Environmental Drilling Services (AEDS) and Groundwater Systems, Inc. were the Phase I and Phase II drilling subcontractors, respectively. Under the direction of a CDM Federal geologist, the subcontractors drilled soil borings and collected soil samples at each monitoring well location and installed monitoring wells.

Split-spoon samples were collected for soil classification from all locations. Samples were collected approximately every 5 ft to a depth of approximately 14 ft during the installation of shallow monitoring wells. During installation of the Phase I deep monitoring wells, split-spoon samples were collected continuously from just below the depth of the deepest shallow well sample. During Phase II, split-spoon samples were collected at a frequency of one split-spoon sample per 2.5-ft interval to the final depth of the boring. A CDM Federal geologist logged descriptions of lithology to be presented in boring logs for use in characterizing the geology and hydrogeology at each site. The data collected during logging of these boreholes was also used to design the monitoring wells.

Shallow monitoring wells were generally completed at depths to sample the uppermost saturated zone, while the deep monitoring wells were designed to sample groundwater in the upper portion of the Yorktown Aquifer. Deep monitoring wells were paired with shallow wells to enable measurement of the vertical distribution of contaminants in groundwater and to measure the magnitude and direction of vertical groundwater flow.

All monitoring wells were constructed of a nominal 2-in. diameter polyvinyl chloride (PVC) well riser and 0.01-in. slot, 10-ft-long PVC screen. Deep monitoring wells were installed with 6-in. PVC isolation casings set in a semi-confining or confining clay layer. All monitoring wells were developed according to the work plan procedures using a surge block assembly and submersible pump. Wells were developed until water quality parameters (pH, specific conductance, temperature and turbidity) had stabilized.

3.5.1 Site 3 Monitoring Well Installation

Six shallow and two deep monitoring wells were installed at Site 3 (Table 3-1, Figure 3-12). One shallow and one deep monitoring well are located north of Site 3 (SJS03-MW01S and SJS03-MW01D) and the remaining monitoring wells are located southeast, south, southwest, and west of the suspected site.

3.5.2 Site 4 Monitoring Well Installation

The locations of the four shallow and two deep monitoring wells installed at Site 4 are shown on Figure 3-13. Two shallow (SJS04-MW01S and SJS04-MW02S) and one deep monitoring well (SJS04-MW01D) are located on the north side of Site 4. Monitoring well SJS04-MW01D is screened in the confining unit above the deep aquifer rather than in the deep aquifer. Shallow monitoring wells SJS04-MW03S and SJS04-MW04S and deep monitoring well SJS04-MW03D are located south of the landfill adjacent to Blows Creek and the Southern Branch of the Elizabeth River.

3.5.3 Site 5 Monitoring Well Installation

The locations of the eight monitoring wells at Site 5 are shown on Figure 3-14. One shallow and one deep monitoring well (SJS05-MW01S and SJS05–MW01D) are located within the northern portion of Site 5. The remaining monitoring wells are located west (SJS05-MW05S), south (SJS05-MW02S, SJS05-MW02D, and SJS05-MW03S), and east (SJS05-MW04S and SJS05-MW04D) of the Site 5 boundary. Well pair SJS05-MW02S/MW02D is constructed at a location west of that originally planned, because the originally proposed location is within a marsh.

3.5.4 Site 6 Monitoring Well Installation

No wells were installed as part of the investigation at Site 6. Although wells SJS05-MW04S and SJS05-MW04D are in close proximity to Site 6, they were installed as part of the investigation for Site 5.

3.6 Monitoring Well Groundwater Sampling

Monitor wells that were installed during Phase I were sampled during three rounds of groundwater sampling (Table 3-1). The first sampling round was conducted in July 1997 followed by subsequent rounds in November 1997 and in May 1999 after the installation of the Phase II monitor wells. Phase II wells were sampled once during the May 1999 round.

During all sampling events, purging and sampling were accomplished using a decontaminated submersible pump and dedicated polyethylene tubing. Samples were analyzed for TCL VOCs, SVOCs, pesticides, PCBs, total and dissolved (unfiltered and filtered) TAL metals, and total phosphorus (Tables 3-2 through 3-4). During the first sampling round at Site 5 (the Burning Grounds), two samples were selected for offsite nitramine analysis based on the results of field screening for TNT. During the third sampling round all groundwater samples were analyzed at an offsite laboratory for nitramines.

Samples were collected using the procedures described in the work plans. During all sampling events, wells were purged and sampled using a decontaminated submersible

Grundfos® pump and dedicated polyethylene tubing. Well purging was conducted in accordance with standard operating procedures.

3.7 Surface Water and Sediment Sampling

Sediment and surface water samples were collected from Sites 3, 4, and 5 (Table 3-1). Due to dry conditions during the Phase I sampling, only one surface water sample was collected (SJS04-SW04 and duplicate). During Phase II, the overall sampling scheme was adjusted so that both a surface water and sediment sample were collected from each site. Additional sampling locations were also added during Phase II.

Sediment samples were collected with stainless-steel bowls and spoons. At some locations at Site 4 where surface water was 6 in. deep, a stainless-steel Wildco dredge was used to collect sediment. Stainless-steel hand augers were used to cut through the root-mat above the sediment in marshy areas of Site 4 and Site 5. Surface water samples were collected directly into sample jars.

Sediment and surface water samples were analyzed for TCL VOCs, SVOCs, pesticides, PCBs, TAL metals, total phosphorus, and TOC (Tables 3-2 through 3-4). Sediment samples collected during Phase II were also analyzed for grain-size distribution. Field measurements of pH, temperature, specific conductance, turbidity, dissolved oxygen (DO) and salinity were collected from all surface water samples but one. Sample SJS04-SW04, the only surface water sample collected during Phase I, was only measured for pH, temperature and specific conductance, in accordance with the original work plan.

3.7.1 Site 3 Sediment and Surface Water Sampling

Nine sediment and surface water samples (seven samples, two duplicates) were collected from the seven locations shown on Figure 3-15. Sample locations are as follows:

- Three locations within the drainage ditch along the east side of the site (SJS03-SD/SW07, -SD/SW02 and -SD/SW08);
- One location in a low-lying area northeast of the site and north of perimeter road (SJS03-SD/SW01);
- One location within a large area of intermittent standing water in the north-central part of the original suspected site boundary (SJS03-SD/SW06); and,
- Two locations within a drainage ditch that runs north to south just west of the site (SJS03-SD/SW03 and -SD/SW04).

3.7.2 Site 4 Sediment and Surface Water Sampling

Sediment and surface water samples were collected from the eight locations shown in Figure 3-16. Samples were collected from the drainage ditch that runs along the east edge of the landfill and from the marsh adjacent to Blows Creek. Samples were collected along the drainage ditch at an upstream location (SJS04-SD/SW01), and at two downstream locations (SJS04-SD/SW02 and SJS04-SD/SW03). Sampling locations within the marsh include:

- Two locations are along Blows Creek on the southwest border of the site (SJS04-SD/SW08 and SD/SW09) and
- Four locations are along the western side of the site (SJS04-SD/SW04, -SD05, -SD/SW06, and -SD/SW07).

3.7.3 Site 5 Sediment and Surface Water Sampling

Site 5 sediment and surface water sampling locations are depicted in Figure 3-17. Seven sediment and surface water samples were collected from the following locations at the Burning Grounds:

- Upstream end of the drainage swale before it enters the Burning Grounds site (SJS05-SD/SW04);
- Point where the drainage swale enters the marsh (SJS05-SD/SW01);
- Point within the marsh (SJS05-SD/SW05);
- Drainage swale at the point that it exits the marsh, immediately downstream from the Burning Grounds (SJS05-SD/SW02);
- Location where the drainage swale crosses the berm (SJS05-SD/SW03) about 300 ft downstream of the Burning Grounds; and,
- About 40 ft into the marsh associated with Blows Creek (SJS05-SD/SW06).

3.8 Surveying

Following installation of all groundwater monitoring wells, the elevations of the ground surface and the top of the inner casing were measured to within 0.01 ft by Patton Harris Rust & Associates of Virginia Beach, Virginia. The horizontal locations of monitoring wells and other sampling locations (soil, sediment, and surface water locations) were surveyed relative to the Virginia State Planar System.

3.9 Groundwater Elevation Monitoring

During the field investigation, depth to groundwater from the top of the PVC casing was measured to the nearest 0.01 ft in each well at Sites 3, 4, and 5. This information was used to determine the depth to the potentiometric surface in each aquifer and evaluate the horizontal flow direction and gradient of groundwater in each hydrostratigraphic unit. Vertical flow directions and gradients were evaluated with data from shallow/deep monitoring well pairs.

Two complete rounds of water level monitoring were conducted at Sites 3, 4, and 5 and at background monitoring wells on May 17 and August 16, 2001. Water levels were also measured at other times at individual sites or in a limited number of monitoring wells.

3.10 Slug Testing Procedures

The purpose of the slug tests was to generate the data necessary to estimate a horizontal hydraulic conductivity (K) value for each of the wells and an average horizontal K value for each hydrostratigraphic unit. Rising head and falling head slug tests were performed on four shallow and two deep wells at Site 3, four shallow and two deep wells at Site 4, and four shallow and three deep wells at Site 5 (Table 3-1). The monitoring wells slug tested at Site 3 were shallow wells SJS03-MW01S, -MW03S, -MW05S, and –MW06S and deep wells SJS03-MW01D and –MW02D. Shallow wells slug tested at Site 4 were SJS04-MW01S through –MW04S. Deep wells slug tested at Site 4 were SJS04-MW01D and –MW03D. Site 5 slug tested monitoring wells were shallow wells SJS05-MW01S, -MW02S, -MW04S, and -MW05S and deep wells SJS05-MW01D, -MW02D, and –MW04D.

The falling head slug tests were conducted by instantaneously submerging a slug, either a 3-ft or 5-ft long section of 1.5-in.-diameter PVC tube sealed at both ends, into the well. The volume of the 5-ft slug was approximately 0.0617 ft^3, which resulted in a theoretical maximum water-level displacement of 2.81 ft. The rate of water-level recovery was measured by a 10-pound-per-square-in. (psi) pressure transducer and was automatically recorded with a data logger. The duration of the slug tests varied and depended on the hydraulic characteristics and associated recovery times for individual wells. The rising head slug tests were conducted by reversing the procedure described above (i.e., instantaneously withdrawing the slug) and recording the rise of the water level with the pressure transducer and data logger.

The slug test data were analyzed with AQTESOLV™ for Windows computer software produced by HydroSOLVE, Incorporated. Two methods were chosen for analyzing the collected data; the Bouwer-Rice (1976 and 1989) method for unconfined and confined aquifers and the Cooper-Bredehoeft-Papadopulos (1967) method for confined aquifers. The well screens for the vast majority of the monitoring wells partially penetrated the aquifer in which they were screened. Both the Bouwer-Rice and Cooper-Bredehoeft-Papadopulos methods can be used for partially penetrating well screens.

Hydraulic conductivity (K) values were calculated using both the falling and rising head test data. Results from falling head tests, however, were not used when the static water level occurred within the screened interval, because flow would not occur under saturated conditions. Introduction of the slug into the aquifer raises the water level above the static height and forces groundwater into the unsaturated filter pack and surrounding vadose zone. Hydraulic conductivity values were reported for both methods for rising and falling head tests when the static level occurred within the riser pipe portion of the monitoring well.

3.11 Tidal Survey

Two distinct tidal surveys were conducted by CDM during the RI; one in November 1997 and one in May 1999. The objective of the tidal survey was to document the tidal influences of the surrounding surface water bodies on the Columbia and Yorktown Aquifers at Sites 3, 4, and 5 (Table 3-5).

A limited scope tidal survey was conducted in November 1997 at Site 5. During this survey, water levels in one shallow well (SJS05-MW01S) and one deep well (SJS05-MW01D) were collected over a period of approximately 10 hours. Water levels were measured on November 4, 1997.

A second tidal survey was conducted in May 1999 at Sites 3, 4, and 5 and at background monitoring well locations. Water-level measurements were continuously recorded every 30 minutes for a time period ranging from 73 to 84 hours from May 1to May 8, 1999 depending on the monitoring well. Monitoring wells SJSBK-MW02D, SJS03-MW01D, SJS04-MW03D, and SJS05-MW02D were monitored from May 1 through 4, 1999. From May 5 through 8, 1999, a different set of wells was measured continuously for water levels. These wells included the following seven shallow wells: SJS03-MW05S, SJS03-MW06S, SJS04-MW02S, SJS05-MW01S, SJS05-MW02S, SJS05-MW04S, and SJS05-MW05S. Water levels were also measured continuously in nearby surface water bodies.

3.12 Deviations from the Work Plan Scope

During the field investigation, the scope of work occasionally deviated from the scope proposed in the work plan. These deviations, the reasons for the deviations, and their impact on the quality and quantity of data, were identified by CDM in their *Draft Remedial Investigation and Human Health Risk Assessment Reports* dated February 20, 1998 and are summarized in Table 3-6.

3.13 Reference

Bouwer, Herman. *The Bouwer and Rice Slug Test – An Update*. Groundwater, Vol. 27 No. 3, May-June 1989.

CDM Federal. *Final Landfill B and the Burning Grounds Work Plan*. St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. May 1997.

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CDM Federal. *Draft Remedial Investigation and Human Health Risk Assessments Landfill B (Site 2) and Burning Grounds (Site 5)*. St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. February 1998.

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CDM Federal. *Final Supplemental Field Investigation Plan Landfill B and the Burning Grounds*. St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. March 1999.

CDM Federal. *Final Supplemental Field Investigation Plan Landfill C and Landfill D*. St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. March 1999.

CH2M HILL. *Technical Memorandum Work Plan for Limits of Waste Delineation at Sites 2, 3, 4, 5, and 6*. St. Juliens Creek Annex. Chesapeake, Virginia. September 2001.

SECTION 4

Physical Characteristics

This section describes the physical characteristics of the regional setting, the SJCA setting and the site-specific settings at Sites 3, 4, 5, and 6. Sections 4.1 through 4.4 respectively discuss regional physiography, climate, and surface water hydrology (Section 4.1); site topography and drainage (Section 4.2); regional geology and hydrogeology (Section 4.3); and site-specific geology and hydrogeology (Section 4.4).

4.1 Regional Physiography, Climate, and Surface Water Hydrology

SJCA is located in the eastern part of the Atlantic Coastal Plain Physiographic Province in Chesapeake, Virginia, within the Tidewater Region (Figure 4-1). Low elevations and relatively flat relief, with few elevations25 ft above mean sea level (msl), characterize this part of the Coastal Plain (Figure 4-1). SJCA lies within the Deep Creek Swale (Oaks and Coch, 1973), with natural elevations ranging from sea level to less than 20 ft above msl in the northeastern portion of the facility (Figure 4-2; Figure 4-3). The Deep Creek Swale is bounded by the Churchland flat and Suffolk Scarp to the west and by the Fentress rise and Hickory Scarp to the east (Figure 4-2). Cederstrom (1957) also describes the regional physiography.

The area encompassing SJCA lies in the James River drainage basin (Figure 4-2). Various sources indicate that the study area receives an average of approximately 46 in. of precipitation annually (FWEI, March 1995). Between 50 and 70 percent of the precipitation is removed from the area via runoff along the relatively flat topography and via evapotranspiration. The remaining 30 to 50 percent (14 to 23 in.) of precipitation recharges the surficial aquifer system by percolation through the upper soils (Siudyala, 1981). This recharge volume is approximately equivalent to 1.5 to 2.5 million gallons per day (MGD) per square mi. (mi^2). Approximately 90 percent of recharged groundwater returns to surface water streams as baseflow.

The Southern Branch of the Elizabeth River defines the eastern boundary of the land occupied by SJCA. St. Juliens Creek, which is a west-to-east flowing tributary of the Southern Branch of the Elizabeth River, defines the southern boundary of SJCA. Blows Creek, also a tributary of the Southern Branch of the Elizabeth River, is located south of Sites 3, 4, 5, and 6 and drains the SJCA area. The Southern Branch of the Elizabeth River is one of several short, northward-flowing rivers and streams that discharge into the James River near Portsmouth. From SJCA, the Southern Branch of the Elizabeth River flows north approximately 10 mi. to its confluence with the James River. Located north of SJCA, Paradise Creek is a tributary of the Southern Branch of the Elizabeth River. The Elizabeth River system is a sub-basin of the James River Basin and drains approximately 300 mi^2. (Fluor Daniel GTI, May 1997). The James River then discharges into the Chesapeake Bay less than 20 mi. from the Atlantic Ocean.

The Southern Branch of the Elizabeth River is part of the Intracoastal Waterway system. It is connected to regional water bodies to the south (the other side) of the James River drainage divide by man-made drainage systems (Figures 4-1 and 4-2). The Southern Branch of the Elizabeth River is connected to Currituck Sound in North Carolina by the Albemarle and Chesapeake Canal. It is also connected to the Albemarle Sound in North Carolina by the Dismal Swamp Canal. Currituck Sound is a northeastern extension of the larger Albemarle Sound.

The Southern Branch of the Elizabeth River and its tributaries (including Blows Creek and St. Juliens Creek) are part of a tidal estuary system. In the vicinity of St Juliens Creek Annex, the mean tide range of the Elizabeth River is approximately 2.8 ft and the spring tide range is approximately 3.4 ft (Baker, March 1998). Fresh water inflow to the system is minimal, composed principally of drainage from the Dismal Swamp and stormwater runoff (Fluor Daniel GTI, May 1997).

4.2 Site Topography and Drainage

Land surface elevations throughout much of SJCA range from sea level to approximately 15 ft above msl. Although topographic relief at SJCA is relatively flat, topography can control local surface water flow, groundwater flow, and groundwater/surface water connectivity.

Most of the high areas of the SJCA, including the landfill slopes at Site 4, are man-made and underlain by a variety of artificial fill materials. A review of the aerial photographs show that artificial fill (including dredge spoils) was placed onto natural geologic surface material throughout most of the Sites 3, 4, 5, and 6 investigation areas. The thickness, distribution, and origin of the fill material are more thoroughly discussed below in Section 4.4.

Surface water at Sites 3, 4, 5, and 6 drains either naturally or through unlined man-made drainage ditches to tidally influenced Blows Creek and the Southern Branch of the Elizabeth River. The 1 to 3 ft deep upland drainage ditches near these sites may contain standing water where surface runoff is stored and is capable of infiltrating to groundwater during seasonal low water-table conditions. The drainage ditches between the sites generally become shallower and are grassed to the north. Marshes between Site 5 and Blows Creek and east of Site 5 may also temporarily store surface water drained from the sites and allow for mixing with discharged groundwater that slowly drains into Blows Creek or the Southern Branch of the Elizabeth River via overland flow or as groundwater baseflow.

4.3 Regional Geology and Hydrogeology

4.3.1 General Regional Geology and Hydrogeologic Framework

Several authors have discussed the geology and hydrogeology of Southeastern Virginia: Cederstrom (1957), Oaks and Coch (1973), Siudyla et al. (1981), Hamilton and Larson (1988), Meng and Harsh (1988), and Harsh and Laczniak (1990) were the primary references for this report.

Southeastern Virginia lies within the Atlantic Coastal Plain physiographic province. This province stretches from Georgia to Long Island, New York. It is underlain by an eastward

thickening wedge of marine and non-marine sediments deposited during Late Cretaceous, Tertiary, and Quaternary time (Figure 4-4). Along the coastline, several thousands of ft of interlayered, unconsolidated sediment, consisting of gravel, sand, silt, and clay deposits overlie pre-Cretaceous crystalline basement rock. Minor amounts of detrital carbonate, shells, and secondary minerals such as glauconite, siderite, and chlorite often distinguish these units. Historical Coastal Plain sedimentation and deposition were controlled by fluctuations in sea level on a subsiding continental margin.

The Virginia Coastal Plain sediment wedge is, for the most part, underformed but generally dips gently to the southeast (Figure 4-4). The average structural dip of the oldest and deepest deposits is approximately 40 ft/mi. and of the youngest and shallowest deposits is less than 3 ft/mi. Differential subsidence produced a series of gently dipping regional structural highs and lows, known as arches and embayments (or basins). The Tidewater Area of Virginia is located along the axis of a regional structural feature known as the Norfolk Arch, as shown in Figure 4-5. The arch is an east-west structural ridge of crystalline basement rock that separates the Salisbury Embayment to the north from Albemarle Embayment to the south. Thicker accumulations of sediment occurred in the basins as compared to over the arches. The arches were partially responsible for characteristic depositional sequences within the different basins, as described below.

In the vicinity of Chesapeake, the Coastal Plain sediments are estimated to be 1,500 to 2,000 ft thick. The eastward dipping sediment package consists of unconsolidated marine, alluvial, and lagoonal deposits. Sediments of the Salisbury Embayment, north of the Norfolk Arch, are characteristically glauconite-rich, while sediments of the Albemarle Embayment, south of the Norfolk Arch, are characteristically carbonate rich.

A generalized stratigraphic column for the Virginia Coastal Plain is presented in Figure 4-6. Both geologic (i.e., time-stratigraphic) units and corresponding hydrostratigraphic units are presented.

Based on the generalized regional column (Meng and Harsh, 1988, Table 1), geologic units present beneath the study area include, from youngest to oldest:

- Holocene (Recent) deposits;
- Undifferentiated Pleistocene deposits;
- The Miocene to Pliocene Chesapeake Group of formations (including the Yorktown Formation);
- The Paleocene to Eocene Pamunkey Group of formations;
- Late Cretaceous undifferentiated sediments; and,
- Early to Late Cretaceous Potomac Formation.

Corresponding to the regional geologic formations and groups listed above are 17 hydro-stratigraphic units: 9 aquifers separated by 8 aquitards or confining units. The hydrostratigraphic units are, from youngest to oldest:

- Holocene to Pleistocene Columbia Aquifer;
- Late Pliocene Yorktown Confining Unit;

- Late Miocene to Pliocene Yorktown-Eastover Aquifer;
- Miocene St. Marys Confining Unit;
- Miocene St. Marys-Choptank Aquifer (not present in the vicinity of Chesapeake);
- Early Miocene Calvert Confining Unit;
- Eocene to Early Miocene Chickahominy-Piney Point Aquifer;
- Late Paleocene to Early Eocene Nanjemoy-Marlboro Clay Confining Unit;
- Paleocene Aquia Aquifer;
- Early Paleocene Brightseat Confining Unit (not present in the vicinity of Chesapeake);
- Early Paleocene Brightseat Aquifer (not present in the vicinity of Chesapeake);
- Late Cretaceous Upper Potomac Aquifer;
- Late Cretaceous Upper Potomac Confining Unit;
- Early Cretaceous Middle Potomac Confining Unit;
- Early Cretaceous Middle Potomac Aquifer;
- Early Cretaceous Lower Potomac Confining Unit; and,
- Early Cretaceous Lower Potomac Aquifer.

Of these regional hydrostratigraphic units, only the youngest three were studied in any detail during the RI activities, because only these three are likely to be affected by SJCA operations.

4.3.2 Regional Geologic and Hydrostratigraphic Unit Description

This section describes the regional geologic and hydrostratigraphic units beneath the Chesapeake, Virginia area. A greater emphasis is placed on the uppermost (i.e., youngest) three hydrostratigraphic units (Columbia Aquifer, Yorktown Confining Unit, and Yorktown-Eastover Aquifer) and their corresponding geologic units. These units make up the uppermost 350 to 400 ft beneath the SJCA facility and are the units most likely impacted by site operations. Although some of the deeper aquifers are much more transmissive than the upper aquifers, they are generally brackish and require evaluation and treatment prior to usage as a potable or industrial water source. For these reasons, along with the escalated cost of installing wells in the deeper aquifers, it is unlikely for the deeper aquifers to be indiscriminately used as a water supply in the area.

Regionally, Holocene deposits include alluvial, marsh, swamp and beach sediments. Holocene alluvium is present along the flood plain of Blows Creek.

The Pleistocene deposits are considered to be undifferentiated in the Coastal Plain region. Locally, Oaks and Coch (1973) differentiated the Pleistocene deposits into several formations or units, each with multiple lithofacies. A lithofacies is an aerially distinct sub-unit of a geologic unit distinguished from surrounding facies by appearance and character and is representative of its environmental origin or setting. In the vicinity of SJCA, Oaks and Coch (1973) generally identifies the surface geology as a facies of the upper member of the Pleistocene Sand Bridge Formation. The facies is fluvial and lagoonal in origin and comprises silt and sand. The Sand Bridge becomes estuarine and tidal-channel clay and sand to the west and marsh and tidal-flat silt and clay to the south. The Sand Bridge is underlain by various sandy facies of the Kempsville, Norfolk, and Great Bridge formations.

The number of formations and facies near the St. Juliens Creek Annex represents the complexity of the local Pleistocene depositional environments, lithologies, and nomenclature. Throughout SJCA, the complex nomenclature is compounded by the presence of abundant fill, which can replace varying thickness of Holocene and Pleistocene deposits or overlie these deposits.

The previous discussion describes the depositional environments and lithologies of the geologic materials underlying SJCA and vicinity, and indicates the complexity of the geology. For the purposes of the RI, the Holocene and Pleistocene nomenclature is simplified by utilizing the term "Columbia Formation" to represent any Holocene or Pleistocene deposits. These post-Pliocene sediments (i.e. those overlying the Yorktown Formation clay) generally consist of clay, silty sand, and sand with intermittent lenses of coarse sand and gravel and shell fragments. To further simplify the nomenclature, the term "Columbia Formation" includes any fill material. The Columbia Aquifer is the Virginia Hydrostratigraphic Unit representing Holocene and Pleistocene age deposits, as described by Meng and Harsh (1988).

The Columbia Aquifer, overlying the Yorktown confining unit, is generally unconfined. Locally, however, clayey sediments within the unit may produce confined or leaky confined conditions and result in areas of perched groundwater. In the Chesapeake vicinity, transmissivity of the Columbia Aquifer is variable, ranging over several orders of magnitude, due to its heterogeneous and anisotropic nature. Transmissivity is generally less than 3,000 gallons per day per ft (gpd/ft) or approximately 400 ft^2per day (ft^2/day) and can be as little as tens to hundreds of gpd/ft.

Underlying the Columbia deposits are the Windsor and Bacons Castle Formations of early Pliestocene and late Pliocene age, which comprise the Yorktown confining unit as identified by Meng and Harsh (1988). This is the confining unit above the Yorktown and Eastover formations and will be referred to as the Yorktown confining unit in this report. The Yorktown confining unit consists of very fine sandy to silty clays that are highly variable in color, varying from multicolored to dark gray. The clays were deposited on a shallow, marine shelf in broad lagoonal and bay areas.

Regionally, this unit varies in thickness with a maximum thickness of approximately 100 ft in northeastern Virginia. In the Chesapeake vicinity (within the Elizabeth River drainage basin) the clay is reportedly approximately 25 to 38 ft thick. Site-specific information on the distribution of the Yorktown Confining Unit is provided in Section 4.4.3.

The Yorktown Formation represents a fining upward marine depositional sequence. It consists of basal coarse sand and gravel, fining upward through a fine to medium, shelly sand facies, and capped by fine silty clay. At SJCA, the Yorktown Formation combines with the underlying Eastover Formation (also a fining upward sequence) and, possibly, the sandy basal portion of the overlying Bacon's Castle Formation, to make up the Yorktown-Eastover Aquifer. In the vicinity of Chesapeake, the elevation of the top of the Yorktown-Eastover Aquifer is at least at 50 ft below msl and appears to range from approximately 50 to 78 ft below msl in a southward trend across the Tidewater area.

More commonly known as the Yorktown Aquifer, this aquifer is thickest in the northeastern Virginia Coastal Plain and is approximately 200 ft thick in the Chesapeake area. The

Yorktown Aquifer is unconfined in the western-most portion of the Virginia Coastal Plain but is a confined to semi-confined aquifer in the area around SJCA. The formation is both heterogeneous and anisotropic. In some areas the Yorktown Aquifer can be divided into Upper, Middle, and Lower Yorktown Aquifers (Siudyla, 1981). In the Chesapeake vicinity, transmissivity values from aquifer testing range from approximately 1,500 gpd/ft to 65,000 gpd/ft (200 to 8700 ft^2/day), with an average of 15,000 to 20,000 gpd/ft (2000 to 2675 ft^2/day). In the area near SJCA, the thickness of the confining unit beneath the Yorktown Aquifer (the St. Marys confining unit) ranges between approximately 40 and 60 ft.

The Chesapeake Group of formations, of which the Yorktown and Eastover formations are a part, also includes the St. Marys, Choptank, Calvert, and Old Church formations. These Formations were deposited in a progressively shallowing, open marine environment. The deposits consist of fine interlayered sands, silts, and clays with shelly material, generally coarsening upward with greater amounts of shells/shelly material.

The Pamunkey Group consists of the Chickahominy, Piney Point, Nanjemoy, Marlboro, Aquia, and Brightseat formations, making up three aquifers and two confining units. With the exception of the Marlboro Clay, deposits of this Group generally are made up of glauconitic sands, silts and clays, with varying amounts of shells and calcareous-cemented shell material. The aquifers are confined throughout the Virginia Coastal Plain. The elevation of the top of the Chickahominy-Piney Point Aquifer (the shallowest aquifer of this Group) is 400 ft below msl.

In the Chesapeake, Virginia vicinity, the top of the Late Cretaceous Aquifer (the Upper Potomac Formation) occurs at elevations between 600 and 700 ft below msl. Transmissivity of the aquifer is typically between 15,000 and 60,000 gpd/ft (2,000 to 8,020 ft^2/day). The top of the Middle Potomac Aquifer occurs at elevations between approximately 850 to 875 ft below msl and the top of the Lower Potomac Aquifer occurs at approximately 1,300 ft below msl (Lower Potomac Aquifer). Transmissivity of both of the Early Cretaceous Aquifers typically is close to 100,000 gpd/ft (13,400 ft^2/day) or greater.

4.3.3 Regional Water Usage

4.3.3.1 Columbia Aquifer

Siudyla et al. (1981) provide considerable information on the water usage in the region. Regionally in Southeastern Virginia, the Columbia Aquifer may be utilized as a source of domestic water supply. Near SJCA, no wells reportedly utilize the Columbia Aquifer for domestic potable supply due to its quality and low yield (Fluor Daniel GTI, May 1997). However, some area residents may utilize the shallow aquifer for such purposes as watering lawns or filling swimming pools. These residents would be upgradient from the SJCA. Well yields for small diameter wells range from 5 to 50 gallons per minute (gpm) and have low specific capacities (1 to 2 gpm/ft of drawdown).

4.3.3.2 Yorktown and Potomac Aquifers

Throughout the eastern portion of the Coastal Plain, the Yorktown Aquifer is used for domestic and public water supply, as well as for industrial purposes. The Yorktown Formation is typically utilized for watering lawns and filling swimming pools as the Columbia Formation typically provides poor water quality, yield, or both. In the area of

SJCA, the Yorktown Aquifer is not known to be used as a potable source of supply and area residences are supplied by the City of Chesapeake's distribution system. The flow direction in the Yorktown Aquifer at SJCA is to the east and southwest, towards Blows Creek and the Southern Branch of the Elizabeth River.

Where the Yorktown Aquifer is utilized in the Tidewater Region, reported well yields are quite variable, as expected due to its heterogeneous nature. Large diameter wells (6 in. or greater) used for public, commercial, and industrial purposes produce from approximately 10 to 300 gpm, and average 85 gpm. These wells exhibit specific capacities ranging from approximately 0.5 to 15 gpm/ft of drawdown. Smaller diameter wells used for domestic purposes yield between 5 and 50 gpm, similar to the Columbia Aquifer.

Although notable water quality and quantity can be produced from the aquifers of the Pamunkey Group (located below the Yorktown Aquifer), large-scale municipal wells near Chesapeake typically bypass these aquifers for the even deeper and more productive Potomac Aquifers.

The City of Chesapeake supplies water to the area using a combination of surface water and deep groundwater supplies. The City of Chesapeake's water supply system consists of surface water from the Northwest River System, purchased finished water from the City of Portsmouth, and deep groundwater from the Western Branch Well Field. The Western Branch Well field consists of three groundwater wells installed in the Upper/Middle or Middle Potomac Aquifers, each with a 3 MGD capacity. One of these wells is utilized as an aquifer storage and recovery well, where treated surface water is injected and later withdrawn. These wells are located 15 mi. west, and hydraulically upgradient of the SJCA.

The only permitted municipal groundwater usage of significance (i.e., several MGD or more) located to the southeast of SJCA is at the Chesapeake Civic Center. Here, approximately 10 mi. from SJCA, a total of 14.9 MGD of groundwater allocation had been permitted from the Yorktown Aquifer, Upper Potomac Aquifer, and Middle Potomac Aquifer (Richardson et al., 1988). It is unknown how this allocation is distributed among the aquifers but it is expected that the use is intermittent and normally considerably less than the total permitted amount. Because the Chesapeake Civic Center well is sufficiently far from the SJCA, and is located on the east (opposite) side of the Southern Branch of the Elizabeth River, it would not be affected by operations at the Annex.

There are 11 commercial/industrial permitted groundwater withdrawals for non-potable use within 5 mi. of SJCA and an additional 9 permitted groundwater withdrawals near the base, outside the 5-mi. radius. With one exception, these groundwater withdrawals are from the deep Potomac Aquifers. Northwest of SJCA, the Elizabeth Manor Golf Club is permitted for groundwater withdrawals from the Yorktown Aquifer for golf course maintenance. These permitted groundwater withdrawals should not be affected by past or current operations at SJCA, given the depths and location of the permitted wells and groundwater barriers formed by the Southern Branch of the Elizabeth River on the east boundary of SJCA and St Juliens Creek on the south.

4.4 Site-Specific Geology and Hydrogeology

As described earlier, the complex nature of the subsurface at SJCA is characterized by facies changes in natural and anthropogenic materials that occur over short distances. Therefore, the subsurface is described in this section based on hydrostratigraphic units (i.e., aquifers and confining units) as opposed to stratigraphic (i.e., geologic time) units or small-scale lithologic properties.

Twenty-two soil and well borings define the surface and subsurface environment beneath Sites 3, 4, 5, and 6. These borings range in depth from just a few ft to 80 ft below msl. Specifically, eight Site 3 borings to a maximum depth of 49 ft below msl, six Site 4 borings to a maximum depth of 80 ft below msl, and eight Site 5 borings to a maximum depth of 58 ft below msl were used to characterize the geology near these sites. A surface soil map shows the distribution of the soil types across the SJCA facility (Figure 4-7). Based on the boring log descriptions, three hydrostratigraphic cross sections were created across Sites 3, 4, 5, and 6 to illustrate the subsurface environment. The locations of these cross sections are depicted in Figure 4-8 and the cross sections are presented in Figures 4-9 through 4-11.

The subsurface at Sites 3, 4, 5, and 6 can be separated into three hydrostratigraphic units: the Columbia Aquifer, the Yorktown Confining Unit, and the Yorktown Aquifer. In order to evaluate hydrogeologic conditions and groundwater flow directions in each aquifer unit, an analysis was conducted to determine where the screen interval of each well fits relative to the site hydrostratigraphic framework. The screened hydrogeologic unit for each well is listed in Table 4-1. Wells generally are not screened across hydrostratigraphic contacts and in general, the wells are confidently associated with a single hydrostratigraphic unit (Table 4-1).

The Columbia and Yorktown Aquifers beneath SJCA are made up of imperfectly connected sandy bodies or lenses that also may contain appreciable amounts of silt or clay. The Yorktown Confining Unit separating the aquifers consists of clay and silt layers containing varying amounts of sand.

Appendix B contains lithologic descriptions from well borings drilled and logged at Sites 3, 4 and 5 and at background locations during the RI. Appendix C contains well construction logs for wells installed during the RI and at background locations. Table 4-1 summarizes well construction information for monitoring wells at Sites 3, 4 and 5 and at background locations. Water levels measured in these wells during the RI are presented in Table 4-2.

Hydrogeologic characteristics at each site were also characterized during slug testing and tidal surveys. Slug test data and tidal survey data are provided in Appendixes D and E, respectively.

4.4.1 Soil Types Identified at Sites 3, 4, 5, and 6

Soil samples were collected in Bohicket, Dragston-Augusta, dredge fill, Munden-Tetotum, and Urban-Udorthents soil types to establish background soil quality as part of the basewide background investigation. The results were incorporated into a Background Investigation for SJCA, dated October 2001. The background soil sample results are included in Appendix G. The distribution of soil types across SJCA is depicted in Figure 4-7.

4.4.1.1 Dredge Fill

Dredge fill can be identified in 1937 and 1949 aerial photographs at Site 3, between Sites 3 and 4, and in the northern portion of Site 4. RI field activities, however, revealed that the dredge fill is more extensive and encompasses Sites 3, 4, 5, and 6. The areal extent of the dredge fill is approximately 62 acres, extending from the northeastern border of the SJCA, west toward Blows Creek, and south toward Blows Creek and the Southern Branch of the Elizabeth River.

The dredge fill originated reportedly from the Southern Branch of the Elizabeth River and Blows Creek. In addition to dredge fill, waste material—including brick, concrete, gravel, and glass and metal debris—have been observed during field investigations at Sites 3, 4, 5, and 6. The fill placed at these sites was likely graded, cut, and otherwise disturbed by construction and earthmoving activities during placement.

The thickness of the dredge fill and waste materials is as much as 15 to 17 ft at Site 3 (SJS03-MW04S) and Site 4 (SJS04-MW01S) (Figures 4-8 through 4-11). The dredge fill thickens to the south of Site 3 and east of Site 5. The dredge fill thins to the west of the study area to approximately 2 ft at Site 5 (SJS05-MW01S and SJS05-MW02S). Borings just west of these monitoring wells (SJS05-MW03S and SJSBK-MW01S) did not indicate the presence of dredge fill.

Boring logs indicate that the poorly sorted dredge fill consists primarily of very dark gray and very dark greenish gray silt and clay with thin lenses of fine sand. Further north and west of the Southern Branch of the Elizabeth River in monitoring wells SJS03-MW01S, SJS05-MW02S, and SJS05-MW04S a greater abundance of coarser grained deposits was observed. It is likely that these soils are, in part, derived from adjacent soils that were mixed with dredge fill during filling and grading to the north and west of the Southern Branch of the Elizabeth River. At Site 5, surface soil east of Craddock Street (SJS05-SB09 and -SB30 through -SB33) was classified as part of the Munden-Tetotum Group (USDA, 1983). However, the SJCA Partnering Team agreed to classify surface soils east of Craddock Street as dredge fill soils based on a potential 20% error in the USDA soil classification mapping.

The dredge fill is complex and heterogeneous and its permeability and drainage is expected to be relatively slow. This complex, highly variable area of the facility remains largely undeveloped. Seasonal wetness is also characteristic for this area. Marsh and swamp areas exist just north of Blows Creek between the creek and Site 5 and to the east of Site 5.

4.4.1.2 Bohicket

The Bohicket series is a deep surface soil formed in marine sediment in tidal marshes. The Bohicket soil is nearly level and very poorly drained. The surface soil is generally dark grayish brown silty clay loam and the substratum is a silty clay. The permeability of this soil is very low. Only one surface soil sample (SJS05-SS18) collected at Site 5 was located in Bohicket soil.

4.4.2 Columbia Aquifer Geology and Hydrogeology

4.4.2.1 Geology

The geologic composition of the Columbia Aquifer is generally similar at Sites 3, 4, 5, and 6. The Columbia Aquifer ranges in thickness from approximately 13.5 ft in the northwestern portion of the facility to 40 ft in the southern portion of the facility. In the Sites 3, 4, and 5 study area, the thickness of the Columbia Aquifer generally increases toward Blows Creek and the Southern Branch of the Elizabeth River. At Site 3, the Columbia Aquifer thickness is about 20 ft, at the northern end of Site 4 the thickness is about 25 ft, and at the southern end of Site 4 the thickness increases to about 32 ft. At Site 5, the thickness of the Columbia Aquifer increases less dramatically from about 14 ft north of Site 5 to about 22 ft south of Site 5 near Blows Creek. The aquifer thickness (approximately 15 ft or less) and ground surface elevation remain fairly constant to the west of Site 5 near the northwestern and the western central boundaries of the facility.

A layer of waste material overlies the native soils, ranging in depth from 0.5 to 2.5 ft bgs. The thickness of the native deposits underlying the dredge fill or waste materials, Bohicket Group surface soils varies across the study area depending on the placement of dredge fill/waste materials. The native deposits vary in thickness from about 4 to 23 ft at Site 4, from about 7 to 12 ft at Site 3, and from about 9 to 22 ft at Site 5 (Figures 4-8 through 4-11).

The native geology underlying the dredge fill and waste materials, Bohicket surface soils consists of several types of deposits. In western and southern portions of the study area, native deposits of clay and silt occur directly beneath the dredge fill and waste materials. More specifically, these finer-grained native deposits underlie Site 5, west of Site 5, and some portions of Site 4, especially the southern portion of Site 4. These clay and silt native deposits tend to occur near Blows Creek and its tributaries and the Southern Branch of the Elizabeth River.

Beneath the finer-grained clay and silt deposits and at locations where these deposits are absent, the native deposits closer to the base of the Columbia Aquifer are primarily composed of well-sorted fine to coarse sand. Occasionally, small amounts of finer-grained silt and clay are interbedded and mixed with the sand. Interbeds and mixing tend to occur directly beneath the clay and silt deposits at depth where the Columbia Aquifer meets the Yorktown Confining Unit. The native deposits range from a yellowish orange or brown color at shallower depths to a gray color above the underlying confining unit.

4.4.2.2 Hydrogeology

Horizontal Groundwater Flow. Depth to groundwater (Columbia Aquifer) is expected to range seasonally between 2 and 6 ft bgs with extreme highs to 1 ft bgs. Groundwater in the surficial Columbia Aquifer generally flows toward and discharges to surficial water bodies (i.e., Blows Creek, St. Juliens Creek, and the Southern Branch of the Elizabeth River) surrounding SJCA. It is also likely that groundwater discharges to the low-lying marsh areas between Site 5 and Blows Creek and east of Site 5. At Site 3, groundwater may discharge to drainage ditches during spring months when high groundwater flow occurs. The drainage ditches also carry overland surface runoff from Sites 3, 4, 5, and 6 to surface water bodies. During transport of surface runoff, water in the unlined drainage ditches may infiltrate soil to groundwater. The drainage ditches at Sites 3 and 5 discharge to Blows

Creek. The Site 4 drainage ditch discharges near the mouth of Blows Creek, where it enters the Southern Branch of the Elizabeth River.

Water levels measured in all shallow monitoring wells, with the exception of SJS03-MW02S and SJS03-MW04S, are representative of the surficial, or Columbia Aquifer. Monitoring wells SJS03-MW02S and SJS03-MW04S are screened through a fine-grained dredge fill deposit. Water-level elevations in these two wells were substantially higher than water-level elevations measured in surrounding wells.

Groundwater flow directions are generally consistent despite seasonal changes in groundwater levels. Overall groundwater flow in the study area is from the northeast (Site 3) to the southwest (Site 5) and south (Site 4) (Figures 4-12 and 4-13). At Site 3, groundwater flows from the northeast to the west, southwest, south, and southeast. Monitoring wells SJS03-MW05S, -MW04S, -MW03S, -MW06S, and -MW02S, and several Site 4 and Site 5 monitoring wells, are downgradient of Site 3. Monitoring well SJS03-MW01S is upgradient or cross gradient of Site 3. Several Site 3 monitoring wells, including SJS03-MW02S, -MW04S, and -MW06S, and Site 4 monitoring well SJS04-MW01S, are upgradient of Site 4. Site 4 monitoring well SJS04-MW02S is cross gradient of Site 4. The remaining two Site 4 monitoring wells SJS04-MW03S and -MW04S are located downgradient of Site 4. Site 3 monitoring wells SJS03-MW01S and -MW05S are upgradient of Site 5. Site 5 well SJS05-MW01S is located within the waste boundary of the site while monitoring wells SJS05-MW02S, -MW03S, and -MW05S are downgradient of Site 5. Although background monitoring wells are located west of Sites 3 and 5, flow pathways do not indicate that background wells are located downgradient of Sites 3, 4, 5, or 6.

Groundwater flow gradients vary across the study area. The horizontal groundwater flow gradient is fairly flat and ranges from approximately.006 to.01 ft/ft. Similar to the land surface, the water table slopes gently toward Blows Creek and the Southern Branch of the Elizabeth River. Groundwater gradients tend to be steeper in finer-grained, less permeable deposits, such as clay and silt, than in sandier deposits. Groundwater gradients are steepest near the northern boundary of Site 4, immediately southwest and west of Site 3 and south of Site 5. The areas immediately east of Site 5, south of Site 3, and Site 5 itself have a flat gradient indicative of highly permeable deposits. The flat gradient in these areas may also represent marsh or swamp conditions where the water table is near or intermittently in contact with the ground surface.

Vertical groundwater flow is discussed in Section 4.4.3.2.

Hydraulic Characteristics. Slug tests were conducted on monitoring wells at Sites 3, 4, and 5. CH2M HILL reviewed the input parameters used by CDM Federal to evaluate slug test data and calculate hydraulic conductivity (K) values. Approximately 49 percent of the slug test data were re-evaluated by CH2M HILL and results for these tests are provided in Appendix D.

Slug test results by their nature are limited in their ability to accurately predict the K of an aquifer because of the filter pack placed around the well during installation. To be able to accurately predict the K of the aquifer, the radius of influence for the test needs to be larger than the radius of the borehole. Guidance provided in the Bouwer and Rice Slug Test – An

Update by Herman Bouwer (1989) was used to identify the best-fit straight line for calculating the K.

The average K for the Columbia Aquifer was calculated to be about 16 ft/day with a standard deviation of about 20 ft/day (Table 4-3). This high standard deviation is due to high K results, about 73 and 68 ft/day, obtained from slug tests at Site 4 monitoring wells SJS04-MW02S and SJS04-MW03S, respectively. The boring logs for these two wells indicate that drilling was difficult due to the presence of fill and that monitoring well installation was difficult due to the presence of sand and shells in augers. The surrounding fill or the well installation may be responsible for the high K values obtained from tests of these wells.

If these two monitoring wells are excluded from the data set, the average K across Sites 3, 4, and 5 is approximately 8 ft/day with a standard deviation of 4 ft/day. These numbers are consistent with the average and standard deviation for the Site 5 tested wells. The Site 3 slug tests yielded only a slightly higher K value (11 ft/day) and a lower standard deviation (2 ft/day).

The Site 4 results, including the slug test results for SJS04-MW02S and -MW03S discussed above, indicate there is a wide disparity between K results for various wells. Localized areas of higher permeability may exist near these two wells while very low K values of about 1.8 ft/day (with a standard deviation of 0.9 ft/ day) are reported for other Site 4 wells. The steep horizontal gradient (closely spaced lines of equipotential) at Site 4 depicted in Figures 4-12 and 4-13 support the very low K values from Site 4 wells SJS04-MW01S and -MW04S.

Tidal Influences. Water levels in shallow monitoring wells at Sites 3, 4, and 5 were continuously observed from May 5 through May 8, 1999. Water level fluctuations in two shallow wells at Site 3, one shallow well at Site 4, and four shallow wells at Site 5 were compared with water level fluctuations in a nearby tidally influenced Blows Creek (Figure 4-14). Water-level fluctuations were monitored in November 1997 and May 1999 in SJS05-MW01S. The tidal survey was designed to determine the inland extent of tidal influences at each site and the magnitude of any tidal influences. CDM did not measure water levels in deep paired monitoring wells during the same time period, thus, no comparisons of flow directions between units and surface water were made. In addition, CDM did not collect water-level elevation data to enable comparison of water level elevations in the Columbia Aquifer during the tidal survey.

The data logger at SJS05-MW05S malfunctioned during the study and water levels could not be evaluated for this well. Tidal influences were observed at SJS03-MW05S, SJS05-MW02S, SJS05-MW01S, and SJS05-MW04S during the tidal survey. Water level fluctuations observed in these wells were minimal and ranged from about 0.5 at SJS05-MW02S near Blows Creek to only a few hundredths of a ft at the other locations. Water level fluctuations of the magnitude observed at SJS05-MW02S near Blows Creek may be indicative of actual flow of river water into and out of the area where this well is located. Where water level fluctuations were only a few hundredths of a ft (at wells SJS03-MW05S, SJS05-MW01S, and SJS05-MW04S) the changes in water levels are likely indicative of a pressure effect rather than actual flow of river water in and out of the area. The lag in water level fluctuations in relation to changes in surface water fluctuations ranged from about 1 hour to 2.5 hours.

The extent of direct tidal influences on Columbia Aquifer groundwater is limited to the area near Blows Creek and the Southern Branch of the Elizabeth River. No tidal effects were observed as far north as SJS04-MW02S. Very small tidal fluctuation, likely related to pressure effects as discussed above extended north to Site 3 well SJS03-MW05S and Site 5 wells SJS05-MW01S and SJS05-MW04S. Actual river flow into and out of the aquifer or direct tidal influences are not likely to occur north of SJS05-MW02S.

4.4.3 Yorktown Confining Unit Geology and Hydrogeology

4.4.3.1 Geology

The Yorktown Confining unit was generally defined as the first significantly continuous clay layer (at least about 10 ft thick) above the more permeable sands and silts of the Yorktown Aquifer. The Yorktown Confining Unit was distinguished from the overlying Columbia Aquifer by the presence of a thick clay layer, greenish gray colored deposits, and the greater abundance of shell fragments.

The geologic composition of the Yorktown Confining Unit is generally similar at Sites 3, 4, 5, and 6. The Yorktown Confining Unit consists primarily of greenish gray clay with occasional yellowish brown mottling at some locations and depths. At most locations, thin (less than a few millimeters) fine to very fine sand lenses are interbedded in the clay at varying depths in the confining unit. Some silt is reportedly occasionally mixed with the clay. Also intermixed in the clay are organic materials and shell fragments. The clay is described to be soft to medium stiff.

The elevation of the top of the Yorktown Confining Unit ranges from about 8 ft below msl to about 15 ft below msl near Blows Creek at SJS05-MW02D and about 28 ft below msl near the mouth of Blows Creek and the Southern Branch of the Elizabeth River at SJS04-MW03D. The slope of the top of the Yorktown Confining Unit is generally towards Blows Creek and the Southern Branch of the Elizabeth River.

As depicted in Figure 4-15, the thickness of the Yorktown Confining Unit ranges from about 9 ft in the southeastern corner of Site 4 at SJS04-MW03D to at least 36 ft near Site 6.

4.4.3.2 Hydrogeology

Vertical Groundwater Flow. Vertical groundwater flow gradients were calculated between the Columbia and Upper Yorktown Aquifers through the Yorktown Confining Unit, using water-level monitoring data from May 17, 1999 and August 16, 2001 (Table 4-4). One Site 3 well pair, two Site 4 well pairs, three Site 5 well pairs, and three background well pairs were evaluated for vertical flow direction and gradients.

Vertical gradients between the Columbia and Yorktown Aquifers indicate that groundwater generally flows downward between these units. The gradients between the two aquifers are more variable and the vertical direction of groundwater flow can reverse in well pairs located adjacent to Blows Creek and its tributaries. Downward vertical gradients ranging from 0.17 to 0.01 are highest in wells located farthest from the Southern Branch of the Elizabeth River and Blows Creek and in areas underlain by dredge spoils at Sites 3 and 4.

Hydraulic Characteristics. Only one slug test was conducted in the Yorktown Confining Unit in well SJS04-MW01D (Table 4-3). The average K measured using the rising- and falling-

head slug tests for this well was about 3.5 ft/day. The average K for the Columbia Aquifer was more than four times the K for the confining unit. The average K for the Yorktown Aquifer was more than 6 times the Yorktown Confining Unit K.

Continuous water level monitoring was not conducted at SJS04-MW01D. Thus tidal influences on the Yorktown Confining Unit were not evaluated as part of this RI.

4.4.4 Yorktown Aquifer Geology and Hydrogeology

4.4.4.1 Geology

The Yorktown Aquifer was distinguished from the overlying Yorktown Confining Unit by the greater appearance of sand at least 5 ft thick and/or the first major sand unit with significant shell material. Within the Yorktown Aquifer a lesser semi-confining unit is occasionally encountered, resulting in the division of the Yorktown Aquifer into an Upper Yorktown Aquifer, Middle Yorktown Confining Unit, and Middle Yorktown Aquifer. The Middle Yorktown Confining Unit, however, is not a continuous unit regionally. The Upper Yorktown Aquifer lies beneath the Yorktown Confining Unit.

The geologic composition of the Yorktown Aquifer is generally similar at Sites 3, 4, 5, and 6. The Yorktown Aquifer consists primarily of fine to medium-grained sand and/or silty sand with a trace to abundant amounts of shell material, along with traces of finer-grained material, gravel, and organic material. The color of these deposits ranges from a light to dark greenish gray to a bluish gray. Occasionally, beds of clay, silt, or sandy clay were observed in the formation. The thickness of these beds ranged from about 1 in. to several tens of ft in SJS04-MW01D. These fine-grained deposits are depicted in Figures 4-9 through 4-11 as the Middle Yorktown Confining Unit.

In the study area, the top of the Yorktown Formation is encountered at elevations ranging from approximately 33 to 43 ft below msl. The top of the aquifer occurs at its lowest elevations (41 and 43 ft below msl) at Site 5 wells SJS05-MW02D and SJS05-MW04D, respectively. These elevations compare well with elevations of the top of the Yorktown Formation at Norfolk Naval Shipyard, which range from about 20 to 60 ft below msl. In the vicinity of Portsmouth, the top of the aquifer reportedly occurs at least 50 ft below msl. The full thickness of the Yorktown Aquifer is not penetrated anywhere onsite, as the deepest well boring in the study area terminates at 80 ft below msl at Site 4.

4.4.4.2 Hydrogeology

Horizontal Groundwater Flow. Groundwater occurring in the Yorktown Aquifer generally flows toward and discharges to the Southern Branch of the Elizabeth River (Figures 4-17 and 4-18). Groundwater flow patterns are generally consistent despite seasonal changes in groundwater levels. Contoured water levels measured in monitoring well SJS03-MW02D during both the May 17, 1999 and August 16, 2001 events resulted in complex groundwater flow directions between Sites 3 and 4 (Figures 4-15 and 4-16). A large portion of the lithologic unit screened by SJS03-MW02D is much finer grained (consisting of clay and sandy clay) than many of the other deep wells used to depict groundwater flow in the Yorktown Aquifer.

Overall groundwater flow in the study area is from the west and northwest (Site 5) to the southeast (Site 4) and east (Site 3) (Figures 4-15 and 4-16). More specifically, Yorktown Aquifer groundwater originating at Site 5 flows to the southwest, with SJS05-MW01D located upgradient of SJS05-MW02D and -MW04D. The elevated water levels at SJS03-MW02D result in a localized reversal of the flow direction near Site 3. Groundwater in the eastern and southern portion of Site 3 and the northern portion of Site 4 flows to the north, south, and west radially from SJS03-MW02D.

Groundwater flows under a very flat gradient across the majority of the study area. The horizontal groundwater flow gradient ranges from approximately 0.0003 to 0.0002 ft/ft across the majority of the study area. The groundwater gradient steepens near Sites 3 and 4 near SJS03-MW02D. Horizontal gradients in this area are still very flat and range from approximately 0.0004 to 0.0008 ft/ft.

Vertical groundwater flow is discussed in Section 4.4.3.2.

Hydraulic Characteristics. Slug tests were conducted on a total of six deep monitoring wells at Sites 3, 4, and 5. The procedures CH2M HILL used to review and evaluate the data are described in Section 4.4.2.2 above. Results for those slug tests reevaluated by CH2M HILL are provided in Appendix D.

The average K for the Yorktown Aquifer was calculated to be about 28 ft/day with a standard deviation of about 31 ft/day (Table 4-3). The highly variable K results are indicative of the composition of the formation screened in each well. For instance, the majority of the SJS03-MW02D well screen is in a finer-grained clay and sandy silt. The same is true for SJS04-MW03D, which is screened in silt and very fine sand deposits. At locations where greater K values were observed (SJS03-MW03D, SJS05-MW01D, -MW02D, and -MW04D) the well screens were located within a zone containing little silt or clay and frequently where more permeable coarse sand and gravel were observed.

Tidal Influences. Water levels in deep monitoring wells at Sites 3, 4, and 5 were continuously observed from May 1 through May 4, 1999. Water level fluctuations in one deep well at Site 3, one deep well at Site 4, one deep well at Site 5, and one deep background well were compared with water level fluctuations in nearby tidally influenced Blows Creek (Figure 4-18). Site 5 deep well SJS05-MW01D was monitored in November 1997.

The tidal survey was designed to determine the inland extent of tidal influences at each site and the magnitude of any tidal influences. CDM did not measure water levels in deep paired monitoring wells during the same time period, thus, no comparisons of flow directions between units and surface water were made. In addition, CDM did not collect water-level elevation data to enable comparison of water level elevations in the Columbia Aquifer during the tidal survey.

Tidal influences were observed at SJS04-MW03D, SJS05-MW02D, and SJSBK-MW02D during the tidal surveys. No tidal influences were observed at the Site 3 deep well SJS03-MW01D, the well located furthest from any surface water body. While surface water levels fluctuated by about 2 ft between low and high tides, the magnitude of the fluctuations in the Yorktown Aquifer wells ranged from approximately a few hundredths of a ft at SJS05-MW01D to more than one ft at SJS04-MW03D. Tidal fluctuations in SJSBK-MW02D were only a few tenths of a ft. Water level fluctuations at SJS05-MW02D were as much as about

0.5 ft. The water level fluctuations lagged behind the surface water fluctuations by about 1.5 to 2 hours (hrs) in SJS05-MW02D and 2 to 2.5 hrs in SJS04-MW03D.

The extent of direct tidal influences on Yorktown Aquifer groundwater is limited to the area near the Southern Branch of the Elizabeth River. No tidal effects were observed as far north as SJS03-MW01D. Very small tidal fluctuation, likely related to pressure effects as discussed above, extended west to well SJSBK-MW02D and to SJS05-MW01D.

4.5 References

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SECTION 5

Nature and Extent of Contamination

Section 5 summarizes the analytical data collected during RI activities at Sites 3, 4, 5, and 6 and discusses the nature and extent of contamination found in the sampled media at these sites. The discussion is divided into four parts. Section 5.1 summarizes the management and evaluation of laboratory analytical data for all media. These include surface soil, subsurface soil, shallow groundwater, deep groundwater, sediment, and surface water. Sections 5.2 through 5.5 present the analytical results for Sites 3, 4, 5, and 6, respectively. Each section is further divided into subsections that present the extent of waste; geophysical survey results; and analytical results for soil, groundwater, sediment, and surface water data.

5.1 Management and Evaluation

This section presents information on the management and evaluation of analytical data collected during the RI. This includes data tracking and validation to ensure data quality. It also includes discussion on the basis for evaluation of non-site-related analytical results, regulatory and risk-based standards, and data presentation and evaluation.

5.1.1 Data Tracking and Validation

The data management and tracking from the time of field collection to receipt of validated electronic analytical results is of primary importance and reflects the overall quality of the analytical results. Field samples and their corresponding analytical tests were recorded on chain-of-custody forms, which were submitted with the samples to the laboratory. Chain-of-custody entries were checked against the RI Work Plans (*Final Supplemental Field Investigation Plan Landfill B and the Burning Grounds*, dated March 1999, *Final Supplemental Field Investigation Plan Landfill C and Landfill D*, dated March 1999) to determine if all designated samples were collected and submitted for the appropriate analyses. On receipt of the samples by the laboratory, a comparison to the field information was made to determine if each sample was analyzed for the correct parameters. In addition, a check was made to ensure that the proper number and types of quality assurance/quality control (QA/QC) samples were collected for each media. QA/QC samples included field blanks, equipment blanks, trip blanks, duplicates, matrix spike/matrix spike duplicates (MS/MSD) samples, and laboratory blanks.

Hard copies and electronic versions of the analytical data reports for the RI were submitted to Environmental Data Quality, Inc., for third-party validation. Electronic versions were provided to CDM Federal and subsequently forwarded to CH2M HILL. CH2M HILL then formatted the files to automatically download data into the CH2M HILL master Oracle database. Validation procedures established by the Region III Modification to the National Functional Guidelines for Organic (USEPA, 1994) and Inorganic Analyses (USEPA, 1993) were adhered to during the validation process. These steps (third party validation and electronic data handling) serve to reduce inherent uncertainties associated with data authenticity and usability.

5.1.2 Data Qualifiers

All analytical data used in the RI were validated. Section 5 tables show the validated results. The data validation qualifiers, or flags, used for the Sites 3, 4, 5, and 6 data and a brief interpretation follow.

- Data qualified with a "B" flag by the data validator indicate that the analytes have also been detected in a field, equipment, or trip blank, or in a laboratory QA/QC sample. The concentration of a "B"-qualified result is less than 10 times the concentration of the constituent for an associated QA/QC result. If the sample concentration is less than 10 times the associated blank concentration, the conclusion is that the parameter was not detected. Further discussion of potential sources of blank contamination is provided in Section 5.1.3 below.
- Data qualified with an "I" indicate that the compound is estimated due to ether interference.
- Data qualified with a "J" flag indicate that the values were estimated.
- Data qualified with a "K" indicate that the analyte is present. The reported value may be biased high and the actual value is expected to be low.
- Data qualified with a "L" indicate that the analyte is present. The reported value may be biased low and the actual value is expected to be higher.
- Data qualified with a "NJ" indicate a tentative identification of the compound and the reported value is estimated.
- Data qualified with a "R" indicate an unusable result. The analyte may or may not be present in the sample and the result is rejected. All rejected data were excluded from the RI evaluation and risk assessments.
- Data qualified with a "U" indicate that the analyte was not detected and the associated number indicates the approximate sample concentration necessary to be detected.
- Data qualified with a "UJ" indicate that the analyte was not detected and the quantitation limit may be inaccurate or imprecise.
- Data qualified with a "UL" indicate that the analyte was not detected and the quantitation limit is probably higher.

5.1.3 Evaluation of Non-Site—Related Analytical Results

Some of the organic and inorganic constituents detected in various media from Sites 3, 4, 5, and 6 might be attributed to non-site-related conditions or activities such as laboratory contaminants, anthropogenic sources, and naturally occurring (background) concentrations of constituents.

5.1.3.1 Laboratory and Sampling Blank Contamination

In some instances, chemical compounds detected in samples may have been introduced during field sampling, transportation to the analytical laboratory, or during laboratory procedures. Thus, a variety of blank samples were analyzed and used in the QA process to

determine if the contamination is site-related or is due to sample handling. Blank samples usually collected include a field blank, to account for ambient conditions during sampling; an equipment or rinsate blank, to determine if the equipment used to collect the samples (e.g., augers, pumps, and sample containers) was adequately clean; and a trip blank, to ascertain if VOCs were introduced during packing or shipping. Additionally, the laboratory analyzes a method blank in each batch of 20 samples to verify instrument cleanliness and function. Common laboratory contaminants that can be introduced during the analytical process are acetone, 2-butanone, methylene chloride, and common phthalate contaminants.

When blank samples are found to contain common laboratory contaminants, each of the aqueous field samples associated with that blank and contain up to 10 times the concentrations in the blanks are qualified during data validation with a "B" for that compound. A "B" qualifier means that the compound may not be attributed to the site at that sample location. When a sampling or laboratory blank contains contaminants other than the common laboratory contaminants, each of the aqueous field samples associated with that blank and that contain up to 5 times the concentrations is qualified during data validation with a "B" for that compound.

To determine if a "B" qualifier should be assigned to a soil sample, a unit conversion is performed whereby soil sample concentrations relative to aqueous samples or laboratory blank concentrations are determined by dividing the soil concentration by the percentage of moisture, then dividing the result by 5. A "B" qualifier designation as described above for aqueous samples can then be applied directly to the converted soil concentrations.

5.1.3.2 Background Data

A basewide soil and groundwater background study was conducted at SJCA (CH2M HILL, 2001). The objective of the investigation was to establish background concentrations of metals, pesticides, and PAHs in surface and subsurface soil, and to a limited extent, groundwater for use in comparison to Installation Restoration Program (IRP) site data to better identify release-related constituents of concern. Background levels are due to naturally occurring (those chemicals expected at a site in the absence of human influence) or anthropogenic (chemicals present in the environment due to man-made, non-site-related) sources. Soil and groundwater sample locations and site soil types are shown on Figure G-1 in Appendix G. Statistical analyses of background results are also provided in Appendix G of this report.

Fifty co-located surface (0 to 6 in. bgs) and subsurface (1 to 3 ft bgs) soil samples were collected for the background study. All soil samples collected were analyzed for TCL pesticides, PAHs, and TAL metals and cyanide. Surface soil samples were also analyzed for TOC and pH. Additionally, groundwater samples were collected in May 1999 from the seven background monitoring wells (four in the Columbia Aquifer and three in the Yorktown Aquifer) installed in April 1999. Samples were analyzed for TCL VOCs (low concentration), TCL SVOCs, TAL metals (filtered and unfiltered), and cyanide.

Site sediment and surface water data were qualitatively compared to upstream reference background sediment and surface water data collected from Blows Creek. There were four co-located surface water and sediment samples (SJSBK-SD/SW07 through SJSBK-SD/SW10) collected during two sampling rounds in April and October 1999; sample locations are shown

on Figure G-2 in Appendix G. The summary statistics for reference sediment and surface water were calculated and are shown in Appendix G on Tables G-3 and G-4, respectively.

5.1.4 Regulatory and Risk-Based Screening Criteria

Analytical results for all media were compared against a variety of regulatory and risk-based standards and criteria. Screening criteria were used to identify constituents that may pose a potential risk at the site. A list of the screening criteria used for each medium is provided below.

5.1.4.1 Surface and Subsurface Soil

- USEPA Region III Risk-Based Concentration (RBC) Levels for residential soil (adjusted for non-carcinogens by 0.1 to account for multiple contaminants)
- USEPA Region III Biological Technical Assistance Group (BTAG) soil flora and fauna criteria (surface soil only)
- VDEQ Underground Storage Tank (UST) Program Reporting Requirement (for TPH only)

5.1.4.2 Groundwater

- Federal Maximum Contaminant Levels (MCLs)
- USEPA Region III RBCs for tap water

5.1.4.3 Sediment

- USEPA Region III RBCs for residential soil (adjusted for non-carcinogens by 0.1 to account for multiple contaminants)
- USEPA Region III BTAG sediment flora and fauna criteria

5.1.4.4 Surface Water

- USEPA Region III RBCs for tap water (adjusted for non-carcinogens by 0.1 to account for multiple contaminants)
- USEPA Region III BTAG marine flora and fauna criteria

5.1.5 Data Evaluation and Presentation

5.1.5.1 Nature and Extent Evaluation

To identify constituents present in site media reflective of a potential site-related release, naturally occurring and anthropogenic compounds (metals, pesticides, and PAH SVOCs) detected at each site were compared to available background data. Screening criteria were used to identify constituents that may pose a potential risk. The nature and extent of potential contaminants at each site were evaluated for each matrix based on exceedances of background and the regulatory and risk-based screening criteria specified in Section 5.1.4.

Soil

Constituents detected in site soil were compared to the background 95-percent upper tolerance levels (UTLs). In addition, constituent concentrations that exceeded the UTL were evaluated through central-tendency population-to-population comparison between site and background soil data to determine if the two populations were statistically similar or if the site is statistically elevated over background. For site/background data sets with normal or lognormal distributions, central-tendency statistical analyses of the populations were conducted using a one-sided t-test. For site/background data sets with nonparametric distributions, central-tendency statistical analyses of the populations were conducted using the Wilcox Rank Sum method.

All constituents detected in soil were also compared to the risk screening criteria described above. Identification of potential site-related contaminants that may pose a potential risk were those compounds that exceed background UTLs with a mean/median population statistically elevated over background, and exceed risk screening criteria. Identification of potential site-related contaminant "hot spots" that may pose a potential risk were those compounds that significantly exceeded background UTLs and risk screening criteria but the population of site data were not statistically elevated over background.

Groundwater

Evaluation of the nature and extent of potential groundwater contamination was based on comparison of site groundwater to available risk screening criteria (tap water RBCs and MCLs). Background data for groundwater is limited to analytical results from four shallow wells (Columbia Aquifer) and three deep wells (Yorktown Aquifer). Due to the limited number of wells, background groundwater UTLs have not been established. Background maximum and mean concentrations and samples from site upgradient wells were used to further evaluate potential groundwater contamination.

Sediment

Although basewide background sediment data are not available for SJCA, four sediment samples (identified SJSBK-SD07 through -SD10) were collected in Blows Creek near Sites 4, 5, and 6 (Figure G-2). Because Blows Creek is tidally influenced, these sediment samples may not reflect true background conditions, but were reviewed qualitatively to assess potential site-related releases to sediment. All constituents detected in sediment were also evaluated with respect to screening criteria described above to identify compounds that may pose potential risks.

For Site 3, the upland ditches constructed near the site to control runoff are comprised of the same soil type as the site soils (dredge fill), remain dry through the majority of the year, are vegetated with grass, and contain no viable aquatic habitat. The SJCA Tier I Partnering Team reached consensus to use background soil UTLs to identify site-related releases in Site 3 upland drainage ditches. Compounds detected in Site 3 sediment that exceeded the soil background UTLs and risk screening criteria were identified as potential site contaminants. Identification of potential site-related contaminant "hot spots" in sediment that may pose a potential risk were those compounds that significantly exceeded background UTLs and risk screening criteria but the population of site data was not statistically elevated over background.

The upland ditches at Sites 4 and 5 also reflect site soil conditions. Although an official consensus was not derived, the team is in general agreement of the approach to compare Sites 4 and 5 upland ditch sediment sample results to background UTLs and risk screening criteria for soil. Therefore, the results from the Sites 4 and 5 sediment samples collected from the upland ditches (SJS04-SD04 and SJS05-SD01) were compared qualitatively to background UTLs and risk-based screening criteria for soil.

5.1.1.1 Surface Water

Although basewide background surface water data are not available for SJCA, four reference surface water samples (identified SJSBK-SW07 through SW10) were collected in Blows Creek near Sites 3 through 6 (Figure G-2). Because Blows Creek is tidally influenced, these surface water samples may not reflect true background conditions, but were reviewed qualitatively to assess potential site-related releases to surface water. All constituents detected in surface water were also evaluated with respect to screening criteria described above to identify compounds that may pose potential risks.

5.1.5.2 Evaluation of Selected Parameters

Subsurface soil data for dioxins and furans were evaluated using toxicity equivalency factors (TEFs) for the congeners detected based on USEPA Office of Solid Waste and Emergency Response (OSWER) Directive 9200.4 (April 1998). These congeners are considered to have dioxin-like toxicity and consist of polychlorinated dibenzodioxins (CDDs), and polychlorinated dibenzofurans (CDFs).

The toxicity equivalency procedure initially assigns TEFs to each of the dioxin-like CDD, and CDF congeners. A TEF of 1.0 is assigned to 2,3,7,8-TCDD and the other congeners are 2,3,7,8-TCDD equivalents with TEF values ranging from 0.5 to 0.00001. The toxic equivalency (TEQ) of a mixture is calculated following assignment of TEF values to congeners. The TEQ is the sum of the products of the concentrations of the individual congeners with their respective TEFs. For congeners not detected, one-half the reported detection limit was used to calculate the compound specific TEQ.

The inorganic constituents calcium, magnesium, potassium, and sodium are not typical in waste streams characteristic of the activities conducted at Sites 3, 4, 5, and 6. These common metals are not considered potential site-related compounds and therefore do not warrant detailed attention or discussion. Additionally, with the exception of magnesium, there are no human health or ecological screening criteria for these metals.

5.1.5.3 Data Presentation

Complete data tables, provided in Appendix H, list analytical results for all constituents analyzed for in the samples from the various media (soil, groundwater, sediment, and surface water) collected from each site. The shaded cells represent those constituents detected in the samples.

Tables 5-1 through 5-27 show constituents that were detected in one or more samples for a given matrix. These tables also contain the background UTL and screening criteria that were used to evaluate the data; detections that exceed the background UTL or screening criteria, as appropriate are shaded in the tables. Dioxin and furan exceedances in subsurface soil at Sites 3, 5, and 6 are presented in Tables 5-4, 5-20, and 5-27, respectively. Shaded cells

indicate values that exceed their respective TEF adjusted RBCs and Region III residential-soil RBC of 0.0043 μg/kg toxicity equivalent. Tables 5-2, 5-8, 5-11, and 5-18 show the population (site) to population (background) central-tendency statistical analysis for Sites 3, 4, and 5 soils and Site 3 sediment. The distribution of parameters in site media based on the evaluation approach described above is shown on Figures 5-2 through 5-16.

5.2 Site 3 Remedial Investigation Results

This section discusses the extent of waste, the geophysical survey results, analytical results obtained from laboratory analyses of various media, and the nature and extent of contaminants identified at Site 3. A quantitative HHRA and ERA through Step 3a are presented in Sections 7 and 8, respectively.

5.2.1 Extent of Waste

The results of the trenching activities indicated visual signs of potentially contaminated soils, construction debris, and spent ordnance at Site 3. The extent of these materials is presented on Figure 5-1.

Three spent ordnance items were found at Site 3. The ordnance included a dummy fuze, a distress flare, and a 40-mm shell. All of the ordnance was considered expended.

Debris waste consisted of construction related material including wires, tin cans, metal strapping, pieces of concrete, and wood. The debris was generally located within the first 2 ft of the test pit. The aerial extent of the debris was confined along the gravel road, which transects the Site 3 with the majority of debris located on the north side of the gravel road.

Soils that were burnt or stained generally consisted of black stained silty sand, which occasionally exhibited petroleum odors. Test pit SJS03-Trench 8 exhibited burnt soils and fire fighting equipment in the soil such as a used fire extinguisher and a fire hose coupling providing further indication that soils at the site were burned at one time or transported to the site after being burnt. The extent of the burnt or stained waste was limited to the north side of the gravel road at Site 3. The burnt/stained soil extended to a maximum depth of 2.5 ft bgs. Based on the results of the trenching activities, the extent of the Site 3 boundaries was adjusted to reflect the extent of waste (see Figure 5-1).

5.2.2 Geophysical Survey Results

An electromagnetic (EM) survey was conducted on a 100-ft grid at Site 3 (Figure 3-1, Appendix F). No anomalies were identified associated with the waste materials. Elevated EM readings over some areas of the site were attributed to changes in the salt or clay content of the soil or groundwater. Fill, specifically dredge spoils from the Southern Branch of the Elizabeth River, were identified in the Site 3 waste area where elevated EM readings indicated a higher salt content than observed in surrounding areas. A linear anomaly extending between the radar testing facilities corresponds to a known utility line.

5.2.3 Soil Analytical Results

5.2.3.1 Surface Soil

Eighteen surface soil samples (SJS03-SS01 through SJS03-SS18) were collected during the Phase I and Phase II sampling events. Sample locations are shown on Figure 5-2. The surface soil samples were analyzed for TAL total metals, TCL VOCs, TCL SVOCs, TCL pesticides/ PCBs, and TPH.

Table 5-1 lists all constituents that were detected in the surface soil samples. A shaded cell indicates that the parameter exceeded the 95-percent background UTL for dredge fill soil. Site/background population-to-population central-tendency statistical analysis results are shown on Table 5-2. The distribution of potential contaminants in surface soil at Site 3 is shown on Figure 5-2.

Inorganics. Twenty-three TAL metals were detected in the surface soil samples. Of the 23 metals detected 15 exceeded the background UTL in one or more samples: antimony, arsenic, barium, beryllium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, vanadium, and zinc. Additionally, cadmium and thallium were detected in one or more site samples but not in background. Samples SJS03-SS09 and SJS03-SS17, located inside the waste boundary, contained the greatest number of metals and generally at the highest concentrations that exceeded background UTLs (Figure 5-2). Outside the limits of waste at SJS03-SS15, antimony (162 mg/kg) and zinc (724 mg/kg) were significantly elevated above the background UTL.

Based on population (site) to population (background) central-tendency statistical analysis, only beryllium indicated a statistical difference from background. Although the population central-tendency analysis of beryllium indicates it to be statistically elevated over background, it should be noted that all dredge fill background beryllium results were qualified "B" and therefore treated as non-detects using one-half the detection limit in statistical analyses. Beryllium was only present at a concentration in the background UTL at SJS03-SS07 adjacent to the north waste boundary.

Thirteen inorganic compounds; aluminum, antimony, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, thallium, vanadium, and zinc; were present at concentrations above the adjusted residential RBCs. All of these compounds with the exception of aluminum were also present at concentrations greater than background. The greatest number of human health criteria and background UTL exceedances occurred in samples SJS03-SS09 and SJS03-SS17, located inside the waste boundary.

Seventeen inorganic compounds; aluminum, antimony, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, and zinc; were reported at concentrations elevated above the BTAG soil flora/ fauna ecological screening criteria. With the exception of aluminum and mercury, these compounds were also present at concentrations greater than background. The greatest number of BTAG criteria and background UTL exceedances occurred in samples SJS03-SS09 and SJS03-SS17, located inside the waste boundary. Beryllium was present at concentrations that exceeded the ecological screening criteria and background UTL at all but one surface soil sample location.

Volatile Organic Compounds. VOCs detected include low estimated concentrations of acetone, chloromethane, tetrachloroethene, and toluene. Excluding acetone, the frequency of detection is less than 0.1. No VOCs exceeded their respective adjusted residential soil RBC values or BTAG criteria.

Semivolatile Organic Compounds. Twenty-three SVOCs were detected in surface soil samples. Ten PAHs (a subset of SVOCs) exceeded the background UTLs, they are: anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i) perylene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene. Of these 10 compounds, only anthracene and phenanthrene indicated a central-tendency statistical difference from background based on population comparisons. The PAH exceedances of background UTLs only occurred within the waste boundary at sample location SJS03-SS09 (Figure 5-2).

SVOCs detected in surface soil with no established background values include: 2-methylnaphthalene, carbazole, dibenzofuran, di-n-butylphthalate, diethylphthalate, bis(2-ethylhexyl)phthalate, and pentachlorophenol. These SVOCs were sporadically detected at estimated concentrations below quantitation limits.

Five PAHs; benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h) anthracene, and indeno(1,2,3-cd)pyrene; were detected at concentrations that exceeded their respective human health screening criteria. Of these, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene also exceeded the background UTLs, but only in sample SJS03-SS09 within the waste. These PAHs did not indicate a central-tendency statistical population difference with background.

Fifteen PAHs; acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h) anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene; were detected at concentrations elevated above the BTAG screening criteria. Ten of the 15 PAHs were reported at concentrations greater than the background UTL and BTAG screening criteria; these occurred at surface soil sample location SJS03-SS09, located within the waste boundary. In addition, anthracene and phenanthrene indicated central-tendency statistical difference from background based on population comparisons.

Pesticides/PCBs. Eight pesticides/PCBs were detected in surface soil samples. There were five pesticides (4,4'-DDD, 4,4'-DDE, 4,4'-DDT, alpha-chlordane, and endosulfan I) that exceeded the background UTLs. However, none of these pesticides indicated a statistical difference from the background data based on central-tendency population comparisons. Background UTL exceedances of pesticides occurred throughout the site. The PCBs aroclor-1254 and aroclor-1260 were sporadically detected in surface soil, predominantly within the waste.

No pesticides exceeded human health screening criteria. Aroclor-1254 exceeded the human health criteria only in the waste boundary duplicate sample SJS03-SS12P (280 J µg/kg); aroclor-1254 in the parent sample SJS03-SS12 was 130 µg/kg (Figure 5-2). Aroclor-1254 in this sample also exceeds the BTAG screening criteria. The pesticide 4,4'-DDT (130 µg/kg) exceeded the BTAG screening criteria and background UTL in samples SJS03-SS07.

Total Petroleum Hydrocarbons. Site history indicated petroleum sludge from Craney Island may have been placed at Site 3. During the trenching activities there was visual and olfactory evidence of petroleum containing soils limited to the Site 3 waste area. Therefore, TPHs in the diesel range were analyzed for in 12 samples at Site 3, SJS03-SS08 through SJS03-SS18. Most of these data, including samples within the waste, were rejected through validation ("R" qualified). Three samples had reported validated low estimated TPH detections, SJS03-SS12 (12 J mg/kg), SJS03-SS15 (3.1 J mg/kg), and SJS03-SS18 (2.9 J mg/kg) outside and to the west of the waste area. The TPH detections in the Site 3 surface soil samples did not exceed the VDEQ underground storage-tank reporting limit for TPH of 100 mg/kg.

5.2.3.2 Subsurface Soil

Twenty subsurface soil samples, SJS03-SB01 through SJS03-SB20, collected during the Phase I and Phase II sampling events. The subsurface soil samples were analyzed for TAL metals, TCL VOCs, TCL SVOCs, TCL pesticides/PCBs, and dioxins/furans. Five subsurface soil samples (SJS03-SB21 through SJS03-SB24 and SJS03-SB26) were collected during the waste delineation investigation (Phase III) and were analyzed for dioxins/furans and TPH.

Tables 5-3 and 5-4 list all constituents that were detected in the subsurface soil samples. On Table 5-3 a shaded cell indicates that the parameter exceeded the 95-percent UTL for dredge fill soil. Central-tendency statistical analysis results are shown on Table 5-2. The distribution of potential contaminants in subsurface soil at Site 3 is shown on Figure 5-3.

Inorganics. Twenty-three TAL metals were detected in subsurface soil at Site 3. Of these, the following 15 metals exceeded the background UTL in one or more samples: aluminum, antimony, arsenic, barium, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, vanadium, and zinc. Samples SJS03-SB09 and SJS03-SB17, located inside the waste boundary, contained the greatest number of metals and at the highest concentrations that exceeded background UTLs (Figure 5-3). Additionally, cadmium and thallium were detected in one or more site samples but not in background. Only beryllium indicated a statistical difference from background based on the population (site) to population (background) central-tendency statistical analysis.

Although the population central-tendency analysis of beryllium indicates it to be statistically elevated over background, it should be noted that all dredge fill background beryllium results were qualified "B" and therefore treated as non-detects using one-half the detection limit in statistical analyses. Beryllium was detected at concentrations greater than the background UTL within the waste at sample locations SJS03-SB09 and SJS03-SB20.

Twelve inorganic compounds; aluminum, antimony, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, thallium, and zinc; were present in subsurface soil at concentrations above the adjusted residential RBCs. All 12 of these compounds also were present at concentrations greater than background in one or more samples. The greatest number of human health criteria and background UTL exceedances occurred in samples SJS03-SB09, SJS03-SB17, and SJS03-SB20, located within the waste boundary.

Volatile Organic Compounds. Seven VOCs; 2-butanone, acetone, carbon disulfide, chloroform, methylene chloride, tetrachloroethene, and toluene; were detected sporadically

at low, mostly estimated concentrations in one or more of the Site 3 subsurface soil samples. No VOCs results exceeded their respective adjusted residential soil RBC values.

Semivolatile Organic Compounds. Twenty-two SVOCs were detected in the subsurface soil samples. There were two PAHs (anthracene and phenanthrene) detected at concentrations that exceeded the background UTLs. Anthracene and phenanthrene were the only PAHs that also indicated a statistical difference from background based on population comparisons. The PAH exceedances of background UTLs occurred outside of the waste, to the west of the Site 3 boundary at SJS03-SB10 and SJS03-SB15 at estimated concentrations only slightly above the UTL (Figure 5-3).

SVOCs with no established background values detected in subsurface soil include: 2-methylnaphthalene, carbazole, dibenzofuran, di-n-butylphthalate, diethylphthalate, and bis(2-ethylhexyl)phthalate. These SVOCs were sporadically detected at estimated concentrations below quantitation limits.

Three PAHs (benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene) exceeded the adjusted residential RBCs in the subsurface soil. None of these compounds exceeded the background UTL. Thirteen subsurface soil samples had reported concentrations of benzo(a)pyrene that exceeded the adjusted residential soil RBC values, primarily at estimated concentrations. Benzo(b)fluoranthene occurred above the human health criteria at sampling locations SJS03-SB02, SJS03-SB05, and SJS03–SB18. Dibenz(a,h)anthracene was only detected above the adjusted residential soil RBCs at SJS03-SB18 and SJS03-SB19, located within the waste boundary.

Pesticides and PCBs. The following pesticides were detected in subsurface soil: 4,4′-DDD, 4,4′-DDE, 4,4′-DDT, dieldrin, alpha-chlordane, and gamma-chlordane. The pesticides 4,4′-DDD, 4,4′-DDE, alpha-chlordane, and gamma-chlordane had reported concentrations that exceeded the background UTLs at sample locations SJS03-SB09 and SJS03-SB17, located within the waste (Figure 5-3). No pesticides indicated a central-tendency statistical population difference with background. No PCBs were detected in subsurface soil samples.

The pesticides were screened against the adjusted residential RBCs and there were no exceedances.

Dioxins. Twenty-five dioxin compounds were detected in the three subsurface soil samples (SJS03-SB21, SJS03-SB23, and SJS03-SB26) collected from within the Site 3 waste boundary. The concentrations of the detected compounds were screened against TEF adjusted residential soil RBC values and the total TEQ against the toxicity equivalent RBC of 0.0043 μg/kg. The results indicate four exceedances of individual compounds in two of the three samples. All three samples exceeded the total TEQ (Figure 5-3).

There were no exceedances of individual compounds in sample SJS03-SB21, however, the sum of the products of the concentrations of the individual congeners with their respective TEFs did exceed the total TEQ at 0.0079 μg/kg. Sample SJS03-SB23 exceeded the TEF adjusted RBC for two compounds, 2,3,4,7,8-pentachlorodibenzofuran and 2,3,7,8-tetrachlorodibenzofuran. This sample also exceeded the total TEQ at 0.032 μg/kg. Sample SJS03-SB26 exceeded the TEF adjusted RBC for four individual compounds, 1,2,3,4,7,8-hexachlorodibenzofuran, 2,3,4,7,8-pentachlorodibenzofuran, 2,3,7,8-TCDD, and 2,3,7,8-tetrachlorodibenzofuran. The sample also exceeded the total TEQ at 0.056 μg/kg.

Total Petroleum Hydrocarbons. TPHs in the diesel range and gasoline range was analyzed for in 16 subsurface soil samples at Site 3. Eleven samples had detects of TPH in the diesel range and 6 samples had TPH gasoline range detects. The most significant TPH detection was in the diesel range at 2,500 J mg/kg in sample SJS03-SB09 within the waste (Figure 5-3). This sample result exceeded the VDEQ underground storage-tank-program reporting requirement for TPH of 100 mg/kg. Additionally, the TPH diesel range result (109 mg/kg) from SJS03-SB24, located within the waste, was just above 100 mg/kg.

5.2.4 Groundwater Analytical Results

5.2.4.1 Shallow Groundwater

Four shallow monitoring wells, SJS04-MW01S through SJS04-MW04S, were sampled during three sampling rounds events conducted in July 1997, November 1997, and May 1999. Samples were analyzed for TAL total metals, TAL dissolved metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Well locations are shown on Figure 5-4.

Table 5-5 lists all constituents detected in the shallow groundwater. A shaded cell indicates that the parameter exceeded the tap water RBC. An outlined cell indicates an exceedance of the MCL. Maximum and mean background concentrations are also shown on the table. The distribution of the exceeded constituents in shallow groundwater from the 1999 sampling event is shown on Figure 5-4.

Inorganics. Twenty-two TAL total metals and 20 TAL dissolved metals were detected in shallow groundwater samples during one or more sampling events. Only two total and dissolved metals exceeded screening criteria and maximum background values in the most recent sampling event in 1999: iron and manganese. The highest concentrations of total and dissolved iron and manganese in 1999 occurred at the downgradient sample location SJS03-MW02S (Figure 5-4).

Arsenic exceeded the tap water RBC and background in one or more samples collected in 1999. In addition, total thallium was reported at a concentration (5.60 L µg/l) that exceeded the MCL and tap water RBC at SJS03-MW06S. Thallium was not detected in the duplicate sample collected at SJS03-MW06S or in the dissolved metals analyses. The presence of thallium above the MCL in shallow groundwater at Site 3 cannot be confirmed with the available data.

Volatile Organic Compounds. The VOCs detected at low concentrations include acetone, ethylbenzene, toluene, and total xylenes. No VOC results exceeded the available screening criteria values in any of the shallow groundwater samples.

Semivolatile Organic Compounds. Four SVOCs were detected at trace estimated (qualified "J") concentrations in the most recent 1999 sampling event; 4-methylphenol, acenaphthene, phenol, and bis(2-ethylhexyl)phthalate in groundwater from three of the six wells sampled. No SVOCs exceeded screening criteria in the most recent sampling event.

Pesticides/PCBs. Heptachlor was detected at an estimated concentration (0.024 J µg/l) above the tap water RBC at SJS03-MW02S in the most recent sampling event.

5.2.4.2 Deep Groundwater

Two deep monitoring wells, SJS03-MW01D and SJS03-MW02D, were sampled during three sampling rounds conducted in July 1997, November 1997, and May 1999. Samples were analyzed for TAL total metals, TAL dissolved metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Well locations are shown on Figure 5-5.

Table 5-6 lists all constituents that were detected in the deep groundwater A shaded cell indicates that the parameter exceeded the tap water RBC. An outlined cell indicates exceedance of the MCL. Maximum and mean background concentrations are also shown on the table. The distribution of exceeded constituents in deep groundwater is shown on Figure 5-5 from the 1999 sampling event.

Inorganics. Fourteen total and 10 dissolved metals were detected in deep groundwater samples collected at Site 3. Only total arsenic in the sample from SJS03-MW01D (4.2 J µg/l) was detected at a concentration that exceeded screening criteria in the most recent sampling event.

There were no exceedances of the MCL in deep groundwater samples from the most recent sampling event.

Volatile Organic Compounds. VOCs detected at very low concentrations included carbon disulfide and chloroform. None of the detected VOCs exceeded available screening criteria in the deep groundwater samples.

Semivolatile Organic Compounds. Bis(2-ethylhexyl)phthalate was the only SVOC detected (1 J µg/l) in the deep groundwater. The detection is below screening criteria and maximum background.

Pesticides/PCBs. Pesticides and PCBs were not detected in any of the deep groundwater samples during any of the sampling events.

5.2.5 Sediment Analytical Results

Seven sediment samples (SJS03-SD01 through SJS03-SD04 and SJS03-SD06 through SJS03-SD08) were collected and analyzed for TAL total metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Sample locations are shown on Figure 5-6. Reference samples collected in Blows Creek (identified SJSBK-) are shown on Figure G-2 in Appendix G.

Table 5-7 lists all constituents that were detected in the sediment samples. As discussed in Section 5.1.5, sediment in upland ditches at Site 3 is evaluated with respect to background dredge fill soil. A shaded cell indicates that the parameter exceeded the 95-percent UTL for dredge fill soil. Central-tendency statistical analysis results are shown on Table 5-8. The distribution of constituents exceeding the 95-percent UTL in sediment at Site 3 is shown on Figure 5-6.

Inorganics. Twenty-three TAL metals were detected in Site 3 sediment samples. The following 14 inorganic constituents exceeded the background UTLs in one or more samples: aluminum, antimony, arsenic, barium, beryllium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, and zinc. Additionally, cadmium and cyanide were detected in one or more site samples but not in background. Based on population (site) to population

(background) central-tendency statistical analysis, beryllium, cadmium, copper, manganese, nickel, and zinc indicated a statistical difference from background. The greatest concentrations of these metals in sediment were present at sample locations SJS03-SD02, SJS03-SD04, and SJS03-SD08 (Figure 5-6). Samples SJS03-SD02 and SJS03-SD08 are near the Site 3 waste boundary and would be expected to receive the greatest amount of runoff from the site. Although not statistically different from background based on central-tendency, lead (1,050 J mg/kg) and antimony (173 J mg/kg) were significantly elevated at SJS03-SD08.

A qualitative comparison with Blows Creek reference sediment samples show that, in general, the dredge fill soil background UTLs were very similar to or slightly lower than the maximum reference sediment sample concentrations. Additionally, with the exception of antimony and lead, the mean concentrations of metals in sediment at Site 3 were also very similar to the mean concentrations in Blows Creek reference samples.

Three inorganic compounds; antimony, arsenic, and iron; were present at concentrations above the adjusted residential RBCs. Antimony, arsenic, and iron were detected at the highest concentrations at SJS03-SD08, located along the eastern drainage ditch.

Eight inorganic compounds; antimony, cadmium, chromium, copper, lead, mercury, nickel, and zinc; were present at concentrations elevated above the BTAG sediment flora/fauna ecological screening criteria. All seven sediment sampling locations had one or more metals that exceeded BTAG criteria. Four of the six metals (cadmium, copper, nickel, and zinc) were present at concentrations that exceeded the ecological screening criteria in five of the seven sediment sample locations.

Volatile Organic Compounds. VOCs infrequently detected at trace estimated concentrations include acetone, carbon disulfide, chloroform, methylene chloride, and toluene. The analytical results of these compounds did not exceed the adjusted residential soil RBCs.

Semivolatile Organic Compounds. Of the 16 SVOCs detected, none exceeded background UTLs or adjusted residential RBCs. Only four compounds; acenaphthylene chrysene, dibenz(a,h)anthracene, and diethylphthalate; were present at concentrations that only slightly exceeded the BTAG criteria at least once in three of the seven sediment samples collected at Site 3.

SVOCs detected in sediment with no established background values were butylbenzylphthalate and diethylphthalate. These SVOCs were sporadically detected at estimated concentrations below quantitation limits.

Pesticides/PCBs. Seven pesticides/PCBs were detected in the Site 3 sediment samples. There were four pesticides (4,4'-DDD, 4,4'-DDE, dieldrin, and gamma-chlordane) that exceeded the background UTLs. 4,4'-DDE indicated a statistical difference from the background based on a central-tendency population comparison and exceeded the background UTL at sample locations SJS03-SD01 (10 µg/kg) and SJS03-SD03 (78 J µg/kg) (Figure 5-6). In general, the mean concentration of pesticides detected at Site 3 was slightly higher than the mean concentration of pesticides in Blows Creek reference sediment samples. Aroclor-1260 was detected in sediment at sample locations SJS03-SD02 (150 µg/kg) and SJS03-SD06 (64 J µg/kg).

The pesticides/PCBs were screened against the adjusted residential RBCs and there were no exceedances. 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, and aroclor-1260 had concentrations that

exceeded the BTAG criteria at least once in six of the seven sediment samples. 4,4'-DDE exceeded the BTAG screening criteria and background UTLs in all seven sediment samples.

5.2.6 Surface Water Analytical Results

Seven surface water samples, co-located with sediment samples (SJS03-SW01 through SJS03-SW04 and SJS03-SW06 through SJS03-SW08) were collected and analyzed for TAL total metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Sample locations are shown on Figure 5-7. Reference samples, designated SJSBK, are shown on Figure G-2 in Appendix G and represent surface water samples collected in Blows Creek.

Table 5-9 lists all constituents that were detected in the surface water samples. A shaded cell indicates that the parameter exceeds 10 times tap water RBC for surface water. An outlined cell indicates that the parameter exceeds the BTAG marine flora/fauna criteria. The distribution of RBC and BTAG exceedances in surface water at Site is shown on Figure 5-7.

Inorganics. Twenty-one total metals were detected in Site 3 surface water samples. Aluminum, arsenic, iron, and manganese exceeded adjusted tap water RBC criteria for surface water. Five surface water samples contained one or more metals that exceeded the human health screening criteria. Aluminum and arsenic were only present at concentrations exceeding the adjusted tap water RBCs for surface water at SJS03-SW01. The highest concentrations of iron (66,900 µg/l) and manganese (6,330 µg/l) occurred at sample location SJS03-SW08 (Figure 5-7).

Based on a comparison of the concentrations of detected metals in surface water samples to BTAG marine flora/fauna criteria, the following metals indicated exceedances at least once in the Site 3 surface water samples: copper, cyanide, lead, manganese, nickel, silver, and zinc. Copper and manganese were present above the BTAG criteria in all seven samples.

Aluminum, iron, manganese, nickel, and zinc exceed the maximum concentration of the reference samples by an order of magnitude in one or more Site 3 samples. Aluminum (70,600 µg/l), nickel (364 µg/l), and zinc (2,720 µg/l) were significantly elevated above reference and other Site 3 samples only at SJS03-SW01. Located northeast of the site and on the north side of the perimeter road, SJS03-SW01 would be expected to receive minimal runoff from Site 3 except during significant rainfall or floods. Additionally, this location is not connected to the drainage ditch near the southeast waste where these metals were not elevated. The turbidity of Site 3 surface water samples and reference samples is not known. Manganese was elevated (1,040 to 6,330 µg/l) above reference sample concentrations (415 µg/l maximum) in most site samples and iron (43,300 to 66,900 µg/l) was elevated above reference sample concentrations (2,400 µg/l maximum) at SJS03-SW03 and SJS03-SW08.

Volatile Organic Compounds. Five VOCs; 1,1-dihloroethene, carbon disulfide, chloromethane, toluene, and trichloroethene; were detected in surface water. With the exception of carbon disulfide, the detections were infrequent and at low estimated concentrations. None of the detected VOCs exceeded the adjusted tap water RBC. However, the BTAG criterion for carbon disulfide was exceeded in all seven Site 3 surface water samples (Figure 5-7). There is no BTAG marine flora/fauna value for chloromethane.

Semivolatile Organic Compounds. Only one SVOC was detected, bis(2-ethylhexyl)phthalate. None of the detected concentrations exceeded either the human health or ecological screening criteria.

Pesticides and PCBs. No PCBs were detected in surface water. Four pesticides; 4,4'-DDD, 4,4'-DDE, alpha-chlordane, and gamma- chlordane; were detected in the surface water sample collected at SJS03-SW03, located in the drainage ditch to the west of Site 3. The concentrations of alpha-chlordane and gamma-chlordane at SJS03-SW03 exceeded the BTAG marine flora/fauna criteria (Figure 5-7).

5.2.7 Summary of Relevant Constituents at Site 3

Constituents in surface and subsurface soils reflective of potential impacts from Site 3 were metals, PAHs, and dioxin. The highest concentrations of metals are limited to the waste area and a potential "hot spot" outside the waste in surface soil at SJS03-SS15. Central-tendency comparisons to dredge fill background show metals concentrations in Site 3 soils were similar to background. Statistically elevated over background, the PAHs anthracene and phenanthrene in surface soil were limited to the waste area and in subsurface soil were below risk screening criteria, which suggests that the PAHs are not very mobile. Elevated TPH (diesel range) was limited to samples within the waste.

In shallow groundwater only iron and manganese were consistently detected in samples above screening criteria and maximum background. The presence of total thallium above the MCL in shallow groundwater (SJS03-MW06S) was not confirmed by the duplicate sample. There were no MCL exceedances in deep groundwater in 1999 samples. Based on constituent concentrations detected in groundwater and the existence of a laterally extensive hydraulic aquitard (Yorktown Confining Unit), the deep groundwater does not appear to have been impacted at Site 3.

In sediment, several metals and pesticides exceeded the soil background UTL, and pose a potential risk based on human health and ecological screening. The greatest concentrations of metals in sediment were near the Site 3 waste boundary (SJS03-SD02 and SJS03-SD08). PCB aroclor-1260 was present near the waste (SJS03-SD02 and SJS03-SD06) above ecological screening criteria. The pesticide 4,4'-DDE was present in sediment in both the eastern and western drainage ditches. Although exceeding ecological screening values, PAHs in sediment were below background and reported at estimated concentrations below quantitation limits.

In surface water, several metals and pesticides pose a potential risk based on human health and ecological screening. The greatest concentrations of metals in surface water were in the eastern drainage ditch (SJS03-SW08) and the greatest concentrations of pesticides in surface water were in the western drainage ditch (SJS03-SW03). Significantly elevated metals were reported in a sample collected from the north side of the perimeter road northeast of Site 3. This location (SJS03-SW01) is not connected to the drainage ditch near the southeast waste boundary and would not receive runoff from Site 3 except during significant storms or floods.

5.3 Site 4 Remedial Investigation Results

This section discusses the geophysical survey results, analytical results obtained from laboratory analyses of various media, and the nature and extent of contaminants identified at the site. A quantitative HHRA and ERA through Step 3a is presented in Sections 7 and 8, respectively.

5.3.1 Geophysical Survey Results

Electromagnetic (EM), magnetic, and ground penetrating radar (GPR) surveys were conducted at Site 4. The geophysical surveys were concentrated in the eastern portion of the landfill due to the presence of heavy vegetation and brush in adjacent Site 4 areas (Figure 3-2). Grid lines in this area were spaced approximately every 50 to 100 ft. Limited surveys were also conducted along several grid lines within Site 4 following the removal of vegetation (Figure 3-2).

The results of all geophysical surveys conducted at this site indicate typical landfilled materials (for example, buried metal) (Figure 3-2, Appendix F). Similar materials were also visually observed on the ground surface during the geophysical survey. The limited GPR survey, conducted in the northeast portion of the landfill, identified numerous buried objects. These objects were most likely concrete blocks, metal pipes, drums, or other reflective materials. Based on results of the geophysical survey, no changes were made to the Site 4 boundary.

5.3.2 Soil Analytical Results

5.3.2.1 Surface Soil

Eighteen surface soil samples (SJS04-SS01 through SJS04-SS18) were collected during the Phase I and Phase II sampling events. The surface soil samples were analyzed for TAL total metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Sample locations are shown on Figure 5-8.

Table 5-10 lists all constituents that were detected in the surface soil samples. A shaded cell indicates that the parameter exceeded the 95-percent background UTL for dredge fill soil. Site/background population-to-population central-tendency statistical analysis results are shown on Table 5-11. The distribution of potential contaminants in surface soil at Site 4 is shown on Figure 5-8.

Inorganics. Twenty-three TAL metals were detected in the surface soil samples. Of the 23 metals detected, 12 exceeded the background UTL in one or more samples: antimony, barium, beryllium, chromium, copper, iron, lead, manganese, nickel, silver, vanadium, and zinc. Additionally, cadmium and thallium were detected in one or more site samples but not in background. Based on population (site) to population (background) central-tendency statistical analysis (Table 5-11), five metals (antimony, copper, lead, nickel, and zinc) indicated a statistical difference from background. All five metals were present in surface soil at sample locations SJS04-SS05, SJS04-SS08, and SJS04-SS11, located within the waste boundary (Figure 5-8). The highest concentrations of antimony, copper, lead, nickel, and zinc occurred in samples SJS04-SS05 and SJS04-SS11. Four of these metals were also present

at sample locations SJS04-SS02, SJS04-SS03, SJS04-SS04, SJS04-SS06, SJS04-SS09, SJS04-SS10, and SJS04-SS14, located within the waste boundary with the exception of SJS04-SS14.

Fourteen inorganic compounds; aluminum, antimony, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, nickel, thallium, vanadium, and zinc; were present at concentrations above the adjusted residential RBCs. Although all 18 surface soil sampling locations had one or more metals that exceeded human health screening criteria, the metals statistically elevated over background (antimony, copper, lead, nickel, and zinc) were only present within the waste boundary at concentrations greater than the adjusted residential RBCs.

Sixteen inorganic compounds; aluminum, antimony, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, thallium, vanadium, and zinc; were present at concentrations elevated above the BTAG soil flora/fauna ecological screening criteria. All 18 surface soil sampling locations had one or more metals that exceeded BTAG criteria, with the greatest number of BTAG criteria exceedances within the waste boundary at SJS04-SS11. With few exceptions, the detected concentrations of antimony, copper, lead, nickel, and zinc exceeded BTAG criteria.

Volatile Organic Compounds. VOCs detected at low and generally estimated concentrations include 2-butanone, 4-methyl-2-pentanone, acetone, chloroform, and toluene. No VOCs exceeded their respective adjusted residential soil RBC values or BTAG criteria.

Semivolatile Organic Compounds. Twenty-three SVOCs were detected in surface soil samples. There were seven PAHs detected at concentrations that exceeded the background UTLs, they are: acenapthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, fluoranthene, phenanthrene, and pyrene. Of these seven compounds, only three indicated a statistical difference from background based on population comparisons (acenapthene, anthracene, and phenanthrene). The only sample locations where these PAHs were present at concentrations greater than the background UTL were SJS04-SS05, SJS04-SS08, and SJS04-SS11 within the waste boundary.

SVOCs detected in surface soil with no established background values include: 2-methylnaphthalene, carbazole, dibenzofuran, and bis(2-ethylhexyl)phthalate. These SVOCs were sporadically detected at estimated concentrations below quantitation limits.

Five SVOCs; benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h) anthracene, and indeno(1,2,3-cd)pyrene; exceeded their respective human health screening criteria. The greatest number of human health criteria exceedances occurred in sample SJS04-SS11 within the waste. Benzo(a)anthracene and benzo(a)pyrene were the only SVOCs, which also exceeded the background UTLs in sample SJS04-SS11 but did not show a central-tendency statistical population difference with background.

Fifteen SVOCs; acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h) anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene; were detected at concentrations elevated above the ecological screening criteria. Seven of the 15 SVOCs (acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, fluoranthene, phenanthrene, and pyrene) also had concentrations greater than the background UTL. All seven of these compounds exceeded BTAG criteria at SJS04-SS11

within the waste boundary. SJS04-SS05 and SJS04-SS08 also contained one or more SVOC exceedances of the ecological screening criteria and the background UTL.

Pesticides/PCBs. Eleven pesticides/PCBs were detected in surface soil samples. There were eight pesticides (4,4'-DDD, 4,4'-DDE, 4,4'-DDT, dieldrin, endrin aldehyde, endrin ketone, alpha-chlordane, and gamma-chlordane) that exceeded the background UTLs. However, none of these pesticides indicated a statistical difference from the background data based on central-tendency population comparisons, and all UTL exceedances occurred within the limits of waste.

With one exception, aroclor-1260 and 1254 were sporadically detected at estimated concentrations in surface soil within the waste boundary or peripheral to the waste boundary. The most significant PCB detection is aroclor-1260 at 6,300 μg/kg in sample SJS04-SS08 within the waste (Figure 5-8).

Aroclor-1260 and dieldrin exceeded the human health criteria and background UTL in sample SJS04-SS08 within the waste boundary. Aroclor-1260 and endrin aldehyde exceeded the BTAG screening criteria and background UTL in sample SJS04-SS08. Aroclor-1260 also exceeded the BTAG screening criteria and background UTL in sample SJS04-SS05 (170 J μg/kg). Both sample locations were within the limits of waste.

5.3.2.2 Subsurface Soil

Eight subsurface samples, SJS04-SB01 through SJS04-SB08, were collected during the Phase I and Phase II investigations. Sample locations are shown on Figure 5-9. Samples were analyzed for TAL total metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs.

Table 5-12 lists all constituents that were detected in the subsurface soil samples. A shaded cell indicates that the parameter exceeded the 95-percent UTL for dredge fill soil. Central-tendency statistical analysis results are shown on Table 5-11. The distribution of 95-percent UTL exceedances in subsurface soil at Site 4 is shown on Figure 5-9.

Inorganics. Twenty-three TAL metals were detected in subsurface soil samples collected at Site 4. Of these, 14 metals exceeded the background UTL in one or more samples: antimony, arsenic, barium, beryllium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, vanadium, and zinc. Additionally, cadmium and thallium were detected in one or more site samples but not in background. Based on population (site) to population (background) central-tendency statistical analysis, 11 of the metals that exceeded the background UTLs indicated a statistical difference from background. Seven out of the eight subsurface soil samples contained two or more metals statistically elevated above background, with the greatest number and, in general, the highest concentrations in sample SJS04-SB06 located within the waste.

Eight inorganic compounds; aluminum, antimony, arsenic, chromium, iron, lead, manganese, and thallium; were present in subsurface soil at concentrations above the adjusted residential RBCs. All eight subsurface soil sampling locations had one or more metals that exceeded human health screening criteria. Five samples (SJS04-SB01, SJS04-SB02, SJS04-SB03, SJS04-SB04, and SJS04-SB06) contained metals at concentrations above both the background UTL and adjusted residential RBC. The greatest number of human health

criteria and background UTL exceedances occurred in samples SJS04-SB02, SJS04-SB03, and SJS04-SB06, located in the south-southeast portions of Site 4.

Volatile Organic Compounds. Five VOCs; 2-butanone, acetone, carbon disulfide, tetrachloroethene, and toluene; were detected at generally low estimated concentrations in one or more of the eight subsurface soil samples. No VOCs exceeded their respective adjusted residential soil RBC values.

Semivolatile Organic Compounds. Thirteen PAHs were detected in subsurface soil samples. There were no PAHs detected in subsurface soil with concentrations that exceeded the background UTLs.

Three PAHs (benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene) exceeded the adjusted residential RBCs in the subsurface soil. Six of the eight subsurface soil sampling locations had concentrations of benzo(a)pyrene that exceeded human health screening criteria. Benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene occurred above the human health criteria only at sampling location SJS04-SB06, located within the waste boundary.

Pesticides and PCBs. The following pesticides/PCBs were detected in subsurface soil: 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, and aroclor-1254. The pesticides 4,4'-DDD and 4,4'-DDE were present at concentrations that exceeded the background UTLs; only 4,4'-DDD indicated a central-tendency statistical population difference with background. 4,4'-DDD exceeded the background UTL at sample locations SJS04-SB02 and SJS04-SB06, located within the waste.

Aroclor-1254 was detected at 42 µg/kg (SJS04-SB02) and 11J µg/kg (SJS04-SB05). The pesticides/PCBs were screened against the adjusted residential RBCs and there were no exceedances.

5.3.3 Groundwater Analytical Results

5.3.3.1 Shallow Groundwater

Four shallow monitoring wells, SJS04-MW01S through SJS04-MW04S, were sampled during three sampling rounds events conducted in July 1997, November 1997, and May 1999. Samples were analyzed for TAL total metals, TAL dissolved metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Well locations are shown on Figure 5-4.

Table 5-13 lists all constituents that were detected in the shallow groundwater. A shaded cell indicates that the parameter exceeded the tap water RBC. An outlined cell indicates an exceedance of the Federal MCL. Maximum and mean background concentrations are also shown on the table. The distribution of the exceeded constituents in shallow groundwater for the 1999 sampling event is shown on Figure 5-4.

Inorganics. Twenty-one TAL total metals and 22 TAL dissolved metals were detected in shallow groundwater samples during one or more sampling events. Total and dissolved iron and manganese exceeded the screening criteria and maximum background values in the most recent 1999 sampling event. The highest concentrations of total and dissolved iron and manganese occurred in the upgradient sample from SJS04-MW01S.

Arsenic exceeded the tap water RBC and maximum background during the 1999 sampling event in samples from two wells. The only MCL exceedance in the most recent 1999 sampling event was lead (30.5 μg/l) in the sample from SJS04-MW03S; however, the duplicate of this sample was reported at 5.3 μg/l, below the MCL.

Volatile Organic Compounds. The VOCs detected at trace concentrations include acetone, carbon disulfide, and methylene chloride. No VOCs results exceeded the available screening criteria values in any of the shallow groundwater samples.

Semivolatile Organic Compounds. Two SVOCs were detected in the most recent 1999 sampling event; acenaphthene and di-n-butylphthalate in the sample from upgradient well SJS04-MW01S. Concentrations of these SVOCs did not exceed the tap water RBCs.

Pesticides/PCBs. No PCBs were detected in shallow groundwater. Endosulfan sulfate was detected only in samples collected during the May 1999 sampling event in all wells except SJS04-MW04S. The only screening criterion available is the tap water RBC; all concentrations were below the tap water RBC.

5.3.3.2 Deep Groundwater

Two deep monitoring wells, SJS04-MW01D and SJS04-MW03D, were sampled during three sampling rounds conducted in July 1997, November 1997, and May 1999. Samples were analyzed for TAL total metals, TAL dissolved metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Well locations are shown on Figure 5-5.

Table 5-14 lists all constituents that were detected in the deep groundwater. A shaded cell indicates that the parameter exceeded the tap water RBC. An outlined cell indicates an exceedance of the Federal MCL. Maximum and mean background concentrations are also shown on the table. The distribution of exceeded constituents in deep groundwater from the 1999 sampling event is shown on Figure 5-5.

Inorganics. Thirteen total and 11 dissolved metals were detected in deep groundwater samples collected at Site 4. Only total and dissolved iron and manganese were detected at concentrations that exceeded the screening criteria and maximum background values. Samples from SJS04-MW01D, upgradient of Site 4, had higher concentrations of total and dissolved iron and manganese than samples from SJS04-MW03D.

There were no exceedances of the MCL in deep groundwater samples.

Volatile Organic Compounds. Only one VOC, carbon disulfide, was detected in deep groundwater during the most recent sampling event. Concentrations of carbon disulfide (0.8J and 4.5 μg/l) were below the tap water RBC.

Semivolatile Organic Compounds. Di-n-butylphthalate was the only SVOCs detected in the 1999 samples. Di-n-butylphthalate was detected (1J μg/l;) below the tap water RBC.

Pesticides/PCBs. No PCBs were detected in deep groundwater. Endosulfan sulfate was detected at a very low concentration (0.0078J μg/l) in sample SJS04-MW03D collected during the May 1999 sampling event. The only screening criterion available for screening was the tap water RBC and the concentration was well below this criterion value.

5.3.4 Sediment Analytical Results

Nine sediment samples (SJS04-SD01 through SJS04-SD09) were collected and analyzed for TAL total metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Sample locations are shown on Figure 5-10. Reference samples, designated SJSBK, are shown on Figure G-2 in Appendix G and represent sediment samples collected in Blows Creek upstream of Site 4.

Table 5-15 lists all constituents that were detected in the sediment samples. A shaded cell indicates that the parameter exceeds the adjusted residential soil RBC (adjusted 10x for sediment). An outlined cell indicates that the parameter exceeds the BTAG sediment flora/fauna criteria. The distribution of constituents exceeding the RBC and BTAG criteria in sediment at Site 4 is shown on Figure 5-10.

Inorganics. There were 24 TAL metals detected in Site 4 sediment samples. Of these, only arsenic and iron exceeded RBC screening criteria. Arsenic concentrations exceeded the adjusted RBC in eight of the nine sediment samples. The highest concentration of arsenic (33.1 mg/kg) was found at SJS04-SD03, collected from the drainage ditch along the southeast perimeter of the waste area, and only slightly exceeds the maximum arsenic concentration in reference samples (22.5 mg/kg). Arsenic concentrations in the remaining site sediment samples were below the maximum reference value, and the mean arsenic concentration in site samples (14.1 mg/kg) is similar to the mean reference concentration (13.1 mg/kg).

Iron concentrations exceeded the adjusted RBC in samples SJS04-SD01, SJS04-SD04, and SJS04-SD06 through SJS04-SD08, with the highest iron concentration at SJS04-SD01. The maximum (50,400 mg/kg) and mean (27,950 mg/kg) iron concentrations in reference samples were similar to Site 4 maximum (56,000 mg/kg) and mean (29,167 mg/kg) iron concentrations.

Seven inorganic compounds; cadmium, chromium, copper, lead, mercury, nickel, and zinc; had concentrations elevated above the BTAG ecological screening criteria. All nine sediment sampling locations had one or more metals that exceeded BTAG criteria. Chromium, copper, and mercury exceeded the BTAG criteria most frequently and were present throughout the site. Mercury in sample SD03 was reported at 6.4 mg/kg, significantly elevated above the other sediment samples and the maximum reference concentration (0.069 mg/kg). Maximum and mean concentrations of copper, lead, and zinc were slightly higher in Site 4 sediment samples than Blows Creek reference samples. Cadmium and nickel concentrations were lower at Site 4 than in reference samples.

The results from the upland drainage sample (SJS04-SD04) were qualitatively compared to the soil screening criteria and seven inorganic compounds (aluminum, arsenic, chromium, iron, lead, manganese, and vanadium) were present at concentrations above the adjusted residential RBCs for soil. Twelve inorganic compounds (aluminum, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, vanadium, and zinc) detected in the sample were present at concentrations elevated above the BTAG soil flora/fauna ecological screening criteria. Beryllium, cobalt, copper, iron, lead, manganese, nickel, silver, and zinc concentrations in the sample collected from SJS04-SD04 exceeded the background UTLs for dredge fill.

Volatile Organic Compounds. VOCs detected include acetone, carbon disulfide, and toluene. The analytical results of these compounds did not exceed the adjusted residential soil RBCs or BTAG criteria. Additionally, their concentrations were less than the maximum concentrations of the reference samples.

Semivolatile Organic Compounds. Of the 21 SVOCs detected, only benzo(a)pyrene (1,200 µg/kg) exceeded the adjusted residential soil RBC in sample SJS04-SD04 and maximum reference for Blows Creek sediment.

Eleven SVOCs; 2-methylnaphthalene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, diethylphthalate, fluoranthene, phenanthrene, and pyrene; exceeded BTAG criteria at least once in six out of the nine sediment samples collected at Site 4. SJS04-SD04, located in the southwestern corner of the site, had the most SVOC exceedances and in general, the highest concentrations, most of which also exceed Blows Creek reference concentrations.

The upland drainage sample, SJS04-SD04, results were qualitatively compared to the soil screening criteria and four SVOCs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene) were present at concentrations above the adjusted residential RBCs for soil. Thirteen of the fifteen SVOCs detected in the sample collected from SJS04-SD04 were present at concentrations elevated above the BTAG soil flora/fauna ecological screening criteria. Fluorene and pyrene were also present at concentrations greater than the background UTLs for dredge fill.

Pesticides/PCBs. Five pesticides/PCBs; 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, dieldrin, and aroclor-1260; were detected in the Site 4 sediment samples. None of the detected pesticides and PCBs exceeded the adjusted RBCs and all were below the maximum concentrations of the reference samples.

Except for dieldrin, which does not have established BTAG criteria, the detected pesticide and PCB concentrations exceeded BTAG criteria in several samples (Figure 5-10). The upstream drainage ditch location, SJS04-SD01, had the most BTAG exceedances of pesticides/PCBs. Pesticides in Site 4 sediment were below the maximum concentrations of the reference samples.

5.3.5 Surface Water Analytical Results

Eight surface water samples, co-located with sediment samples (SJS04-SW01 through SJS04-SW04 and SJS04-SW06 through SJS04-SW09) were collected and analyzed for TAL total metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. Sample locations are shown on Figure 5-11. Reference samples, designated SJSBK, are shown on Figure G-2 in Appendix G and represent surface water samples collected in Blows Creek upstream of Site 4.

Table 5-16 lists all constituents that were detected in the surface water samples. A shaded cell indicates that the parameter exceeded 10 times tap water RBC for surface water and an outlined cell indicates the parameter exceeded BTAG marine flora/fauna screening criterion. Sample locations and the distribution of RBC and BTAG exceedances in surface water at Site 4 are shown on Figure 5-11.

Inorganics. Twenty-two total metals were detected in Site 4 surface water samples. Five metals exceeded adjusted tap water RBC criteria for surface water, they are aluminum, arsenic, iron, lead, and manganese. Of significance is the elevated concentration of metals in sample SJS04-SW04 relative to other Site 4 sample results, in particular the total lead concentration of 746 µg/l. Six surface water sampling locations had one or more metals that exceeded human health screening criteria. All five metals that exceeded the adjusted RBC for surface water were present at sample location SJS04-SW04, located in the southwest corner of the waste boundary. In addition, all exceedances of the adjusted RBCs for surface water also exceeded the maximum concentrations of the Blows Creek reference samples. Aluminum and lead exceeded the adjusted RBC only in sample SJS04-SW04. The three southernmost surface water sampling locations; SJS04-SW06, SJS04-SW08, and SJS04-SW09; did not show inorganic exceedances of human health criteria.

Based on a comparison of the concentrations of detected metals in surface water samples to BTAG marine flora/fauna criteria, the following metals indicated exceedances at least once in the eight sampling locations: arsenic, chromium, copper, cyanide, lead, manganese, mercury, nickel, and zinc. Manganese and zinc were present above the BTAG criteria in all eight samples but only exceeded the maximum Blows Creek reference concentrations in a few samples.

Volatile Organic Compounds. Two VOCs; acetone and carbon disulfide; were detected in surface water. None of the detected VOCs exceeded the adjusted tap water RBC. However, the BTAG criterion for carbon disulfide was exceeded in samples SJS04-SW01 and SJS04-SW02. There is no BTAG marine flora/fauna value for acetone.

Semivolatile Organic Compounds. Of the six SVOCs detected, only dibenz(a,h)anthracene (3 J µg/l) and indeno(1,2,3-cd)pyrene (2 J µg/l) exceeded adjusted tap water RBCs in the duplicate sample for sample SJS04-SW09. These SVOCs were not detected in the parent sample. BTAG criteria were not exceeded in any samples.

Pesticides and PCBs. No pesticides/PCBs were detected in the surface water.

5.3.6 Summary of Relevant Constituents at Site 4

Surface and subsurface soils contained several inorganic compounds elevated above background (UTL and population central-tendency). These were antimony, copper, lead, nickel, and zinc in surface soil and antimony, arsenic, barium, beryllium, copper, iron, lead, manganese, mercury, vanadium, and zinc in subsurface soil. The surface soils also contained PAHs, pesticides, and PCBs. None of the pesticides indicated a statistical difference from the background data based on central-tendency population comparisons, and all pesticide UTL exceedances occurred within the limits of waste. The most significant PCB detection was aroclor-1260 at 6,300 µg/kg in sample SJS04-SS08 within the waste. In general, these potential site contaminants were restricted to the soils located within the limits of waste. The soil sample locations along the north-southwest perimeter, adjacent to the aerial extent of waste, indicated elevated concentrations of metals in surface and subsurface soils.

In shallow and deep groundwater, several total and dissolved inorganic compounds were detected above tap water RBCs and maximum background values. Of these, only iron and

manganese were consistently detected in samples from both shallow and deep site monitoring wells above screening criteria and background and the highest concentrations were upgradient of the site. Based on constituent concentrations detected in groundwater and the existence of a laterally extensive hydraulic aquitard (Yorktown Confining Unit), deep groundwater does not appear to have been impacted at Site 4.

In sediment, several metals and PAHs pose a potential risk based on human health and ecological screening. Of significance is mercury in sediment sample SJS04-SD03 in the eastern drainage ditch at 6.4 mg/kg. Although exceeding ecological screening criteria, most PAHs, with the exception of SJS04-SD04, were reported at estimated concentrations below quantitation limits.

In surface water, several metals and carbon disulfide exceeded screening criteria. Of significance is the elevated concentration of metals in surface water sample SJS04-SW04, including a total lead concentration of 746 µg/l.

In general, similar concentrations of constituents found in Site 4 groundwater, surface water and sediment were found in the upgradient Site 3 groundwater, surface water and sediment.

5.4 Site 5 Remedial Investigation Results

This section discusses the extent of waste, the geophysical survey results, analytical results obtained from laboratory analyses of various media, and the nature and extent of contaminants identified at Site 5. A quantitative HHRA and ERA through Step 3a is presented in Sections 7 and 8, respectively.

5.4.1 Extent of Waste

The results of the trenching activities indicated visual signs of potentially contaminated soils, construction debris, and spent ordnance material at Site 5. The extent of these materials is presented on Figure 5-12.

Two spent ordnance items were found at Site 5. The ordnance included a spent percussion primer and a Mark 7 cartridge case. Both of the ordnance items were considered expended.

Waste debris consisted of construction-related material including wires, ceramics, brass, glass, and wood. A sub-grade barrier/liner used for holding soils in place was found within the first 12 in. of soil at locations 2, 3, 6, 9, and 40. Debris was generally located within the first 16 in. of the test pits. The aerial extent of the debris was generally located on the northern side of the original Site 5 boundary.

Soils that were considered burnt or stained generally consisted of black silty sand that was occasionally friable to hand pressure. The majority of the burnt or stained waste was concentrated in the northern side of the site, east of Building 272. This area is where the greatest thickness of waste was also encountered, 12 in. at SJS05-Trench13. The burnt/stained soils were identified to a depth of no more than 26 in. (2.3 ft) below ground.

Historical aerial photographs identified three burning areas at the site. Based on the results of the trenching activities, the extent of the Site 5 boundaries were adjusted to the north to reflect the extent of waste encountered during trenching (Figure 5-12). From a comparison

of aerial photographs and trenching it is likely that material was burnt on the south side of the site and that the burnt soils and debris were then spread to the east and north of the burning grounds.

5.4.2 Geophysical Survey Results

The EM survey at Site 5 focused on the central portion of the site (i.e., the northern and far southern portions of the site were not surveyed). The majority of the EM anomalies identified at Site 5 are associated with metallic and other objects on the ground surface. Only two EM anomalies were not found to be associated with surface materials. The locations of these anomalies are depicted in Appendix F and are located about 230 ft and 200 ft south of Building 272. Buried materials or changes in salt or clay content of the soil may have caused these anomalies.

5.4.3 Soil Analytical Results

5.4.3.1 Surface Soil

Thirty-four surface soil samples (SJS05-SS01 through SJS05-SS28 and SJS05-SS30 through SJS05-SS35) were collected during the Phase I and Phase II sampling events. The surface soil samples were analyzed for TAL metals, TCL VOCs, TCL SVOCs, TCL pesticides/PCBs, and explosives. Sample locations are shown on Figure 5-13.

Table 5-17 lists all constituents that were detected in the surface soil samples. A shaded cell indicates that the parameter exceeded the background UTL. The background values represent the 95-percent UTLs for dredge fill and Bohicket soil. With the exception of sample SJS05-SS18, which was compared to the Bohicket soil background UTLs, all samples were compared to the dredge fill background. The distributions of parameters in surface soil exceeding background UTLs at Site 5 are shown on Figure 5-13. Central-tendency population (site) to population (background) comparisons were conducted for parameters in dredge fill soils exceeding background UTLs. The limited number of samples in Bohicket soils precluded background central-tendency comparisons for those site samples. Central-tendency statistical analysis results for dredge fill site/background samples are shown on Table 5-18.

Inorganics. All TAL metals were detected in Site 5 surface soil samples. One or more metals exceed background UTLs in all of the 34 samples. The only metal not to have at least one background UTL exceedance was selenium. The constituents with one or more samples elevated above background UTLs were antimony, arsenic, barium, beryllium, chromium, cobalt, copper, iron, lead, manganese, nickel, and zinc. Cadmium and thallium were not detected in background dredge fill but were detected in one or more site samples. Seven of the metals however were only slightly above their respective UTLs and were limited to three or fewer samples; these are: beryllium, chromium, cobalt, and nickel. Central-tendency statistical comparisons of site and background populations show that five metals; barium, beryllium, copper, lead, and zinc were statistically different from background. Although population central-tendency analysis of beryllium indicated it to be statistically elevated over background, it should be noted that all dredge fill background beryllium results were qualified "B" and therefore treated as non-detects using one-half the detection limit in statistical analyses.

A review of the distribution of metals in dredge fill surface soil at Site 5 showed significantly elevated levels of barium (2,850 mg/kg), copper (6,470 mg/kg), lead (7,210 mg/kg), and zinc (8,490 mg/kg) present in the northern portion of the waste area (SJS05-SS01 and SJS05-SS10). East of this northern portion of the waste area significantly elevated levels of barium (6,470 mg/kg) and zinc (831 mg/kg), as well as arsenic (152 mg/kg) were present at sample location (SJS05-SS11). Arsenic was also elevated (81.6 to 111 mg/kg) in two samples (SJS05-SS09 and SJS05-SS32) southwest of the waste area.

Lead concentrations (817 to 899 mg/kg) were also elevated southeast of the waste area (SJS05-SS03, SJS05-SS05, SJS05-SS07, and SJS05-SS14). Additionally, high concentrations of barium (1,220 mg/kg), lead (4,740 mg/kg) and zinc (1,290 mg/kg), as well as chromium (687 mg/kg) and antimony (10.8 J mg/kg) were found south of the waste area (SJS05-SS19) midway to Blows Creek (Figure 5-13).

Sample SJS05-SS18 south of Site 5, nearest Blows Creek, was the only sample in Bohicket soil type. Cadmium was not detected in Bohicket background soil and is the only parameter elevated above background in the sample. The low concentration of cadmium at SJS05-SS18 (0.24 J mg/kg) is consistent with other Site 5 samples.

Twelve inorganic compounds; aluminum, antimony, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, thallium, and zinc; were present at concentrations above the adjusted residential RBCs. Of these, only barium, copper, lead, and zinc showed a statistical central-tendency population difference with background (Table 5-18).

Seventeen inorganic compounds; aluminum, antimony, barium, beryllium, cadmium, chromium, copper, cyanide, iron, lead, manganese, mercury, nickel, silver, thallium, vanadium, and zinc were present at concentrations elevated above the BTAG soil flora/fauna ecological screening criteria. Of these, barium, beryllium, copper, lead, and zinc indicated a statistical central-tendency population difference with background.

Volatile Organic Compounds. VOCs detected in surface soil include total 1,2-dichloroethene, 2-butanone, acetone, chloroform, chloromethane, methylene chloride, styrene, tetrachloroethene, toluene, trichloroethene, and total xylene. The frequency of detection for most of these VOCs was less than 0.2 (20 percent) and they were generally detected at trace estimated concentrations. Low levels of trichloroethene (3 to 58 µg/kg) were reported for the four samples (SJS05-SS25 through SJS05-SS28) near the drop tower. No VOCs exceeded their respective adjusted residential soil RBC values or BTAG criteria.

Semivolatile Organic Compounds. Twenty-four SVOCs were detected in surface soil samples at Site 5 below the established background UTLs. SVOCs with no established background values detected in surface soil include: 2-methylnaphthalene, carbazole, bis(2-ethylhexyl)phthalate, 2,4-dinitrotoluene, 2,6-dinitrotoluene, and n-nitrosodiphenylamine. With the exception of 2,4-dinitrotoluene, these SVOCs were sporadically detected at estimated concentrations below quantitation limits. The SVOC 2,4-dinitrotoluene was reported at 3,200 µg/kg at SJS05-SS03 and 580 µg/kg at SJS05-SS01.

Four SVOCs; benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h) anthracene exceeded their respective human health screening criteria. Benzo(a)pyrene most frequently exceeded the RBC. The greatest number of human health criteria exceedances

occurred in sample SJS05-SS26, located near the drop tower, and at SJS05-SS35, south of the waste area.

Eleven SVOCs; benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h) anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene; were detected at concentrations elevated above the ecological screening criteria across the site.

Pesticides/PCBs. Five pesticides were detected in one or more surface soil samples at concentrations greater than the background UTLs. These were: 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, dieldrin, and alpha BHC. Of these, 4,4'-DDD and 4,4'-DDE indicated a statistical difference from the dredge fill background data based on central-tendency population comparisons. The pesticide 4,4'-DDE was detected in most surface soil samples with a frequency of detection of 0.9 (90 percent). Significantly elevated concentrations of 4,4'-DDE (1,300 to 4,700 µg/kg) were reported in four samples (SJS05-SS09, SJS05-SS13, SJS05-SS32, and SJS05-SS35) none of which were located within the limits of waste (Figure 5-13).

4,4'-DDE and 4,4'-DDT exceeded the adjusted residential RBC and background UTL, however only 4,4'-DDE was statistically different from the background population, exceeding the adjusted residential RBC in two samples (SJS05-SS09 and SJS05-SS35).

The pesticides 4,4'-DDD, 4,4'-DDE, 4,4'-DDT exceeded BTAG screening criteria and the background UTLs. 4,4'-DDE exceeded BTAG screening criteria and the background UTL in 10 samples.

Aroclor-1260 was detected in two samples SJS05-SS02 (30 J µg/kg) and SJS05-SS08 (39 µg/kg), located within and south of the waste boundary. Concentrations are below both the adjusted residential RBC and BTAG screening criteria.

Explosives. Two explosive compounds, 2,4-dinitrotoluene and 2-amino-4,6-dinitrotoluene, were detected in the surface soil at Site 5. The compound 2,4-dinitrotoluene was also analyzed as a SVOC and was discussed above. Explosive analysis (method SW-846 8330) detected 2,4-dinitrotoluene in two samples (SJS05-SS12 at 303 µg/kg and SJS05-SS14 at 638 µg/kg). The compound 2-amino-4,6-dinitrotoluene was detected in one sample (SJS05-SS24) at a concentration of 417 µg/kg (Figure 5-13). The concentrations of these compounds were below the adjusted residential RBCs; there is no BTAG flora/fauna screening criteria established for these compounds.

5.4.3.2 Subsurface Soil

Eighteen subsurface samples, SJS05-SB01 through SJS05-SB08 and SJS05-SB12 through SJS05-SB21, were collected and analyzed during the Phase I and Phase II investigations. Samples were analyzed for TAL metals, TCL VOCs, TCL SVOCs, TCL pesticides/PCBs, and explosives. During the Phase II investigation selected subsurface samples were analyzed for dioxin/furans. During Phase III, four subsurface soil samples were collected and analyzed for dioxins/furans only. Sample locations are shown on Figure 5-14.

Tables 5-19 and 5-20 list all constituents that were detected in the subsurface soil samples. On Table 5-19 a shaded cell indicates that the parameter exceeded the dredge fill background

UTL. Central-tendency statistical analysis results are shown on Table 5-18. The distribution of 95-percent UTL exceedances in subsurface soil at Site 5 is shown on Figure 5-14.

Inorganics. All 23 metals were detected in the subsurface samples. Fifteen of the 23 metals exceed the background UTLs in one or more samples. These metals include aluminum, arsenic, barium, beryllium, chromium, cobalt, copper, iron, lead, mercury, nickel, manganese, silver, vanadium, and zinc. Cadmium and thallium were detected in site samples, but were not detected in background dredge fill. Central-tendency statistical comparisons of site and background populations show that eight metals, aluminum, barium, beryllium, chromium, iron, manganese, vanadium, and zinc were statistically different from background. Although population central-tendency analysis of beryllium indicated it to be statistically elevated over background, it should be noted that all dredge fill background beryllium results were qualified "B" and therefore treated as non-detects using one-half the detection limit in statistical analyses. It should also be noted that most of these metals were only slightly above their respective UTL and do not reflect significant levels of contamination. The greatest number of metals exceeding background UTLs is found within the waste boundary at SJS05-SB02 and the most significantly elevated metal in subsurface soil was zinc (1,810 mg/kg) at SJS05-SB16, within the waste boundary (Figure 5-14).

Eight inorganic compounds, aluminum, arsenic, barium, chromium, iron, manganese, thallium, and vanadium, were present at concentrations above the adjusted residential RBCs. With the exception of arsenic and thallium, these metals also indicated a statistical central-tendency population difference with background.

Volatile Organic Compounds. Five VOCs were detected in 9 of the 18subsurface soil samples. The detected VOCs include 2-butanone, acetone, carbon disulfide, methylene chloride, and tetrachloroethene. The frequency of detection for most of these VOCs was less than 0.2 and they were detected at trace estimated concentrations. No VOC exceeded adjusted residential soil RBCs.

Semivolatile Organic Compounds. Fourteen SVOCs were detected in subsurface soil samples. With the exception two phthalate compounds all are PAHs. None of the PAHs exceeded the background UTL. Benzo(a)pyrene exceeded the adjusted residential soil RBC in two samples (SJS05-SB03 and SJS05-SB07) at low estimated concentrations.

Pesticides and PCBs. Three pesticides were detected in subsurface soil: 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT. These pesticides exceeded the background UTL in two samples (SJS05-SB05 and SJS05-SB15), and 4,4'-DDD and 4,4'-DDT in sample SJS05-SB20. Central-tendency statistical comparisons of site and background populations indicated that 4,4'-DDD and 4,4'-DDE were statistically different from background. No pesticides exceeded their respective adjusted residential soil RBCs. PCBs were not detected in any of the subsurface samples.

Dioxins and Furans. The following nine samples were analyzed for dioxins and furans: SJS05-SB02, SJS05-SB03, SJS05-SB04, SJS05-SB06, SJS05-SB07, SJS05-SB22, SJS05-SB24, SJS05-SB25, and SJS05-SB26. All sample locations, with the exception of SJS05-SB07 were within the limits of waste. Twenty-six dioxin-like compounds were detected in one or more samples as shown in Table 5-20. The concentrations of the detected compounds were evaluated with respect to the TEF adjusted residential soil RBC, and the Total TEQ was compared with the toxicity equivalent RBC of 0.0043 μg/kg. Samples with total TEQ values

greater than the TEF adjusted residential soil RBC are shown on Figure 5-14. The total TEQ for samples SJS05-SB02, SJS05-SB03, SJS05-SB07, SJS05-SB22, SJS05-SB24, and SJS05-SB25 exceeded the total TEF adjusted RBC of 0.0043 µg/kg.

Explosives. Explosives analyses were performed on subsurface samples SJS05-SB15 through SJS05-SB21. Only one compound, 2,4-dinitrotoluene, was detected (566 µg/kg) in sample SJS05-SB16. This concentration was below the adjusted residential soil RBC (Figure 5-14).

5.4.4 Groundwater Analytical Results

5.4.4.1 Shallow Groundwater

Five shallow monitoring wells, SJS05-MW01S through SJS05-MW05S, were sampled one or more times in July 1997, November 1997, and May 1999. Samples were analyzed for TAL total metals, TAL dissolved metals, TCL VOCs, TCL SVOCs, TCL pesticides/PCBs, and explosives. Well locations are shown on Figure 5-4.

Table 5-21 lists all constituents that were detected in the shallow groundwater. A shaded cell indicates that the parameter exceeds the tap water RBC and an outlined cell indicates an exceedance of the MCL. Maximum and average background concentrations from the four background well samples are also shown on the table. The distribution of constituents in shallow groundwater exceeding screening criteria from the 1999 sampling event is shown on Figure 5-4.

Inorganics. Twenty-one TAL total metals and 20 TAL dissolved metals were detected in shallow groundwater samples during one or more sampling events. Total beryllium (9.1 µg/l), total and dissolved cadmium (5.7 µg/l), and total and dissolved lead (18 µg/l) slightly exceeded the MCL in the downgradient well SJS05-MW03S; total and dissolved beryllium (4.5 J µg/l) also exceeded the MCL in the downgradient sample form SJS05-MW02S (Figure 5-4). These metals also exceeded maximum background concentrations.

Total and dissolved iron and manganese concentrations exceeded the tap water RBCs in 1999 samples from all five shallow monitoring wells. Average concentrations of iron and manganese in 1999 shallow groundwater samples at Site 5 are 43,740 µg/l and 2,760 µg/l, respectively. Total arsenic concentrations were reported above the tap water RBC at SJS05-MW01 through SJS05–MW04 in at least one sampling event.

Volatile Organic Compounds. The VOCs detected at low concentrations include 2-butanone, acetone, carbon disulfide, and toluene. No VOCs exceeded the available screening criteria in any of the shallow groundwater samples.

Semivolatile Organic Compounds. Three SVOCs were detected at low estimated (qualified "J") concentrations in the most recent 1999 sampling event; 4-methylphenol, di-n-butylphthalate, and phenol; in shallow groundwater from two of the five wells sampled. Concentrations of these SVOCs did not exceed the MCL or human health screening criteria in the most recent sampling event.

Pesticides/PCBs. No PCBs were detected in shallow groundwater. Two pesticides; 4,4'-DDD and 4,4'-DDT; were detected at trace concentrations in 1999 samples from shallow groundwater wells SJS05-MW04S and SJS05–MW05S, side-gradient of Site 5.

Explosives. No explosives were detected in any of the samples analyzed.

5.4.4.2 Deep Groundwater

Groundwater samples were collected from Yorktown Aquifer wells SJS05-MW01D, SJS05-MW02D, and SJS05-MW04D and analyzed for TAL total metals, TAL dissolved metals, TCL VOCs, TCL SVOCs, TCL pesticides/PCBs, and explosives. Well locations are shown on Figure 5-5.

Table 5-22 lists all constituents detected in the deep groundwater. A shaded cell indicates that the parameter exceeded the tap water RBC. An outlined cell indicates the parameter exceeded the MCL. Maximum and mean background concentrations are also shown on the table. The distribution of constituents exceeding criteria in deep groundwater from the 1999 sampling event is shown on Figure 5-5.

Inorganics. Fifteen total and 13 dissolved metals were detected in deep groundwater during one or more sampling events. There were no MCL exceedances in any of the deep groundwater samples. In the most recent 1999 samples, all concentrations were below both the maximum background and tap water RBC screening criteria.

Volatile Organic Compounds. VOCs detected at low concentrations included carbon disulfide and chloroform. None of the detected VOCs exceeded available screening criteria in the deep groundwater samples collected in 1999.

Semivolatile Organic Compounds. Bis(2-ethylhexyl)phthalate was the only SVOC detected (1J µg/l) in the deep groundwater. The detection is below screening criteria and maximum background.

Pesticides/PCBs. No PCBs were detected in deep groundwater. In the 1999 sampling event only, 4,4'-DDT (0.00570 J µg/l) and heptachlor (0.0330 J µg/l) were detected at concentrations below screening criteria in the sample from SJS05-MW01D and the duplicate sample of SJS05-MW04D, respectively.

Explosives. RDX was detected at an estimated concentration (1.6 J µg/l) in the sample SJS05-MW01D within the limits of waste (Figure 5-5). This result was above the tap water RBC. RDX was not detected in Site 5 soils. Based on results of the trenching activities, SJS05-MW01D was located within the area of waste.

5.4.5 Sediment Analytical Results

Seven sediment samples (SJS05-SD01 through SJS05-SD07) were collected from a drainage ditch running north-south along the eastern side of Site 5. Samples were analyzed for TAL total metals, TCL VOCs, TCL SVOCs, TCL pesticides/PCBs, and explosives. Sample locations are shown on Figure 5-15. Reference samples, designated SJSBK, are shown on Figure G-2 in Appendix G and represent sediment samples collected in Blows Creek.

Table 5-23 lists all constituents that were detected in the sediment samples. A shaded cell indicates that the parameter exceeded the adjusted residential soil RBC. An outlined cell indicates that the parameter exceeds the BTAG criteria. The distribution of constituents exceeding criteria in sediment at Site 5 is shown on Figure 5-15.

Inorganics. All 24 TAL metals were detected in sediment samples collected at Site 5. Arsenic concentrations exceeded the adjusted RBC in five of the seven sediment samples. The highest concentration of arsenic (23.2 mg/kg) in the sample from SJS05-SD01 was only slightly above Blows Creek maximum reference concentration of 22.5 mg/kg, and the remaining samples were lower than the reference concentration. Iron concentrations exceeded the adjusted RBC in samples SJS05-SD01 (57,600 mg/kg) and SJS05-SD02 (161,000 mg/kg), significantly exceeding maximum reference sample concentration (50,400 mg/kg) in sample SJS05-SD02. Thallium was only detected at SJS05-SD02 (5.7 mg/kg), slightly above the adjusted RBC of 5.5 mg/kg (Figure 5-15).

Eight inorganic compounds; cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc were present at concentrations elevated above the BTAG sediment flora/fauna screening criteria. All seven sediment sampling locations contained one or more metals that exceeded BTAG criteria. Chromium, copper, lead, and mercury exceeded the BTAG criteria most frequently and were present in sediment throughout the site. Of these metals, copper, lead, silver, and zinc exceed the maximum concentration of the reference samples by an order of magnitude in one or more Site 5 samples. SJS05-SD01 (where the drainage ditch enters the marsh) and SJS05-SD02 (where the drainage ditch exits the marsh) to the east of the waste area had the greatest number of metals concentrations that were significantly elevated above reference and other Site 5 samples (Figure 5-15).

The results from the upland drainage sample (SJS05-SD01) were qualitatively compared to the soil screening criteria and seven inorganic compounds (aluminum, arsenic, barium, chromium, iron, manganese, and vanadium) were present at concentrations above the adjusted residential RBCs for soil. Thirteen inorganic compounds (aluminum, barium, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, vanadium, and zinc) detected in the sample from SJS04-SD04 were present at concentrations elevated above the BTAG soil flora/fauna ecological screening criteria. Barium, beryllium, cobalt, copper, iron, lead, manganese, nickel, silver, and zinc were present at concentrations greater than the background UTLs for dredge fill.

Volatile Organic Compounds. VOCs infrequently detected at low concentrations include 2-butanone, acetone, carbon disulfide, chloroform, and methylene chloride. The analytical results of these compounds did not exceed the adjusted residential soil RBCs. Additionally, these VOCs were also detected in Blows Creek reference samples and site concentrations are less than the maximum concentration of reference samples.

Semivolatile Organic Compounds. Twenty SVOCs were detected in the Site 5 sediment samples. SVOCs in sediment did not exceed the maximum reference sample concentrations or the adjusted residential soil RBCs. Eleven compounds; acenapthene, acenaphthylene, anthracene, benzo(a)anthracene, chrysene, dibenz(a,h)anthracene, diethylphthalate, fluorene, phenanthrene, pyrene, and n-Nitrosodiphenylamine, were present at concentrations that exceeded the BTAG criteria at sample locations SJS05-SD01, SJS05-SD02, SJS05-SD03, and the duplicate sample of SJS05-SD07.

The sample results collected in the upland drainage (SJS05-SD01) were qualitatively compared to the soil screening criteria and three SVOCs (benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene) were present at concentrations above the adjusted residential RBCs for soil. Thirteen of the sixteen SVOCs detected in the sample

collected from SJS05-SD01 were present at concentrations elevated above the BTAG soil flora/fauna ecological screening criteria. No SVOCs detected at SJS05-SD01 were present at concentrations greater than the background UTLs for dredge fill.

Pesticides/PCBs. No PCBs were detected in Site 5 sediment samples. Five pesticides were detected in Site 5 sediment samples. There were no exceedances of the adjusted residential RBCs.

Three pesticides (4,4'-DDD, 4,4'-DDE, and 4,4'-DDT) exceeded the BTAG screening criteria. All three of these compounds were reported at concentrations greater than the BTAG sediment flora/fauna criteria in samples at SJS05-SD01 through SJS05-SD04. The highest concentrations of 4,4'-DDD (160 µg/kg), 4,4'-DDE (320 µg/kg), and 4,4'-DDT (240 µg/kg) occurred at levels significantly above the maximum background reference sample concentrations at SJS05-SD01. 4,4'-DDT was also detected above BTAG screening criteria at SJS05-SD05.

At SJS05-SD01, located in the upland ditch, the pesticides 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT were compared to the soil screening criteria and all three pesticides were present at concentrations above the BTAG soil flora/fauna ecological screening criteria and the background UTLs for dredge fill.

5.4.6 Surface Water Analytical Results

Seven surface water samples (SJS05-SW01 through SJS05-SW07), co-located with sediment samples, were collected and analyzed for TAL total metals, TCL VOCs, TCL SVOCs, TCL pesticides/PCBs, and explosives. Sample locations are shown on Figure 5-16. Reference samples, designated SJSBK, are shown on Figure G-2 in Appendix G and represent surface water samples collected in Blows Creek.

Table 5-24 lists all constituents detected in the surface water samples. A shaded cell indicates that the parameter exceeded the adjusted tap water RBC and an outlined cell indicates the parameter exceeded BTAG marine flora/fauna screening criterion. Sample locations and the distribution of exceedances in surface water at Site 5 is shown on Figure 5-16.

Inorganics. Nineteen total metals were detected in one or more of the seven surface water samples collected at Site 5. Four metals exceeded adjusted tap water RBC criteria for surface water; they are arsenic, iron, lead, and manganese. Based on a comparison to BTAG marine flora/fauna, the following compounds exceeded criteria at least once in the seven samples: arsenic, copper, cyanide, lead, manganese, nickel, and zinc. Copper, manganese, and zinc were present above the BTAG marine flora/fauna criteria in all seven surface water samples.

Arsenic, copper, cyanide, iron, lead, manganese, nickel, and zinc in one or more Site 5 samples exceed the maximum concentration of the reference samples by an order of magnitude as well as exceeding screening criteria. Of significance is the very high concentration of lead (4,760 µg/l), manganese (7,590 µg/l), iron (46,900 µg/l), nickel (245 µg/l), zinc (4,690 µg/l), arsenic (12.6 µg/l), and copper (215 µg/l) in sample SJS05-SW05, located within the marsh to the east of Site 5. Manganese and zinc were also elevated with respect to screening criteria and reference samples in other site samples.

Volatile Organic Compounds. Four VOCs; acetone, carbon disulfide, toluene, and total xylenes; were detected in surface water. None of the detected VOCs exceeded the adjusted tap water RBC. However, the BTAG criterion for carbon disulfide was exceeded in sample SJS05-SW06.

Semivolatile Organic Compounds. Only two SVOCs were detected, 4-methylphenol and bis(2-ethylhexyl)phthalate, in the duplicate samples of SJS05-SW06 and SJS05–SW07. The detected concentrations did not exceed either the human health or ecological screening criteria.

Pesticides and PCBs. No PCBs were detected in surface water. Two pesticides; 4,4′-DDD and 4,4′-DDE; were detected at low levels in the surface water samples collected at SJS05-SW06 and SJS05-SW04, respectively. The detected concentrations did not exceed either the human health or ecological screening criteria.

Explosives. No explosives were detected in any of the surface water samples analyzed.

5.4.7 Summary of Relevant Constituents at Site 5

In soils, inorganic compounds, explosives, and dioxins reflected potential contamination within the limits of waste. The metals in soil most indicative of site-related activities were characterized by samples within the northern portion of the waste area and included, barium, copper, lead, and zinc. Outside the waste boundary arsenic, barium, lead, chromium, and zinc were elevated in surface soil in localized areas: arsenic northeast (SJS05-SS11) and southwest (SJS05-SS09 and SJS05-SS32) of the waste area, lead in the marsh to the southeast (SJS05-SS03, SJS05-SS05, SJS05-SS07, and SJS05-SS14) of the waste area, and antimony, barium, chromium, lead, and zinc south towards Blows Creek (SJS05-SS19). There was not widespread metals contamination in subsurface soil at Site 5. Pesticides were most frequently detected in soils west of Site 5 along the perimeter road and near the drop tower to the southeast of the waste area with no definitive pattern to indicate that these compounds are related to the waste.

In shallow groundwater (Columbia Aquifer) total and dissolved beryllium, cadmium, and lead exceeded the MCL in one downgradient groundwater sample, SJS05-MW03S. Total and dissolved iron and manganese were elevated in samples from all shallow wells. A few VOCs and SVOCs were infrequently detected at low estimated concentrations in groundwater below the human health and ecological screening criteria. In deep groundwater (Yorktown Aquifer) the explosive RDX was detected in the 1999 sample from SJS05-MW01D located within the waste.

In sediment, metals and pesticides were elevated in localized areas of the upland drainage ditch and the low-lying marsh area east of Site 5. Although present in some sediment samples, PAH concentrations were similar to Blows Creek reference concentrations.

In surface water, metals were elevated in the marsh area east of Site 5. Sample SJS05-SW05 is significant with arsenic, copper, iron, lead, manganese, nickel, and zinc at concentrations that exceeded the maximum concentration of the reference samples by an order of magnitude as well as screening criteria.

5.5 Site 6 Remedial Investigation Results

This section discusses the extent of waste, the geophysical survey results, soil analytical results obtained from laboratory analyses, and the nature and extent of contaminants identified in Site 6 soil. Site 6 was investigated as part of Site 5 because it covers a relatively small area and is in close proximity to Site 5. Site 6 influences the same groundwater, surface water, and sediment as Site 5; therefore, groundwater, surface water, and sediment samples were not collected at Site 6.

5.5.1 Extent of Waste

The actual extent of waste was not determined at Site 6, however, trenching was conducted to identify the former location of the Small Arms Pit. The results of the two test pits excavated (SJS06-Trench1 and SJS06-Trench2) did not indicate any visual signs of potentially contaminated soils, though concrete and an ordnance was encountered at Site 6. The extent of these materials is presented on Figure 5-12.

One potential live ordnance was found at Site 6. An M3 initiator switch used for aircraft emergency escape systems was encountered at SJS06-Trench2. No determination could be made as to whether the ordnance was live and the Naval Amphibious Base (NAB) – Little Creek Explosives Ordnance Detachment (EOD) was notified and removed the ordnance.

Waste debris was limited to concrete located within the first 6 in. of one test pit, SJS06-Trench1. The extent of Site 6 was not altered from its previous boundaries based on the trenching activities.

No burnt or stained soils were encountered and soils at Site 6 were generally brown, silty sands. The maximum depth of the two test pits was 40 in. (3.3 ft) bgs.

5.5.2 Geophysical Survey Results

An EM survey was conducted on a 150 ft by 300 ft grid at Site 6 (Appendix F). Following an initial survey, additional grid lines were added to create a 10-ft spacing over a 60 by 100-ft area. The survey conducted in the area of the caged pit identified conductivity and magnetic anomalies. This area is considered to be the former caged pit area. The data were used in the field to locate the Phase I subsurface soil sampling locations as well as test pit locations during Phase III.

5.5.3 Soil Analytical Results

Because Site 6 was investigated as part of Site 5, samples were identified "SJS05-". Based on the limited number of surface soil (one sample and one duplicate) and subsurface soil samples (four samples and two duplicates) collected at Site 6, population (site) -to-population (background) comparisons were not conducted. However, based on the proximity of Site 6 to Site 5, and because Site 6 soil sample concentrations were lower than concentrations found in Site 5 soils, the population-to-population comparison of Site 5 data were used to identify parameters at Site 6 with potential population exceedances of background.

5.5.3.1 Surface Soil

One surface soil sample (SJS05-SS29) and one duplicate sample were collected during the Phase II (May 1999) investigation. Sample locations are shown on Figure 5-13. The surface soils samples were analyzed for TAL metals, TCL VOCs, TCL SVOCs, and TCL pesticides/ PCBs.

Table 5-25 lists all constituents that were detected in the surface soil sample and duplicate sample. A shaded cell indicates that the parameter exceeded the 95-percent background UTL for dredge fill soil. Site/background population-to-population central-tendency statistical analysis results for Site 5 are shown on Table 5-18. The distribution of potential contaminants in surface soil at Site 6 is shown on Figure 5-13.

Inorganics. Twenty-two TAL metals were detected in the surface soil sample or duplicate sample. Of the 22 metals detected seven exceeded the background UTL: antimony, barium, copper, lead, manganese, silver, and zinc. Silver exceeded the background UTL in the duplicate sample only.

Based on population (site) to population (background) central-tendency statistical analysis for Site 5, four compounds indicated a statistical difference from background; barium, copper, lead, and zinc.

Seven of the inorganic compounds; aluminum, antimony, arsenic, barium, chromium, iron, and, manganese; were present at concentrations above the adjusted residential RBCs. Chromium exceeded the adjusted residential RBC in the duplicate sample only. Antimony, barium, and manganese were the only metals also present at concentrations greater than background UTLs.

Sixteen inorganic compounds; aluminum, antimony, barium, beryllium, cadmium, chromium, copper, cyanide, iron, lead, manganese, mercury, nickel, silver, vanadium, and zinc; were reported at concentrations elevated above the BTAG soil flora/fauna ecological screening criteria. Cadmium, cyanide, and manganese exceeded the BTAG soil flora/fauna ecological screening criteria in the duplicate sample only. Six of these compounds were also present at concentrations greater than background UTLs; antimony, barium, copper, lead, manganese, and zinc.

Volatile Organic Compounds. No VOCs were detected in the surface soil sample SJS05-SS29.

Semivolatile Organic Compounds. Only one SVOC, di-n-butylphthalate, was detected in the parent sample SJS05-SS29. Seven PAHs were detected in the duplicate sample at trace estimated concentrations; benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene, fluoranthene, phenanthrene, and pyrene.

None of the PAHs exceeded their background UTL. Based on population (site) to population (background) central-tendency statistical analysis for Site 5, only phenanthrene indicated a statistical difference from background.

None of the SVOCs exceeded its respective adjusted residential soil RBC or BTAG soil flora/fauna ecological screening criteria.

Pesticides/PCBs. Three pesticides were detected in the surface soil sample and duplicate sample; 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT. 4,4'-DDE exceeded the background UTL in the parent sample and 4,4'-DDT exceeded the background UTL in the duplicate sample.

Based on population (site) to population (background) central-tendency statistical analysis with Site 5 data, all three pesticides indicated a statistical difference from background.

All three pesticides were detected below the adjusted soil residential RBC, however all three did exceed their BTAG soil flora/fauna ecological screening criteria.

5.5.3.2 Subsurface Soil

Four subsurface soil samples were collected, three from Phase I (SJS05-SB09 through SJS05-SB11) and one from Phase III (SJS06-SB01). The three samples collected during the Phase I investigation were analyzed for TAL metals, TCL VOCs, TCL SVOCs, and TCL pesticides/PCBs. The Phase III sample was analyzed for dioxins/furans only. Sample locations are shown on Figure 5-14. All four samples were collected within the suspected boundary of the Small Arms Pit.

Tables 5-26 and 5-27 list all constituents that were detected in the subsurface soil samples. A shaded cell indicates that the parameter exceeded the 95-percent background UTL for dredge fill soil on Table 5-26. Site/background population-to-population central-tendency statistical analysis results for Site 5 are shown on Table 5-18. The distribution of potential contaminants in subsurface soil at Site 6 is shown on Figure 5-14.

Inorganics. Fourteen TAL metals were detected in subsurface soil at Site 6. Antimony exceeded the background UTL in sample SJS05-SB09. SJS05-SB11 contained the greatest number of detected metals and at the highest concentrations, however, none of the constituents were present at concentrations above the background UTL.

Based on population (site) to population (background) central-tendency statistical analysis for Site 5, antimony did not show a statistical difference from background.

Two inorganic compounds; arsenic and iron; were present in subsurface soil at concentrations above the adjusted residential RBCs, though arsenic was detected just over that level and undetected in the duplicate sample. Neither of these compounds indicated exceedances of background UTL in any samples.

Volatile Organic Compounds. Only one VOC, acetone, was detected in all of the Site 6 subsurface soil samples. Acetone concentrations ranged from 11 J to 23 µg/kg and were well below adjusted residential soil RBC.

Semivolatile Organic Compounds. Three PAHs were detected in the subsurface soil samples; benzo(b)fluoranthene, fluoranthene, and pyrene (SJS05-SB10 or SJS05-SB11) at estimated concentrations. None of the PAHs exceeded the background UTLs.

Based on population (site) to population (background) central-tendency statistical analysis for Site 5, none of the detected compounds indicated a statistical difference from background.

None of the PAHs exceeded the adjusted residential RBCs in the subsurface soil.

Pesticides and PCBs. No pesticides or PCBs were detected in any of the samples.

Dioxins. Nine compounds were detected in the sample SJS06-SB01 and its duplicate. The concentrations of the detected compounds were screened against TEF adjusted residential soil RBC values and the total TEQ against the toxicity equivalent RBC of 0.0043 µg/kg. The results indicate no exceedances of individual compounds against the adjusted residential soil RBCs. The sample did not exceed the total TEQ.

5.5.4 Summary of Relevant Constituents at Site 6

Site 6 was investigated as part of Site 5, consequently, groundwater, surface water, and sediment samples were not collected at Site 6.

Constituents in surface soil reflective of potential impacts from Site 6 are the metals barium and zinc, present at an order of magnitude greater than the background UTL and with central-tendency statistically elevated over the background population. Only barium also exceeded the adjusted residential soil RBC and both compounds exceed the BTAG soil flora/fauna screening values.

5.6 References

CDM Federal. *Final Supplemental Field Investigation Plan Landfill B and the Burning Grounds.* St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. March 1999.

CDM Federal. *Final Supplemental Field Investigation Plan Landfill C and the Landfill D.* St. Juliens Creek Annex. Chesapeake, Virginia. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Norfolk, Virginia. March 1999.

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USEPA. Drinking Water Standards and Health Advisories. Summer 2000.

USEPA Region III. Risk Based Concentration (RBC) Table. Superfund Technical Support Section, Philadelphia, PA. October 2002.

VDEQ, 2001. *Storage Tank Program Technical Manual.* Document #01-2024. Third Edition, October 2001.

SECTION 6

Contaminant Fate and Transport

The fate and transport of constituents of interest (COIs) at Sites 3, 4, 5, and 6 (Table 6-1) at SJCA and their interactions with the soil, groundwater, surface water, and sediment are discussed in this section. Constituents of interest represent potentially site-related compounds identified within the waste area that exceed background UTLs or, in the absence of background, potentially site-related compounds that and/or exceed Virginia Groundwater Standards, USEPA Region III tap water RBCs, Federal Groundwater Maximum Contaminant Levels, BTAG sediment flora/fauna, USEPA Region III soil RBCs, and BTAG marine flora/fauna screening criteria. The fate and transport of COIs are described to support potential risk management and aid in defining the effectiveness of potential remedial alternatives.

6.1 Mobility and Persistence of COIs

The probable behavior of the COIs at each site is determined by their physical, chemical, and biological interaction with the environment. The mobility and persistence of the chemicals are key characteristics in determining probable behavior in the environment. Mobility is the potential for a chemical to migrate from a site, and persistence is a measure of how long a chemical will remain in the environment. Environmental factors that affect the mobility and persistence of the COIs include: pH, concentration of other chemicals in the media, soil moisture, oxidation-reduction potential (ORP) (measured as Eh), water chemistry, organic-matter content, and the presence of microorganisms.

The behavior is also determined by the physical and hydraulic properties of the water-bearing units through which the COIs are being transported. These properties control the advection and dispersion of the COIs.

The following sections address the physical and chemical properties of the chemical groups of COIs, and the physical and hydraulic properties of the water-bearing units at the sites. Sections 6.2, 6.3, and 6.4 address the observed constituent migration and attenuation at Sites 3, 4, 5, and 6. Because Site 6 covers a relatively small area, had only a few samples collected, is in close proximity to Site 5, and influences the same surface water and sediment as Site 5, the discussion of constituent migration and attenuation is combined for Sites 5 and 6.

6.1.1 Chemical Groups

Many organic and inorganic constituents were detected in environmental media at Sites 3, 4, 5, and 6. Discussing the fate and transport of all these chemicals would be complicated and may not illustrate overall trends and relationships between potential sources and environmental impact. To simplify the analysis and interpretation of these data, this section focuses on the chemical groups of COIs. Chemical groups and representative COIs, were selected to reflect the range of chemicals associated with the sites on the basis of concentrations exceeding background UTLs, exceeding screening criteria, frequency of occurrence,

occurrence in several media, variable migration potential, and potential contribution to overall risk to human health and the environment. The COIs and chemical groups discussed in this section are listed in Table 6-1. Quantification of a COI's contribution to human health and ecological risk is presented in Sections 7 and 8, respectively.

6.1.2 Physical and Chemical Properties

Various basic physical and chemical properties affect the transport of constituents in the environment at the sites. The following are considered to be the most important properties:

- Sorption
- Volatilization
- Degradation
- Transformation
- Bioaccumulation

Table 6-2 contains data for the representative chemicals including the physical and chemical properties relevant to fate and transport. Appendix I contains data on pH, specific conductance, turbidity, temperature, salinity, DO, and oxidation/reduction potential in groundwater samples obtained from monitoring wells. Properties affecting the transport of constituents in the environment are discussed below.

6.1.2.1 Sorption

Sorption is the tendency for chemicals to adsorb to and desorb from materials in the media through which the chemicals are transported. The subsurface materials likely to sorb chemicals typically are clays and organic material, both of which exist in abundance in the environment at the sites. In addition, inorganic chemicals adsorb onto iron, manganese, and aluminum oxyhydroxide or oxide coatings on soil and sediment grains. Adsorption of metals can be irreversible because of the process of fixation.

The conventional measure of sorption is the distribution (or partitioning) coefficient (K_d) of soil and geologic material for the chemical. The K_d for organic chemicals is the product of an organic carbon partition coefficient (K_{oc}) and the fraction of organic carbon (f_{oc}) in the soils. In general, chemicals with higher K_{oc} values, have higher degrees of adsorption and consequentially lower mobility, whereas chemicals with lower K_{oc} values have lower degrees of adsorption and consequentially higher mobility. The K_d for inorganic chemicals is a complex function of pH, organic content, oxide coatings, and other factors; therefore, K_d is not easily estimated by methods other than site-specific testing. As shown in Table 6-2, the representative chemicals have a wide range of K_d values. The K_d values for organic compounds are estimated as follows:

$$K_d = K_{oc} \times f_{oc}$$

where: K_{oc} = Organic partitioning coefficient (ml/g)

f_{oc} (fraction of organic carbon in soil) = Average site total organic carbon (TOC) concentration (mg/kg) ÷ 1,000,000

The migration rates of dissolved chemicals range widely between different chemicals because of their degree of adsorption. As a first estimate, they will move at the rate of

groundwater flow, or by advection. The rate of groundwater flow is estimated using Darcy's Law and dividing it by the effective porosity:

$$v = K \times \nabla h / n_e$$

where v = Groundwater flow velocity (ft/day)

K = Hydraulic conductivity (ft/day)

∇h = Hydraulic gradient (dimensionless)

n_e = Effective porosity (dimensionless)

Typically, constituents will not move as rapidly as the groundwater because of adsorption on various geologic media. For each COI detected at a site, it is theoretically possible to calculate a retardation coefficient (R), which is an estimate of the degree to which the COI is slowed by adsorption in relation to the groundwater flow velocity. The retardation coefficient is calculated according to the following equation:

$$R = 1 + p_b \times K_d / n_e$$

Where: R = Retardation coefficient (dimensionless)

p_b = Soil bulk density (g/cm^3)

K_d (Distribution coefficient (ml/g)) = $k_{oc} \times f_{oc}$ (for organic compounds)

The retardation effect is estimated by dividing the groundwater flow velocity by R, which provides a value of migration either equal to (in the case of no retardation) or less than the flow rate (in the presence of retardation).

To estimate the K_d of the soil for a particular organic chemical, it is necessary to have an estimate of the total organic carbon (TOC) content in the soil. Site-specific measurements of TOC in the saturated soil zone are not available but TOC in sediment ranged from 27,600 mg/kg at Sites 3 and 5 to 66,600 mg/kg at Site 4 and averaged approximately 38,200 mg/kg over all the sites. The site sediment TOC average concentrations are being used in this report to estimate f_{oc} values and subsequently K_d values, but it should be noted that sediment TOC concentrations would be expected to be greater that the saturated soil at the sites.

Total organic carbon concentrations in sediment can be converted to a f_{oc} by dividing by 1,000,000 resulting in an average f_{oc} of 0.04 over all the sites. The K_d was then estimated by multiplying the f_{oc} by the K_{oc} (literature values) for the particular organic chemical (Table 6-2). These results are also listed in Table 6-3. For inorganics, this simple relationship is not applicable and site-specific K_d values were not collected. Therefore, K_d estimates obtained from the literature and provided in Table 6-2 were used; these values are also listed in Table 6-3.

Retardation coefficients for each of the major chemical groups were estimated and are provided in Table 6-3. A bulk density of 1.5 grams per cubic centimeter and an effective porosity of 0.30 were assumed. A range of values was calculated to show the effects of the variability in the K_d. Both the range in lower values and the range in upper values of K_d for metals were used because many metals, such as arsenic and chromium, vary widely in their mobility depending upon their valence state.

The estimates of retardation provided in Table 6-3 indicate a wide range. Using the average hydraulic conductivity of the Columbia Aquifer (16.3 ft/day) calculated from slug tests conducted during the RI, an effective porosity of 0.30, and a median hydraulic gradient of 0.008 observed across the sites, a groundwater velocity of 0.43 ft/day was calculated for the Columbia Aquifer. When the groundwater velocity of 0.43 ft/day is divided by the retardation coefficient of 51 for carbon disulfide, the migration rate would be approximately 0.008 ft/day. SVOCs and PCBs show the largest range in retardation, which would produce migration rates as low as 0.00003 ft/day for SVOCs with a groundwater flow rate of 5.4×10^{-6} ft/day.

The K_d values of the COIs associated with the sites vary widely between the organic and inorganic analytes. The K_d values of the inorganic analytes also vary widely depending upon the valence state of some of the analytes and the pH and other conditions encountered in the subsurface. The data provided in Table 6-2 are from various reports and documents in the literature, not from the site. Therefore, the estimates of R have an even greater level of uncertainty than do the estimates of the rates of groundwater flow. As a result, estimates of the rates of contaminant migration are very approximate.

6.1.2.2 Volatilization

Volatilization is the tendency for some chemicals, particularly VOCs, to change from a liquid or adsorbed state to a gas. A conventional measure of volatility is Henry's Law Constant (K_h). Values of K_h for the representative chemicals are provided in Table 6-2.

Compounds with K_h values higher than 10^{-3} atmosphere-cubic meter per mole (atm-m^3/mol) (e.g., carbon disulfide) are expected to volatilize readily from water to air, whereas those chemicals with K_h values lower than 10^{-5} atm-m^3/mol (e.g., chrysene and 2,3,7,8-TCDD) are relatively non-volatile. Most inorganic chemicals are not volatile under normal temperature and pressure conditions.

6.1.2.3 Degradation

Degradation is the transformation of one chemical to another by such processes as hydrolysis, photolysis, and biodegradation. Hydrolysis is the reaction of a chemical with water and photolysis is the result of exposing the chemical to light.

Degradation is commonly expressed as a half-life that composites the degradation by whatever processes may be operating. Estimates of half-lives for the representative chemicals are provided in Table 6-2. For example, in groundwater, 4,4'-DDTwould be expected to degrade much more rapidly than would 2,3,7,8-TCDD.

6.1.2.4 Transformation

Transformation occurs when metals are increased or reduced in valence state by oxidation or reduction, respectively. Transformation may have a significant effect on the mobility of a metal, either increasing or decreasing it. Transformation can be caused by Eh and pH changes and by microbial or non-microbial (abiotic) processes. This process commonly affects arsenic and chromium.

6.1.2.5 Bioaccumulation

Bioaccumulation is the extent to which a chemical will partition from water into the lipophilic parts (e.g., fat) of an organism. Bioaccumulation commonly is estimated by the octanol-water partition coefficient (K_{ow}). Chemicals with high values of K_{ow} tend to avoid the aqueous phase and remain in soil longer or bioaccumulate in the lipid tissue of exposed organisms. Accumulation of a chemical in the tissue of the organism can be quantified by a bioconcentration factor (BCF), which is the ratio of the concentration of the chemical in the tissue to the concentration in the water. Bioaccumulation factors are both chemical-specific and species-specific.

Estimates of the values of K_{ow} and BCF for the representative chemicals are provided in Table 6-2. Many inorganic chemicals, SVOCs, PCBs, and dioxins tend to have higher K_{ow} values, so they bioaccumulate more extensively than VOCs. For example, the BCF for aroclor-1260 ranges from 270,000 to 340,000, while the BCF for chloroform is only 1.4, chloroform is not considered a COI, but is used here as an example.

6.1.3 Representative Chemicals

The following profiles briefly describe how the chemical and physical properties of the representative chemicals (Table 6-1) affect their mobility and persistence in the environment. In some cases chemical groups (chemicals that behave similarly) are discussed with reference to specific chemicals and their properties. Most of the information provided in these profiles was obtained from:

- Spectrum Laboratories chemical fact sheets available at website http://www.speclab.com/ compound/chemabc.htm
- Agency for Toxic Substance and Disease Registry (ATSDR), and agency of the U.S. Department of Health and Human Services, at http://www.atsdr.cdc.gov/toxfaq.html

6.1.3.1 Carbon Disulfide

Carbon disulfide is a natural product of anaerobic biodegradation and is released to the atmosphere from oceans and land masses. Geothermal sources also contribute to carbon disulfide emissions. There are a number of manufacturing and industrial processes that utilize carbon disulfide, such as the vulcanization of rubber, generating petroleum catalysts, and the removal of metals from wastewater.

If released on land, carbon disulfide will primarily be lost by volatilization. It may also readily leach into the ground, where it may biodegrade. If released into water, carbon disulfide will be primarily lost due to volatilization with a half-life of 2.6 hours. Adsorption to sediment and bioconcentration in fish should not be significant. In the atmosphere carbon disulfide degrades by reacting with atomic oxygen and photochemically produced hydroxl radicals. Soil may be a natural sink for the chemical by adsorbing and subsequently degrading the carbon disulfide.

6.1.3.2 SVOCs

Due to the number of different SVOCs found at Site 3, 4, 5, and 6, a general description of the physical, chemical, and biological behavior of this class of compounds in the

environment is discussed below. The discussion may not be representative of each compound, and its attributes, detected across the sites.

SVOCs identified as COIs at the sites are primarily the PAHs. In general the release of SVOCs to the environment is commonly widespread since most are the ubiquitous product of incomplete combustion. They are largely associated with airborne particulate matter, soil, and sediment; are reasonably stable in the atmosphere; and are capable of long-distance transport. When released to air, PAHs may be subject to direct photolysis, although adsorption to particulates apparently can retard this process.

If released to soil, PAHs will be expected to adsorb very strongly to the soil and not to appreciably leach to the groundwater, although their presence in some samples of groundwater illustrates that they can be transported. They will not be expected to hydrolyze or significantly evaporate from soil and other organic surface. They may be subject to appreciable biodegradation in soil. Biodegradation of SVOCs (especially PAHs) is well-documented and is likely the ultimate fate of most SVOCs. Limited nutrient and oxygen availability and the presence of such potential microbe inhibitors as arsenic could limit the effectiveness of biodegradation.

Human exposure will be from inhalation of contaminated air and consumption of contaminated food and water. Especially high exposure will occur through the smoking of cigarettes and the ingestion of certain foods (e.g., smoked and charcoal broiled meats and fish).

Semivolatile organic compounds tend to bioconcentrate in organisms unable to metabolize the chemical.

6.1.3.3 Aroclors -1254 and -1260

PCBs in general are characterized by low water solubility, low volatility, high affinity for organic matter, and high resistance to chemical or biological degradation. Aroclors are mixtures of different congeners of chlorobiphenyl and the relative importance of the environmental-fate mechanisms generally depends on the degree of chlorination. In general, the persistence of the PCB congeners increases with an increase in the degree of chlorination. Screening studies have shown that aroclors generally are resistant to biodegradation. It has also been shown that the higher chlorinated PCB congeners are susceptible to reductive dechlorination by anaerobic microorganisms found in aquatic sediments.

The PCB congeners present in aroclors will become tightly adsorbed to the soil particles if they are released to soil. Due to their low solubility and high tendency to adsorb to soil, PCBs in the soil generally do not cause significant groundwater contamination and do not do so at any of the sites investigated under this RI. The affinity for aroclors to adsorb generally increases as the degree of chlorination of the individual congeners increases. PCBs in surface water or groundwater are likely to be removed from solution by adsorbing onto suspended sediment.

PCBs may migrate off sites with erosion by surface runoff and by particle entrainment in the air. They then may be deposited in sediments in surface water bodies. Adsorption to sediment and suspended matter will be an important fate process if released to water. Although adsorption can immobilize aroclors for relatively long periods of time, eventual

re-solution into the water column has been shown to occur. The PCB composition in water will be enriched in the lower chlorinated PCBs because of their greater water solubility, and the least water-soluble PCBs (i.e., highest chlorine content) will remain adsorbed.

Aroclors have been shown to bioconcentrate significantly in aquatic organisms.

6.1.3.4 Pesticides

The pesticides 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT are the primary pesticide compounds found at Sites 3, 4, 5, and 6.

4,4'-DDD and 4,4'-DDE are impurities in 4,4'-DDT as well as biodegradation products of 4,4'-DDT. Therefore, they may occur in the environment as a result of the use of 4,4'-DDT as an insecticide.

If released to soil, they will adsorb very strongly to the soil and will not be expected to leach through soil to groundwater. They will not hydrolyze under normal environmental conditions and are not subject to significant biodegradation. Evaporation from the surface of soils with low organic content (such as sandy soils) may be significant, but adsorption of them to soil may reduce the rate of evaporation. If released to water, they will adsorb very strongly to sediment and bioconcentrate in aquatic organisms.

6.1.3.5 Dioxin

Screening criteria for dioxins and furans are based on a TEF multiplier of the 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) screening criteria. Limited physical and chemical characteristic data are available for dioxins and furans; thus 2,3,7,8-TCDD is used in the following discussion to describe the behavior of dioxins and furans in the environment.

Although 2,3,7,8-TCDD has a relatively low vapor pressure, it has been shown to be volatile and to occur in the atmosphere in both the gaseous- and particulate-phase. The half-life for atmospheric 2,3,7,8-TCDD destroyed through hydroxyl radical reactions is estimated to be about 8.3 days. Direct photolysis degradation of atmospheric 2,3,7,8-TCDD may occur at a faster rate. Data are not sufficient to estimate the photolysis half-life of 2,3,7,8-TCDD in the particulate phase. Particulate-phase 2,3,7,8-TCDD may be physically removed from air by wet and dry deposition. Monitoring data indicate that 2,3,7,8-TCDD can be transported large distances through the atmosphere.

Photodegradation of 2,3,7,8-TCDD on terrestrial surfaces and volatilization from surface soils may be an important mechanism for transforming 2,3,7,8-TCDD. Volatilization of 2,3,7,8-TCDD from subsurface soils is likely to be extremely slow. If released to soil, 2,3,7,8-TCDD is not expected to readily leach into water.

Volatilization from the water column and photodegradation near the water's surface may be a significant removal processes, but adsorption to sediment will limit the overall rate by which 2,3,7,8-TCDD is removed from water. In lakes, 2,3,7,8-TCDD has been estimated to have a half-life in excess of 1.5 years. 2,3,7,8-TCDD released to water will be predominantly associated with sediments and suspended material.

Migration of 2,3,7,8-TCDD in soil is likely to be on soil colloids and particles to which it binds because it is only slightly soluble in water. Migration of 2,3,7,8-TCDD in water is

limited due to its low solubility. Migration of 2,3,7,8-TCDD may occur through surface erosion of soil or soil particles and flooding.

Aquatic sediments may serve as an ultimate environmental sink for releases of 2,3,7,8-TCDD. Screening studies indicate that 2,3,7,8-TCDD is generally resistant to biodegradation. Bioconcentration of this constituent in aquatic organisms has been demonstrated.

6.1.3.6 Antimony

Antimony is released to the environment from natural sources and from industry. Antimony behaves very similarly to arsenic and is most frequently found as Sb^{3+} and Sb^{5+} under typical environmental conditions. The Sb^{3+} and Sb^{5+} states are stable under reducing and oxidizing conditions, respectively.

Oxides of antimony are more soluble at extremely high and extremely low pH values. Antimony tends to adsorb to oxide and silicate clays and is moderately mobile in soils. Reducing conditions will lessen the mobility of antimony in the environment.

Human exposure to antimony occurs primarily from affected food, drinking water, and air.

6.1.3.7 Arsenic

The predominant soluble form of arsenic in oxidizing environments is usually arsenate (As^{5+}). Under slightly reducing acidic conditions, the more toxic and mobile arsenite (As^{3+}) form dominates. Arsenite and methylated arsine predominate in moderately reducing soil found in areas such as tidal marshes and consistently flooded soil. In natural environments, arsenic also may exist in the As^{3-} and As^{0} states, but only under highly reducing conditions.

Transport and partitioning of arsenic (and all other metals) in water depends on the oxidation state of the arsenic and on interactions with other materials present. Organic matter, divalent metals, and dissolved sulfide enhance the reduction of the arsenic valence state to a more mobile form.

Soluble forms move with water, but arsenic may be adsorbed from water onto sediment or soil, especially clay particles, iron oxyhydroxides and oxides, aluminum hydroxides, manganese compounds, and organic matter. Adsorption to oxyhydroxides is the most important natural adsorption process.

Microbes are capable of methylating arsenic to trimethylarsine gas, which is a more volatile and mobile form than inorganic arsenic; this gas likely would be released to the atmosphere.

Bioaccumulation of arsenic occurs in aquatic organisms, particularly algae and lower invertebrates. Although some fish and invertebrates may contain high levels of arsenic compounds, the predominant arsenic form, arsenobetaine, is relatively inert. Biomagnification in aquatic food chains does not appear to be significant.

6.1.3.8 Barium

Barium occurs only in the Ba^{2+} state. Because barium is usually associated with silicates, it is a relatively immobile element in soils.

Some barium compounds, typically sulfates and carbonates, dissolve easily in water and are found in lakes, streams, and rivers. Barium is commonly found in foods at low levels and fish and aquatic organisms accumulate barium.

Humans are exposed to low levels of barium in the air, drinking water, and food.

6.1.3.9 Chromium

Chromium is a naturally occurring element found in animals, plants, soil, and water. Chromium is present in the environment in several different forms. The most common forms are Cr^0 and Cr^{3+} (trivalent), and Cr^{6+} (hexavalent). Trivalent chromium occurs naturally in the environment and is an essential nutrient. Industrial processes generally produce Cr^{6+} and Cr^0. The metal chromium, which is the Cr^0 form, is used for making steel. Hexavalent chromium and trivalent chromium are used for chrome plating, dyes and pigments, leather tanning, and wood preservation.

Chromium enters the environment mostly in its trivalent chromium and hexavalent chromium forms. In air, chromium compounds are present mostly as fine dust particles that eventually settle over land and water after removal by rain and snow. Chromium compounds will usually remain in the air for less than 10 days. Chromium strongly binds to soil and only a small amount can dissolve in water and move deeper in the soil to groundwater. The mobility of chromium in soil and groundwater depends on the type and condition of the soil and other environmental factors. Chromium compounds are very persistent in surface water systems, where they are present in the dissolved phase and in particulate form as sediment. Some of the particulate chromium would remain as suspended matter and ultimately be deposited in sediments. Although most of the soluble chromium in surface waters may be present as hexavalent chromium, a small amount may be present as trivalent chromium organic complexes. Hexavalent chromium is the major stable form of chromium in seawater; however, hexavalent chromium may be reduced to trivalent chromium by organic matter present in water, and may eventually deposit in sediments.

Chromium uptake by plants is generally low; it was found to be greater from ultrabasic soils by a factor of 5-40 than on calcareous or silica-based soils. Fish do not accumulate much chromium in their bodies from water. Though few data are available, there is a high potential for bioconcentration of chromium in aquatic organisms. Snails showed an accumulation factor of $1x10^6$.

6.1.3.10 Copper

Copper exists in two oxidation states: Cu^{1+} and Cu^{2+}. Many compounds of Cu^{1+} are unstable in aqueous solutions; the only Cu^{1+} compounds stable in aqueous solutions are highly insoluble (e.g., CuCl, CuCN). Most Cu^{2+} salts also are relatively insoluble. Cu^{2+} forms coordination compounds or complexes with inorganic and organic ligands such as ammonia, chloride, and humic acids. These complexes tend to enhance both its solubility and adsorption to clay and other surfaces. In soil, copper is strongly adsorbed and most of it remains within the upper few inches of soil. Copper has the greatest potential to leach in sandy soils with low pH. In general, copper binds to soil more strongly than other divalent cations.

Copper bioaccumulates and can be toxic to aquatic organisms at high concentrations.

6.1.3.11 Iron

Iron is a common element in minerals of many rocks and sediment. When these minerals encounter water, the iron often is released, but generally is reprecipitated nearby. The behavior of iron in aquatic environments is strongly dependent on the system's pH and reduction/oxidation (redox) status. The solubility of iron is favored in the presence of acidifying or oxidizing conditions. Under typical soil conditions of pH and redox potential, it is present in the form of an insoluble hydroxide or oxide that has little potential to leach. Under oxidizing conditions, the ferric form of iron Fe^{3+} is predominant, where it forms insoluble iron sulfides. Conversely, the more mobile ferrous iron Fe^{2+} predominates under reducing conditions. Microorganisms are often an integral part of redox reactions involving iron.

6.1.3.12 Manganese

Manganese-containing minerals are widely distributed in oxides, silicates, and carbonates. In the presence of oxygen, manganese occurs as MnO_2. Manganese is reduced to soluble Mn^{2+} in groundwater and other oxygen-deficient water, such as tidally influenced and marshy areas.

Manganese often precipitates as $MnCO_3$ in water with high concentrations of carbonate. The rate of oxidation of manganese to higher insoluble states is pH dependent with high pH favoring more rapid oxidation.

Relatively high levels of insoluble Mn^{4+} are also frequently found in water as colloidal material, which are difficult to remove. These metals may be associated with humic colloids or organic material that binds to colloidal metal oxides, stabilizing the colloid.

Manganese is relatively nontoxic to animals, but is toxic to plants at higher concentrations.

6.1.3.13 Mercury

Mercury is a naturally occurring element in minerals, rocks, and sediment. The Hg^{2+} cationic form is most common, as the reduced state (Hg^{1+}) has a limited stability in the environment. The metallic elemental form (Hg^0) is easily achieved in soils by both biological and chemical reactions. This elemental form is somewhat volatile and the vapors are extremely toxic to organisms. Mercury combines with other elements, such as chlorine, sulfur, and oxygen to form inorganic mercury compounds. Mercury is moderately mobile in the environment, more so when exchangeable ions such as lead and copper are present. Salinity will also increase the mobility of mercury in the environment. Acid oxidizing conditions tend to stabilize mercury as the Hg^{2+} form when sulfide compounds are formed.

Mercury also forms organometallic complexes by combining with carbon. The most common organic mercury compound is methylmercury, which is produced by microscopic organisms in the water and soil under anaerobic conditions. Methylmercury builds up in the tissue of fish and larger and older fish tend to have the highest mercury levels.

Humans are most commonly exposed to mercury by ingesting fish or shellfish and by breathing mercury vapors.

6.1.3.14 Lead

The dominant species of lead in the aqueous solution is Pb^{2+} under acidic conditions and Pb^{2+}-carbonate complexes under alkaline conditions. Adsorption and precipitation increase with increasing pH, with most lead precipitating out at pH greater than 6. In oxidizing systems, the least soluble common forms of lead are the carbonate, hydroxide, and hydroxy-carbonate. In reducing conditions where sulfur is present, lead sulfide is the stable solid.

Lead is an extremely stable metal, although it dissolves in acid. Due to its very low vapor pressure, volatilization of lead from the soil and water is negligible, although benthic microbes may convert methylate lead to tetramethyl lead, which tends to volatilize to the atmosphere. Lead forms complexes with organic matter and clay minerals that limit its mobility. Only a small fraction of lead in soil will be in a water-soluble form.

Lead is effectively removed from water to the sediment by adsorption to organic matter and clay minerals, precipitation as insoluble salt (especially as lead sulfide), and the reaction with hydrous iron and manganese oxide. Under most circumstances, adsorption predominates as the process for removing lead from solution. If released into the water, metallic lead will sink into the sediment.

Lead may bioconcentrate in fish or other biota.

6.1.3.15 Nickel

Nickel predominantly occurs as Ni^{2+}. It is reasonably mobile in soil with low pH and cation-exchange capacity, and less mobile in basic mineral soils and those with high organic content. Nickel in water typically is associated with suspended particles. Although nickel is extremely persistent in soil, it has the potential to leach, and enter groundwater. Organic complexing agents restrict the movement and availability of nickel in soil.

In organic-rich polluted water, organic materials will keep nickel solubilized by complexation, with half existing as simple salts and half as stable organic complexes. In water where anaerobic conditions exist, nickel will precipitate out of solution as nickel sulfide in the presence of sulfides.

Nickel is significantly accumulated in some (but not all) aquatic organisms. However, no data have been found that suggest that nickel undergoes any biological transformation process by microorganisms in water.

6.1.3.16 Zinc

In the environment, zinc occurs primarily in the Zn^{2+} oxidation state and has the tendency to strongly sorb to such substrates as hydrous metal oxides, clays, and organic matter. Free Zn^{2+} in the aquatic environment tends to be adsorbed by suspended solids, such as humic and fulvic acids. In this way, zinc's mobilization can be increased.

Zinc has been shown to bioaccumulate in aquatic organisms, where concentrations can be as much as 1,000 times that found in water.

6.1.4 Site Conceptual Models

Waste materials and impacted soil, sediment, surface water, and groundwater are sources for contaminant migration and transport at the sites. The principal mechanisms for transport of constituents from the waste areas are from surface water runoff and erosion resulting in potential leaching and dissolution of constituents from soil, as well as physical transport to the drainage ditches where suspended particulates settle to sediment.

Based on the distribution of potential site-related constituents in site media, other potential but less prominent mechanisms for transport and migration are: (1) infiltrating precipitation and flow through the vadose zone resulting in the leaching of constituents from soil to the groundwater system, followed by groundwater discharge to low-lying marsh areas and Blows Creek, and during high water-table elevations to the upland drainage ditches, (2) infiltration of surface water in upland drainage ditches during low water-table conditions through the vadose zone resulting in the leaching of constituents from sediment to the groundwater system, (3) suspension and dissolution of constituents from sediment to surface water and transport of surface water and sediment to Blows Creek, and (4) in the southeastern portions of Site 4 it is likely that the water table intersects the waste resulting in potential transport of COIs to the groundwater, and during high water-table conditions groundwater may come in contact with the waste at Sites 3, 5, and 6 and discharge to the upland drainage ditches. Because the sites are vegetated and volatile compounds are not prevalent in site media, wind erosion and volatilization to the atmosphere are not pathways of concern at the sites.

6.1.4.1 General Conceptual Model of Groundwater Flow

The general conceptual model of groundwater flow is applicable for all the Sites. The following physical mechanisms control the fate and transport of constituents dissolved in groundwater during migration:

- Advection, the transport of dissolved constituents by the bulk motion of flowing groundwater, is the primary transport mechanism for dissolved constituents along the hydraulic gradient. Advection controls the rate and direction of constituent migration.
- Dispersion, the spreading of dissolved constituents from the path they would be expected to follow during advection, results from the spatial variation in aquifer permeability, fluid mixing, and molecular diffusion. Dispersion primarily controls the concentration of the constituent at any point in the flow system.

Dispersion occurs in moving groundwater because of local variations in flow velocities caused by the variability of the hydraulic conductivity of the porous media. Typically, the degree of dispersion is greater in the direction of water flow than perpendicular to it. The concentrations of the chemicals at the center of the contaminant plume will decrease as dispersion dilutes the contaminant mass. Some contaminants will migrate more rapidly than the center of mass of the concentration and some will migrate more slowly. The center of mass would move at the rate estimated by dividing the groundwater flow velocity by the retardation coefficient of the migrating chemical, as described earlier in this section.

The shallow groundwater system (Columbia Aquifer) occurs in dredge fill and the underlying naturally occurring aquifer deposits. Dredge fill consists of poorly sorted silt

and clay with thin lenses of fine sand. Native deposits of clay, silt, and sand occur directly beneath the dredge fill. Beneath dredge fill deposits and at locations where these deposits are absent, the native deposits closer to the base of the Columbia Aquifer are primarily composed of well-sorted fine to coarse sand. Underlying the surficial aquifer is the Yorktown Confining Unit, a clay unit with interbedded fine sand and silt, that separates the overlying Columbia Aquifer from the sand and silty sand of the underlying Upper Yorktown Aquifer.

Recharge to the groundwater system from precipitation that does not run off toward drainage ditches may be evaporated or transpired into the air, or infiltrate through the soil to the groundwater. Surface water that collects in drainage ditches may also infiltrate to the groundwater system during seasonal low groundwater water-table conditions, and where topography is low-lying during extreme low water-table conditions. Groundwater is expected to discharge to surface water in low-lying marsh areas throughout much of the year, and in upland drainage ditches during extreme high water-table conditions. Shallow groundwater at Site 3 flows towards Sites 4 and 5 before discharging to Blows Creek and wetland marsh areas. Groundwater flow in the Upper Yorktown Aquifer discharges to the Southern Branch of the Elizabeth River.

The infiltrating water moves by gravity downward through the unsaturated soil. Depth to groundwater (Columbia Aquifer) at the sites is expected to range seasonally between 3 and 6 ft bgs. Recharge to the groundwater system underlying the sites also occurs via movement of upgradient groundwater through the area of Sites 3, 4, 5, and 6.

The water table gradient is relatively flat (.006 to 0.01 ft/ft) with groundwater flow from the northeast (Site 3) to the south (Site 4) and southwest (Site 5), toward Blows Creek (Figures 4-12 and 4-13). The average groundwater flow rate for the Columbia Aquifer was calculated to be about 16 ft/day (Section 4.4.2.2).

Horizontal groundwater flow in the Yorktown Aquifer generally flows from the west-northwest to the east-southeast towards, and discharges to, the Southern Branch of the Elizabeth River (Figures 4-16 and 4-17). Based on differences in hydraulic head between the Columbia Aquifer and Upper Yorktown Aquifer indicate vertical groundwater flow potential is downward from the Columbia Aquifer to the Upper Yorktown Aquifer under a very low gradient of approximately 0.17 ft/ft. The rate of vertical seepage across the Yorktown Confining Unit was not estimated.

6.1.5 General Conceptual Model of Surface Water Flow

The general conceptual model of surface water flow is applicable for all the Sites. Surface water flow occurs as overland flow across the waste areas to and in drainage ditches and marshes. The upland drainage ditches are primarily man made and are less than 2 ft in depth. Gradients of the ground surface, upland drainage ditches, and marsh areas are gentle across the sites; typical surface water flow velocities are low with drainage across the sites to the south and east.

Precipitation that does not evaporate, transpire into the air, or infiltrate through the soil to the groundwater will ultimately flow through upland drainage ditches to discharge at Blows Creek and the Elizabeth River. Flow across the southeastern portions of Site 5 is to the phragmites marsh area, and flow across the southwestern portions of Site 4 is to low marsh

areas of Blows Creek. The marsh area at Site 5 is expected to receive groundwater discharge during normal seasonal groundwater-table conditions. The marsh area east of Site 5 is above mean high tide, but could receive tidal influx during extreme storm events.

6.2 COI Migration at Site 3

The source areas for potential transport and migration of site-related constituents at Site 3 consist of ash and burnt/stained soil from waste materials burned at the site and shallow debris consisting of metal, brick, concrete, and glass. Affected soil, surface water, sediment, and groundwater also provide a source for migration of site-related constituents.

6.2.1 Potential Releases from Soil to the Atmosphere

The movement of impacted soil to the atmosphere by constituent volatilization and wind erosion into the air is possible release mechanisms at Site 3.

Volatilization is the primary mechanism for releasing volatile compounds from soil to the atmosphere. Volatile organic compounds were not identified as COIs in soil at Site 3. The metals, pesticides, PCBs, and SVOCs present in site soils have a low ability to volatilize (Table 6-2). Therefore, volatilization is not considered to be a significant part of potential constituent release at the site.

Wind erosion of constituents in soil is considered a potential mechanism for releases of Site 3 COIs from surface soil to the atmosphere. However, the majority of Site 3 is covered with vegetation, which will inhibit wind erosion, and the remainder of the site is graveled/paved. Therefore, the potential for releases from Site 3 soil to the atmosphere is considered low. Soil could be exposed to potential wind erosion in the case of excavation, where vegetation is removed.

It has been noted that dust migrates onto SJCA towards Site 3 from a dirt road offsite along the northern property boundary. The contribution of non-volatile potential contaminants due to wind erosion from offsite sources is possible.

6.2.2 Potential Releases from Soil to Surface Water and Sediment

The releases of COIs in surface soil to surface water and sediment can occur either by wind or surface water runoff erosion. Transport of impacted Site 3 surface soil by wind erosion or surface runoff to the surface water and sediment in the drainage ditches and eventually to Blows Creek and the Southern Branch of the Elizabeth River is restricted because the majority of the site is vegetated. Constituents may be transported by surface runoff either in the dissolved phase or as suspended particulates.

Constituents in the site soil may be transported by surface runoff as suspended particulates to the drainage ditches located to the east and west, which then may settle out into the sediment.

Although the contribution is expected to be minimal, leaching of COIs from subsurface soil laterally through the vadose zone into the upland drainage ditches is also possible.

6.2.2.1 Potential Releases from Soil to Surface Water

This section discusses potential releases from the soils to the surface water for specific chemical groups analyzed at Site 3.

VOCs. Only a few VOCs were detected at low concentrations and infrequently in surface and subsurface soil. Carbon disulfide was the only COI identified in Site 3 surface water. Soil is not likely to be the source of carbon disulfide in surface water because carbon disulfide was not detected in surface soil, was detected infrequently at low levels in subsurface soil, and would be expected to volatilize during flow or seepage to upland drainage ditches.

SVOCs. Although there were a number of SVOCs detected in the surface and subsurface soil, because they adsorb very strongly to the soil there appears to be no impact to surface water by these compounds. Bis(2-ethylhexyl)phthalate was the only SVOC detected in surface water and the detections were at low estimated concentrations in only two samples.

Pesticides/PCBs. Two pesticides (4,4'-DDD and 4,4'-DDE) were identified as COIs in Site 3 surface and subsurface soil and one PCB (aroclor-1254) was identified as a COI in the surface soil. However, pesticides and PCBs do not tend to readily dissolve in water and because they will adsorb very strongly to soil, there appears to be little impact on surface water from these compounds. The frequency of detections and concentrations were low for pesticides in surface water, and PCBs were not detected in surface water samples. Therefore, Site 3 soil does not appear to be a significant source of pesticides/PCBs to surface water.

Inorganics. Sources of metals to surface water from soil are likely to be primarily leaching and erosion of surface soil through surface runoff across the site. Copper, iron, lead, manganese, nickel, and zinc were determined to be COIs in surface water at Site 3. These same metals were also COIs in soil. The highest concentrations of metals in surface water were found north of the perimeter road and the Site 3 waste area in SJS03-SW01. This sample location is not connected to the drainage ditch that runs from the southeast extent of the Site 3 waste area to Site 4 and the sample may reflect a particularly turbid sample or suggest potential contribution of surface water runoff or wind erosion from offsite. It is possible that metals in surface water in the drainage ditches west of and at the southeast extent of Site 3 may migrate south within the drainage ditch and eventually discharge at Blows Creek.

Dioxins. Dioxins are present in Site 3 subsurface soils but were not analyzed for in surface water.

6.2.2.2 Potential Releases from Soil to Sediment

This section discusses potential releases from the soils to the sediment for specific chemical groups analyzed at Site 3.

VOCs and SVOCs. Although VOCs and SVOCs were detected in the surface and subsurface soil, there appears to be no impact to sediment by these compounds in the upland drainage ditches at Site 3. VOCs were infrequently detected at low concentrations in soil and will readily volatilize. No VOCs are considered COIs in Site 3 sediment. SVOCs adsorb strongly to sediment and although were detected in sediment are below background UTLs and therefore not identified as COIs in the upland ditch sediments constructed in Site 3 dredge fill.

Pesticides/PCBs. Two pesticides (4,4'-DDD and 4,4'-DDE) were identified as COIs in Site 3 surface and subsurface soil and one PCB (aroclor-1254) was identified as a COI in the surface soil. The same pesticides (4,4'-DDD and 4,4'-DDE) are identified as COIs in Site 3 sediment. In addition, the PCB aroclor–1260 is identified as a COI in sediment. Surface soil erosion and deposition as sediment in drainage ditches is a possible source of the pesticides found in sediment at Site 3.It is possible that historical application of pesticides at SJCA and surrounding areas contributes to the levels of pesticides found in sediment.

Inorganics. The metals antimony, copper, iron, lead, manganese, nickel, and zinc were identified as COIs in sediment at Site 3. These same metals were also found to be COIs in soil. Surface soil erosion and deposition to sediment in drainage ditches is a possible source of the metals found in sediment at Site 3. It is possible that these constituents may migrate to the south within the drainage ditch to discharge at Blows Creek.

Dioxins. Dioxins are present in Site 3 subsurface soils but were not analyzed for in sediment.

6.2.3 Potential Releases from Sediment to Surface Water and from Surface Water to Sediment

6.2.3.1 Potential Releases from Sediment to Surface Water

Two potential release mechanisms of COIs from sediment to surface water are suspension and dissolution. Suspension and dissolution can occur during a rain event through surface water runoff that flows into the drainage ditches. Dissolution of inorganics from the sediment into the surface water is possible. The inorganic COIs identified in sediment are also identified as COIs in surface water. Therefore, the drainage ditch sediment is a viable pathway for inorganic impacts to the drainage ditch surface water. Site 3 upland drainage ditches remain dry except during rain events and extreme high groundwater water-table conditions, at which time it is possible that these suspended or dissolved constituents in surface water may migrate to the south to discharge at Blows Creek.

Other COIs identified in sediment include the pesticides 4,4'-DDD and 4,4'-DDE and the PCB aroclor-1260. However, these relatively insoluble compounds strongly adsorb to sediment and are not present in surface water.

6.2.3.2 Potential Releases from Surface Water to Sediment

Two potential release mechanisms of COIs from surface water to sediment are settling of suspended particulates and chemical precipitation. Following a rain event, settling of suspended particulates would most likely occur in low-lying areas of ponded water. The potential for suspended particulates to settle out in the drainage ditches as sediment will depend on the amount of rainfall and subsequent surface water flow velocities. Because physical and chemical properties of surface-water (i.e. pH, temperature, salinity) resulting from surface runoff into the drainage ditches are not likely to change significantly, chemical precipitation of COIs from surface water to sediment is not expected to be a significant migration pathway.

There is a potential for the inorganic COIs identified in surface water to be transported as suspended particulates and settle as sediment in the drainage ditches and low-lying ponded

area. The inorganic COIs identified in surface water are the same as those identified in the sediment.

6.2.4 Transport of Constituents from Soil, Sediment, and Surface Water to the Columbia Aquifer

Infiltration of precipitation through the surface soil vadose zone and infiltration of surface water through sediment may dissolve some adsorbed COIs and transport them to the underlying Columbia (water table) Aquifer. Leaching of COIs from soil in low-lying areas and sediment in the upland drainage ditches into the shallow groundwater may occur during low groundwater water table elevations.

Site 3 is not affected by tidal influx from Blows Creek; therefore, the transport of COIs from surface water to the Columbia Aquifer is limited to surface water recharge to groundwater through soil and sediment.

Iron and manganese are the only COIs present in the Columbia Aquifer and also present in soil, sediment, and surface water. Metals other than iron and manganese are identified as COIs in soil, sediment, and surface water but are not identified as COIs in shallow groundwater at Site 3. The dissolution and infiltration of constituents from soil, sediment, and surface water to groundwater is a viable pathway; however, it does not appear to have a significant impact on the Columbia Aquifer at Site 3 based on the fact that many of the other metals elevated in the soil, sediment, and surface water are not elevated in groundwater.

6.2.5 Migration of Constituents in Groundwater

This section describes the potential migration of constituents in both the Columbia Aquifer (water table or shallow) and Upper Yorktown (deep) Aquifer. The water table aquifer occurs in the dredge fill and underlying native aquifer sediments. Thickness of the dredge fill at Site 3 ranges from approximately 5 to 15 ft, and the native deposits vary in thickness from about 7 to 12 ft. Constituents in the groundwater will migrate in the direction of groundwater flow. Horizontal groundwater flow in the Columbia Aquifer is to the west-southwest and south-southeast at Site 3. Water levels from wells penetrating the Upper Yorktown Aquifer indicate mounding of groundwater at SJS03-MW02D, with horizontal groundwater flow flowing south-southwest towards Site 4 and Blows Creek. The vertical direction of groundwater flow is downward from the Columbia Aquifer to the Upper Yorktown Aquifer, allowing potential downward migration of constituents from the Columbia to the Upper Yorktown Aquifer.

The metals iron and manganese were found to be COIs in both the Columbia and Yorktown Aquifers at Site 3. The Columbia Aquifer may be a source of iron and manganese to the Upper Yorktown Aquifer. Iron and manganese concentrations increased in samples at the downgradient southeast extent of Site 3 waste suggesting some transport and migration of COIs from the waste to shallow groundwater. Metals from Site 3 may migrate through groundwater during high groundwater conditions and discharging to the drainage ditches as surface water flow toward Sites 4 and 5/6 and eventually toward Blows Creek and the Southern Branch of the Elizabeth River.

Low concentrations of VOCs, SVOCs, and one pesticide were found in samples from the upgradient well in the Columbia Aquifer at Site 3. No VOCs, SVOCs, pesticides, or PCBs in

the Columbia or Yorktown Aquifers were identified as COIs. Therefore, Site 3 does not appear to be a significant source of VOCs, SVOCs, or pesticides/PCBs to groundwater downgradient of the site.

The rate of horizontal advective flow (v) in the groundwater system underlying the site was estimated, using the equations described in Section 6.1.2.1:

- Columbia Aquifer:

  Horizontal Hydraulic Conductivity (K_h) = Geometric mean ranging from 8.7 to 14.1 ft/day for Site 3

  $\nabla h = 0.008$

  Effective Porosity (n_e) = 0.3

  Horizontal velocity (v) = Range of 0.23 to 0.38 ft/day

- Upper Yorktown Aquifer:

  K_h = Average of 8.9 ft/day

  $\nabla h = 0.0003$

  $n_e = 0.3$

  v = Average of 0.009 ft/day

Due to variability of aquifer properties this is only an approximation of the likely groundwater flow velocity.

Based on the horizontal groundwater flow velocity estimated above (average of 0.31 ft/day) and assuming no retardation of COIs, the shallow groundwater underlying Site 3 would be expected to migrate from the central portion of Site 3 to Blows Creek and the Elizabeth River in approximately 12 and 8 years, respectively. Using the horizontal groundwater flow velocity of 0.009 ft/day estimated for the Upper Yorktown Aquifer and assuming no retardation of COIs, the deep groundwater underlying Site 3 would be expected to migrate from the central portion of Site 3 to Blows Creek in approximately 680 years and the Elizabeth River in approximately 324 years.

6.2.6 Site 3 Summary of Fate and Transport Conclusions

The primary fate and transport mechanisms for COIs that would be expected at Site 3 are:

- Leaching of metals in soil by surface water runoff and erosion to surface water and sediments. Suspension of metals, SVOCs, pesticides, and arcolor-1254 adsorbed to soils in surface water runoff across the site and transport in drainage ditches and deposition to sediment;
- Suspension of metals, SVOCs, pesticides, and arcolor-1254 adsorbed to soils in surface water runoff across the site and transport in drainage ditches and deposition to sediment;
- Dissolution of metals in sediments into surface water;

- Leaching of iron and manganese in soils and sediments and infiltration through the vadose zone to shallow groundwater;
- Discharge of metals in groundwater to surface water; and
- Transport of dissolved metals from the Columbia Aquifer to the Upper Yorktown Aquifer.

6.3 COI Migration at Site 4

The source areas for potential transport and migration of site-related constituents at Site 4 consist of landfill materials, including possible PCB containing waste, disposed of at the site, and impacted soil, surface water, sediment, and groundwater. The depth of waste at Site 4 is unknown, but it likely lies below the water table during normal seasonal fluctuations.

6.3.1 Potential Releases from Soil to the Atmosphere

The movement of impacted soil to the atmosphere by constituent volatilization and wind erosion into the air is possible release mechanisms at Site 4.

Volatilization is the primary mechanism for releasing volatile compounds from soil to the atmosphere. Volatile organic compounds were not identified as COIs in soil at Site 4. The metals, pesticides, PCBs, and SVOCs present in site soils have a low ability to volatilize to air (Table 6-2). Therefore, volatilization is not considered to be a significant potential constituent release at the site.

Wind erosion of constituents in soil is considered a potential mechanism for releases of Site 4 COIs from surface soil to the atmosphere. However, Site 4 is covered with vegetation, which will inhibit wind erosion. Therefore, the potential for releases from Site 4 to the atmosphere is considered low. Soil could be exposed to potential wind erosion in the case of excavation, where vegetation is removed.

6.3.2 Potential Releases from Soil to Surface Water and Sediment

The releases of COIs in surface soil to surface water and sediment can occur either by wind or surface water runoff erosion. Transport of impacted Site 4 surface soil by wind erosion or surface runoff to the surface water and sediment in the drainage ditches, marsh, Blows Creek, and the Southern Branch of the Elizabeth River is restricted because much of the site is vegetated. Constituents may be transported by surface runoff either in the dissolved phase or as suspended particulates.

Constituents in the site soil may be transported by surface runoff as suspended particulates to the drainage ditches, which then may settle out into the sediment.

6.3.2.1 Potential Releases from Soil to Surface Water

This section discusses potential releases from the soils to the surface water for specific chemical groups analyzed at Site 4.

VOCs. Only a few VOCs were infrequently detected at low concentrations in surface and subsurface soil. Carbon disulfide was the only COI identified in Site 4 surface water. Soil is

not likely to be the source of carbon disulfide in surface water because carbon disulfide was not detected in surface or subsurface soil.

SVOCs and Pesticides/PCBs. Although SVOCs and pesticides/PCBs were detected in surface and subsurface soil, is no apparent impact on surface water from these compounds. The relatively insoluble pesticides/PCBs were not detected in surface water and no SVOCs are considered COIs in Site 4 surface water.

Inorganics. Sources of metals to surface water are likely to be primarily leaching and erosion of surface soil. Arsenic, copper, iron, lead, manganese, nickel, and zinc were identified as COIs in surface water at Site 4. Some of these same metals were also observed as COIs in surface and subsurface soil at the site. Total and dissolved inorganic constituents present in surface water may be transported south from Site 4 within the drainage ditch to discharge to Blows Creek and the Southern Branch of the Elizabeth River. Concentrations of metals measured in Blows Creek surface water (SJS04-SW08 and SJS04-SW09) at Site 4 are significantly less than in site drainage ditches, however the transport and migration of constituents in onsite surface water may be a source to Blows Creek.

6.3.2.2 Potential Releases from Soil to Sediment

This section discusses potential releases from the soils to the sediment for specific chemical groups analyzed at Site 4.

VOCs. Although some VOCs were detected infrequently at low concentrations in the surface and subsurface soil, there appears to be no impact to sediment by these compounds. No VOCs were identified as COIs in Site 4 sediment.

SVOCs. The SVOCs exceeding screening criteria and Blows Creek upstream reference concentrations in sediments at Site 4 are present at locations where surface water runoff and impacted surface soil deposition would likely occur. The SVOCs found in sediments are also found in surface soils at Site 4; therefore, the surface soils are a potential source of releases to sediment.

Pesticides/PCBs. Two pesticides (4,4'-DDD and 4,4'-DDE) were identified as COIs in Site 4 surface and subsurface soil and one PCB (aroclor-1260) was identified as a COI in the surface soil. The same pesticides and PCB are identified as COIs in Site 4 sediment. Surface soil erosion and deposition as sediment in drainage ditches is a potential source of the pesticides/PCB found in sediment at Site 4. Pesticides/PCBs in sediment are most highly concentrated along the eastern edge of the site in the drainage ditch. The Site 3 drainage ditch extends to the eastern side of Site 4, and along with the historical application of pesticides at SJCA and surrounding areas may contribute to the levels of pesticides found in Site 4 sediment.

Inorganics. Several metals (arsenic, copper, iron, lead, mercury, nickel, and zinc) were identified as COIs in sediment at Site 4. These same metals were also found to be COIs in the soil. Metals concentrations in sediment are highest along the site's eastern edge. The distribution of metals in sediment indicates that the primary source of metals to sediment is likely erosion and deposition of soil. Transport of metals in sediment from the upland drainage ditch east of Site 3 may also contribute to metals in sediment at Site 4. Sediment

concentrations of inorganics in Blows Creek at sampling locations SJS04-SD08 and SJS04-SD09 suggest that these constituents may have been transported to Blows Creek from Site 4.

6.3.3 Potential Releases from Sediment to Surface Water and from Surface Water to Sediment

6.3.3.1 Potential Releases from Sediment to Surface Water

Two potential release mechanisms of COIs from sediment to surface water are suspension and dissolution. Suspension can occur during a rain event with the surface water runoff that flows into the drainage ditches and by tidal influx from Blows Creek and the Southern Branch of the Elizabeth River. Dissolution of inorganics from suspended or bottom sediment into the surface water is a potential release mechanism. The inorganic COIs identified in sediment are also identified as COIs in surface water. Therefore, the sediment is a viable pathway for inorganic impacts to the surface water. The upland extent of Site 4 drainage ditches remain fairly dry except during rain events, at which time it is possible that these suspended or dissolved constituents in drainage ditch surface water may be transported to the south to discharge at Blows Creek.

Other COIs identified in sediment include SVOCs and pesticides. However, there are only infrequent SVOCs detected at low levels and no detections of the relatively insoluble pesticides in Site 4 surface water.

6.3.3.2 Potential Releases from Surface Water to Sediment

Potential release mechanisms of COIs from surface water to sediment are settling of suspended particulates and chemical precipitation. The potential for suspended particulates to settle out in the drainage ditches as sediment will depend on the amount of rainfall and subsequent surface water flow velocities. The upland extent of Site 4 drainage ditches remain dry except during rain events, at which time there is potential for sediment transport to Blows Creek and the adjacent marsh. The inorganic COIs identified in surface water are the same as those identified in the sediment.

Chemical precipitation of COIs from surface water to sediment is possible in Blows Creek and the marsh area adjacent to Blows Creek but is not expected to be a significant migration pathway.

6.3.4 Transport of Constituents from Soil, Sediment, and Surface Water to Shallow Groundwater

Infiltration of precipitation through the surface soil vadose zone and infiltration of surface water through sediment may dissolve some adsorbed COIs and transport them to the underlying Columbia Aquifer. The depth of waste at Site 4 is unknown, but may lie below the water table in the southeast portions of the site during high seasonal water-table conditions. Leaching of COIs will occurs to a greater extent within the waste where the groundwater table intersects the landfill materials. The southern extent of Site 4 is expected to be affected by tidal influx from Blows Creek and the Southern Branch of the Elizabeth River.

No VOCs, SVOCs, pesticides, or PCBs are considered COIs in groundwater at Site 4, therefore, it is unlikely that Site 4 represents a significant source of VOCs, SVOCs, pesticides, and PCBs to shallow groundwater.

Iron and manganese are the only COIs present in shallow groundwater, soil, sediment, and surface water. Metals other than iron and manganese are identified as COIs in soil, sediment, and surface water but are not identified as COIs in the Columbia Aquifer at Site 4. The migration and transport of constituents from soil, sediment, and surface water is a viable pathway, however, does not appear to have a significant impact on groundwater at Site 4, based on the fact that many of the other metals elevated in the soil, sediment, and surface water are not COIs in groundwater. Elevated concentrations of iron and manganese were observed in Site 3 monitoring wells upgradient of Site 4, therefore Site 3 is also a potential source of the elevated metals concentrations observed in Site 4 groundwater.

6.3.5 Migration of Constituents in Groundwater

The water table aquifer occurs in the landfill materials, dredge fill, and underlying native aquifer sediments. Dredge fill at Site 4 ranges from approximately 5- to 17-ft thick. The native deposits vary in thickness from about 4 to 23 ft at Site 4. Depth to groundwater at Site 4 ranges from approximately 2 to 6 ft across the site. Constituents in the groundwater will migrate in the direction of groundwater flow. Shallow groundwater at Site 4 generally flows to the south-southwest. Groundwater flow in the Upper Yorktown Aquifer is south-southeast towards Blows Creek and the Southern Branch of the Elizabeth River. Blows Creek is located adjacent to the southern boundary of the site and the Southern Branch of the Elizabeth River lies along the eastern site boundary. The vertical direction of groundwater flow is downward between the Columbia and Upper Yorktown Aquifer, allowing potential downward migration of constituents from the Columbia to the Upper Yorktown Aquifer. The rate of vertical advective flow across the Yorktown Confining Unit was not estimated.

Groundwater beneath Site 3 is upgradient of Site 4. Concentrations of iron and manganese elevated in upgradient groundwater at Site 3 will be transported beneath Site 4 and to Blows Creek. Infiltration and recharge through Site 4 soils and sediment are also possible sources of iron and manganese to the Columbia Aquifer at Site 4.

Low concentrations of VOCs, SVOCs, and one pesticide were found in samples from upgradient wells. No VOCs, SVOCs, pesticides, or PCBs in the shallow or deep groundwater were identified as COIs. Therefore, Site 4 does not appear to be a significant source of VOCs, SVOCs, or pesticides/PCBs to groundwater downgradient of the site.

The rate of horizontal advective flow (v) in the groundwater system underlying the site were estimated, using the equations described in Section 6.1.2.1:

- Columbia Aquifer:

  K = Geometric mean ranging from 0.7 to 79 ft/day for Site 4

  $\nabla h = 0.008$

  $n_e = 0.3$

  v = Range of 0.02 to 2.1 ft/day

- Upper Yorktown Formation Aquifer:

  K = Average of 1.6 ft/day

  $\nabla h = 0.0003$

  $n_e = 0.3$

  v = Average of 0.002 ft/day

These values are simply approximations of the likely groundwater flow velocities in the groundwater system at the site due to variability of aquifer properties.

Based on the horizontal groundwater flow velocity range estimated and assuming no retardation of COIs, the shallow groundwater at Site 4 would be expected to migrate from the central portion of Site 4 to Blows Creek and the Elizabeth River in approximately 59 years. Using the horizontal groundwater flow velocity of 0.002 ft/day estimated for the Upper Yorktown Aquifer and absent retardation of COIs, the deep groundwater at Site 4 would be expected to migrate from the central portion of Site 4 to Blows Creek and the Elizabeth River in approximately 250 years. The southern portion of Site 4 is directly adjacent to Blows Creek and the Elizabeth River. The constituents in groundwater in the southern most portion of Site 4 would be expected to migrate to Blows Creek and the Elizabeth River in hours or days.

6.3.6 Site 4 Summary of Fate and Transport Conclusions

The primary fate and transport mechanisms for COIs that would be expected at Site 4 are:

- Dissolution of metals in soil by surface water runoff and erosion and transport to surface water and sediment;
- Suspension of metals, SVOCs, pesticides, and arcolor 1260 adsorbed to soil in surface water runoff across the site and transport to surface water in drainage ditches and deposition to sediment;
- Dissolution of metals in sediments into surface water;
- Leaching of iron and manganese in soils and sediments and infiltration through the vadose zone to shallow groundwater;
- Discharge of metals in groundwater to surface water; and
- Transport of dissolved metals from the Columbia Aquifer to the Upper Yorktown Aquifer.

6.4 COI Migration at Site 5/6

The source areas for potential transport and migration of site-related constituents at Site 5 consist of burned/stained soil and debris wastes including spent ordnance materials and fuses as well as residual waste from burning of various types of refuse and potential fire training at the site, as well as affected soil, surface water, sediment, and groundwater. At Site 6 the waste providing a potential source for transport and migration of site-related constituents consist of the remnants of the caged pit and metals and pesticides in soil.

6.4.1 Potential Releases from Soil to the Atmosphere

The movement of impacted soil to the atmosphere by constituent volatilization and wind erosion into the air are possible release mechanisms at Site 5/6.

Volatilization is the primary mechanism for releasing volatile compounds from soil to the atmosphere. Volatile organic compounds were not identified as COIs in soil at Site 5/6. The metals, pesticides, PCBs, and SVOCs present in site soils have a low ability to volatilize (Table 6-2). Therefore, volatilization is not considered to be a significant part of potential constituent release at the site.

Wind erosion of constituents in soil is a potential mechanism for releases of Site 5/6 COIs from surface soil to the atmosphere. However, the majority of Site 5/6 is covered with vegetation, which will inhibit wind erosion. The remainder of the site is graveled/paved. Therefore, the potential for releases from Site 5/6 to the atmosphere is considered low. Soil could be exposed to potential wind erosion in the case of excavation, where vegetation is removed.

6.4.2 Potential Releases from Soil to Surface Water and Sediment

Transport of COIs in surface soil at the site to the drainage swales, marsh, and eventually to Blows Creek is moderately restricted because much of the site is vegetated or covered with gravel. The COIs in soil can be transported by wind erosion and by surface water flow erosion. Precipitation runoff is a potential source of COIs to sediment. Constituents in the site soil may be transported by surface runoff as suspended particulates or in the dissolved phase to the drainage swales, marsh, and Blows Creek where they may settle out into the sediment.

The area east of Site 5 is a phragmites marsh, and although no major drainage ditches have been identified in the marsh, the area discharges to Blows Creek. This marsh area is above mean high tide but may contribute to the surface water and sediment COIs to Blows Creek during high water or storm events.

Although the contribution is expected to be minimal, leaching of COIs from subsurface soil laterally through the vadose zone into the marsh and drainage swales is also possible.

6.4.2.1 Potential Releases from Soil to Surface Water

This section discusses potential releases from the soils to the surface water for specific chemical groups analyzed at Site 5/6.

VOCs. Only a few VOCs were detected at low concentrations and infrequently in surface and subsurface soil. Carbon disulfide was the only COI identified in Site 5/6 surface water. Soil is not likely to be the source of carbon disulfide in surface water because carbon disulfide was not detected in surface soil and detected infrequently at low concentrations in subsurface soil.

SVOCs and Pesticides/PCBs. No SVOCs, pesticides, or PCBs are considered COIs in surface water at Site 5/6. The infrequent detections and low concentrations of SVOCs and pesticides/PCBs observed in surface water as well as other media combined with the

relative insolubility of these compounds indicate that no significant SVOCs or pesticide/ PCB sources to surface water exists at Site 5/6.

Inorganics. Sources of metals to surface water are primarily leaching and erosion of surface soil. Iron, lead, manganese, nickel, and zinc were determined to be COIs in surface water at Site 5/6. These same metals were also found to be COIs in soil. Significantly elevated metals observed in surface water at location SJS05-SW05 may be a result of metals being leached or eroded and transported to the marshy drainage east of the site. Surface water COIs, mainly metals, attributed to Site 5/6 may migrate further south within the drainage to discharge at Blows Creek.

6.4.2.2 Potential Releases from Soil to Sediment

This section discusses potential releases from the soils to the sediment for specific chemical groups analyzed at Site 5/6.

VOCs. VOCs were detected infrequently at low concentrations in the surface and subsurface soil, however, volatilization would likely occur during transport. There appears to be no impact to sediment by these compounds. No VOCs are considered COIs in Site 5/6 sediment.

SVOCs. SVOCs in sediments at Site 5/6 have been identified as COIs because they exceed ecological screening criteria, however concentrations are below maximum Blows Creek reference samples. SVOCs in surface and subsurface soil at Site 5 are below dredge fill background UTLs and not identified as COIs. The occurrence of SVOCs in sediment may be due to surface soil erosion and subsequent deposition east of the site. Site 5/6 soils are a potential source of SVOCs in sediment.

Pesticides. Pesticides (4,4'-DDD, 4,4'-DDT, and 4,4'-DDE) detected in sediment at Site 5/6 are considered COIs. Erosion and transport of Site 5/6 surface soil is a potential source of the pesticides in Site 5/6 sediment. Concentrations of pesticides observed in Site 5/6 sediment are above ecological screening criteria but are below maximum Blows Creek reference samples. Site 5/6 soils are a potential source of pesticides to sediment. Historical application of pesticides at SJCA and surrounding areas may also contribute to the levels of pesticides found in sediment.

PCBs. Aroclor-1260 was detected in two surface soil samples below screening criteria at Site 5/6. PCBs were not detected in sediment and there appears to be no impact to site sediments by these compounds.

Inorganics. The metals chromium, copper, iron, mercury, and lead are considered COIs in Site 5/6 sediment. Metals concentrations in sediment were highest in the northern portion of Site 5/6. The distribution of metals in sediment indicates that a potential source of metals to sediment at Site 5/6 is erosion and deposition of site surface soil. It is likely that exposed surface soils near surface water swales and drainage ditches will be eroded as overland flow occurs and the entrained materials are carried to and deposited in the swales and ditches.

6.4.3 Potential Releases from Sediment to Surface Water and from Surface Water to Sediment

6.4.3.1 Potential Releases from Sediment to Surface Water

Potential release mechanisms of COIs from sediment to surface water are suspension and dissolution. Suspension can occur during a rain event with surface water runoff into the drainage swales. Dissolution of inorganics from the sediment into the surface water is possible. The inorganics iron and lead were identified in both surface water and sediment as COIs in the marsh area east of the site. Therefore, the marsh sediment is a viable pathway for inorganic impacts to surface water. No ditches feeding or draining the marsh area at Site 5/6 have been identified, but during storm events it is possible that suspended sediment in surface water may discharge at Blows Creek.

Other COIs identified in sediment include pesticides and SVOCs. However, these relatively insoluble compounds are not present in surface water.

6.4.3.2 Potential Releases from Surface Water to Sediment

Potential release mechanisms of COIs from surface water to sediment are settling of suspended particulates and chemical precipitation. Following a rain event, settling of suspended particulates would most likely occur in low-lying areas such as the marsh. The inorganic COIs identified in both surface water and sediment are iron and lead. The potential for suspended particulates to settle out as sediment will depend on the amount of rainfall and subsequent surface water flow velocities. Physical and chemical properties of surface water (i.e., temperature, salinity, and pH) resulting from surface runoff into the drainage swales are not likely to change significantly. Vegetation and low flow velocities in the marsh area may alter the physical and chemical properties of surface water to affect chemical precipitation of COIs from surface water to sediment. Chemical precipitation is not expected to be a significant migration pathway. During storm events it is possible that dissolved COIs and suspended sediment in surface water may discharge to Blows Creek.

6.4.4 Transport of Constituents from Soil, Sediment, and Surface Water to the Columbia Aquifer

Infiltration of precipitation through the surface soil vadose zone and infiltration of surface water through sediment may dissolve some adsorbed COIs and transport them to the underlying shallow groundwater.

Iron manganese, beryllium, cadmium, and lead are COIs in shallow groundwater, soil, sediment, and surface water. Concentrations of these metals in surface and subsurface soil were generally elevated within the waste and east and southeast of Site 5 upgradient of the elevated concentrations in groundwater. Leaching of the site surface soil and subsurface soil is a potential source of metals to shallow groundwater. There is potential for surface water migration to groundwater in the marsh area when water table elevations are extremely low.

6.4.5 Migration of Constituents in Groundwater

The water table aquifer occurs in the waste materials, dredge fill, and underlying native aquifer sediments. The fill thickness at Site 5/6 ranges from approximately 0 to 7 ft. The

native deposits vary in thickness from about 9 to 22 ft at Site 5/6. The depth to groundwater is expected to range between 2 to 6 feet bgs across the site. Constituents in the groundwater will migrate in the direction of groundwater flow. The water table at the site is relatively flat and slopes to the south and southwest from the site towards Blows Creek. In the Upper Yorktown Aquifer, groundwater is transported to the south and southwest toward Blows Creek.

The rate of vertical advective flow across the Yorktown Confining Unit was not estimated. The vertical direction of groundwater flow is downward between the Columbia and Upper Yorktown Aquifer, indicating there is a possibility of downward migration of constituents from the Columbia to the Upper Yorktown Aquifer. The greatest downward gradient measured for Site 5/6 is 0.07 ft/ft.

Columbia Aquifer groundwater discharges into marsh area east of the Site 5/6 during periods of very high groundwater elevations, and also into Blows Creek. Groundwater flow in the Upper Yorktown Aquifer discharges into Blows Creek.

The rates of horizontal advective flow (v) in the groundwater system underlying the site were estimated, using the equations described in Section 6.1.2.1:

- Columbia Aquifer:

  K_h = Geometric mean ranging from 5.7 to 15.1 ft/day for Site 5

  $\nabla h = 0.008$

  $n_e = 0.3$

  v = Range of 0.15 to 0.40 ft/day

- Upper Yorktown Aquifer:

  K_h = Average of 39.2 ft/day

  $\nabla h = 0.0003$

  $n_e = 0.3$

  v = Average of 0.04 ft/day

These values are approximations of the likely groundwater flow velocities in the groundwater system at the site due to variability of aquifer properties.

Based on the horizontal groundwater flow velocity estimated above (average of 0.28 ft/day) and assuming no retardation of COIs, the shallow groundwater COIs at Site 5/6 could migrate to Blows Creek from the southern portion of the site in approximately 3.5 years. Using the groundwater flow velocity of 0.04 ft/day estimated for the Upper Yorktown Aquifer and assuming no retardation of COIs, deep groundwater COIs at Site 5/6 could migrate to Blows Creek from the southern portion of the site in approximately 29 years. The horizontal direction of groundwater flow in the Columbia Aquifer is to the south. The horizontal direction of groundwater flow in the Upper Yorktown Aquifer is to the southwest.

No VOCs, SVOCs, pesticides, or PCBs were identified as COIs in the Columbia or Upper Yorktown Aquifers at Site 5/6. VOCs were infrequently detected at low concentrations.

SVOCs, pesticides, and PCBs adsorb strongly to soil and sediment and have not impacted shallow or deep groundwater. The explosive RDX is considered a COI in Site 5/6 deep groundwater, although the transport mechanism may have been from well installation through the waste.

Concentrations of iron and manganese were elevated in Site 5 shallow wells and concentrations of these metals in the deep wells downgradient of Site 5 increased relative to upgradient groundwater towards Site 3.

Shallow groundwater may be a source of iron and manganese to the deep aquifer due to the downward gradient observed at the site.

6.4.6 Site 5/6 Summary of Fate and Transport Conclusions

The primary fate and transport mechanisms for COIs that would be expected at Site 5 are:

- Dissolution of metals in soil by surface water runoff and erosion and transport to surface water and sediment;
- Suspension of metals, SVOCs, pesticides, and explosives adsorbed to soil in surface water runoff across the site and transport to surface water in drainage swales and deposition to sediment;
- Dissolution of metals in sediments into surface water;
- Leaching of iron and manganese in soils and sediments and infiltration through the vadose zone to shallow groundwater;
- Discharge of metals in groundwater to surface water; and
- Transport of dissolved metals from the Columbia Aquifer to the Upper Yorktown Aquifer.

SECTION 7

Baseline Human Health Risk Assessment

7.1 Introduction

This section presents the results of an assessment of potential human health risks associated with the presence of site-related contaminants at Site 3 (Waste Disposal Area), Site 4 (Landfill D), and Sites 5 (Burning Grounds) and 6 (Caged Pit) combined, at the SJCA of the Norfolk Naval Base, in Chesapeake, Virginia. Data for Site 6 are included with those for Site 5 and these sites are noted herein as Site 5/6 because Site 6 is immediately adjacent to Site 5 and much of the site characterization data were collected together. Analytical results from surface soil, soil (surface and subsurface soil combined), sediment, surface water, and groundwater were used to examine the potential human health risks from exposure to these media for each of these sites. This baseline risk assessment was conducted to assess the potential human health impacts from the sites under current conditions, as well as to determine if further actions are needed at the sites to be sufficiently protective of human health. This risk assessment has been prepared using conservative assumptions, and feasible exposure pathways based on current site conditions and current and potential future site use were evaluated. The risk assessment incorporates the general methodology described in *Risk Assessment Guidance for Superfund (RAGS), Volume 1, Human Health Evaluation Manual, Part A* (USEPA, 1989), *Risk Assessment Guidance for Superfund (RAGS), Volume 1, Human Health Evaluation Manual, Part D* (USEPA, 1997a), USEPA Region III Technical Guidance Manuals for Risk Assessment, and the *St. Juliens Creek Annex Technical Approach Memorandum for Human Health Risk Assessment* (Technical Approach Memorandum) dated April 12, 2000 (CDM Federal, 2000) which was provided to the regulatory agencies for their review and concurrence prior to preparation of this HHRA. The Technical Approach Memorandum outlines the assumptions that were made for this risk assessment.

The results of the baseline HHRA will be used to document the potential for endangerment to human health, to assist in identifying the exposure media that may need to be addressed through remedial action, and to provide a basis to select action levels.

7.1.1 Overview

Site 3 (Waste Disposal Area) covers approximately 2 acres along the northern edge of the St. Juliens Creek Annex and is accessible by Patrol Road. The area was originally a mudflat where refuse was allowed to burn; the ash was then used to fill the area. Refuse disposed of at Site 3 included solvents, acids, bases, and mixed municipal waste. The total volume of solvent, waste oil, and oily sludge disposed was estimated to be 27,778 cubic yards prior to burning. Two pits reportedly used for disposal of oils and oily sludges, as well as for periodic burning, were located at Site 3. Currently, the area is grass-covered with no visible signs of debris or refuse. A communications and/or radar facility is located in the northeastern area of the Site. The downgradient direction of Site 3 appears to be toward Site 4 and Blow's Creek.

Site 4 (Landfill D) is about 12.5 acres (previously reported as 5 acres) and is approximately 300 feet south of Site 3. Site 4 is characterized by raised surface features and areas that lack vegetation. A brush line borders the northern edge of the landfill with brush also extending beyond the western and southern edges. Metal and concrete piles are dispersed throughout the site. While in operation, Site 4 was an unlined trench and fill landfill. The first trench was approximately 1,000 feet long and was located parallel to and 500 feet north of Blows Creek. Soil from subsequent trenches was used to cover previous trenches. The total number of trenches dug in the landfill is not known. Refuse disposed of at Site 4 included PCBs and drums of unknown wastes. Previous investigatory reports have indicated that several tanks with undetermined wastes were also once located in the area. The total volume of material disposed of at Site 4 is unknown.

Site 5 (Burning Grounds) is approximately 3 acres located off of Craddock Street in the northern part of the facility. The site currently consists of an open field with areas overgrown with high reeds. A significant part of the area is covered with a thick (18-in.) layer of gravel. Wastes disposed of at the Burning Grounds included ordnance materials such as black powder, smokeless powder, explosive D, Composition A-3, tetryl, TNT, and fuses. Non-ordnance materials included carbon tetrachloride, TCE, paint sludges, pesticides, and various types of refuse. In 1977, the surface was burned with straw, diced, and burned again, in an effort to decontaminate the soil.

Site 6 (Caged Pit) is approximately located 150 feet directly east of Site 5. The Caged Pit was used as a pit to burn small arms including igniters and fuzes. No surface evidence of the pit remains.

7.1.2 Scope of Risk Assessment

The HHRA is comprised of the following components:

- **Identification of COPCs**—identifies and characterizes the distribution of COPCs found onsite. Chemicals identified as COPCs are the focus of the subsequent evaluation in the risk assessment.
- **Exposure Assessment**—identifies potential pathways by which exposure could occur, characterizes the potentially exposed populations (e.g., residents, construction workers, other workers, and trespassers) and estimates the magnitude, frequency, and duration of exposures.
- **Toxicity Assessment**—identifies the types of adverse health effects associated with exposure to the COPCs, lists available toxicity factors (e.g., cancer slope factors [CSFs] and reference dose values), and summarizes the relationship between magnitude of exposure and occurrence of adverse health effects.
- **Risk Characterization**—integrates the results of the exposure assessment and toxicity assessment to estimate the potential risks to human health. Both cancer and noncancer human health effects are evaluated. Pathways that pose a risk greater than USEPA target risk levels based on quantitative risk characterization are identified.
- **Uncertainty Assessment**—identifies sources of uncertainty associated with the data, methodology, and the values used in the risk assessment estimation.

These components are described briefly in the following sections. Spreadsheets prepared in accordance with USEPA's *RAGS, Volume 1, Human Health Evaluation Manual, Part D* were used to screen for COPCs, and to calculate estimated exposures and health risks associated with the COPCs. These spreadsheets (Standard Tables 1 through 10) are presented in Appendix J for Site 3, Appendix K for Site 4, and Appendix L for Site 5/6.

7.2 Identification of Chemicals of Potential Concern

The identification of COPCs includes data collection, data evaluation, and data screening steps. The data used for the quantitative risk analysis were all validated and found to meet data quality objectives prior to use in the risk assessment. The data collection and evaluation steps involve gathering and reviewing the available site data and identifying a set of data of acceptable quality for the risk assessment. This data set is then screened against concentrations that are protective of human health to reduce the data set to those chemicals and media of potential concern.

Section 7.2.1 discusses the selection of data used for the quantitative risk assessment. The data were selected from the set of validated data determined usable for risk assessment. Section 7.2.2 discusses the methodology used to reduce the risk assessment data set to the constituents and media of primary concern to human health. Section 7.2.3 identifies the COPCs that were quantitatively assessed in the risk assessment.

7.2.1 Data Evaluation and Selection

The available data set consists of data collected during RI Phases I and II. Surface soil, subsurface soil, sediment, and shallow and deep groundwater data were collected during the Phase I RI in 1997 and the Phase II RI follow-up sampling conducted in 1999. Surface water data were collected for Site 4 during the Phase I RI and for Sites 3, 4, and 5/6 during the Phase II RI follow-up sampling. Subsurface soil samples were collected at Sites 3 and 5/6 in June 2001 for dioxin analyses. Data collected during both phases of the RI and in June 2001 associated with Sites 3, 4, and 5/6 were combined and evaluated quantitatively in the risk assessment.

The environmental sampling and analysis conducted for the RI at Sites 3, 4, and 5/6 was designed to cover the range of potential site contaminants associated with historical site activities. Detailed results of the sampling program for Sites 3, 4, and 5/6 are presented in Section 5 of this report. A summary of the data used in the risk assessment is presented in this section. Tables 7-1, 7-2, and 7-3 summarize the samples that were used to estimate potential exposures and risks in each medium for Sites 3, 4, and 5/6, respectively.

Several surface and subsurface soil samples were excluded for use in the human health risk evaluation based on their locations in relation to respective sites such that runoff from the site does not affect these sample locations. For Site 4, the following co-located surface and subsurface samples were excluded because they were collected north of the site and, hence, were converted to background samples: SS19 (renamed SJSBK-SS48) and SB48, SS20 (renamed SJSBK-SS49) and SB49, SS21 (renamed SJSBK-SS47) and SB47, and SS22 (renamed SJSBK-SS50) and SB50. For Site 5, collocated surface and subsurface samples SS13 and SB19, and SS15 and SB21 were excluded. Surface samples SS17 and SS22 and subsurface soil samples SB9 through SB15 were also excluded. The locations of these samples are across the

drainage ditch to the east of Site 5 and not affected by surface runoff from the site. In the area of the Drop Tower, samples SS25, SS26, SS27, and SS28 were excluded because they were collected to the southeast of and across a drainage ditch from Site 5 and not influenced by surface runoff.

Available data were reviewed and used, as follows, to determine their reliability for the quantitative risk assessment.

- Estimated values, flagged with a J, K, or L qualifier, were treated as unqualified detected concentrations.
- Data qualified with an R (rejected) were not used in the risk assessment.
- Data qualified with a B (blank contamination) were used in the risk assessment as if they were non-detects, with the blank-related concentration of each constituent used as the sample quantitation limit (SQL). One-half of the blank-related concentration was used to calculate EPCs in the risk assessment.
- One-half of the SQL was used in the risk assessment for cases where no detectable contaminant concentrations were found in a sample, but the contaminant was detected in that medium at the site.
- For duplicate samples, the higher of the two concentrations was used as the sample concentration. In calculating the frequency of detection and the 95-percent upper confidence limit (UCL), the duplicate samples were counted as a single sample.

7.2.2 Data Summary

All samples collected during Phases I and II from shallow and deep groundwater, surface and subsurface soil, surface water, and sediment at Sites 3, 4, and 5/6 were analyzed for TCL organic constituents (including VOCs, SVOCs, pesticides, and PCBs), TAL inorganic constituents (including metals and cyanide), and phosphorous. During Phase I, selected samples collected from surface soil, subsurface soil, and groundwater at Site 5/6 were analyzed for explosives. During Phase II, selected samples from Site 5/6 were analyzed for explosives since this site has a history of potentially explosive material disposal. Subsurface soil samples were collected at Sites 3 and 5/6 in June 2001 for dioxin analyses.

All of the data used in the risk assessment were validated following USEPA Region III Modifications to the USEPA *National Functional Guidelines*. For each medium, chemical-specific summary statistics are presented for the data set used for risk calculations, including frequency of detection, minimum and maximum detected values, normal and lognormal arithmetic mean, results of the Shapiro-Wilk W-test or the D'Agostino test, and 95-percent UCLs for normal and lognormal distributions. These tables are presented in Appendixes J K, and L, for Sites 3, 4, and 5/6, respectively. Methods for calculating EPCs, arithmetic means, and the 95-percent UCL values for the detected chemicals are discussed in Section 7.3.3.

Background data were collected for soil and groundwater at St. Juliens Creek, and are presented in the RAGS Part D Tables 2's included in Appendixes J, K, and L. A comparison to background data was not used to select the COPCs, but is discussed in the uncertainty section, Section 7.6.1.

7.2.2.1 Site 3

Surface Soil. Surface soil samples collected from 18 locations at Site 3 using a stainless-steel spoon and bowl following protocols described in Section 2 were evaluated in the risk assessment. Seven surface soil samples were collected during Phase I (SJS03-SS01 though SJS03-SS07) and 11 surface soil samples were collected during Phase II (SJS03-SS08 through SJS03-SS18). The surface soil samples were analyzed for TCL VOCs, SVOCs, pesticides/ PCBs, TAL inorganics, and phosphorus. Table 7-1 summarizes the surface soil samples included in the Site 3 HHRA data set and the corresponding analysis.

Surface soil sampling locations are shown on Figure 3-4. Discussions of the nature and extent of COPCs in surface soil can be found in Section 5. Appendix J presents the analytical results for the surface soil data used in the risk assessment.

Groundwater. Shallow and deep monitoring wells have been installed at Site 3. Shallow monitoring wells were designed to sample the upper most saturated zone, while the deep monitoring wells were designed to sample groundwater in the Yorktown Aquifer. At two locations (SJS03-GW01 and SJS03-GW02), deep monitoring wells were paired with shallow wells in order to provide an indication of the vertical profile of groundwater quality and an indication of the vertical groundwater flow direction. All wells installed during Phase I of the RI (deep monitoring wells SJS03-GW01D and SJS03-GW02D; shallow monitoring wells SJS03-GW01S, SJS03-GW02S, SJS03-GW03S, and SJS03-GW04S) were sampled twice (once in July 1997 and again in November 1997). In addition, all existing monitoring wells from Phase I field activities and all wells installed during the Phase II field activities (shallow monitoring wells SJS03-GW05S and SJS03-GW06S) were sampled in June 1999. The wells were sampled using a decontaminated submersible pump and clean tubing. The groundwater samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics (filtered and unfiltered) and phosphorus. During Phase II, low concentration VOC analysis was conducted on groundwater. Table 7-1 summarizes each sample and the corresponding analysis.

The shallow and deep aquifers are evaluated independently in the risk assessment.

In accordance with the USEPA Region III *Draft Guidance on the Selection of Analytical Metal Results from Monitoring Well Samples for Use in the Quantitative Assessment of Risk* (USEPA 1992a), unfiltered groundwater samples were used to determine inorganic constituent exposure concentrations. This was because a review of the groundwater data determined that the results from the filtered samples were similar to those from the unfiltered groundwater samples.

Groundwater sampling locations are shown on Figure 3-12. Discussions of the nature and extent of COPCs in groundwater can be found in Section 5. Appendix J presents the analytical results for the groundwater data that were used in this risk assessment.

Surface Water. Due to dry conditions, no surface water samples were collected during Phase I of the RI. During Phase II, seven surface water samples were collected. Samples SJS03-SW01 through SJS03-SW04 and SJS03-SW06 through SJS03-SW08 were collected. Surface water samples were collected directly into a sample jar. The surface water samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus. Table 7-1 lists the surface water samples collected at Site 3 and the corresponding analysis.

Surface water sampling locations are shown on Figure 3-15. Discussions of the nature and extent of COPCs detected in surface water are presented in Section 5. Appendix J presents the analytical results for the surface water data used in the risk assessment.

Sediment. During Phase I, sediment samples were collected with stainless-steel bowls and spoons. During Phase II, where there was more than 6 in. of standing water, samples were collected with a stainless-steel petite (mini) ponar dredge or equivalent. Four sediment samples (SJS03-SD01 through SJS03-SD03 and SJS03-SD06) were collected during Phase I. Three sediment samples (SJS03-SD04, SJS03-SD07, and SJS03-SD08) were collected during Phase II. The sediment samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus. Table 7-1 lists each sample and the corresponding analysis.

Sediment sampling locations are shown on Figure 3-15. Discussions of the nature and extent of COPCs detected in sediment are presented in Section 5. Appendix J presents the analytical results for the sediment data used in the risk assessment.

Subsurface Soil. DPT was used to collect most of the subsurface soil samples during RI Phases I and II. This method involves the use of a truck-mounted rig. However, some of the proposed Phase II sampling locations included areas of heavy brush, others that were potentially wet, or where surface soils were saturated. In order to avoid the unnecessary destruction of wetlands, or time-consuming brush clearance operations, a stainless-steel hand auger was used to collect subsurface soil samples in these areas. The truck-mounted DPT rig was used at all other locations.

A total of 23 subsurface soil samples collected from Site 3 were included in the HHRA data set. Seven subsurface soil samples (SJS03-SB01 through SJS03-SB07) were collected during Phase I and 16 subsurface soil samples (SJS03-SB08 through SJS03-SB20, SJS03-SB21, SJS03-SB23, and SJS03-SB26) were collected during Phase II. The subsurface soil samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, dioxins, and phosphorus. Table 7-1 summarizes the subsurface soil samples included in the Site 3 data set and the corresponding analysis.

Subsurface soil sampling locations are shown on Figure 3-7. Discussions of the nature and extent of COPCs detected in subsurface soils are presented in Section 5. Appendix J presents the analytical results for the subsurface soil data used in the risk assessment.

7.2.2.2 Site 4

Surface Soil. Surface soil samples were collected from 18 locations using a stainless-steel spoon and bowl following protocols described in Section 2. Ten surface soil samples were collected during Phase I (SJS04-SS01 though SJS04-SS10) and eight surface soil samples were collected during Phase II (SJS04-SS011 through SJS04-SS18). Samples SJS04-SS19 through SJS04-SS22, which were hydraulic dredge spoil samples, were not evaluated in the risk assessment. The surface soil samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus. Table 7-2 lists each sample and the corresponding analysis.

Surface soil sampling locations are shown on Figure 3-5. Discussions of the nature and extent of the surface soil COPCs for Site 4 can be found in Section 5. Appendix K presents the analytical results for the surface soil data used in the risk assessment.

Groundwater. Shallow and deep monitoring wells have been installed at Site 4. Shallow monitoring wells were designed to sample the uppermost saturated zone, while the deep monitoring wells were designed to sample groundwater in the Yorktown Aquifer. At two locations (SJS04-GW01 and SJS04-GW03), deep monitoring wells were paired with shallow wells in order to provide an indication of the vertical profile of groundwater quality and an indication of the vertical groundwater flow direction. All Site 4 monitoring wells were installed during Phase I of the RI (deep monitoring wells SJS04-GW01D and SJS04-GW03D; shallow monitoring wells SJS04-GW01S through SJS04-GW04S). All wells were sampled twice during the Phase I RI (once in July 1997 and again in November 1997) and once during the Phase II RI in June 1999. The wells were sampled using a decontaminated submersible pump and clean tubing. The groundwater samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics (filtered and unfiltered) and phosphorus. During Phase II, low concentration VOC analysis was conducted on the groundwater samples. Table 7-2 lists each groundwater sample and the corresponding analysis.

The shallow and deep aquifers are evaluated independently in the risk assessment.

In accordance with the USEPA Region III *Draft Guidance on the Selection of Analytical Metal Results from Monitoring Well Samples for Use in the Quantitative Assessment of Risk* (USEPA 1992a), unfiltered groundwater samples were used to determine inorganic constituent exposure concentrations because a review of the groundwater data determined that the results from the filtered samples were similar to those from the unfiltered groundwater samples.

Groundwater sampling locations are shown on Figure 3-13. Discussions of the nature and extent of the COPCs in Site 4 groundwater can be found in Section 5. Appendix K presents the analytical results for the groundwater data that were used in this risk assessment.

Surface Water. One surface water sample (SJS04-SW04) was collected during the Phase I RI. During Phase II, seven surface water samples (SJS04-SW01 through SJS04-SW03 and SJS04-SW06 through SJS04-SW09) were collected. Surface water samples were collected directly into a sample jar. The surface water samples were analyzed for TCL VOCs, SVOCs, pesticides//PCBs, TAL inorganics, and phosphorus. Table 7-2 summarizes each sample and the corresponding analysis.

Surface water sampling locations are shown on Figure 3-16. Discussions of the nature and extent of COPCs detected in surface water are presented in Section 5. Appendix K presents the analytical results for the surface water data used in the risk assessment.

Sediment. During Phase I, sediment samples were collected with stainless-steel bowls and spoons. During Phase II, where there was 6 in. of standing water, samples were collected with a stainless-steel petite (mini) ponar dredge or equivalent. Four sediment samples (SJS04-SD01 through SJS04-SD04) were collected during Phase I. Five sediment samples (SJS04-SD05 through SJS04-SD09) were collected during Phase II. The sediment samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus.

Table 7-2 summarizes the sediment samples collected at Site 4 and the corresponding analysis.

Sediment sampling locations are shown on Figure 3-16. Discussions of the nature and extent of COPCs detected in sediment are presented in Section 5. Appendix K presents the analytical results for the sediment data used in the risk assessment.

Subsurface Soil. DPT was used to collect most of the subsurface soil samples during RI Phases I and II. However, some proposed sampling locations for Phase II included areas of heavy brush , others potentially wet, or where surface soils were saturated. In order to avoid the unnecessary destruction of wetlands, or time-consuming brush clearance, a stainless-steel hand auger was used to collect subsurface soil samples in these areas. The truck-mounted DPT rig was used at all other locations.

A total of eight subsurface soil samples were collected from Site 4. Three subsurface soil samples (SJS04-SB01 through SJS04-SB03) were collected during Phase I and five subsurface soil samples (SJS04-SB04 through SJS04-SB08) were collected during Phase II. The subsurface soil samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus. Table 7-2 summarizes the subsurface soil samples collected at Site 4 and the corresponding analysis.

Subsurface soil sampling locations are shown on Figure 3-8. Discussions of the nature and extent of COPCs detected in subsurface soils are presented in Section 5. Appendix K presents the analytical results for the subsurface soil data used in the risk assessment.

7.2.2.3 Sites 5 and 6

Surface Soil. Surface soil samples collected from 27 locations using a stainless-steel spoon and bowl following protocols described in Section 2 were evaluated in the risk assessment. Nine surface soil samples were collected during Phase I (SJS05-SS01 though SJS05-SS09) and 18 surface soil samples were collected during Phase II (SJS05-SS10 through SJS05-SS12, SJS05-SS14, SJS05-SS16, SJS05-SS18 through SJS05-SS21, SJS05-SS23, SJS05-SS24, and SJS05-SS29 through SJS05-SS35). The surface soil samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus. During Phase I, two samples were selected, using field-screening techniques for TNT, for nitramine analysis by an offsite laboratory. During Phase II, the surface soil samples were also analyzed for explosives since this site has a history of potentially explosive material disposal. Table 7-3 summarizes the surface soil samples included in the Site 5/6 risk assessment data set and the corresponding analysis.

Surface soil sampling locations are shown on Figure 3-6. Discussions of the nature and extent of COPCs in surface soil can be found in Section 5. Appendix L presents the analytical results for the surface soil data used in the risk assessment.

Groundwater. Shallow and deep monitoring wells have been installed at Site 5/6. Shallow monitoring wells were designed to sample the upper most saturated zone, while the deep monitoring wells were designed to sample groundwater in the Yorktown Aquifer. At three locations (SJS05-GW01, SJS05-GW02, and SJS05-GW04), deep monitoring wells were paired with shallow wells in order to provide an indication of the vertical profile of groundwater quality and an indication of the vertical groundwater flow direction. All wells installed

during Phase I of the RI (deep monitoring wells SJS05-GW01D and SJS05-GW02D; shallow monitoring wells SJS05-GW01S, SJS05-GW02S, and SJS05-GW03S) were sampled twice (in July 1997 and again in November 1997). In addition, all existing monitoring wells from Phase I and all wells installed during the Phase II field activities (deep monitoring well SJS05-GW04D; shallow monitoring wells SJS05-GW04S and SJS05-GW05S) were sampled in June 1999. The wells were sampled using a decontaminated submersible pump and clean tubing. The groundwater samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics (filtered and unfiltered) and phosphorus. During Phase I, one sample was selected, based on the results of field screening, and analyzed by an offsite laboratory for nitramine. During Phase II, low concentration VOC analysis was conducted on the groundwater samples. Phase II groundwater samples were also analyzed for explosives since this site has a history of potentially explosive material disposal. Table 7-3 summarizes the groundwater samples collected at Site 5/6 and the corresponding analysis.

The shallow and deep aquifers are evaluated independently in the risk assessment.

In accordance with the USEPA Region III *Draft Guidance on the Selection of Analytical Metal Results from Monitoring Well Samples for Use in the Quantitative Assessment of Risk* (USEPA 1992a), unfiltered groundwater samples were used to determine inorganic constituent exposure concentrations because a review of the groundwater data determined that the results from the filtered samples were similar to those from the unfiltered groundwater samples.

Groundwater sampling locations are shown on Figure 3-14. Discussions of the nature and extent of COPCs in groundwater can be found in Section 5. Appendix L presents the analytical results for the groundwater data that were used in this risk assessment.

Surface Water. Due to dry conditions, surface water samples were not collected during Phase I of the RI. During Phase II, seven surface water samples were collected. Samples SJS05-SW01 through SJS05-SW07were collected at Site 5/6. Surface water samples were collected directly into a sample jar. The surface water samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus. During Phase II, surface water samples were also analyzed for explosives since this site has a history of potentially explosive material disposal. Table 7-3 summarizes each sample and the corresponding analysis.

Surface water sampling locations are shown on Figure 3-17. Discussions of the nature and extent of COPCs detected in surface water are presented in Section 5. Appendix L presents the analytical results for the surface water data used in the risk assessment.

Sediment. During Phase I, sediment samples were collected with stainless-steel bowls and spoons. During Phase II, where there was 6 in. of standing water, samples were collected with a stainless-steel petite (mini) ponar dredge or equivalent. Three sediment samples (SJS05-SD01 through SJS05-SD03) were collected during Phase I. Four sediment samples (SJS05-SD04 through SJS05-SD07) were collected during Phase II. The sediment samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus. Phase II sediment samples were also analyzed for explosives since this site has a history of potentially explosive material disposal. Table 7-3 summarizes each sample and the corresponding analysis.

Sediment sampling locations are shown on Figure 3-17. Discussions of the nature and extent of COPCs detected in sediment are presented in Section 5. Appendix L presents the analytical results for the sediment data used in the risk assessment.

Subsurface Soil. DPT was used to collect most of the subsurface soil samples during RI Phases I and II. However, some of the proposed sampling locations for Phase II included areas of heavy brush, others potentially wet, or where surface soils were saturated. In order to avoid the unnecessary destruction of wetlands, or time-consuming brush clearance operations, a stainless-steel hand auger was used to collect subsurface soil samples in these areas. The truck-mounted DPT rig was used at all other locations.

Twenty subsurface soil samples collected from Site 5/6 were included in the HHRA data set. Eleven subsurface soil samples (SJS05-SB01 through SJS05-SB11) were collected during the Phase I RI. Nine subsurface soil samples (SJS05-SB16 through SJS05-SB18, SJS05-SB20, SJS05-SB22, SJS05-SB24 through SJS05-26, and SJS06-SB01) were collected during Phase II. The subsurface soil samples were analyzed for TCL VOCs, SVOCs, pesticides/PCBs, TAL inorganics, and phosphorus. During Phase I, one sample was selected, using field-screening techniques for TNT, and sent to an offsite laboratory for nitramine analysis. Five samples were also analyzed for dioxin. Phase II subsurface soil samples were also analyzed for explosives since this site has a history of potentially explosive material disposal. Five of the Phase II subsurface soil samples collected in June and July of 2001 were only analyzed for dioxins. Table 7-3 summarizes the subsurface soil samples included in the Site 5/6 data set and the corresponding analysis.

Subsurface soil sampling locations are shown on Figure 3-9. Discussions of the nature and extent of COPCs detected in subsurface soils are presented in Section 5. Appendix L presents the analytical results for the subsurface soil data used in the risk assessment.

7.2.3 Selection of Chemicals of Potential Concern

As discussed in the Technical Approach Memorandum (CDM Federal, 2000), all of the detected constituents were screened to select the COPCs in accordance with USEPA Region III guidelines (USEPA, 1993), with additional analysis (tiered approach) using the steps described below. The COPC selection process was conservative to ensure selection of constituents that contribute the greatest to the potential risk associated with the sites. The maximum detected concentration of each constituent in each medium at each site was compared to a screening value to select the COPCs for the media. If the maximum concentration of a constituent exceeded the screening value, the constituent was selected as a COPC and retained for the risk evaluation.

Constituents that are essential nutrients (magnesium, calcium, potassium, and sodium) were not considered further in the quantitative risk assessment as they are present at low concentrations in site media and are only toxic at very high doses.

As indicated in the Technical Approach Memorandum (CDM Federal, 2000), a tiered approach was used for the selection of COPCs. The first tier follows the methodology presented in USEPA Region III's *Selection of Exposure Routes and Contaminants of Concern by Risk-Based Screening* (USEPA 1993). Maximum detected concentrations of site contaminants were compared to residential RBCs. A second tier screening was used for soil (surface and subsurface soil combined), and sediment for the non-residential scenarios (i.e., trespasser,

construction worker, and other worker). The tier II screening compared maximum detected concentrations to USEPA Region III RBCs for industrial soil, instead of the RBCs for residential soil. Details of both the first and second tier screenings are discussed below. Results of the screening process are shown on Standard Tables 2.1 through 2.12 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively.

For constituents not in the USEPA Region III RBC table, appropriate constituents were chosen as surrogates and their RBCs were used as the screening value. If an appropriate surrogate was not available (i.e., for phosphorus), the constituent was discussed in the uncertainty assessment, Section 7.6.3.

7.2.3.1 Comparison with Health-based Criteria for Surface Soil

Tier I screening (comparison to USEPA Region III residential soil RBCs) was not completed for the surface soil because residential exposure to surface soil is not evaluated in the risk assessment. Tier II screening was conducted for the trespasser scenario by comparing maximum detected surface soil concentrations to current USEPA Region III RBCs for industrial soil (Standard Tables 2.1 and 2.2 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively). RBCs based on noncarcinogenic effects were divided by 10 to account for exposure to multiple constituents. RBCs based on carcinogenic effects were used as presented in the RBC Table (USEPA, 2002a). Constituents with maximum detected concentrations below the RBC were not retained as COPCs. Lead concentrations in surface soil were compared to the USEPA Region III recommended soil-screening value of 1,000 ppm.

7.2.3.2 Comparison with Health-based Criteria for Groundwater

Only Tier I screening was performed for the groundwater. Maximum detected groundwater concentrations were compared to tap water RBCs for all scenarios (Standard Tables 2.3, 2.4 and 2.12 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively). RBCs based on noncarcinogenic effects were divided by 10 to account for exposure to multiple constituents. As a result of using these lower screening criteria to select COPCs for the risk assessment, some constituents previously identified as below applicable criteria (and not considered COPCs) were identified as COPCs for the HHRA. RBCs based on carcinogenic effects were used as presented in the RBC Table (USEPA, 2001a2002a). Constituents with maximum detected concentrations below the RBC were not retained as COPCs. Lead concentrations in groundwater were compared to the Safe Drinking Water Act action level of 15 ppb.

7.2.3.3 Comparison with Health-based Criteria for Surface Water

Only Tier I screening was conducted for the surface water. Maximum detected surface water concentrations were compared to 10 times the tap water RBCs for all scenarios (Standard Tables 2.5 and 2.10 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively). The rationale is that surface water exposure occurs much less frequently than exposure to tap water. RBCs based on noncarcinogenic effects were used as presented in the RBC Table (USEPA, 2002a). RBCs based on carcinogenic effects were multiplied by a factor of ten. Constituents with maximum detected concentrations below the RBC were not retained as COPCs. Lead concentrations in surface water were compared to the Safe Drinking Water Act action level of 15 ppb.

7.2.3.4 Comparison with Health-based Criteria for Sediment

For Tier I screening (performed for the residential scenarios), maximum detected chemical concentrations in sediment were compared to 10 times the residential soil RBCs (Standard Table 2.11 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively). The rationale is that sediment exposure occurs much less frequently than exposure to soil. RBCs based on noncarcinogenic effects were used as presented in the RBC table (USEPA, 2002a). RBCs based on carcinogenic effects were multiplied by a factor of 10. Constituents with maximum detected concentrations below the RBC were not retained as COPCs. Lead concentrations in sediment were compared to the USEPA residential child soil-screening value of 400 ppm as determined by the IEUBK model (USEPA, 1994).

Tier II screening was conducted for the trespasser scenario by comparing maximum detected sediment concentrations to 10 times the USEPA Region III RBCs for industrial soil (Standard Table 2.6 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively). RBCs based on noncarcinogenic effects were used as presented in the RBC Table (USEPA, 2002a). RBCs based on carcinogenic effects were multiplied by a factor of ten. Constituents with maximum detected concentrations below the RBC were not retained as COPCs. Lead concentrations in sediment were compared to the USEPA Region III recommended soil-screening value of 1,000 ppm.

7.2.3.5 Comparison with Health-based Criteria for Soil

For Tier I screening, which was conducted for the residential scenarios, maximum detected soil (surface soil and subsurface soil combined) concentrations were compared to USEPA Region III RBCs for residential soil (USEPA, 2002a) (Standard Table 2.7 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively). RBCs based on noncarcinogenic effects were divided by 10 to account for exposure to multiple constituents. RBCs based on carcinogenic effects were used as presented in the RBC Table (USEPA, 2002a). Constituents with maximum detected concentrations below the RBC were not retained as COPCs. Lead concentrations in soil were compared to the USEPA residential child soil-screening value of 400 ppm as determined by the IEUBK model (USEPA, 1994).

Tier II screening was conducted for the non-residential scenarios (construction worker and other worker) by comparing maximum detected soil (surface and subsurface soil combined) concentrations to USEPA Region III RBCs for industrial soil (Standard Tables 2.8 and 2.9 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively). RBCs based on noncarcinogenic effects were divided by 10 to account for exposure to multiple constituents. RBCs based on carcinogenic effects were used as presented in the RBC Table (USEPA, 2002a). Constituents with maximum detected concentrations below the RBC were not retained as COPCs. Lead concentrations in soil were compared to the USEPA Region III recommended soil-screening value of 1,000 ppm.

Dioxin congener concentrations were converted to 2,3,7,8-tetrachlorodibenzodiozin (2,3,7,8-TCDD) equivalent concentrations by multiplying by TEFs. These concentrations were then compared to the screening values for 2,3,7,8-TCDD.

7.2.4 Chemicals of Potential Concern

Tables 7-4, 7-5, and 7-6 list the chemicals selected as COPCs for Site 3, Site 4, and Site 5/6, respectively, based on the above screening methodology for all media. The screening process is shown in Standard Tables 2.1 through 2.12 for Sites 3, 4, and 5/6 in Appendixes J, K, and L, respectively.

7.3 Exposure Assessment

Exposure refers to the potential contact of an individual with a chemical. The exposure assessment identifies pathways and routes by which an individual may be exposed to the COPCs and estimates the magnitude, frequency, and duration of potential exposure. The magnitude of exposure is determined by estimating the amount of a constituent available at the exchange boundaries (i.e., the lungs, gastrointestinal tract, and skin).

Contaminant fate and transport is evaluated in Section 6, which discusses the potential release mechanisms at each site. A conceptual exposure model showing potential exposure scenarios identified under current and potential future conditions is presented in Standard Table 1 in Appendixes J, K, and L for Sites 3, 4, and 5/6, respectively, and summarized in Table 7-7 for all three sites. The following sections discuss the three components of exposure assessment:

- Characterization of exposure setting
- Identification of exposure pathways
- Quantification of exposure

7.3.1 Characterization of Exposure Setting

Characterizing an exposure setting consists of two parts: (1) presenting the physical characteristics of the site as they relate to exposure, and (2) characterizing human populations on or near the site.

7.3.1.1 Physical Characteristics

Basic site characteristics such as physical setting, climate, groundwater hydrology, and the presence and location of surface water are summarized in Sections 2 and 3 for each site.

7.3.1.2 Potentially Exposed Populations

Potentially exposed populations are identified based on their locations relative to the site, their activity patterns, and the presence of potential sensitive subpopulations. Standard Table 1 in Appendixes J, K, and L, for Sites 3, 4, and 5/6, respectively, details the potentially exposed populations evaluated in this risk assessment. The pathways evaluated in the risk assessment are also shown in Table 7-7, for all three sites.

7.3.1.3 Current Land Use for All Sites

Site 3 (Waste Disposal Area) is a grass-covered former waste disposal area. Site 4 (Landfill D) is a former trench and landfill characterized by raised surface features and areas, which lack vegetation. Site 5 (Burning Grounds), a former burning ground, is an open field. Site 6 (Caged Pit) is a former burn pit is located in close proximity to Site 5. All of these

sites are currently unused. Therefore, no industrial or commercial (occupational) scenarios are evaluated for any of the sites under current land use. However, a communications and/or radar facility is located in the northeastern area of Site 3.

For all three sites, the deep groundwater is evaluated under the current residential scenario even though groundwater beneath these sites is not currently used as a potable water supply. Private wells exist locally (within the Cities of Chesapeake and Portsmouth) that are permitted for irrigation. As a conservative evaluation, it is assumed that residential use of these wells can occur. For all sites, the shallow groundwater is not currently used at or near the site, and therefore, exposure to shallow groundwater is not evaluated under current land use.

For all sites, surface soil, surface water, and sediment are accessible to trespassers. Surface water is not used for swimming due to the shallow depth of water; however, there is a potential for trespassers to wade in these areas and contact both surface water and sediment.

7.3.1.4 Potential Future Use For All Sites

Future land use at all the sites is expected to be either industrial or commercial. Future residential development of the three sites is unlikely; however, it is evaluated as the most conservative future use of the sites. Deep groundwater is evaluated under the future residential scenario because if the site is used for future development, the deep aquifer could be used as a potable water supply. Additionally, as mentioned under current use, deep aquifer groundwater is used for irrigation near the base, and could be used as a potable water supply. According to officials from the VDEQ, groundwater from the shallow aquifer at the SJCA is not considered to be drinkable. As a result, shallow groundwater was not evaluated for exposure through potable use. Shallow groundwater is evaluated for the construction worker because the depth to groundwater ranges from 2 to 6 ft at the three sites, and construction workers could contact this water during excavation activities.

The potential future exposure scenarios assume that the subsurface soil may be disturbed during construction and excavation activities and be placed on the surface. Therefore, potential future receptors (residents, construction workers and other workers) may be exposed to the combined surface and subsurface soil. As for the current site use, surface soil, surface water, and sediment are accessible to trespassers under future site use. Surface water is not used for swimming due to the shallow depth of water; however, there is a potential for residents and trespassers to wade in the drainage features and ponded areas at the sites.

7.3.2 Identification of Exposure Pathways

An exposure pathway can be described as a mechanism that moves a COPC from its source to an exposed population or individual, referred to as a receptor. An exposure pathway must be complete or exposure cannot occur. A complete exposure pathway has five elements:

- A source (e.g., chemical residues in soil)
- A mechanism for release and migration of chemical (e.g., leaching)
- An environmental transport medium (e.g., groundwater)

- A point or site of potential human contact (exposure point, e.g., drinking water)
- A route of intake (e.g., ingestion of groundwater used as a drinking water source)

All five elements must be present for a pathway to be considered complete. If one or more elements are not present, then the pathway is incomplete and there is no possibility of exposure. The following subsections discuss the elements as they pertain to Sites 3, 4, and 5/6.

7.3.2.1 Contaminant Sources

Refuse disposed of at Site 3 (Waste Disposal Area) included solvents, acids, bases, and mixed municipal waste. Two pits reportedly used for disposal of oils and oily sludge, as well as for periodic burning, were also located at the Site 3.

Refuse disposed of at Site 4 (Landfill D) included PCBs and drums of unknown wastes. Several tanks with undetermined wastes may have also been located in the area.

Wastes disposed at Site 5 (Burning Grounds) include ordnance materials such as black powder, smokeless powder, explosive D, Composition A-3, tetryl, TNT, and fuses. Non-ordnance materials disposed of at Site 5 included carbon tetrachloride, TCE, paint sludges, pesticides, and various types of refuse. Site 6 (Caged Pit) was used to burn small arms including igniters and fuses.

Contaminants associated with the material disposed of and/or burned at the three sites may be present in the soils at these sites.

7.3.2.2 Release and Transport Mechanisms

The fate and transport of chemicals in soil, sediment, surface water, and groundwater are determined by physical characteristics of the site as well as by the chemical and physical properties of the chemicals. A detailed description of the fate and transport analysis of the site contamination conditions is included in Section 6.

Contaminants placed on the surface and in the ground at the sites may have migrated from the surface through the surface soil to the subsurface soil and from the surface into the air through fugitive dust and volatile emissions. Contaminants may have also leached through the soil to the groundwater. Contaminants may be transported downgradient from the site in the groundwater. Additionally, runoff of contaminants from the surface may have resulted in contamination in the sediment and surface water of the drainage features and ponded waters at the site. Contamination from the surface water and sediment may also be leaching to the shallow groundwater.

7.3.2.3 Potential Exposure Points and Exposure Routes

Exposure points are locations where humans could come in contact with contamination. Onsite exposure points for all three sites include surface soil, soil (surface and subsurface soil combined), surface water, sediment, and shallow groundwater beneath the site. Offsite exposure points include the deep aquifer groundwater and surface water downgradient of the sites. Only onsite exposure points are evaluated in this risk assessment since it is assumed dilution and degradation of contamination would occur downgradient of the sites, resulting in lower concentrations, and therefore, lower risks than those calculated for the sites.

Potential exposure routes are evaluated for current site use and potential future site use. The potentially complete pathways of exposure evaluated in this risk assessment are presented in Standard Table 1 in Appendixes J, K, and L for Sites 3, 4, and 5/6, respectively, and in Table 7-7.

7.3.2.4 Current Exposure Routes

Current receptors for Sites 3, 4, and 5/6 are identical and are described below.

Receptors for deep groundwater include current offsite residents (adult and child receptors, conservatively evaluated using onsite data). Shallow groundwater is not currently used as a source of potable water either at the sites or downgradient of the sites, and is therefore not a currently exposed medium. As mentioned previously, surface soil, surface water, and sediment are currently accessible to trespassers.

In summary, the current exposure routes include:

- Trespasser (adult and adolescent): incidental ingestion of and dermal contact with surface soil, inhalation of fugitive dust from surface soil; dermal contact with surface water through wading; and incidental ingestion of and dermal contact with sediment through wading
- Resident (adult): ingestion of and dermal contact with deep groundwater, and inhalation of volatiles from deep groundwater while showering
- Resident (child): ingestion of deep groundwater, and dermal contact with deep groundwater while bathing

Incidental ingestion of surface water was not evaluated in the risk assessment since the receptors would be wading in the surface water and not swimming in the surface water. While incidental ingestion of surface water would occur during swimming since the head is in the water, incidental ingestion of surface water is expected to be insignificant during wading. Incidental ingestion of sediment while wading was assumed to be a potential pathway since the sediment from the shallow surface water body and the banks of the surface water body may stick to the hands and may be transferred to the mouth at a later time.

7.3.2.5 Future Exposure Routes

Future receptors for Sites 3, 4, and 5/6 are identical and are described below.

In the unlikely event the site is used for residential development in the future, receptors of deep groundwater from beneath the site include child and adult residents. Additionally, deep aquifer groundwater at or downgradient of the site could be used as a potable water supply in the future. Exposure to shallow groundwater is evaluated for the construction worker because of the potential for exposure during excavation activities. The potential future exposure scenarios for exposure to soil assume that the subsurface soil will be excavated and placed on the surface. Therefore, potential future receptors (residents and other workers) may be exposed to the surface and subsurface soil. Excavation activities at the site may also expose the construction worker to the surface and subsurface soil.

Surface soil, surface water, and sediment are currently accessible to trespassers, and assumed to be accessible to trespassers in the future. Surface water is not used for swimming due to the shallow depth of water; however, there is a potential for future residents and trespassers to wade in these areas.

In summary, the future land use exposure routes include:

- Trespasser (adult and adolescent): incidental ingestion of and dermal contact with surface soil; inhalation of fugitive dust from surface soil; dermal contact with surface water through wading; and incidental ingestion of and dermal contact with sediment through wading.
- Resident (adult): ingestion of deep groundwater, dermal contact with deep groundwater, and inhalation of volatiles from deep groundwater while showering; incidental ingestion of and dermal contact with soil (surface and subsurface soil combined); dermal contact with surface water through wading; and incidental ingestion of and dermal contact with sediment through wading.
- Resident (child): ingestion of deep groundwater, and dermal contact with deep groundwater while bathing; incidental ingestion of and dermal contact with soil (surface and subsurface soil combined); dermal contact with surface water through wading; and incidental ingestion of and dermal contact with sediment through wading.
- Construction Worker: incidental ingestion of and dermal contact with soil (surface and subsurface soil combined); inhalation of fugitive dust from soil; and dermal contact with shallow groundwater during excavation activities.
- Other Worker: incidental ingestion of and dermal contact with soil (surface and subsurface soil combined).

All of these pathways were quantified for potential exposure.

7.3.3 Estimation of Exposure Point Concentrations

Exposure point concentrations (EPCs) are estimated chemical concentrations that a receptor may contact and are specific to each exposure medium. EPCs may be directly monitored or estimated using environmental models. The Foster and Chrostowski shower model (Foster and Chrostowski 1987) was used to estimate concentrations of contaminants in air, which volatilize from groundwater while showering. Results of the modeling are presented in Tables 7.7.RME Supplement and 8.6.RME Supplement in Appendixes J, K, and L for Sites 3, 4, and 5/6, respectively. Fugitive emissions from soil were estimated using the particulate emission factor (PEF) calculated in USEPA's Soil-screening Guidance (USEPA 1996a). This calculation is included in Tables 7.3, 7.4, 7.14, 8.3, 8.4, and 8.12 in Appendixes J, K, and L for Sites 3, 4, and 5/6, respectively. Both reasonable maximum exposure (RME) and central-tendency (CT) EPCs were calculated in this risk assessment.

The EPC for the RME scenario is based on the 95-percent UCL of the mean (95-percent UCL) for media in which five or more samples were collected. The maximum detected concentration was used in place of the 95-percent UCL when the calculated 95-percent UCL was greater than the maximum detected value or less than five samples were collected. For each medium, a statistical test was used to determine if the data fit a lognormal or normal

distribution. The Shapiro-Wilk W-test was used for media in which 50 samples or less were collected. The D'Agostino test was used for media in which 50 samples were collected. The 95-percent UCL from the distribution the data best fit was chosen as the EPC. If the W-test or D'Agostino's test was inconclusive, the larger of the 95-percent UCL from the lognormal or normal distribution was selected.

CT risk evaluations were performed for exposure pathways that resulted in a risk above 1E-05 or a Hazard Index (HI) above 1. The EPC for the CT evaluation is based on the mean value. The maximum detected concentration was used as the CT EPC when the mean was greater than the maximum detected value. The Shapiro-Wilk W-test or the D'Agostino test was used to determine if the data fit a lognormal or normal distribution. If the test indicated the data fit a normal distribution, the mean based on the normal distribution was used as the EPC. If the test indicated the data fit a lognormal distribution, the mean based on the lognormal distribution was used as the EPC. If the W-test or D'Agostino's test was inconclusive, the larger of the mean value from the lognormal or normal distribution was selected as the CT EPC.

The 95-percent UCL for a lognormal distribution was calculated as follows:

$$\text{95-percent UCL} = \exp(TM + 0.5*s^2 + (s*H/(n-1)^{0.5}))$$

Where:

exp= natural log
TM = transformed mean
s= standard deviation of the transformed data
H= H-statistic
n= sample size

The 95-percent UCL for a normal distribution was calculated as follows:

$$95\%\ \text{UCL} = NM+(t*s/(n)^{0.5})$$

Where:

NM= normal arithmetic mean
t= t-statistic
s= standard deviation
n= sample size

The EPC for dioxins was calculated as a 2,3,7,8- TCDD equivalent concentration. The concentrations of the individual dioxin congeners were multiplied by the TEF to calculate the toxicity equivalent concentration to 2,3,7,8-TCDD. The toxicity equivalent concentration for each of the congeners was summed to calculate the total 2,3,7,8-TCDD equivalent concentration in each sample. This concentration was then treated as one constituent, and the EPC was calculated as discussed above for all COPCs.

Standard Tables 3.1 through 3.12 located in Appendix J for Site 3, Appendix K for Site 4, and Appendix L for Site 5/6 present the EPCs for the COPCs for each medium and the rationale for the selected EPC.

7.3.4 Estimation of Chemical Intakes for Individual Pathways

Chemical intake is the amount of the chemical contaminant entering the receptor's body. Chemical intakes are generally expressed as follows:

$$I = \frac{C \; x \; CR \; x \; EF \; x \; ED}{BW \; x \; AT} = (mg/kg/day)$$

Where:

I = intake (mg/kg-day)

C = chemical concentration at exposure point (mg/l, mg/kg, mg/m^3)

CR = contact rate, or amount of contaminated medium contacted per unit time or event (L/day, mg/event, m^3/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight of exposed individual (kg)

AT = averaging time, or period over which exposure is averaged (days)

The intake equation requires specific exposure parameters for each exposure pathway. Exposure parameters are often assumed values, and their magnitude influences the estimates of potential exposure (and risk). The reliability of the values chosen can also contribute substantially to the uncertainty of the resulting risk estimates. Many of the exposure parameters have default values, which were used for this assessment. These assumptions based on estimates of body weights, media intake levels, and exposure frequencies and duration are provided by USEPA guidance. Other assumptions required consideration of location-specific information and were determined using professional judgment. Standard Tables 4.1 through 4.25 in Appendixes J, K, and L, for Sites 3, 4, and 5/6, present the exposure factors used for different scenarios for all three sites. Both RME and CT intake parameters are included in these tables.

For dermal contact with soil and sediment, an absorption factor is required. The absorption factors used for this evaluation were 10 percent for semivolatile organics and pesticides, 3 percent for dioxins, 3.2 percent for arsenic, and 1 percent for other metals (USEPA, 1995). For the dermal contact with water scenario, skin permeability rates were obtained from *Dermal Exposure Assessment: Principles and Applications* (USEPA, 1992b). All permeability constants used in this risk assessment are presented in the supplemental tables to the Standard Tables 7s and 8s in Appendixes J, K, and L, for Sites 3, 4, and 5/6.

For dermal exposure to groundwater, the quasi-steady state or non-steady state model was used to estimate the absorbed dose for the organic constituents, and the steady state model was used to estimate the absorbed dose for the inorganic constituents, as discussed in *Dermal Exposure Assessment: Principles and Applications* (USEPA, 1992b).

7.4 Toxicity Assessment

Toxicity assessment defines the relationship between the magnitude of exposure and possible severity of adverse effects, and weighs the quality of available toxicological evidence. Toxicity assessment generally consists of two steps: hazard identification and dose-response assessment. Hazard identification is the process of determining the potential adverse effects from exposure to the chemical along with the type of health effect involved. Dose-response assessment is the process of quantitatively evaluating the toxicity information and characterizing the relationship between the dose of the contaminant administered or received and the incidence of adverse health effects in the exposed population. Toxicity criteria (e.g., reference doses and cancer slope factors) are derived from the dose-response relationship.

Health effects are divided into two broad groups: noncarcinogenic and carcinogenic effects. This division is based on the different mechanisms of action currently associated with each category. Chemicals causing noncarcinogenic health effects are evaluated independently from those having carcinogenic effects. Some chemicals may produce both noncarcinogenic and carcinogenic effects, and are therefore evaluated in both groups. This section discusses noncarcinogenic and carcinogenic effects separately.

The primary source of toxicity values is the USEPA's Integrated Risk Information System (IRIS) database, which contains up-to-date health risk and USEPA regulatory information. IRIS includes only reference doses (RfDs) and cancer slope factors (CSFs) that have been verified by USEPA work-groups. The IRIS database is the USEPA's preferred source of toxicity information. The Health Effects Assessment Summary Tables (HEAST), which are issued by USEPA's Office of Research and Development, were consulted when data were not available in IRIS. If data were not available from either of these sources, USEPA's National Center for Environmental Assessment (NCEA) was consulted. If no toxicity values were available through the NCEA, then toxicity values found on the current USEPA Region III RBC table (USEPA, 2002a) were used.

7.4.1 Toxicity Information for Noncarcinogenic Effects

Noncarcinogenic health effects include a variety of toxic effects on body systems, ranging from renal toxicity (toxicity to the kidneys) to central nervous system disorders. Noncarcinogenic health effects are grouped into two basic categories: acute toxicity and chronic toxicity. Acute toxicity can occur after a single exposure (usually at high doses), where the effect is most often seen immediately. Chronic toxicity generally occurs after repeated exposure (usually at low doses) and is seen weeks, months, or years after the initial exposure. The toxicity of a chemical is assessed through a review of toxic effects noted in short-term (acute) animal studies, long-term (chronic) animal studies, and epidemiological investigations.

USEPA (USEPA, 1989) defines the chronic RfD as a dose that is likely to be without appreciable risk of deleterious effects during a lifetime of exposure. Chronic RfDs are specifically developed to be protective for long-term exposure to a compound (7 years to a lifetime), and consider uncertainty in the toxicological database and sensitive receptors.

Chronic RfDs may be overly protective if used to evaluate the potential for adverse health effects resulting from short-term exposure. USEPA's NCEA develops subchronic RfDs for short-term exposure (2 weeks to 7 years). Subchronic RfDs have been peer-reviewed by the Agency and outside reviewers, but they have not undergone verification by an intra-agency workgroup, and as a result are considered interim rather than verified toxicity values. Chronic and subchronic RfDs are developed for both the inhalation and oral exposures. In this risk assessment, subchronic RfDs were used for the construction worker scenario because the exposure duration is 0.5 year, and for the child resident because the exposure duration is 6 years.

In the development of RfDs, all available studies examining the toxicity of a chemical following exposure are considered based on their scientific merit. Several uncertainty factors (UFs) and modifying factors (MFs) may be applied account for uncertainty. UFs account for uncertainties such as poor data quality, extrapolation of data from animal studies to human exposures, or the use of subchronic studies to develop chronic criteria. These UFs and MFs range between 10 to 10,000, and are based on professional judgment. Therefore, there are varying degrees of uncertainty in the toxicity criteria.

USEPA-derived oral and inhalation chronic RfDs and associated UF and MF values available for the COPCs are listed in Standard Tables 5.1 and 5.2 in Appendixes J, K, and L, for Sites 3, 4, and 5/6, respectively.

Per USEPA guidance, oral RfDs were adjusted from administered dose to absorbed dose for evaluating dermal toxicity. The RfDs were adjusted using oral absorption factors from USEPA (USEPA, 1999). The adjusted dermal RfDs for all the sites are summarized in Standard Table 5.1 in Appendixes J, K, and L, for Sites 3, 4, and 5/6, respectively.

7.4.2 Toxicity Information for Carcinogenic Effects

Potential carcinogenic effects are quantified using oral CSFs, inhalation CSFs, or unit risk factors that convert estimated exposures directly to incremental lifetime cancer risks. SFs are expressed in units of per milligram per kilogram of body weight per day $(mg/kg\text{-}day)^{-1}$, and unit risk factors are expressed in units of per micrograms per cubic meter $(\mu g/m^3)^{-1}$.

CSFs may be derived from the results of chronic animal bioassays, human epidemiological studies, or both. Animal bioassays are usually conducted at dose levels much higher than are likely to be encountered in the environment. This design detects possible adverse effects in the relatively small test populations used in the studies.

A number of mathematical models and procedures have been developed to extrapolate from the high doses used in the studies to the low doses typically associated with environmental exposures. The USEPA-preferred linearized multistage (LMS) model is usually used to estimate the largest linear slope (within the upper 95-percent UCL) at low extrapolated doses consistent with the data. The 95-percent UCL slope of the dose-response curve is subjected to various adjustments, and an inter-species scaling factor is usually applied to derive a CSF or inhalation unit risk factor for humans. It is assumed that if a cancer response occurs at the dose level in the study, there is some probability that a response will occur at all lower exposure levels (i.e., a dose-response relationship with no threshold is assumed). Dose-response data derived from human epidemiological studies are

fitted to dose-time-response curves on an ad hoc basis. In both types of analyses, conservative (e.g., health protective) assumptions are applied and the models are believed to provide rough estimates of the upper limits on potential lifetime risk.

USEPA-derived oral and inhalation CSFs are listed in Standard Tables 6.1 and 6.2 in Appendixes J, K, and L, for Sites 3, 4, and 5/6, respectively. The adjusted dermal SFs are also summarized in the Standard Tables 6.1 for each site.

Per USEPA guidance, oral CSFs were adjusted from administered doses to absorbed doses for evaluating dermal exposure toxicity. The CSFs were adjusted using oral absorption factors from USEPA (USEPA, 1999). The adjusted dermal CSFs are summarized in Standard Table 6.1 in Appendixes J, K, and L, for Sites 3, 4, and 5/6, respectively.

In addition to deriving a quantitative estimate of cancer potency, USEPA also assigns weight-of-evidence classifications to potential carcinogens. Chemicals are classified as Group A, Group B1, Group B2, Group C, Group D, or Group E carcinogens.

- Group A chemicals (known human carcinogens) are agents for which there is sufficient evidence to support the causal association between exposure to the agents in humans and cancer.
- Group B1 chemicals (probable human carcinogens) are agents for which there is limited evidence of possible carcinogenicity in humans with sufficient evidence of carcinogenicity in laboratory animals.
- Group B2 chemicals (probable human carcinogens) are agents for which there is sufficient evidence of carcinogenicity in animals but inadequate evidence in humans.
- Group C chemicals (possible human carcinogens) are agents for which there is limited evidence of carcinogenicity in animals and inadequate or a lack of human data.
- Group D chemicals (not classifiable as to human carcinogenicity) are agents with inadequate human and animal evidence of carcinogenicity or for which no data are available.
- Group E chemicals (evidence of noncarcinogenicity in humans) are agents for which there is no evidence of carcinogenicity from human or animal studies, or both.

7.4.3 Chemicals for Which No USEPA Toxicity Values Are Available

Most of the chemicals detected at the site have toxicity factors, or if not, appropriate surrogate values were chosen from similar chemicals to use for the COPC screening. Phosphorus and lead are the only COPCs that do not have available published toxicity factors.

For residential exposure, lead is evaluated by USEPA based on blood-lead uptake using a physiologically-based pharmakokinetic model referred to as IEUBK model (USEPA, 1994), in the event that lead is present at the site above USEPA recommended residential screening levels. Risks associated with non-residential adult exposure to lead in soil and sediment are evaluated based on *Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposure to Lead in Soil* (USEPA, 1996) when lead is present at the site above USEPA recommended industrial screening levels. This

approach utilizes a methodology to relate soil lead intake to blood-lead concentrations in women of childbearing age. The methodology focuses on estimating the fetal blood-lead concentration in women exposed to lead contaminated soils. This guidance provides a set of default parameter values that can be used in cases where high quality data are not available to support site-specific estimates. The adult lead model is present in Table 7-8. Maximum lead concentrations are screened against: 400 mg/kg in soil and sediment for the residential receptor, 1,000 mg/kg in surface soil, soil, and sediment for non-residential receptors, and 15 μg/l in groundwater and surface water for all receptors.

For Site 3, lead was detected in surface soil at a maximum concentration of 2,070 mg/kg, in soil at a maximum concentration of 2,990 mg/kg, and in sediment at a maximum concentration of 1,050 mg/kg, all of which exceed the screening values. Lead was detected in surface water at a maximum concentration of 27.8 μg/l, which exceeds the screening value. Lead was not detected in the deep or shallow groundwater at levels that exceed the screening value. Therefore, lead in groundwater was not evaluated further in this assessment.

For Site 4, lead was detected in surface soil and soil at a maximum concentration of 1,110 mg/kg, and in sediment at a maximum concentration of 441 mg/kg, both of which exceed the screening values. Lead was detected in surface water at a maximum concentration of 822 μg/l, and in the shallow aquifer groundwater at a maximum concentration of 30.5 μg/l, which exceed the screening value. Lead was not detected in the deep aquifer groundwater at levels that exceed the screening value. Therefore, lead in deep groundwater was not evaluated further in this assessment.

For Site 5/6, lead was detected in surface soil and soil at a maximum concentration of 7,210 mg/kg, which exceeds the screening values. Lead was detected in surface water at a maximum concentration of 4,760 μg/l, which exceeds the screening value. Lead was detected in the shallow groundwater at a maximum concentration of 26.1 μg/l, which exceeds the screening value. Lead was not detected in the sediment or deep groundwater at levels that exceed the screening values. Therefore, lead in sediment and deep groundwater was not evaluated further in this assessment.

7.4.3.1 Site 3

The maximum detected lead concentrations for surface soil, soil, and sediment exceeded the soil-screening value of 1,000 mg/kg, and lead was retained as a COPC for surface soil, soil, and sediment. The mean concentrations of lead in the surface soil (115 mg/kg), in the soil (276 mg/kg), and in the sediment (126 mg/kg) are below the lead concentrations calculated using the adult lead model in Table 7-8 (1,113 mg/kg). This concentration is based on a blood-lead concentration of 10 μg/dL, the concentration expected not to result in harm to a fetus.

The maximum detected concentrations of lead in soil and sediment exceed the residential soil-screening level of 400 mg/kg, and lead was retained as a COPC for soil and sediment. Following USEPA guidance, the mean lead concentration is used to evaluate exposure to lead. The mean lead soil concentration of 276 mg/kg (see Standard Table 3.7 in Appendix J) and sediment concentration of 126 mg/kg (see Standard Table 3.11 in Appendix J) are below the residential lead soil-screening level. However, because of the exceedance of the maximum detected concentrations, risks associated with lead in soil and sediment were evaluated using the USEPA's IEUBK model.

The principal assumption associated with the use of the IEUBK model is that a child from age 0 to 6 is the receptor for the potential exposure to lead in soil and sediment. The results of the IEUBK model are presented in Appendix J for Site 3. The IEUBK evaluation resulted in geometric mean blood concentrations of 4.3 μg/dL and 2.9 μg/dL for children 0 to 72 months old exposed to the mean lead soil and sediment concentration, respectively. These concentrations are below USEPA's recommended level of 10 μg/dL. Approximately 3.2 percent of the population had a blood-lead level above USEPA's recommended level of 10 μg/dL when exposed to the mean lead soil concentration. Approximately 0.37 percent of the population had a blood-lead level above USEPA's recommended level when exposed to the mean lead sediment concentration. With the exception of the lead soil and sediment concentrations (which were set equal to the average site lead concentration for each run of the model), the default parameters associated with the IEUBK model were used in the evaluations. Potential exposure to children by lead in the soil and sediment from Site 3 is not expected to result in blood-lead concentrations above USEPA's recommended levels.

7.4.3.2 Site 4

The maximum detected lead concentrations for surface soil and soil exceed the soil-screening value of 1,000 mg/kg, and lead was retained as a COPC for surface soil and soil for the industrial scenario. Following USEPA guidance, the mean lead concentration is used to evaluate exposure to lead. The mean concentrations of lead in the surface soil (204 mg/kg) and in the soil (120 mg/kg) are below the lead concentrations calculated using the adult lead model in Table 7-8 (1,113 mg/kg). This concentration is based on a blood-lead concentration of 10 μg/dL, the concentration expected not to result in harm to a fetus.

The maximum detected concentrations of lead in soil and sediment exceeded the residential soil-screening level of 400 mg/kg, and lead was retained as a COPC for soil and sediment. The mean lead soil concentration of 120 mg/kg (see Standard Table 3.7 in Appendix K) and sediment concentration of 132 mg/kg (see Standard Table 3.11 in Appendix K) are below the residential lead soil-screening level. However, because of the exceedance of the maximum detected concentrations, risks associated with lead in soil were evaluated using the IEUBK model.

The results of the IEUBK modeling are presented in Appendix K for Site 4. The IEUBK evaluation resulted in geometric mean blood concentrations of 2.8 μg/dL and 2.9 μg/dL for children 0 to 72 months old exposed to the mean lead soil and sediment concentration, respectively. These concentrations are below USEPA's recommended level of 10 μg/dL. Approximately 0.31 percent of the population had a blood-lead level above USEPA's recommended level of 10 μg/dL when exposed to the mean lead soil concentration. Approximately 0.41 percent of the population had a blood-lead level above USEPA's recommended level when exposed to the mean lead sediment concentration. With the exception of the lead soil and sediment concentration (which was set equal to the average site lead concentration), the default parameters associated with the IEUBK model were used in the evaluations. Potential exposure to children by lead in the soil and sediment from Site 4 is not expected to result in blood-lead concentrations above USEPA's recommended levels.

7.4.3.3 Site 5/6

The maximum detected lead concentrations for surface soil and soil exceed the soil-screening value of 1,000 mg/kg, and lead was retained as a COPC for surface soil and soil for the industrial scenario. Following USEPA guidance, the mean lead concentration is used to evaluate exposure to lead. The mean concentrations of lead in the surface soil (239 mg/kg) and in the soil (118 mg/kg) are below the lead concentrations calculated using the adult lead model in Table 7-8 (1,113 mg/kg). This concentration is based on a blood-lead concentration of 10 µg/dL, the concentration expected not to result in harm to a fetus.

The maximum detected concentration of lead in soil exceeds the residential soil-screening level of 400 mg/kg, and lead was retained as a COPC for soil. Lead was not detected in the sediment at levels that exceeded the screening value. Therefore, lead in the sediment was not evaluated further in this assessment. The mean lead soil concentration of 118 mg/kg (see Standard Table 3.7 in Appendix L) is below the residential lead soil-screening level, however, because the maximum detected concentration is above the screening level, the risks associated with lead in soil were evaluated using the IEUBK model.

The results of the IEUBK modeling are presented in Appendix L for Site 5/6. The IEUBK evaluation resulted in geometric mean blood concentration of 2.8 µg/dL for children 0 to 72 months old exposed to the mean lead soil concentration. This concentration is below USEPA's recommended level of 10 µg/dL. Approximately 0.29 percent of the population had a blood-lead level above USEPA's recommended level of 10 µg/dL when exposed to the mean lead soil concentration. With the exception of the lead soil concentration (which was set equal to the average site lead concentration), the default parameters associated with the IEUBK model were used in the evaluation. Potential exposure to children by lead in the soil from Site 5/6 is not expected to result in blood-lead concentrations above USEPA's recommended levels.

One constituent that was detected at all of the sites, phosphorus, does not have any published toxicity factors, appropriate surrogate constituents, or any way to evaluate risks associated with exposure. The RDA for phosphorus is 800 mg/day for children and adults, and 1,200 mg/day for adolescents. The concentrations detected in the site media would result in intakes of phosphorus much lower than the RDA. Therefore, phosphorus would not be a health concern at Sites 3, 4, and 5/6. Additionally, the observed range of concentrations of phosphorus in soils of the Eastern United States is <20 to 6,800 ppm, with a mean concentration of 200 ppm (Shacklette and Boerngen, 1984). The concentrations detected in soil and sediment at Sites 3, 4, and 5/6 fall within this range.

7.4.4 Toxicity Profiles of Chemicals of Potential Concern

Appendix I contains toxicological profiles for selected COPCs (those that present the majority of the risk to the receptors, as calculated in Section 7.5.2) for all sites. More detailed toxicity information can be found in USEPA's IRIS database, ATSDR's toxicological profiles, and other published literature.

7.5 Risk Characterization

Risk characterization is the process of integrating the previous elements of the risk assessment into quantitative and semi-quantitative expressions of risk. The quantification of risk is then used an integral component in remedial decision making and selection of potential remedies or actions.

7.5.1 Noncarcinogenic and Carcinogenic Risk Estimation Methods

Potential human health risks are discussed independently for carcinogenic and noncarcinogenic contaminants because of the different toxicological endpoints, relevant exposure duration, and methods used to characterize risk. Some chemicals may produce both noncarcinogenic and carcinogenic effects, and were evaluated in both groups. The methodology used to estimate noncarcinogenic hazards and carcinogenic risk are described below. Following the description of the methodology, the noncarcinogenic hazards and carcinogenic risks are discussed for all three sites.

7.5.1.1 Noncarcinogenic Hazard Estimation

Noncarcinogenic health risks are estimated by comparing the calculated exposure levels to threshold concentrations (or RfDs). The calculated intake divided by the RfD is equal to the hazard quotient (HQ):

Hazard Quotient (HQ) = Intake / RfD

The intake and RfD are expressed in the same units (mg/kg-day) and represent the same exposure period (i.e., chronic and subchronic). The intake and RfD also represent the same exposure route (i.e., inhalation intakes are divided by the inhalation RFD, oral intakes are divided by the oral RfDs, and dermal intakes are divided by an adjusted oral RFD). An HQ that exceeds 1 (i.e., intake exceeds the RfD) indicates a potential for adverse health effects associated with exposure to that chemical.

To assess the potential for noncarcinogenic health effects posed by exposure to multiple chemicals, a "hazard index" approach is used (USEPA, 1989). This approach assumes that noncarcinogenic hazards associated with exposure to more than one chemical are additive. Synergistic or antagonistic interactions between chemicals are not accounted for. The HI may exceed 1 even if all of the individual HQs are less than one. The chemicals may then be separated by similar mechanisms of toxicity and toxicological effects, and separate HIs derived based on mechanism and target organ affected.

7.5.1.2 Carcinogenic Risk Estimation

The potential for carcinogenic effects due to exposure to site-related contamination is evaluated by estimating the excess lifetime carcinogenic risk. Excess lifetime cancer risk is the incremental increase in the probability of developing cancer during one's lifetime in addition to the background probability of developing cancer.

Potential carcinogenic risks associated with exposure to individual carcinogens were calculated using the CSFs presented in Section 7.4 and the intakes calculated in Section 7.3. The carcinogenic risk is calculated by multiplying the intake by the CSF as shown below:

Risk = Intake x CSF

The combined risk from exposure to multiple chemicals was evaluated by adding the risks from individual chemicals. Risks were also added across the exposure routes if an individual would be exposed through multiple pathways.

When a cumulative carcinogenic risk to an individual receptor under the assumed RME exposure conditions exceeds 100 in a million (10^{-4} excess cancer risk), CERCLA generally requires remedial action to reduce the risks at the site (USEPA, 1991). If the cumulative risk is less than 10^{-4}, action is generally not required, but may be warranted if a risk-based chemical specific standard (for example, MCL is exceeded). A risk-based remedial decision could be superceded by the presence of noncarcinogenic impact or environmental impact requiring action at the sites.

7.5.2 Risk Assessment Results

RME risks were evaluated for all media and exposure scenarios described previously for each site. RME risks were evaluated using upper-bound estimates of the exposure parameters (Appendixes J, K, and L, Standard Tables 4.1 through 4.25) and the RME EPC (Standard Tables 3.1 through 3.12 located in Appendix J for Site 3, Appendix K for Site 4, and Appendix L for Site 5/6). CT risks were calculated for those scenarios that had an RME HI greater than 1 and/or RME carcinogenic risk greater than 1E-05. CT risks were evaluated using median estimates of the exposure parameters (Appendixes J, K, and L, Standard Tables 4.1 through 4.25) and the CT EPC (Standard Tables 3.1 through 3.12 located in Appendix J for Site 3, Appendix K for Site 4, and Appendix L for Site 5/6). Risks were evaluated for all of the complete exposure pathways identified in Sections 7.3.2.4. and 7.3.2.5. The calculated risks are discussed below for Site 3, Site 4, and Site 5/6.

For residential exposure to deep groundwater, soil, sediment, and surface water, lifetime risks were calculated for carcinogenic constituents. Lifetime risks were calculated using the equations presented in Standard Tables 4s in Appendixes J, K, and L, for the appropriate media.

7.5.2.1 Site 3

Surface Soil. RME hazard estimates for exposure to surface soil via inhalation were not calculated for current/future adult and adolescent trespassers (Appendix J, Standard Tables 7.3.RME and 7.4.RME) because there were no RfDs available for the COPCs. However, RME hazard estimates for exposure to surface soil via incidental ingestion and dermal contact were calculated for current/future adult and adolescent trespassers (Appendix J, Standard Tables 7.1.RME and 7.2.RME, and summarized in Tables 7-9 and 7-10). RME carcinogenic risk estimates for exposure to surface soil via incidental ingestion, dermal contact, and inhalation of fugitive dust were also evaluated (Appendix J, Standard Tables 8.1.RME through 8.4.RME).

The noncarcinogenic hazards associated with exposure to surface soil via incidental ingestion, dermal contact, and inhalation for all receptors are below USEPA's target HI of 1. The carcinogenic risks associated with exposure to surface soil via incidental ingestion, dermal contact, and inhalation by current/future adult and adolescent trespassers are within or below USEPA's target risk range of 1E-04 to 1E-06. Since the calculated risks and

hazards are below the target risk of 1E-05 and target HI of 1, CT calculations were not performed.

Lead was also selected as a COPC for surface soil because the maximum detected concentration exceeded the soil-screening value of 1,000 mg/kg. Therefore, the adult lead model was used to evaluate the potential impacts on the receptors (see Section 7.4.3). The adult lead model, which is based on the mean lead concentration, showed that the lead detected in the surface soil is not expected to impact human health at levels above USEPA's acceptable criteria.

Deep Groundwater. RME risk estimates for exposure to deep groundwater were calculated for current/future adult and child residents (Appendix J, Standard Tables 7.5.RME through 7.7.RME, and Tables 8.5.RME and 8.6.RME and summarized in Tables 7-9 and 7-10). Exposure to deep groundwater via incidental ingestion, dermal contact, and inhalation through showering (adults only) was evaluated.

The noncarcinogenic hazard associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future adult residents is 2, which is above USEPA's target HI of 1. The risk to the adult is primarily attributable to ingestion of thallium, arsenic, and manganese in the groundwater. However, individual hazard quotients for these constituents are below or equal to one, and when separated by target organ, the HIs are also equal to or below 1. The noncarcinogenic hazard associated with exposure to deep groundwater via inhalation through showering by current/future adult residents is below USEPA's target HI of 1.

The noncarcinogenic hazard associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future child residents is 5 and exceeds USEPA's target HI of 1. The hazard to the child resident is primarily attributable to thallium, manganese, and arsenic. The ingestion pathway contributes to over 99 percent of the total HI. Both thallium and manganese contribute individual HIs above 1. It should be noted that thallium was only detected in one of the six groundwater samples evaluated in the risk assessment, the 1997 sample from the upgradient well, and was not detected in the subsequent sampling rounds.

The carcinogenic risks associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future adult and child residents and via inhalation through showering by current/future adult residents are within USEPA's target risk range of 1E-04 to 1E-06.

Since both adult and child resident exposure pathways exceed a HI of 1, and the lifetime resident scenario exceeds a carcinogenic risk of 1E-05, CT risk estimates for exposure to deep groundwater were calculated (Appendix J, Standard Tables 7.20.CT and 7.21.CT and Table 8.16.CT, and summarized in Tables 7-12 and 7-13).

The CT noncarcinogenic hazards for both receptors are equal to or below USEPA's target hazard of 1. The CT carcinogenic risks for the lifetime residential receptors are within or below USEPA's target risk range of 1E-04 to 1E-06.

Surface Water. RME risk estimates for exposure to surface water were calculated for current/future adult and adolescent trespassers as well as future adult and child residents

(Appendix J, Standard Tables 7.8.RME, 7.9.RME, 7.15.RME, 7.16.RME, 8.7.RME, 8.8.RME, and 8.13.RME). Exposure to surface water via dermal contact was evaluated for all receptors.

The noncarcinogenic hazards for all receptors are below USEPA's target HI of 1. The carcinogenic risks for all receptors are below USEPA's target risk range of 1E-04 to 1E-06.

Lead was selected as a COPC in surface water because the maximum detected concentration slightly exceeds the action level of 15 µg/l. However, the action level of 15 µg/l is not necessarily applicable to the surface water, since it is based on potable use of water, and surface water will not be used as a drinking water supply. Dermal contact is the pathway of exposure for surface water. Additionally, the average concentration of lead detected in the surface water is below the action level. Therefore, it is not expected that the lead detected in the surface water will adversely impact human health.

Sediment. RME risk and hazard estimates for exposure to sediment were not calculated for current/future adult and adolescent trespassers because there were no COPCs retained for quantitative evaluation. However, RME risk and hazard estimates for exposure to sediment were calculated for future adult and child residents (Appendix J, Standard Tables 7.17.RME, 7.18.RME, and 8.14.RME and summarized in Tables 7-9 and 7-10). Exposure to sediment via incidental ingestion and dermal contact was evaluated.

The noncarcinogenic hazard associated with exposure to sediment by future adult residents was below USEPA's target HI of 1. The noncarcinogenic hazard of 16 associated with exposure by child residents exceeds USEPA's target HI. The hazard to the child resident is primarily associated with dermal contact with antimony and iron in the sediment. The ingestion route also contributes a HI of above 1, due to antimony and arsenic, however, individually the constituents do not contribute HQs above 1 via ingestion.

The carcinogenic risk associated with exposure to sediment by future adult and child residents is within USEPA's target risk range of 1E-04 to 1E-06.

Since the lifetime residential exposure pathway exceeds the carcinogenic risk of 1E-05 and the child residential exposure pathway exceeds a HI of 1, CT risk and hazard estimates for exposure to sediment were calculated for the lifetime and child scenarios (Appendix J, Standard Tables 7.23.CT and 8.19.CT).

The CT noncarcinogenic hazard associated with exposure to sediment by future child residents is below USEPA's target HI of 1 (Table 7-12). The carcinogenic risks associated with exposure to sediment by future lifetime residents are below USEPA's target risk range of 1E-04 to 1E-06.

Lead was selected as a COPC because the maximum detected concentration exceeds the soil-screening level of 400 mg/kg for residential receptors. Therefore, the IEUBK model was used to evaluate the potential impact of lead on the residential receptors (see Section 7.4.3). Potential exposure to children by lead in the sediment is not expected to result in blood-lead concentrations above USEPA's recommended level.

Lead was also selected as a COPC because the maximum detected concentration exceeds the soil-screening level of 1,000 mg/kg for non-residential receptors. Therefore, the adult lead model was used to evaluate the potential impacts to the non-residential receptors (discussed

in Section 7.4.3). The model results indicate that exposure to lead in the sediment by adults is not expected to impact human health at levels above USEPA's acceptable criteria.

Soil (Surface Soil and Subsurface Soil Combined). RME risk and hazard estimates for exposure to soil were calculated for future adult and child residents, construction workers, and other workers (Appendix J, Standard Tables 7.10.RME through 7.14.RME and 8.9.RME through 8.12.RME and summarized in Tables 7-9 and 7-10). Exposure to soil via incidental ingestion and dermal contact was evaluated for all receptors. For the construction worker, exposure to soil via inhalation of fugitive dust was also evaluated.

The noncarcinogenic hazard associated with exposure to soil by future child residents is 5, which exceeds USEPA's target HI of 1. The hazard to the child resident is primarily attributable to ingestion of arsenic and iron. Iron is the only COPC, which contributes an individual HQ above 1. The noncarcinogenic hazards associated with exposure to the remaining receptors are at or below USEPA's target HI of 1. A RME hazard estimate for exposure to soil via inhalation was not calculated for future construction workers (Appendix J, Standard Tables 7.14.RME) because there are no inhalation RfDs available for the COPCS.

The carcinogenic risks associated with exposure to soil for all receptors are within or below USEPA's acceptable risk range of 1E-04 to1E-06.

Since the lifetime residential exposure pathway exceeds the carcinogenic risk of 1E-05 and the child residential exposure pathway exceeds the target HI of 1, CT risk estimates for exposure to soil were calculated (Appendix J, Standard Tables 7.22.CT and 8.17.CT, and summarized in Tables 7-12 and 7-13).

The CT noncarcinogenic hazard associated with exposure to soil by future child residents is below USEPA's target HI of 1. The CT carcinogenic risk associated with exposure to soil by future lifetime residents is within USEPA's target risk range of 1E-04 to 1E-06.

Lead was selected as a COPC for soil because the maximum detected concentration exceeded the soil-screening level of 400 mg/kg for residential receptors. Therefore, the IEUBK model was used to evaluate the potential impact of lead on the residential receptors (discussed in Section 7.4.3). Results of the model indicate that potential exposure to lead in the soil by children is not expected to result in blood-lead concentrations above USEPA's recommended levels.

Lead was also selected as a COPC because the maximum detected concentration exceeded the soil-screening level of 1,000 mg/kg for non-residential receptors. Therefore, the adult lead model was used to evaluate the potential impacts to the non-residential receptors (see Section 7.4.3). Based on the results of this model, lead in the soil is not expected to impact human health at levels above USEPA's acceptable criteria.

Shallow Groundwater. RME risk estimates for exposure to shallow groundwater via dermal contact were calculated for future adult construction workers (Appendix J, Standard Tables 7.19.RME and 8.15.RME, and summarized in Tables 7-9 and 7-10).

The noncarcinogenic hazard is below USEPA's target HI of 1. The carcinogenic risk is below USEPA's target risk range of 1E-04 to 1E-06. Since the estimated calculated risk is below the target risk of 1E-05 and the hazard is less than 1, CT calculations were not performed.

7.5.2.2 Site 4

Surface Soil. RME risk estimates for exposure to surface soil were calculated for current/future adult and adolescent trespassers (Appendix K, Standard Tables 7.1.RME through 7.4.RME and Tables 8.1.RME through 8.4.RME and summarized in Tables 7-15 and 7-16). Exposure to surface soil via incidental ingestion, dermal contact, and inhalation of fugitive dust from the surface soil was evaluated.

The noncarcinogenic hazards associated with exposure to surface soil via incidental ingestion, dermal contact, and inhalation for all receptors are below USEPA's target HI of 1. The carcinogenic risks associated with exposure to surface soil via incidental ingestion, dermal contact, and inhalation by current/future adult and adolescent trespassers are within USEPA's target risk range of 1E-04 to 1E-06. Since the calculated risks and hazards are below the target risk of 1E-05 and HI of 1, CT calculations were not performed.

Lead was selected as a COPC for surface soil because the maximum detected concentration exceeded the soil-screening value of 1,000 mg/kg. The adult lead model was used to evaluate the potential impacts on the receptors (see Section 7.4.3). The adult lead model, which is based on the mean lead concentration, showed that the lead detected in the surface soil is not expected to impact human health at levels above USEPA's acceptable criteria.

Deep Groundwater. RME risk estimates for exposure to deep groundwater were calculated for current/future adult and child residents (Appendix K, Standard Tables 7.5.RME through 7.7.RME, and Tables 8.5.RME and 8.6.RME and summarized in Tables 7-15 and 7-16). Exposure to deep groundwater via incidental ingestion, dermal contact, and inhalation through showering (adults only) was evaluated.

The noncarcinogenic hazard associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future adult residents is 26, which is above USEPA's target HI of 1. The risk to the adult is primarily attributable to ingestion of iron and manganese in the groundwater. Arsenic also contributes an HQ above 1. The noncarcinogenic hazard associated with exposure to deep groundwater via inhalation through showering by current/future adult residents is equal to the USEPA's target HI of 1, associated with inhalation of chloroform.

The noncarcinogenic hazard associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future child residents is 60, which exceeds USEPA's target HI of 1. The hazard to the child resident is primarily attributable to manganese and iron with a small contribution attributable to arsenic. The ingestion pathway contributes over 98 percent of the total HI.

The carcinogenic risk associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future adult and child residents and via inhalation through showering by current/future adult residents exceeds the upper bound of USEPA's target risk range of 1E-04 to 1E-06. The risk is mainly associated with ingestion of arsenic; however, ingestion of bis(2-ethylhexyl)phthalate and chloroform contribute risks within USEPA's target risk range. Bis(2-ethylhexyl)phthalate and chloroform are known potential lab contaminants and it is suspected that the samples reflect artifacts of the analysis process. Additionally, chloroform was detected in the July 1997 samples from both two wells at

concentrations below the MCL, and was not detected in either samples in the two subsequent sampling events conducted.

Since both adult and child resident exposure pathways exceed a HI of 1, and the lifetime resident scenario exceeds a carcinogenic risk of 1E-05, CT risk estimates for exposure to deep groundwater were calculated (Appendix K, Standard Tables 7.20.CT and 7.21.CT and Table 8.16.CT, and summarized in Tables 7-18 and 7-19). The CT noncarcinogenic hazards associated with exposure to deep groundwater via ingestion and dermal contact by current/future adult and child receptors are 5 and 16, respectively, and exceed USEPA's target HI of 1. The hazard to both the adult and child residents is primarily attributable to iron and manganese through the ingestion pathway.

The CT carcinogenic risk associated with exposure to deep groundwater for the lifetime resident is within USEPA's target risk range of 1E-04 to 1E-06.

Surface Water. RME risk estimates for exposure to surface water were calculated for current/future adult and adolescent trespassers, as well as future adult and child residents (Appendix K, Standard Tables 7.8.RME, 7.9.RME, 7.15.RME, 7.16.RME, 8.7.RME, 8.8.RME, and 8.13.RME and summarized in Tables 7-15 and 7-16). Exposure to surface water via dermal contact was evaluated for all receptors.

The noncarcinogenic hazards for all receptors are below USEPA's target hazard of 1. The carcinogenic risks for all receptors are below USEPA's target risk range of 1E-04 to 1E-06.

Lead was selected as a COPC in surface water because the maximum detected concentration of 822 μg/l exceeds the action level of 15 μg/l. However, the action level of 15 μg/l is not necessarily applicable to the surface water, since it is based on potable use of water, and surface water will not be used as a drinking water supply. Dermal contact is the pathway of exposure for surface water. Additionally, the average concentration of lead detected in the surface water (12 μg/l) is below the action level. Therefore, it is not expected that the lead detected in the surface water will adversely impact human health.

Sediment. RME risk and hazard estimates for exposure to sediment were not calculated for current/future adult and adolescent trespassers because there were no COPCs retained for quantitative evaluation. However, RME risk and hazard estimates for exposure to sediment were calculated for future adult and child residents (Appendix K, Standard Tables 7.17.RME, 7.18.RME, and 8.14.RME, and summarized in Tables 7-15 and 7-16). Exposure to sediment via incidental ingestion and dermal contact was evaluated.

The noncarcinogenic hazard associated with exposure to sediment by future adult residents is below USEPA' target HI of 1. The noncarcinogenic hazard of 3 associated with exposure by child residents exceeds USEPA's target HI. The hazard to the child resident is primarily associated with dermal contact with iron in the sediment.

The carcinogenic risk associated with exposure to sediment by future lifetime residents is within USEPA's target risk range of 1E-04 to 1E-06.

Since the lifetime residential exposure pathway exceeded the carcinogenic risk of 1E-05 and the child residential scenario exceeded the HI of 1, CT risk estimates for exposure to

sediment were calculated for lifetime and child scenarios (Appendix K, Standard Tables 7.23.CT and 8.19.CT, and summarized in Tables 7-18 and 7-19).

The CT noncarcinogenic hazard associated with exposure to sediment by a child resident is below USEPA's target HI of 1. The CT carcinogenic risk associated with exposure to sediment by future lifetime residents is within USEPA's target risk range of 1E-04 to 1E-06.

Lead was selected as a COPC because the maximum detected concentration exceeded the soil-screening level of 400 mg/kg for residential receptors. Therefore, the IEUBK model was used to evaluate the potential impact of lead on the residential receptors (see Section 7.4.3). Model results indicate that potential exposure to children by lead in the sediment is not expected to result in blood-lead concentrations above USEPA's recommended level.

Lead was also selected as a COPC because the maximum detected concentration exceeded the soil-screening level of 1,000 mg/kg for non-residential receptors. The adult lead model was used to evaluate the potential impacts to the non-residential receptors (discussed in Section 7.4.3). Exposure to lead in the sediment by adults is not expected to impact human health at levels above USEPA's acceptable criteria.

Soil (Surface Soil and Subsurface Soil Combined). RME risk and hazard estimates for exposure to soil were calculated for future adult and child residents, construction workers, and other workers (Appendix K, Standard Tables 7.10.RME through 7.14.RME and 8.9.RME through 8.12.RME, and summarized in Tables 7-15 and 7-16). Exposure to soil via incidental ingestion and dermal contact was evaluated for all receptors. For the construction worker, exposure to soil via inhalation of fugitive dust was also evaluated.

The noncarcinogenic hazard associated with exposure to soil by future child residents is 5, which exceeds USEPA's target HI of 1. The hazard to the child resident is primarily attributable to arsenic and iron through the ingestion route. Aluminum, antimony, manganese, and thallium via ingestion and manganese via dermal contact also contribute to the hazard, although their individual HQs are below 1. The noncarcinogenic hazards associated with exposure to the remaining receptors are at or below USEPA's target HI of 1.

The carcinogenic risk associated with exposure to soil for all receptors, except the future lifetime resident, are within or below USEPA's acceptable risk range of 1E-04 to1E-06. The carcinogenic risk to the future lifetime resident is 1.3E-04, and is mainly associated with arsenic and benzo(a)pyrene.

Since the lifetime residential and other worker exposure pathways exceed the carcinogenic risk of 1E-05 and the child residential exposure pathway exceeds the target HI of 1, CT risk estimates for exposure to soil were calculated (Appendix K, Standard Tables 7.22.CT, 8.17.CT, and 8.18.CT, and summarized in Tables 7-18 and 7-19).

The CT noncarcinogenic hazard associated with exposure to soil by future child residents is equal to USEPA's target HI of 1. The CT carcinogenic risk associated with exposure to soil by future lifetime residents and future other workers are within or below USEPA's target risk range of 1E-04 to 1E-06.

Lead was selected as a COPC because the maximum detected concentration exceeded the soil-screening level of 400 mg/kg for residential receptors. Therefore, the IEUBK model was used to evaluate the potential impact of lead on the residential receptors (discussed in

Section 7.4.3). Model results indicate that potential exposure to children by lead in the soil is not expected to result in blood-lead concentrations above USEPA's recommended levels.

Lead was also selected as a COPC because the maximum detected concentration exceeded the soil-screening level of 1,000 mg/kg for non-residential receptors. The adult lead model was used to evaluate the potential impacts to the non-residential receptors (see Section 7.4.3). Based on the results of this model, lead in the soil is not expected to impact human health at levels above USEPA's acceptable criteria.

Shallow Groundwater. RME risk estimates for exposure to shallow groundwater via dermal contact were calculated for future adult construction workers (Appendix K, Standard Tables 7.19.RME and 8.15.RME, and summarized in Tables 7-15 and 7-16).

The noncarcinogenic hazard is below USEPA's target HI of 1 and the carcinogenic risk is below USEPA's target risk range of 1E-04 to 1E-06. Since the estimated calculated risk is below the target risk of 1E-05 and the hazard is less than 1, CT calculations were not performed.

Lead was retained as a COPC in shallow groundwater. The maximum detected concentration in the shallow groundwater, 31 μg/l slightly exceeds the action level of 15 μg/l. However, the action level of 15 μg/l is not necessarily applicable to the shallow groundwater, since it is based on potable use of water, and shallow groundwater will not be used as a drinking water supply. Dermal contact is the pathway for exposure to shallow groundwater. Additionally, the mean concentration of lead in the groundwater, 2.5 μg/l, is below the action level. Therefore, it is not expected that the lead detected in the shallow groundwater will adversely impact human health.

7.5.2.3 Sites 5 and 6

Surface Soil. RME risk estimates for exposure to surface soil were calculated for current/future adult and adolescent trespassers (Appendix L, Standard Tables 7.1.RME through 7.4.RME and Tables 8.1.RME through 8.4.RME, and summarized in Tables 7-21 and 7-22). Exposure to surface soil via incidental ingestion, dermal contact, and inhalation of fugitive dust from the surface soil was evaluated.

The noncarcinogenic hazards associated with exposure to surface soil via incidental ingestion, dermal contact, and inhalation for all receptors are below USEPA's target HI of 1. The carcinogenic risks associated with exposure to surface soil via incidental ingestion, dermal contact, and inhalation by current/future adult and adolescent trespassers are within USEPA's target risk range of 1E-04 to 1E-06. Since the estimated calculated risks and hazards are below the target risk range of 1E-05 and target HI of 1, CT calculations were not performed.

Lead was selected as a COPC for surface soil because the maximum detected concentration exceeded the soil-screening value of 1,000 mg/kg. The adult lead model was used to evaluate the potential impacts on the receptors (see Section 7.4.3). The adult lead model, which is based on the mean lead concentration, showed that the lead detected in the surface soil is not expected to impact human health at levels above USEPA's acceptable criteria.

Deep Groundwater. RME risk estimates for exposure to deep groundwater were calculated for current/future adult and child residents (Appendix L, Standard Tables 7.5.RME through

7.7.RME, and Tables 8.5.RME and 8.6.RME and summarized in Tables 7-21 and 7-22). Exposure to deep groundwater via incidental ingestion, dermal contact, and inhalation through showering (adults only) was evaluated.

The noncarcinogenic hazard associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future adult residents is equal to USEPA's target HI of 1. The noncarcinogenic hazard associated with exposure to deep groundwater via inhalation through showering by current/future adult residents is 3, which exceeds USEPA's target HI of 1. The hazard from inhalation to the adult resident is attributable to chloroform. A review of the data shows that chloroform was detected in two July 1997 samples from SJS05-MW01D and SJS05-MW02D, but was not detected in the subsequent sampling rounds. Additionally, chloroform is a known potential lab contaminant and it is suspected that the July 1997 sample results reflect artifacts of the sampling and analysis process.

The noncarcinogenic hazard associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future child residents is 3 and exceeds USEPA's target HI of 1. The hazard to the child resident is primarily attributable to antimony, arsenic, iron, and manganese through the ingestion pathway. Individual hazard quotients for these constituents and all target organs are all equal to or below 1. The ingestion pathway contributes over 99 percent of the total HI.

The carcinogenic risk associated with exposure to deep groundwater via incidental ingestion and dermal contact by current/future adult and child residents and via inhalation through showering by current/future adult residents is equal to the upper bound of USEPA's target risk range of 1E-04 to 1E-06.

Since both adult and child resident exposure pathways exceed a HI of 1, and the lifetime resident scenario exceeds a carcinogenic risk of 1E-05, CT risk estimates for exposure to deep groundwater were calculated (Appendix L, Standard Tables 7.20.CT, 7.21.CT, and 8.16.CT and summarized in Tables 7-24 and 7-25). The CT noncarcinogenic hazard for the child residential receptor is below USEPA's target HI of 1, however, the CT noncarcinogenic hazard for the adult resident receptor is 2, which exceeds USEPA's target hazard index. The CT carcinogenic risk associated with exposure to deep groundwater for the lifetime resident is within USEPA's target risk range of 1E-04 to 1E-06.

Surface Water. RME risk estimates for exposure to surface water were calculated for current/future adult and adolescent trespassers, as well as future adult and child residents (Appendix L, Standard Tables 7.8.RME, 7.9.RME, 7.15.RME, 7.16.RME, 8.7RME, 8.8.RME, and 8.13.RME, and summarized in Tables 7-21 and 7-22). Exposure to surface water via dermal contact was evaluated for all receptors.

The noncarcinogenic hazards for all receptors are below USEPA's target hazard of 1. The carcinogenic risks for all receptors are below USEPA's target risk range of 1E-04 to 1E-06.

Lead was selected as a COPC in surface water because the maximum detected concentration of 4,760 μg/l (and the mean concentration of 684 μg/l) exceeds the action level of 15 μg/l. However, the action level of 15 μg/l is not necessarily applicable to the surface water, since it is based on potable use of water, and surface water will not be used as a drinking water

supply. Dermal contact is the pathway of exposure for surface water. Therefore, it is not expected that the lead detected in the surface water will adversely impact human health.

Sediment. RME risk and hazard estimates for exposure to sediment were not calculated for current/future adult and adolescent trespassers because there were no COPCs retained for quantitative evaluation. However, RME risk and hazard estimates for exposure to sediment were calculated for future adult and child residents (Appendix L, Standard Tables 7.17.RME, 7.18.RME, and 8.14.RME, and summarized in Tables 7-21 and 7-22). Exposure to sediment via incidental ingestion and dermal contact was evaluated.

The noncarcinogenic hazard associated with exposure to sediment by future adult residents was below USEPA' target HI of 1. The noncarcinogenic hazard associated with exposure to sediment by future child residents is 5, which exceeds USEPA's target HI. The hazard to the child resident is primarily associated with ingestion and dermal contact with iron in the sediment.

The carcinogenic risk associated with exposure to sediment by future lifetime residents is within USEPA's target risk range of 1E-04 to 1E-06.

Since the child residential exposure pathway exceeds the HI of 1, and the lifetime residential exposure pathway exceeds the carcinogenic risk of 1E-05, CT risk estimates for exposure to sediment were calculated (Appendix K, Standard Tables 7.23.CT and 8.18.CT).

The CT noncarcinogenic hazard associated with exposure to sediment by future child residents is below USEPA's target HI of 1. The CT carcinogenic risk associated with exposure to sediment by future lifetime residents is within USEPA's target risk range of 1E-04 to 1E-06.

Soil (Surface Soil and Subsurface Soil Combined). RME risk and hazard estimates for exposure to soil were calculated for future adult and child residents, construction workers, and other workers (Appendix L, Standard Tables 7.10.RME through 7.14.RME and 8.9.RME through 8.12.RME, and summarized in Tables 7-21 and 7-22). Exposure to soil via incidental ingestion and dermal contact was evaluated for all receptors. For the construction worker, exposure to soil via inhalation of fugitive dust was also evaluated.

The noncarcinogenic hazard associated with exposure to soil by future child residents is 5 and exceeds USEPA's target HI of 1. The hazard to the child resident is primarily attributable to arsenic and iron through the ingestion pathway. The noncarcinogenic hazards associated with exposure to the remaining receptors are equal to or below USEPA's target HI of 1.

The carcinogenic risk associated with exposure to soil for all receptors are within USEPA's acceptable risk range of 1E-04 to1E-06.

Since the lifetime residential exposure pathway exceeds the carcinogenic risk of 1E-05 and the child residential exposure pathway exceeds the target HI of 1, CT risk estimates for exposure to soil were calculated (Appendix L, Standard Tables 7.22.CT and 8.17.CT, and summarized in Tables 7-24 and 7-25).

The CT noncarcinogenic hazards associated with exposure to soil by future child residents are below USEPA's target HI of 1. The CT carcinogenic risk associated with exposure to soil by future lifetime residents is within USEPA's target risk range of 1E-04 to 1E-06.

Lead was selected as a COPC because the maximum detected concentration exceeded the soil-screening level of 400 mg/kg for residential receptors. Therefore, the IEUBK model was used to evaluate the potential impact of lead on the residential receptors (discussed in Section 7.4.3). Results of the model indicate that potential exposure to children by lead in the soil is not expected to result in blood-lead concentrations above USEPA's recommended levels.

Lead was also selected as a COPC because the maximum detected concentration exceeded the soil-screening level of 1,000 mg/kg for non-residential receptors. The adult lead model was used to evaluate the potential impacts to the non-residential receptors (see Section 7.4.3). Based on the results of this model, lead in the soil is not expected to impact human health at levels above USEPA's acceptable criteria.

Shallow Groundwater. RME risk estimates for exposure to shallow groundwater via dermal contact were calculated for future adult construction workers (Appendix L, Standard Tables 7.19.RME and 8.15.RME, and summarized in Tables 7-21 and 7-22).

The noncarcinogenic hazard is below USEPA's target HI of 1. The carcinogenic risk is below USEPA's target risk range of 1E-04 to 1E-06. Since the estimated calculated risk is below the target risk of 1E-05 and the hazard is less than 1, CT calculations were not performed.

Lead was retained as a COPC in shallow groundwater. The maximum detected concentration of 26.1 μg/l in the shallow groundwater slightly exceeds the action level of 15 μg/l. However, the action level of 15 μg/l is not necessarily applicable to the shallow groundwater, since it is based on potable use of water, and shallow groundwater will not be used as a drinking water supply. Dermal contact is the pathway for exposure to shallow groundwater. Additionally, the average concentration of lead detected in the shallow groundwater (3.1 μg/l) is below the action level. Therefore, it is not expected that the lead detected in the shallow groundwater will adversely impact human health.

7.5.3 Summary of Total Risks Across Pathways and Media

Total potential risks were summarized for current/future adult and adolescent trespassers, current adult, child, and lifetime residents, future adult, child, and lifetime residents, future adult construction worker, and future adult other worker for each site. Tables 7-11, 7-17, and 7-23 present the RME risks to each receptor for Sites 3, 4, and 5/6 respectively. Standard Tables 9.1.RME through 9.10.RME summarize the RME total potential risks to each receptor. Tables 7-14, 7-20, and 7-26 present the CT risks to each receptor for Sites 3, 4, and 5/6, respectively. Standard Tables 9.11.CT through 9.16.CT summarize the CT total potential risks for receptors that have RME risks that exceed the target risk levels of 1E-05 for cancer risk or an HI greater than 1. Standard Table 10s present a summary that shows only the COPCS that contribute a hazard greater than 0.1 or a carcinogenic risk greater than 1E-06 to receptors with noncarcinogenic hazards or carcinogenic risks greater than 1 or 1E-05, respectively. Standard Tables 9s and 10s are located in Appendix J for Site 3, Appendix K for

Site 4, and Appendix L for Site 5/6. The risk assessment results for each site are summarized in the following sections.

7.5.3.1 Site 3

Current/Future Trespasser, Adult (Appendix J, Table 9.1.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to surface soil, surface water, or sediment.

Current/Future Trespasser, Adolescent (Appendix J, Table 9.2.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to surface soil, surface water, or sediment.

Current Resident, Adult (Appendix J, Table 9.3.RME): HI greater than 1 mainly associated with ingestion of manganese and thallium in the groundwater. Neither of these constituents pose HQs above 1, and when separated by target, the HIs are all below 1. The CT hazard is below USEPA's benchmark value (Appendix J, Table 9.11.CT).

Current Resident, Child (Appendix J, Table 9.4.RME): HI exceeds 1, due to ingestion of groundwater. Manganese and thallium each contribute HQs above 1 to the total hazard. The CT current child resident HI is equal to the USEPA benchmark (Appendix J, Table 9.12.CT).

Current Lifetime Resident (Appendix J, Table 9.5.RME): The carcinogenic risk posed by the Site 3 groundwater COPCs to the age-adjusted current lifetime resident is above the target USEPA risk range. Ingestion of arsenic in groundwater is associated with the risk. The CT current lifetime resident carcinogenic risk is within the USEPA target risk range (Appendix J, Table 9.13CT).

Future Resident, Adult (Appendix J, Table 9.6.RME): HI greater than 1 from exposure to groundwater and soil. Chloroform in groundwater contributes an HI above 1 through inhalation while showering. The CT hazard is below USEPA's benchmark value (Appendix J, Table 9.14.CT).

Future Resident, Child (Appendix J, Table 9.7.RME): HI exceeds 1, due to exposure to groundwater, combined surface and subsurface soil, and sediment. Arsenic, manganese, and thallium are the main contributors to the hazard from exposure to deep groundwater. Arsenic and iron (through ingestion) contribute to the HI associated with exposure to the soil, and antimony and iron (through dermal contact) contribute to the HI associated with sediment. The CT future child resident HI exceeds the USEPA benchmark value (Appendix J, Table 9.15.CT), although none of the individual media contributes HIs above 1.

Future Lifetime Resident (Appendix J, Table 9.8.RME): The carcinogenic risk posed by the Site 3 COPCs in deep groundwater, soil, surface water, and sediment to the age-adjusted future lifetime resident is above the target USEPA risk range. This risk is associated with exposure to groundwater, soil, and sediment, however none of the media individually contributes risks above the target USEPA risk range. The arsenic detected in the groundwater, soil, and sediment is the main contributor to this risk. The CT future lifetime resident carcinogenic risk is within the USEPA target risk range (Appendix J, Table 9.16CT).

Future Construction Worker (Appendix J, Table 9.9.RME): HI is equal to USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to soil or shallow groundwater.

Future Other Worker (Appendix J, Table 9.10.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range associated with exposure to combined surface and subsurface soil. No unacceptable health threats are posed to this receptor for exposure to soil.

7.5.3.2 Site 4

Current/Future Trespasser, Adult (Appendix K, Table 9.1.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to surface soil, surface water, or sediment.

Current/Future Trespasser, Adolescent (Appendix K, Table 9.2.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to surface soil, surface water, or sediment.

Current Resident, Adult (Appendix K, Table 9.3.RME): HI greater than 1 mainly associated with ingestion of arsenic, iron, and manganese in the groundwater. The CT hazard is above USEPA's benchmark value (Appendix K, Table 9.11.CT).

Current Resident, Child (Appendix K, Table 9.4.RME): HI exceeds 1, due to ingestion of groundwater. Arsenic, iron, and manganese contribute HQs above 1 to the total hazard. The CT current child resident HI exceeds the USEPA benchmark (Appendix K, Table 9.12.CT).

Current Lifetime Resident (Appendix K, Table 9.5.RME): The carcinogenic risk posed by the Site 4 groundwater COPCs to the age-adjusted future lifetime resident is above the target USEPA risk range. Ingestion of arsenic, bis(2-ethylhexyl)phthalate, and chloroform in groundwater is associated with the risk. The CT current lifetime resident carcinogenic risk is above the USEPA target risk range (Appendix K, Table 9.13CT).

Future Resident, Adult (Appendix K, Table 9.6.RME): HI greater than 1 from exposure to groundwater. Arsenic, iron, and manganese in groundwater contribute HIs above 1 through ingestion. The CT hazard is above USEPA's benchmark value (Appendix K, Table 9.14.CT).

Future Resident, Child (Appendix K, Table 9.7.RME): HI exceeds 1, due to exposure to groundwater, combined surface and subsurface soil, and sediment. Arsenic, iron, and manganese are the main contributors to the hazard from exposure to deep groundwater, which contributes the greatest overall HI. Arsenic and iron (through ingestion) contribute to the HI associated with exposure to the soil, and iron (through dermal contact) contributes to the HI associated with sediment. The CT future child resident HI exceeds the USEPA benchmark value (Appendix K, Table 9.15.CT). Groundwater is the only medium with an HI above 1.

Future Lifetime Resident (Appendix K, Table 9.8.RME): The carcinogenic risk posed by the Site 4 COPCs in deep groundwater, soil, surface water, and sediment to the age-adjusted future lifetime resident is above the target USEPA risk range. This risk is associated with exposure to groundwater soil, and sediment, however groundwater is the only medium that

individually contributes a risk above the target USEPA risk range. The risk associated with groundwater is primarily from ingestion of the arsenic detected in the groundwater. The risk associated with soil is from ingestion of arsenic, and the risk associated with sediment is from dermal contact with arsenic. The CT future lifetime resident carcinogenic risk is greater than the USEPA target risk range (Appendix K, Table 9.16CT).

Future Construction Worker (Appendix K, Table 9.9.RME): HI is equal to USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to soil or shallow groundwater.

Future Other Worker (Appendix K, Table 9.10.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range associated with exposure to combined surface and subsurface soil. No unacceptable health threats are posed to this receptor for exposure to soil.

7.5.3.3 Sites 5 and 6

Current/Future Trespasser, Adult (Appendix L, Table 9.1.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to surface soil, surface water, or sediment.

Current/Future Trespasser, Adolescent (Appendix L, Table 9.2.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to surface soil, surface water, or sediment.

Current Resident, Adult (Appendix L, Table 9.3.RME): HI greater than 1 mainly associated with inhalation of chloroform while showering with the groundwater. The CT hazard is above USEPA's benchmark value (Appendix L, Table 9.11.CT).

Current Resident, Child (Appendix L, Table 9.4.RME): HI exceeds 1, due to ingestion of arsenic, iron, and manganese in groundwater. None of the individual constituents contribute HQs above 1 to the total hazard. The CT current child resident HI is below the USEPA benchmark (Appendix L, Table 9.12.CT).

Current Lifetime Resident (Appendix L, Table 9.5.RME): The carcinogenic risk posed by the Site 5 groundwater COPCs to the age-adjusted future lifetime resident is equal to the upper bound of the target USEPA risk range. Ingestion of arsenic in groundwater is the main risk driver. The CT current lifetime resident carcinogenic risk is within the USEPA target risk range (Appendix L, Table 9.13CT).

Future Resident, Adult (Appendix L, Table 9.6.RME): HI greater than 1 from exposure to groundwater with a small contribution from exposure to combined surface and subsurface soil. Chloroform in groundwater contributes an HI above 1 through inhalation. The CT hazard is above USEPA's benchmark value (Appendix L, Table 9.14.CT).

Future Resident, Child (Appendix L, Table 9.7.RME): HI exceeds 1, due to exposure to groundwater, combined surface and subsurface soil, and sediment. Arsenic, iron, and manganese are the main contributors to the hazard from exposure to deep groundwater. Arsenic and iron (through ingestion) contribute to the HI associated with exposure to the soil, and iron (through dermal contact) contributes to the HI associated with sediment. The

CT future child resident HI exceeds the USEPA benchmark value (Appendix L, Table 9.15.CT). Sediment is the only medium with a CT HI above 1.

Future Lifetime Resident (Appendix L, Table 9.8.RME): The carcinogenic risk posed by the Site 5 COPCs in deep groundwater, soil, surface water, and sediment to the age-adjusted future lifetime resident is above the target USEPA risk range. None of the media individually contributes a risk above the target USEPA risk range. The risk associated with groundwater is primarily from ingestion of the arsenic detected in the groundwater. The risk associated with soil is from ingestion of arsenic, and the risk associated with sediment is from dermal contact with arsenic. The CT future lifetime resident carcinogenic risk is within the USEPA target risk range (Appendix L, Table 9.16CT).

Future Construction Worker (Appendix L, Table 9.9.RME): HI is equal to USEPA benchmark value and carcinogenic risk is within USEPA target risk range. No unacceptable health threats are posed to this receptor for exposure to soil or shallow groundwater.

Future Other Worker (Appendix L, Table 9.10.RME): HI is below USEPA benchmark value and carcinogenic risk is within USEPA target risk range associated with exposure to combined surface and subsurface soil. No unacceptable health threats are posed to this receptor for exposure to soil.

7.6 Uncertainty Associated with Human Health Risk Assessment

The risk measures used in Superfund site risk assessments are not fully probabilistic estimates of risk but are conditional estimates given that a set of assumptions about exposure and toxicity are realized. Thus it is important to specify the assumptions and uncertainties inherent in the risk assessment to place the risk estimates in proper perspective (USEPA, 1989a).

A site-specific discussion on the uncertainties associated with the individual components of the risk assessment is presented in the following sections.

7.6.1 General Uncertainty in COPC Selection

The sampling conducted at all the sites focused on areas of known or suspected contamination. Therefore, the uncertainty in sampling and possibility of missing a contaminated location is expected to be minimal. The uncertainty associated with the data analysis is minimal, as the data have been fully validated prior to use in the risk assessment. The general assumptions used in the COPCs selection process were conservative to ensure that the true COPCs were not eliminated from the quantitative risk assessment and that the highest possible risk was estimated.

Background data were not used to select the COPCs, adding another source of uncertainty in the identification of COPCs. However, soil and groundwater data were compared to background data in Tables 2.1 through 2.12, in Appendices J, K, and L, for Sites 3, 4, and 5, respectively.

The maximum concentration of each COPC selected for Site 3 was above reported background concentrations, except for dibenzo(a,h)anthracene in combined surface and subsurface soil. Elimination of this constituent as a COPC, based on a comparison to background, would not change the results of the Site 3 risk analysis.

The maximum concentration of each COPC selected for Site 4 was above reported background concentrations, except for bis(2-ethylhexyl)phthalate in groundwater and dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, and aluminum in combined surface and subsurface soil. Elimination of these constituents, as COPCs, based on a comparison to background, would not change the results of the Site 4 risk analysis.

The maximum concentration of each COPC selected for Site 5 was above reported background concentrations, except for manganese in deep groundwater and benzo(a)pyrene and benzo(b)fluoranthene in combined surface and subsurface soil. Elimination of these constituents as COPCs, based on a comparison to background, would not change the results of the Site 5/6 risk analysis.

7.6.2 Uncertainty Associated with Exposure Assessment

Some of the exposure pathways evaluated in the risk assessment are assumed, and exposure factors used for quantitation of exposure are conservative and reflect the worst-case or upper-bound assumptions.

The future soil exposure scenario adds additional conservatism by assuming that the subsurface soil will become surface soil after the completion of any potential construction activities at the site. During many construction projects, clean fill material is placed over soil disturbed by excavation. The clean fill is generally needed to support growth of grass and other landscape plants.

The current groundwater exposure scenario is conservative since there are no currently known residential groundwater users, and the risk assessment assumes that concentrations at the exposure point are the same as the concentrations at each site.

The percent of a chemical absorbed through the skin is likely to be affected by many parameters, including soil loading, soil moisture content, organic content, pH, and presence of other constituents. The availability of a chemical for absorption through the skin depends onsite-specific fate and transport properties of the chemical species available for eventual absorption of skin. Chemical concentrations, specific properties of the chemical, and soil release kinetics all impact the amount of a chemical absorbed. These factors contribute to the uncertainty associated with dermal absorption estimates and make quantitation of the amount of certain chemicals absorbed from soil and sediment difficult. The uncertainly in this estimation may especially be seen in the evaluation of absorption of sediment constituents through the skin, which is based on an extremely high sediment absorption factor, particularly for children.

Site-related contamination would be expected to decrease with time. The risk assessment assumed concentrations would remain constant throughout the exposure period (30 years for the residential and trespasser scenarios, 25 years for the other worker, and 0.5 years for the construction worker). This will result in an over-estimation of risk.

7.6.3 Uncertainty Associated with Toxicity Assessment

Uncertainty associated with the noncarcinogenic toxicity factors is included in Standard Tables 5.1 and 5.2 in Appendixes J, K, and L. The uncertainty associated with CSFs is mostly associated with the low dose extrapolation where carcinogenicity at low doses is assumed to be straight-line responses. This is a conservative assumption, which introduces a high uncertainty into SFs, which are from this extrapolated area of the dose-response curve. Most of the experimental studies indicate existence of a threshold for carcinogenicity, which is not accounted for in the development of the CSF.

Carcinogenic SFs developed by the USEPA represent upper bound estimates. Any carcinogenic risks generated in this assessment should be regarded as an upper bound estimate on the potential carcinogenic risks rather than an accurate representation of carcinogenic risk. The true carcinogenic risk is likely to be less than the predicted value.

Additional uncertainty is in the prediction of relative sensitivities of different species of animals and the applicability of animal data to humans.

There is a large degree of uncertainty associated with the oral to dermal adjustment factors (based on chemical-specific gastrointestinal absorption) used to transform the oral RFDs and CSFs based on administered doses to dermal RFDs and CSFs based on absorbed doses. It is not known if the adjustment factors result in an underestimate or overestimate of the actual toxicity associated with dermal exposure.

7.6.4 Uncertainty in Risk Characterization

The uncertainties identified in each component of risk assessment ultimately contribute to uncertainty in risk characterization. The addition of risks and HIs across pathways and chemicals contributes to uncertainty based on the interaction of chemicals such as additivity, synergism, potentiation, and susceptibility of exposed receptors. The simple assumption of additivity used for this assessment may or may not be accurate and may or may not over- or under-estimate risk, however, a better alternative is not available at this time.

7.7 Summary

This baseline risk assessment was conducted to evaluate the potential human health risks associated with the presence of site-related surface soil, soil (surface and subsurface soil combined), surface water, sediment, and deep and shallow groundwater contamination at Site 3, Site 4, and Site 5/6 at the SJCA in Chesapeake, Virginia. This baseline risk assessment was conducted to characterize the current and potential future human health risks at each site if no additional remediation is implemented. As long as the sites are used for industrial purposes only (and not residential uses), there would be no unacceptable hazards or risks to potential receptors, as discussed below. Concentrations of site-related detected constituents in groundwater downgradient of the sites is expected to be less than those onsite, and therefore, downgradient uses of groundwater would result in much lower risks than those calculated at the sites.

7.7.1 Site 3

Appendix J, Standard Tables 9.1.RME through 9.10.RME and Tables 9.11.CT through 9.16.CT summarize the RME and CT potential hazards and risks to each receptor. Appendix J, Standard Tables 10.1.RME through 10.6.RME and 10.7.CT and 10.8.CT show only the chemicals that contributed total HIs greater than 1 or total carcinogenic risks greater than 10^{-5}.

Current and future carcinogenic risks are within or below USEPA's risk range of 1E-04 to 1E-06 for all media for all exposure scenarios (RME and CT) except for the current and future lifetime residents (adult and child combined). A total risk of 2E-04 from all COPCs and pathways for these receptors exceeds USEPA's target risk range (Table 7-11). The main risk driver is arsenic in the deep groundwater, with much smaller contributions from arsenic in the soil and the sediment (for the future scenario only). The CT carcinogenic risk for these receptors is within USEPA's target risk range. Arsenic was not detected in the background groundwater samples, and therefore is expected to be site-related.

Current and future RME noncarcinogenic hazards are at or below USEPA's target HI of 1 for surface soil, surface water, and shallow groundwater for all exposure scenarios.

For deep groundwater, RME noncarcinogenic HIs exceed USEPA's target HI of 1 for current adult and child residents (HIs of 2 and 5, respectively). The HI exceedances are primarily attributable to the ingestion pathway due to the presence of manganese, thallium, and arsenic. The CT noncarcinogenic hazards for these receptors are at or below USEPA's target level of 1.

RME noncarcinogenic hazards exceed USEPA's target HI of 1 for the future adult and child resident scenarios. The adult HI of 4 is primarily attributable to the ingestion of manganese, thallium, and arsenic in the groundwater, however, the individual hazard quotients for each of these constituents are equal to or below 1. The child HI of 30 is primarily attributable to ingestion of manganese, thallium, and arsenic in the groundwater, incidental ingestion of arsenic and iron in the soil, and dermal contact with antimony and iron in the sediment. The CT noncarcinogenic hazard for the future adult receptor is below USEPA's target level of 1. However, the CT noncarcinogenic hazard for the future child receptor of 3 exceeded USEPA's target level. The child HI is primarily attributable to thallium and manganese in deep groundwater and iron in the soil, however, the individual hazard quotients for each of these constituents are below 1. Based on a comparison of the maximum detected concentrations to the background concentrations, all of these constituents are present in site-related media at concentrations above the background levels. It should be noted that thallium exceeded the tap water RBC and MCL in a 1997 sample from the upgradient well but was not detected in the subsequent sampling rounds.

7.7.2 Site 4

Appendix K, Standard Tables 9.1.RME through 9.10.RME and Tables 9.11.CT through 9.16.CT summarize the RME and CT potential hazards and risks to each receptor. Appendix K, Standard Tables 10.1.RME through 10.7.RME and 10.8.CT through 10.14.CT show only the chemicals that contributed total HIs greater than 1 or total carcinogenic risks greater than 10^{-5}.

Current and future carcinogenic risks are within or below USEPA's risk range of 1E-04 to 1E-06 for all media for all exposure scenarios (RME and CT) except for the current and future lifetime residents. A total risk from all COPCs and all pathways of 4E-04 for the current lifetime resident exceeds USEPA's target risk range. The main risk driver is arsenic in the groundwater, with some contribution from bis(2-ethylhexyl)phthalate and chloroform. Bis(2-ethylhexyl)phthalate and chloroform are known potential lab contaminants and it is suspected that the samples reflect artifacts of the analysis process. Additionally, chloroform was detected in the July 1997 samples from both two wells at concentrations below the MCL, and was not detected in either samples in the two subsequent sampling events conducted. The CT carcinogenic risk for this receptor also exceeds USEPA's target risk range. The carcinogenic risk to future lifetime residents (6E-04) exceeds USEPA's target risk range. The main risk drivers are the same as those for the current lifetime residents, with the addition of a small contribution from arsenic in the soil.

Current and future RME noncarcinogenic hazards are within or below USEPA's target HI of 1 for surface soil, surface water, and shallow groundwater for all exposure scenarios.

For deep groundwater, RME noncarcinogenic HIs exceed USEPA's target HI of 1 for current adult and child residents (HIs of 27 and 60, respectively). The HI exceedances are primarily attributable to arsenic, iron, and manganese via the ingestion pathway. The CT noncarcinogenic hazards for these receptors are 6 and 16 for adult and child receptors, respectively, which exceed USEPA's target level of 1. These hazards may primarily be attributed to iron and manganese through the ingestion pathway.

RME noncarcinogenic hazards exceed USEPA's target HI of 1 for the future adult and child resident scenarios. The adult HI of 28 is primarily attributable to the ingestion of iron and manganese in the groundwater. The child HI of 65 is primarily attributable to ingestion of arsenic, iron, and manganese in the groundwater, incidental ingestion of arsenic and iron in the soil, and dermal contact with the iron in the sediment. The CT noncarcinogenic hazards for these receptors are 5 and 17 for adult and child receptors, respectively, which exceed USEPA's target level of 1. The main components contributing to the HI include iron, manganese, and chloroform in the groundwater for the adult and iron and manganese in the groundwater for the child.

The majority of the risks and hazards associated with exposure to Site 4 media are associated with inorganic constituents. Comparison of maximum detected site data to background data does not result in elimination of any of these constituents as COPCs.

7.7.3 Sites 5 and 6

Appendix L, Standard Tables 9.1.RME through 9.10.RME and Tables 9.11.CT through 9.16.CT summarize the RME and CT potential hazards and risks to each receptor. Appendix L, Standard Tables 10.1.RME through 10.6.RME and 10.7.CT and 10.8.CT show only the chemicals that contributed total HIs greater than 1 or total carcinogenic risks greater than 10^{-5}.

Current and future risks are within or below USEPA's risk range of 1E-04 to 1E-06 for all media for all exposure scenarios (RME and CT) except for the future lifetime resident (adult and child combined). A total risk from all COPCs and pathways of 2E-04 for this receptor exceeds USEPA's target risk range (Table 7-23). The risk drivers are arsenic in the deep groundwater, the soil, and the sediment, and chloroform in the deep groundwater. The CT

carcinogenic risk for this receptor is within USEPA's target risk range. Current and future RME hazards are at or below USEPA's target HI of 1 for surface soil, surface water, and shallow groundwater for all exposure scenarios.

For deep groundwater, RME noncarcinogenic HIs exceed USEPA's target HI of 1 for current adult and child residents (HIs of 5 and 3, respectively). The HI exceedances are primarily attributable to chloroform via the inhalation pathway for adults and contributions from the ingestion pathway due to the presence of antimony, arsenic, iron, and manganese for adult and child residents. None of the individual contributors to the ingestion HI exceed an HQ of 1. The CT noncarcinogenic hazard for the child is below USEPA's target level of 1. The CT noncarcinogenic hazard for the adult exceeds USEPA's target level of 1 due to inhalation of chloroform in the groundwater. A review of the data shows that chloroform was detected in two July 1997 samples from SJS05-MW01D and SJS05-MW02D but was not detected in the subsequent sampling rounds. Additionally, chloroform is a known potential lab contaminant and it is suspected that the July 1997 sample results reflect artifacts of the sampling and analysis process.

RME noncarcinogenic hazards exceed USEPA's target HI of 1 for the future adult and child resident scenarios. The adult HI of 6 is primarily attributable to the inhalation of chloroform via showering and ingestion of arsenic, iron, and manganese in the groundwater. The child HI of 18 is primarily attributable to ingestion of antimony, arsenic, iron, and manganese in the groundwater, the incidental ingestion of arsenic and iron in the soil, and incidental ingestion of and dermal contact with arsenic and iron in the sediment. The CT noncarcinogenic hazard for the future adult receptor of 3 exceeds USEPA's target level. The adult HI is primarily attributable to chloroform in deep groundwater. The CT noncarcinogenic hazard to the future child receptor of 2 is primarily attributable to antimony, arsenic, iron, and manganese in the deep groundwater, iron in the soil, and arsenic in the sediment, however, the individual hazard quotients for each of these constituents are below 1.

7.8 References

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SECTION 8

Screening Ecological Risk Assessment and Step 3

This section presents a screening ecological risk assessment (SERA) and Step 3 of the Baseline Ecological Risk Assessment (BERA) for Sites 3 (Waste Disposal Area), 4 (Landfill D), 5 (Burning Grounds), and 6 (Caged Pit) of the St. Juliens Creek Annex, Chesapeake, Virginia. The SERA, which constitutes Steps 1 and 2 of the 8 step ecological risk assessment (ERA) process, was conducted in accordance with the Navy policy for conducting ERAs (CNO, 1999). This approach is generally consistent with the Navy/Tier II ERA approach developed for Region 3 and the general approach developed by the USEPA for conducting ERAs (USEPA, 1997). The objectives of the SERA are to:

- Determine if (1) assessment is necessary beyond the conservative screening steps of the ERA process (ecological risks possible), (2) one or more sites can be removed from further ecological consideration (no potential ecological risks), and (3) one or more chemicals can be eliminated from further evaluation based on the absence of potential exposure pathways or a potential site-related risk.
- Identify potential data gaps or unacceptable uncertainty requiring the collection of additional data to support ERA evaluations beyond the screening level.

At the conclusion of the SERA, there are four possible decision points:

- **No further action is warranted.** This decision is appropriate if the SERA indicates that sufficient data are available on which to base a conclusion of no unacceptable risk with acceptable uncertainty.
- **Further evaluation is warranted.** This decision is appropriate if the SERA indicates that there is the potential for unacceptable risks for some pathways, receptors, and chemicals. In this instance, the ERA would progress to Step 3 of the 8-step process.
- **Further data are required.** This decision is appropriate if the SERA indicates that there are insufficient data on which to base a risk estimate. This decision may also be appropriate if the potential for unacceptable risks is identified following the SERA and additional data to refine these estimates (e.g., additional analytical data, measures of bioavailability, etc.) are needed for Step 3.
- **Remedial action required.** This decision may be appropriate for circumstances in which the potential for unacceptable risks was identified following the SERA but these potential risks could best be addressed through remedial action (e.g., presumptive remedy, soil removal) rather than additional study.

[1] Because of its small size and proximity to the Burning Grounds, Site 6 was combined with Site 5 for analysis in the ERA. The combined Sites 5 and 6 will be referred to as Site 5/6 throughout the remaining portions of this risk assessment.

Since the results of the SERA indicated the potential for unacceptable risks (see Section 8.3), this evaluation also includes the first step (Step 3) of the baseline ecological risk assessment (BERA). The CNO policy, which describes a process consisting of eight steps organized into three tiers, is an interpretation of the eight-step process outlined in U.S. Environmental Protection Agency (USEPA) ERA guidance for the Superfund program (USEPA 1997). The major differences between the Navy ERA policy and the USEPA ERA guidance are: (1) the Navy policy provides clearly defined criteria for exiting the ERA process at specific points, (2) the Navy policy divides Step 3 (the first step of the baseline ERA) into two distinct sub-steps (Steps 3A and 3B), with a potential exit point after Step 3A, and (3) the Navy policy incorporates risk management considerations throughout all tiers of the ERA process.

In Step 3A, a refined evaluation of media concentrations and exposure estimates is conducted using more realistic assumptions and additional methodologies relative to those used in the SERA, which is intended to be a very conservative assessment. If risk estimates (and their associated uncertainty) are acceptable following Step 3A, the site will meet the conditions of the exit criterion specified in the Navy guidance and the ERA process is complete. If the Step 3A evaluation does not support an acceptable risk determination, the site continues to Step 3B. In Step 3B, the preliminary conceptual model presented in the SERA is refined based on the results of Step 3A to develop a revised list of receptors, COPCs, assessment endpoints, and measurement endpoints. Based upon the revised conceptual model, the lines of evidence to be used in characterizing risk are determined. The revised problem formulation serves as a basis for development of necessary site-specific studies (Step 4) if they are needed.

The SERA and Step 3A are presented as follows:

- **Section 8.1—Facility Background and Environmental Setting.** Describes the environmental setting (e.g., physiographic features, habitats and biota) of the St. Juliens Creek Annex and Sites 3, 4, and 5/6[2].

- **Section 8.2—General Approach and Methodology**. Develops the preliminary problem formulation for Sites 3, 4, and 5/6 and outlines and describes the specific technical approaches, methodologies, models, and parameter values that are used in the SERA for the exposure estimation, effects evaluation, and risk calculation. This section includes those items that are common to all of the sites evaluated in this SERA. This section also describes the refinement of the conservative exposure assumptions used in Step 3A.

- **Section 8.3—Chemical Concentrations and Risk Calculations (Steps 2 and 3A).** Provides summaries of the media-specific/site-specific chemical data, a summary of the SERA and BERA (Step 3A) risk calculation results (i.e., HQs) and a list of COPCs. Uncertainties associated with risk estimates are discussed in this section.

- **Section 8.4—Problem Formulation Revision (Step 3B).** Further characterizes and evaluates the potential ecological risks indicated in Step 3A by comparing site-related chemical concentrations to available background concentrations, evaluating the bioavailability of selected COPCs, and characterizing the distribution of chemicals associated with the site.

[2] Because of its small size and proximity to the Burning Grounds, Site 6 was combined with Site 5 for analysis in the ERA. The combined Sites 5 and 6 will be referred to as Site 5/6 throughout the remaining portions of this risk assessment.

- **Section 8.5- Baseline Problem Formulation (Step 3B).** Identifies complete exposure pathways and revises assessment endpoints and risk hypotheses/questions based on the outcomes of the Step 3A risk calculations and Problem Formulation Revision.

Supporting technical data for this ERA are provided in Appendix M.

8.1 Facility Background and Environmental Setting

This section describes the environmental setting (e.g., physiographic features, habitats and biota) of Sites 3, 4, 5/6. Please refer to earlier sections of the RI for a detailed description of the Annex location and history and a summary of past site investigations.

8.1.1 Physiographic Features

The following sections describe the soil type and surface water resources present at the St. Juliens Creek Annex. Please refer to earlier sections of the RI for a detailed description of climate and topography at the Annex.

8.1.1.1 Soils

Soils on and in the vicinity of the Annex have been surveyed and identified (USDA-NRCS, 1983). Figure 8-1 depicts the soil types at Site 3, 4 and 5/6. The predominant soil type is dredge fill, which comprises more than 95-percent of the soil type on these sites. Dredge fill consists of former sediment or river/stream bank material removed from the Southern Branch of the Elizabeth River and possibly Blows Creek. This soil is comprised of silty or sandy material and is typically poorly drained. Bohicket soil, which consists of poorly drained silt clay loam, borders Blows Creek.

8.1.1.2 Surface Water

The primary water body in the vicinity of Sites 3, 4, and 5/6 is Blows Creek, a tributary to the Southern Branch of the Elizabeth River. This tidally-influenced brackish water body is located to the south of Sites 3, 4, and 5/6. The main headwaters of Blows Creek originate in the Craddock District, a residential housing area located to the north/northwest of the Annex, though most (>90 percent) of the length of Blows Creek is located on Annex property. Blows Creek joins the Southern Branch of the Elizabeth River immediately to the southeast of Site 4. The Southern Branch of the Elizabeth River originates approximately 4 to 5 mi. southwest of the Annex near the Dismal Swamp. From the swamp lands, the Southern Branch of the Elizabeth River passes through highly developed areas upstream and adjacent to the Annex before it discharges into the James River (about 7 mi. to the north). The James River joins the southern reaches of the Chesapeake Bay about 5 mi. to the east of the Annex.

Surface water quality parameters (e.g., temperature, DO, temperature, salinity) and sediment characteristics (e.g., grain size, TOC) measured in the drainage ditches associated with the site and in Blows Creek are summarized in Table 8-1.

8.1.2 Habitats and Biota

The following sections provide a general overview of the terrestrial, wetland, and aquatic habitats and biota present at the Annex and a detailed description of the habitats present on

each of the sites. Figure 8-2 depicts the habitat types and distribution occurring in the study area. Information regarding rare, threatened and endangered species is also presented in this section.

8.1.2.1 Terrestrial and Wetland Habitats

As shown in Figure 8-2, mowed grass fields represent the dominant habitat type on Sites 3, 4, and 5/6. These fields are dominated by pioneering species that can exist in degraded habitats, such as crab grass, Kentucky bluegrass, and deer tongue. Scrub/shrub habitats represent another important habitat type, occurring mostly as transitional zones between forested areas and grassy fields and in previously disturbed but unmowed areas around the Sites. Scrub/shrub habitats are comprised mostly of raspberry, poison ivy, honeysuckle, and Virginia creeper. Forested communities around Sites 3, 4, and 5/6 typically represent fringes of larger communities that extend offsite to adjacent areas. The forested area canopy consist of loblolly pine, sweet gum, red oak, red cedar, tree of heaven, northern catalpa, and white mulberry. The sub-canopy consists of black locust, black cherry, choke cherry, and silver maple. Green briar, poison ivy, Virginia creeper, honeysuckle, and saplings of the canopy and sub-canopy trees make up the majority of the groundcover.

Emergent wetlands are present along inland drainages, some seasonally flooded depressions, and along the Blows Creek shoreline. The inland wetland areas associated with the drainages and depressions are dominated by common reed, phragmites, high-tide bush, wax myrtle, and/or a variety of grasses. The wetlands along Blows Creek are dominated by smooth cordgrass with patches of black rush.

The grassy and woodland habitats at Sites 3, 4 and 5/6 are expected to support a variety of soil invertebrates (e.g., insects and earthworms) and a variety of small mammals such as mice, shrew, and squirrel. Small mammals in the grassy field, scrub/shrub and forested habitats likely forage on a variety of invertebrate and plant material (e.g., seeds, nuts, berries, etc.). A variety of larger mammals, such as the gray fox, are known to occur in this area and are expected to feed on small mammals and birds. A diversity of bird species are known to frequent the Annex. Birds such as blackbirds, crow, towhee, dove, vireo and bobwhite can be supported by the invertebrates and vegetation in upland habitats. Avian predators such as the osprey, kestrel, red-tailed hawk also have been observed at the Annex. Osprey feed primarily on fish, while hawk and kestrel feed primarily on small mammals, birds, reptiles, and insects. A representative list of the terrestrial and wetland wildlife species known or expected to occur on the sites being evaluated is provided in Appendix M.

8.1.2.2 Aquatic Habitats

Blows Creek and the Southern Branch of the Elizabeth River, into which Blows Creek discharges, comprise the largest aquatic habitats associated with Sites 3, 4, and 5/6. The aquatic habitats present in the tidally-influenced portion of Blows Creek (consisting of the main body of Blows Creek and the lower reaches of the site-related drainages) are expected to support a variety of both resident and migratory aquatic species similar to those present in the Southern Branch of the Elizabeth River, while the drainages above the area of tidal influence are expected to provide periodic habitat for a limited number of opportunistic freshwater aquatic species. The drainages above the area of tidal influence are expected to provide limited aquatic habitat for the following reasons:

- Drainages above the area of tidal influence are very small and in many cases only contain water immediately following storm events,
- Limited/transient water in these drainages provides little opportunity for aquatic life from the main body of Blows Creek to disperse into these upstream areas; and,
- Upland drainages contain little or no sediment and in many cases are covered with grass/mowed lawn or hard-packed clay, thus providing little viable substrate for aquatic species, particularly benthic-dwelling organisms.

The portions of the drainages above the area typically influenced by tidal flux are identified as "upland drainage" in Figure 8-2, while the portions of the drainages within the area typically influenced by tidal flux are identified as "lower drainage." As shown in Figure 8-2, the division between the upland and lower drainages is also the approximate location where the mixed forest/scrub shrub habitat transitions to wetland/marsh habitat. A more detailed evaluation of the viability of each upland drainage is presented in the Section 8.1.2.3.Benthic invertebrates inhabiting the tidally-influenced portion of the drainages, Blows Creek, and the Southern Branch of the Elizabeth River (i.e., near the Annex) are expected to include aquatic insects (e.g., chironomids, hellgrammites), crustaceans (e.g., amphipods, isopods, and crab), annelids (e.g., polychaetes and oligochaetes), and mollusks (e.g., clams, mussels, whelk) that are typical of brackish habitats in the Chesapeake Bay. Water column dwelling aquatic invertebrates known to occur in these waters include cnidarians (e.g., jellyfish and anemones), crustaceans (e.g., shrimp, crabs, and amphipods), and aquatic insects (e.g., diving beetles, water boatman, and water striders).

It is likely that several fish species occurring in the upper Bay as larvae or eggs, spawn in the waters adjacent to the Annex (Lippson and Lippson, 1997). In addition, various marine and freshwater (brackish tolerant) fish species use these areas as important feeding habitats. A representative list of the fish species likely to occur in these areas is presented in Appendix M and discussed below.

The most common benthic feeding fish species likely to be found in Blows Creek and the Elizabeth River include the catfish *(Ictalurus sp.)*, brown bullhead (*Ameriurus nebulosus*), carp (*Cyprinus carpio*), marine spot (*Leiostomus xanthurus*), eel (*Anguilla rostrata*), hogchocker (*Trinectes maculatus*), and killifish (*Fundulus* spp.), such as the mummichog (*Fundulus heteroclitus*). Catfish are omnivorous, spawning in the spring or early summer. Carp are predominantly herbivorous fishes, also spawning in the spring or early summer. Spot *(Leiostomus xanthurus)* are abundant and robust bottom foraging fishes located throughout the reaches of the Chesapeake Bay. Spot prefer mud substrates and are predators of shallow benthic invertebrate communities (Funderburk et al., 1991). Eels are catadromous fishes, living in fresh water but spawning in Atlantic Ocean waters. Hogchokers are small flatfishes that remain in rivers, shallows, and deep water year-round and spawn in the summer. Killifish (*Fundulus* spp.) such as the mummichog (*Fundulus heteroclitus*) are small omnivorous fishes that tend to inhabit shallow areas along the shoreline and in creeks and are very tolerant to a wide range of temperature, salinity, and oxygen-depleted waters.

Some of the most common water column feeding species likely to be found in the lower reaches of Blows Creek and the Elizabeth River (i.e., near the Annex) include striped bass (*Morone saxatilis*), Atlantic menhaden (*Brevoortia tyrannus)*, and white perch (*Morone*

americana). White perch are semi-anadromous fishes that occupy an important link between small invertebrates and higher piscivorous predators. Striped bass spawn in tidal tributaries during the middle of spring and their eggs, larvae, and juveniles are also important prey for higher predators (Funderburk et al., 1991). Atlantic menhaden are the second most harvested fishes in the United States, spawning mostly in coastal ocean waters. Menhaden are prey to many predatory fish and birds, thus providing an important link in the food web.

A number avian species and, to a lesser extent, mammals and reptiles are likely to forage in the aquatic habitats associated with the Annex. The diets of birds such as the belted kingfisher, great blue heron, and snowy egret are comprised almost entirely of fish and aquatic invertebrates. Other wading shore birds such as the ruddy turnstone, and the greater or lesser yellowlegs forage on aquatic invertebrates along the waters edge and muddy flats. Water fowl such as mergansers, mallard ducks, and cormorants typically feed on the small crustaceans and fish from the shallows, while mallards graze mostly on aquatic vegetation, algae, snails and insects. Appendix M provides a representative list of birds that are thought to utilize aquatic habitats on or adjacent to the Annex.

A variety of mammal species are expected to forage in surface waters associated with Blows Creek. Muskrat, for example, commonly forage for crustaceans and fish in fresh and brackish water streams and rivers. Raccoon also commonly forage in these shallow water habitats. Appendix M provides a representative list of mammals that are thought to utilize habitats on or adjacent to the Annex.

The herpetofaunal community is likely to be somewhat limited by the salinity levels associated with Blows Creek and the Southern Branch of the Elizabeth River. The freshwater habitats provided by the drainages are expected to support a greater diversity of these species. At least seven species of turtles, three species of frogs, and two species of snakes can potentially occur around these areas. A representative list of amphibian and reptile species that are likely to be associated with this habitat is provided in Appendix M.

8.1.2.3 Site-Specific Habitats

This section provides a detailed description of the habitats present on Sites 3, 4, and 5/6. Figure 8-2 depicts the distribution of habitats present on each of these areas.

Site 3. The majority of Site 3 (98 percent) is comprised of grassy field that is managed and maintained by regular mowing. Seasonally flooded depressions occur throughout the field, supporting wetland vegetative communities. There are two possible wetland areas on Site 3 that comprise approximately 2 percent of the total habitat area. One possible wetland area is located along the drainage ditch at the western side of the site and is dominated by common reed. Another possible wetland area is located along the northern boundary of the Site and contains a variety of grass species.

Drainage ditches and depressions on Site 3 temporarily contain surface water following storm events. Site 3 is, accordingly, not expected to support a viable aquatic community.

Site 4. Scrub/shrub community and mowed grassland habitat comprise the dominant Site 4 habitat. Scrub/shrub community and mixed forest comprises approximately 55 percent of the total Site 4 habitat area in the central to western section of Site 4. Mowed grassland habitat comprises approximately 25 percent of the Site 4 habitat area and is located in the

north to northeastern portion of Site 4. Wetland habitats, which comprise approximately 20 percent of the Site 4 habitat area, are present in some isolated, seasonally flooded depressions (freshwater) and adjacent to Blows Creek. Small isolated freshwater wetlands are, for example, located just north of the landfill. Most of these habitats represent portions of larger communities that extend to areas outside the bounds of Site 4 (see Figure 8-2).

The vegetative communities along Blows Creek are influenced by man-made alterations to the topography. For example, a berm is located along the north side of Blows Creek. The berm forms a dividing line between the wetland habitat adjacent to Blows Creek and the contiguous forested area. A distinct topographic change is also present between the scrub/shrub area and the wetlands associated with the landfill.

The drainage diverting fresh water run-off into Blows Creek, along the eastern side of Site 4, contains water for limited time periods and is expected to provide habitat for a limited number of opportunistic species (i.e., tolerant and transient aquatic species)

Site 5/6. The habitats within and adjacent to Site 5/6 include grassland, scrub/shrub, wetlands, and forested habitats. The majority of the Burning Grounds is mowed grassland (approximately 75 percent of Site 5/6 total habitat area; located in the northern portion of the Burning Grounds), gravel and/or paved (approximately 15 percent of the total habitat area), scrub/shrub habitat (approximately 5 percent of Site 5/6 total habitat area; along the transition to the grassland at the southern edge of the Burning Grounds), and isolated forest (approximately 5 percent of Site 5/6 total habitat area; located to the west of the Burning Ground and adjacent to the caged pit to the south). A drainage ditch aligned approximately north/south between the Burning Grounds and the Caged Pit carries storm water to the south towards Blows Creek. Wetland communities, which comprise approximately 5 percent of the Site 5/6 habitat area, are associated with this drainage ditch. This drainage is expected to provide fresh water habitat for a limited number of opportunistic species (i.e., tolerant and transient aquatic species) in the area above tidal influence.

8.1.2.4 Rare, Threatened, and Endangered Species

Rare, threatened, and endangered species information was requested from the Virginia Department of Conservation and Recreation, Division of Natural Heritage (DNH), the Commonwealth of Virginia Department of Game and Inland Fisheries, Office of Plant and Pest Services, and the U. S. Fish and Wildlife Service (USFWS). Correspondence with these agencies can be seen in Appendix M. These results were updated and verified by checking the DNH, Virginia Department of Game and Inland Fisheries, and USFWS web sites for rare and endangered species (http://www.dcr.state.va.us/dnh/rare.htm, http://www.dgif.state.va.us/wildlife/index.cfm, and http://endangered.fws.gov/). The updated information, in conjunction with the earlier reports indicate that no rare, threatened, or endangered wildlife species are known to occur at the Annex, with the possible exception of occasional transient species.

The following three listed species reside or migrate through southeastern Virginia and could periodically occur at the Annex:

- **Peregrine falcon (*Falco peregrinus*)-** Listed as endangered in the commonwealth of Virginia, the peregrine falcon can be found in coastal areas during migration, particularly in September and October. In addition, hacking stations (release areas) have

been established for the peregrine falcon on the Eastern Shore and in Back Bay National Wildlife Refuge (RGH, 1984).

- **Bald eagle (*Haliaeetus leucocephalus*)**—This species is listed as endangered in the Commonwealth of Virginia and threatened in portions of the lower 48 United States. The bald eagle was proposed for removal from the federal list in July 1999. Virginia provides prime habitat for the bald eagle. In 1978, 37 active nests were located in the state (RGH, 1984). There are currently no known bald eagles nesting within the Annex. Some eagles, however, do winter along area beaches or pass through the region during migration.
- **Swainson's warbler (*Limnothlypis swainsonii*)**—This species is known to inhabit areas with abundant giant cane. However, this habitat does not occur at the Annex, limiting the potential for this species to occur onsite.

According to the DNH report, no natural heritage resources have been documented within a 2-mile radius of the St. Juliens Creek Annex. Outside of the 2-mile radius several natural heritage resources were documented. A list of these species is provided in Appendix M.

8.2 General Approach and Methodology

The following sections develop the approach and methodology that was used in the SERA and Step 3A evaluation of Sites 3, 4, and 5/6. This section first develops preliminary conceptual models for the site as part of the overall problem formulation (Section 8.2.1). The conceptual model identifies transport and exposure pathways/routes, measurement/assessment endpoints, the risk hypotheses and the selection of surrogate receptors. Following development of the problem formulation, the approach for calculating risk to potential ecological receptors from direct exposure to chemicals and from exposure to chemicals accumulated in the food web is established. This includes a description of the approach for identifying/calculating toxicity values for screening potential effects (Section 8.2.2), estimating exposure of receptors to chemicals via direct contact and food web exposure (Section 8.2.3), and calculating risk for both direct contact and food web scenarios (Section 8.2.4). These latter sections describe the approach used for calculating risk with both the screening level and Step 3A risk scenarios.

8.2.1 Screening-Level Problem Formulation

The problem formulation establishes the goals, scope, and focus of the SERA. As part of problem formulation, a conceptual model is developed that describes potential sources, potential transport pathways, potential exposure pathways and routes, and potential receptors associated with each site. Assessment endpoints, measurement endpoints, and risk hypotheses are then selected to evaluate receptors for which complete and potentially significant exposure pathways are likely to exist. The fate and transport of the chemicals present at a site are also considered during this process.

8.2.1.1 Preliminary Conceptual Model

Important components of the preliminary conceptual model include the identification of potential contaminant sources, transport pathways, exposure media, potential exposure

routes, and potential receptor groups. A summary of pathways/routes by which ecological receptors could be exposed to chemicals originating from each site, which is an important component of the overall conceptual model, is presented in Figure 8-3 and discussed in the following sections.

8.2.1.2 Transport Pathways

A transport pathway describes the mechanisms whereby chemicals may be transported from a source of contamination to ecologically relevant media. Potentially complete pathways identified in this section are subsequently evaluated in the ERA.

Chemicals are likely to have entered surface soil at Sites 3, 4, and 5/6 via direct release associated with historic activities. As discussed above, viable terrestrial habitats occur throughout all of the sites and terrestrial life could be exposed to chemicals in this media. Chemicals could reach subsurface soil by past site activities (primarily at Sites 3 and 4) and by historic ignition and burning activities within the caged pit and burning grounds at Site 5/6. Once present in surface soil, chemicals also have the potential to reach subsurface soil via infiltration. Subsurface soil is considered inaccessible to most wildlife and was not selected as an exposure medium for evaluation in the SERA.

Several surface soil samples were excluded for use in the SERA based on their locations with respect to their respective sites. For Site 3, the following samples were excluded: SS01 because it was collected from across the road north of the site; samples SS15 and SS16 were collected from a drainage ditch to the west and across from the site. For Site 4, the following samples were excluded because they were collected north of the site and, hence, were converted to background samples: SS19 (renamed SJSBK-SS48), SS20 (renamed SJSBK-SS49), SS21 (renamed SJSBK-SS47), and SS22 (renamed SJSBK-SS50). For Site 5, SS17 was excluded because it was collected from across the drainage ditch to the east of the site in an area where runoff from Site 5 will not be received. Moreover, samples SS25, SS26, SS27, and SS28 were excluded because they are not related to Site 5. They were collected to the southeast of and across a drainage ditch from Site 5 in the vicinity of the drop tower.

Chemicals in subsurface soil at all sites could infiltrate into groundwater. Once in groundwater, chemicals are considered inaccessible to wildlife. There is, however, the potential for chemicals in groundwater to discharge through sediment to surface water and would once again be accessible to wildlife. There is the potential for groundwater from the Columbia (surficial) Aquifer at all sites to discharge to sediment and surface water in Blows Creek and in the site drainages during high groundwater table conditions. This potential exposure pathway was accordingly considered in this ERA.

The direct evaluation of groundwater (for its potential to impact surface water and sediment) is most relevant in situations where there is little or no sediment or surface water data. Surface water and sediment data were collected at all sites and in Blows Creek and will therefore be the primary source of data used to quantitatively evaluate the potential for groundwater to adversely affect potential ecological receptors. As a conservative measure, however, chemicals detected in groundwater were screened to determine if this media could be a source of chemicals to surface water.

Chemicals at all sites could enter surface water bodies via surficial runoff from soil. Surficial runoff from all sites has the potential to enter drainage ditches where it could be transported

to Blows Creek and ultimately to the Southern Branch of the Elizabeth River and potentially adversely affect aquatic life. Drainage ditches associated with the southern portions of Sites 4 and 5/6 contain adequate water to be considered viable aquatic habitats. Accordingly, chemicals originating from Sites 4 and 5/6 have the potential to adversely affect aquatic life in these areas. The ditches associated with Site 3 are dry throughout most of the year and do not provide viable aquatic habitat. As discussed above, however, chemicals originating from all sites (including Site 3) have the potential to be transported via surface water/sediment to Blows Creek and the Elizabeth River where a broader range of aquatic life could be exposed to chemicals.

In addition to the site-related sources discussed above, chemicals originating from non site-related sources have potential to enter Blows Creek. Surficial runoff from the Craddock District could transport chemicals present in the surface soils and storm water runoff from this residential area to Blows Creek and the Elizabeth River. Typical urban residential chemicals that might be found on the surface and thus occur in the Creek include pesticides, herbicides, and petroleum compounds. Non site-related chemicals originating in the sediments and surface water of the Southern Branch of the Elizabeth River could also be transported up into Blows Creek, primarily as a result of tidal flux. Finally, Annex-related activities unrelated to Sites 3, 4, and 5/6 (e.g., AOC 1 may contribute PAHs) could also be a potential source of chemicals to Blows Creek and the Southern Branch of the Elizabeth River. Following transport, aquatic life present in these water bodies could be exposed to these non site-related chemicals.

Chemicals could partition to sediment following discharge to surface water. In general, chemical concentrations in sediment resulting from these transport pathways are a function of distance from the source(s), chemical fate properties, sediment type, and water velocity. The water velocity is expected to be low in the ditches/marshes immediately downgradient from Sites 3, 4, and 5/6. These potentially site-impacted areas are accordingly expected to constitute depositional sinks where chemicals could adsorb and precipitate to sediments. Chemicals may be remobilized and transported from these sinks by various physical events and chemical processes (e.g., storm events, tidal forces).

8.2.1.3 Exposure Pathways and Routes

An exposure pathway links a source of contamination with one or more receptors. Exposure, and thus potential risk, can only occur if complete exposure pathways exist. Figure 8-3 shows the potentially complete exposure pathways. A discussion of these pathways and routes that are evaluated in the SERA is provided in this section.

An exposure route describes the specific mechanism(s) by which a receptor is exposed to a chemical present in an environmental medium. Terrestrial plants may be exposed through their root surfaces during water and nutrient uptake to chemicals present in surface soils. Unrooted, floating aquatic plants, and rooted submerged vascular aquatic plants and algae, may be exposed to chemicals directly from the water or, for rooted plants, from sediments.

Animals may be exposed to chemicals through: (1) the inhalation of gaseous chemicals or of chemicals adhered to particulate matter; (2) the incidental ingestion of contaminated abiotic media (e.g., soil or sediment) during feeding activities; (3) the ingestion of contaminated water; (4) the ingestion of contaminated plant and/or animal tissues for chemicals which

have entered the food chain; and/or (5) dermal contact with contaminated abiotic media. These exposure routes, where applicable, are also depicted in the preliminary conceptual models.

Based on the expected fate properties (e.g., relatively high adsorption to solids) of the chemicals commonly present on these sites (generally inorganic chemicals and PAHs) and the protection offered by hair or feathers, dermal and inhalation exposures for upper trophic level receptor species are not considered significant relative to ingestion exposures and are therefore not evaluated in the SERA. Incidental ingestion of soil or sediment during feeding, preening, or grooming activities is, however, considered in the risk estimates. Direct contact is considered for lower trophic level receptors (e.g., invertebrates).

Direct ingestion of drinking water is only considered at sites where the salinity is below 15 parts per thousand (ppt), the approximate toxic threshold for wildlife receptors (Humphreys, 1988). The salinity measured in the site-associated ditches ranged from 0.1 to 9.7 ppt and the salinity measured in Blows Creek ranged from 0.8 to 12.1 ppt, which is below the toxic threshold. Because the drainage ditch adjacent to Site 4 and the phragmites area located east of Site 5/6 are freshwater and because the salinity of Blows Creek is below the toxic threshold it was concluded these water bodies are probable sources of drinking water. Thus, drinking water exposures were evaluated for Sites 4 and 5/6. Site 3 is considered unlikely to be a source of drinking water because it is dry throughout most of the year and would not provide a meaningful source of drinking water.

Based on salinity, Blows Creek and the Southern Branch of the Elizabeth River are unlikely to support amphibians. Amphibians, however, could occur in the freshwater habitats provided by the drainages and wetland areas at Sites 4 and 5/6. Potentially complete exposure pathways are expected to be present for reptiles at most sites.

Endpoints and Risk Hypotheses. The conclusion of the screening-level problem formulation includes the selection of ecological endpoints, which are based on the conceptual model. Two types of endpoints, assessment endpoints and measurement endpoints, are defined as part of the ERA process as are risk hypotheses or risk questions (USEPA, 1992, 1997, 1998). An assessment endpoint is an explicit expression of the environmental component or value that is to be protected. A measurement endpoint is a measurable ecological characteristic that is related to the component or value chosen as the assessment endpoint. The considerations for selecting assessment and measurement endpoints are summarized in USEPA (1992, 1997) and discussed in detail in Suter (1989, 1990, 1993). Risk hypotheses are testable hypotheses about the relationship among the assessment endpoints and their predicted responses when exposed to contaminants.

Endpoints in the SERA define ecological attributes that are to be protected (assessment endpoints) and a measurable characteristic of those attributes (measurement endpoints) that can be used to gauge the degree of impact that has or may occur. Assessment endpoints most often relate to attributes of biological populations or communities, and are intended to focus the risk assessment on particular components of the ecosystem that could be adversely affected by chemicals attributable to the site (USEPA, 1997). Assessment endpoints contain an entity (e.g., muskrat population) and an attribute of that entity (e.g., survival rate) to be protected. Individual assessment endpoints usually encompass a group of species or

populations (the receptor) with some common characteristic, such as specific exposure route or contaminant sensitivity.

Assessment and measurement endpoints may involve ecological components from any level of biological organization, from individual organisms to the ecosystem itself (USEPA, 1992). Effects on individuals are important for some receptors, such as rare and endangered species, while population- and community-level effects are typically more relevant to ecosystems and are most often the focus of evaluations. Population- and community-level effects are usually difficult to evaluate directly without long-term and extensive study. However, measurement endpoint evaluations at the individual level, such as an evaluation of the effects of chemical exposure on reproduction, can be used to predict effects on an assessment endpoint at the population or community level. In addition, use of criteria values designed to protect the vast majority (e.g., 95 percent) of the components of a community (e.g., Ambient Water Quality Criteria for the Protection of Aquatic Life) can be useful in evaluating potential community- and/or population-level effects. A summary of the assessment and measurement endpoints identified for evaluation in the ERA is summarized in Table 8-2.

8.2.1.4 Selection of Surrogate Receptors

Because of the complexity of natural systems, it is generally not possible to directly assess the potential impacts to all ecological receptors present within an area. Therefore, specific receptor species (e.g., belted kingfisher) or species groups (e.g., fish) are often selected as surrogates to evaluate potential risks to larger components of the ecological community (guilds; e.g., piscivorous birds) used to represent the assessment endpoints (e.g., survival and reproduction of piscivorous birds). Selection criteria typically include those species that:

- Are known to occur, or are likely to occur, at the site
- Have a particular ecological, economic, or aesthetic value
- Are representative of taxonomic groups, life history traits, and/or trophic levels in the habitats present at the site for which complete exposure pathways are likely to exist
- Can, because of toxicological sensitivity or potential exposure magnitude, be expected to represent potentially sensitive populations at the site
- Have sufficient ecotoxicological information available on which to base an evaluation

Lower trophic level receptor species are evaluated in the SERA based on those taxonomic groupings for which screening values have been developed. These groupings and screening values are used in most ecological risk assessments. As such, specific species of aquatic biota (e.g., fish and macroinvertebrates) are not chosen as receptors because of the limited information available and because aquatic biota are dealt with on a community level via a comparison to surface water and sediment screening values. Similarly, terrestrial plants and soil invertebrates (earthworms are the standard surrogate) are evaluated using soil-screening values developed for these two communities.

The potential for adverse affects to aquatic life in the southern portions of drainages at Sites 4 and 5/6 is evaluated in the ERA. As discussed above, Site 3 is dry during most of the year and does not provide habitat for aquatic life, though it could represent a source of chemicals

to downgradient aquatic habitats. Accordingly, the potential for Site 3 to act as a source of chemicals is screened in the SERA, but is not quantitatively evaluated beyond Step 3A.

Risk to amphibians is evaluated using aquatic life as surrogates because of limitations in the relevant toxicity values available for these receptors. Risk to reptiles also is evaluated using birds as surrogates based on limitations in relevant toxicity data. Using this approach, potential risks indicated to selected surrogate receptor groups should be interpreted as also indicating potential risk to the selected receptors.

The following upper trophic level receptor species have been chosen for exposure modeling based on the criteria listed above, the general guidelines presented in USEPA (1991), and the relevant assessment endpoints:

- Short-tailed shrew (*Blarina brevicauda*) — terrestrial mammalian insectivore
- Deer mouse (*Peromyscus maniculatus*) — terrestrial mammalian omnivore
- Raccoon (*Procyon lotor*) — semi-aquatic mammalian omnivore
- Muskrat (*Ondatra zibethicus*) — aquatic mammalian herbivore
- Mink (*Mustela vison*) — aquatic mammalian piscivore
- Red fox (*Vulpes vulpes*) — terrestrial mammalian carnivore
- American robin (*Turdus migratorius*) — terrestrial avian insectivore/omnivore
- Red-tailed hawk (*Buteo jamaicensis*) — terrestrial avian carnivore
- Belted kingfisher (*Ceryle alcyon*) — wetland/aquatic avian piscivore/omnivore
- American Woodcock (*Scolopax minor*) — wetland/terrestrial avian insectivore

A summary of the assessment endpoints, measurement endpoints, risk hypotheses, and surrogate receptors identified for evaluation in the ERA is summarized in Table 8-2.

8.2.2 Screening-Level Effects Evaluation

The purpose of the screening-level effects evaluation is to establish chemical exposure levels (screening values) that represent conservative thresholds for adverse ecological effects. One set of screening values is typically developed for each selected assessment endpoint.

8.2.2.1 Medium-Specific Screening Values

Medium-specific screening values are established for ecologically relevant media, including soil, sediment, and surface water. The salinity measured in Blows Creek (0.8 to 12.1 ppt) approximates the range of salinity defined by USEPA (1996b) as brackish (1 to 10 ppt). Accordingly, the lower of freshwater and marine toxicity values from the scientific literature were selectively used to screen chemical concentrations detected in site sediment and surface water. This approach was also used as a conservative screen of chemicals in the drainage ditch sediments and surface water, which are expected to be freshwater in their upper reaches.

The screening values used in the SERA represent either Region III BTAG screening values (USEPA, 1995a) or alternate screening values selected from the open scientific literature (CH2M HILL, 2000). Table 8-3 summarizes these screening values. Where more than one final screening value was available for a chemical within a medium (e.g., one for soil fauna and flora), the lower of the values was selected for use in the SERA.

8.2.2.2 Ingestion Screening Values

Ingestion screening values for dietary exposures were derived for each avian/mammalian receptor species and bioaccumulating chemical. Toxicological information from the literature for wildlife species most closely related to the receptor species was used, where available, but was supplemented by laboratory studies of non-wildlife species (e.g., laboratory mice) where necessary. The ingestion screening values are expressed as milligrams of the chemical per kilogram body weight of the receptor per day (mg/kg-BW/day).

Growth and reproduction were emphasized as assessment endpoints since they are the most relevant, ecologically, to maintaining viable populations and because they are generally the most studied chronic toxicological endpoints for ecological receptors. If several chronic toxicity studies were available from the literature, the most appropriate study was selected for each receptor species based on study design, study methodology, study duration, study endpoint, and test species. No Observed Adverse Effect Levels (NOAELs) based on growth and reproduction were utilized, where available, as the screening values. When chronic NOAEL values were unavailable, estimates were derived or extrapolated from chronic Lowest Observed Adverse Effect Levels (LOAELs) or acute values as follows:

- When values for chronic toxicity were not available, the median lethal dose (LD_{50}) was used. An uncertainty factor (UF) of 100 was used to convert the acute LD_{50} to a chronic NOAEL (i.e., the LD_{50} was multiplied by 0.01 to obtain the chronic NOAEL).
- A UF of 10 was used to convert a reported LOAEL to a NOAEL.

Ingestion screening values for mammals and birds are summarized in Tables 8-4 and 8-5, respectively.

8.2.3 Screening-Level Exposure Estimate

The available analytical data were evaluated and selected to represent the relevant environmental media at Sites 3, 4, and 5/6. Subsequently, maximum concentrations in surface soil and/or sediment (as appropriate to each site) and surface water were used in the SERA to conservatively estimate potential chemical exposures (direct and food web exposures) for the ecological receptors selected to represent the assessment endpoints at each site (direct and food web exposures).

8.2.3.1 Selection Criteria for Analytical Data

Analytical data from the Phase I RI and Phase II RI was used to estimate media concentrations in this ERA. These analytical data were selected for use in the SERA according to the following selection criteria:

- Data must have been validated by a qualified data validator using acceptable data validation methods. Rejected (R) values were not used in the SERA. Unqualified data and data qualified as J, L, or K were treated as detected. Data qualified as U or B were treated as non-detected.
- For groundwater, only samples from the most recent sampling event were considered since these represent the best estimate of current exposures.

- For surface soil, samples collected from depths of 0 to 6 inches were used since this range best represents the depth of exposure for most ecological receptors evaluated in terrestrial habitats. Sediment samples from depths of 0 to 6 inches were also used since this also captures the zone of greatest activity and exposure for sediment-dwelling species.
- For surface water, total (unfiltered) chemical concentrations were used in the SERA for conservatism.

For chemicals not detected in any samples of a particular medium, the maximum reporting limit was used to estimate exposure concentration. For samples with duplicate analyses, the higher of the two detected concentrations was used in screening if both values were detects while the higher detection limit was used in screening if both values were non-detects. In cases where one result was a detection and the other a non-detect, the detected value was used in screening.

A summary of the samples selected for use in the SERA and the data groupings for surface soil, sediment, and surface water at Sites 3, 4, and 5/6 is summarized in Table 8-6. A summary of the raw data for each of the selected sample locations is presented in Appendix H.

8.2.3.2 Direct Exposure

The maximum detected chemical concentrations in soil, sediment, and surface water at each site were used in the SERA to conservatively estimate potential direct chemical exposures for the ecological receptors selected for evaluation.

8.2.3.3 Food Web Exposure

All chemicals identified as potentially bioaccumulative in USEPA (2000) were evaluated in food web exposure models for upper trophic level receptors. In these models, exposure is estimated based on the assumption that chemicals can accumulate in the dietary components of receptors. The concentration of each dietary item (i.e., tissue concentrations) was estimated from the maximum detected concentrations of these chemicals in soil, sediment, and/or surface water.

Dietary items for which tissue concentrations were modeled included terrestrial plants, soil invertebrates (earthworms), small mammals, aquatic plants, aquatic invertebrates and fish. The uptake of chemicals from the abiotic media into these dietary items was based (where available) on conservative (e.g., maximum or 90th percentile) BCFs or bioaccumulation factors (BAFs) from the literature. Default factors of 1.0 were used when data were not available for a chemical in the literature. Incidental ingestion of soil or sediment was also included when calculating total exposure. In the models it was assumed that chemicals were 100-percent bioavailable to the receptor and that each receptor spent 100 percent of its time on the site (i.e., an area use factor of 1.0 was assumed). Exposure via drinking water was included in the food web models at Site 4 and 5/6, the only sites evaluated with a consistent potential source of freshwater for drinking. Based on its highly ephemeral nature, surface water at Site 3 is not expected to provide an important source of drinking water to terrestrial life. However, for the purposes of estimating risk under a conservative scenario, exposure to

chemicals from the ingestion of surface water at Site 3 was also included in the food web model.

The methodology and models used to derive tissue concentration estimates are described in the following subsections.

8.2.3.4 Tissue Concentrations

Terrestrial Plant Tissue. Tissue concentrations in the above-ground vegetative portion of terrestrial plants were estimated by multiplying the maximum measured surface soil concentration for each chemical by chemical-specific soil-to-plant BCFs obtained from the scientific literature. The BCF values used were based on root uptake from soil and on the ratio between dry-weight soil and dry-weight plant tissue. Literature values based on the ratio between dry-weight soil and wet-weight plant tissue were converted to a dry-weight basis by dividing the wet-weight BCF by the estimated solids content for terrestrial plants (15 percent [0.15]; Sample et al. 1997).

For inorganic chemicals without literature based BCFs, a soil-to-plant BCF of 1.0 was assumed. For organic chemicals without literature based BCFs, soil-to-plant BCFs were estimated using the algorithm provided in Travis and Arms (1988):

$$\log B_v = 1.588 - (0.578)\ (\log K_{ow})$$

where: B_v = Soil-to-plant BCF (unitless; dry weight basis)

K_{ow} = Octanol-water partitioning coefficient (unitless)

The log K_{ow} values used in the calculations were obtained mostly from USEPA (1995b; 1996a). The soil-to-plant BCFs used in the SERA are shown in Table 8-7.

Earthworms Tissue. Tissue concentrations in soil invertebrates (earthworms) were estimated by multiplying the maximum measured surface soil concentration for each chemical by chemical-specific BCFs or BAFs obtained from the literature. BCFs are calculated by dividing the concentration of a chemical in the tissues of an organism by the concentration of that same chemical in the surrounding environmental medium (in this case, soil) without accounting for uptake via the diet. BAFs consider both direct exposure to soil and exposure via the diet. Since earthworms consume soil, BAFs are more appropriate values and are used in the food web models when available. BAFs based on depurated analyses (soil was purged from the gut of the earthworm prior to analysis) were given preference over undepurated analyses when selecting BAF values since direct ingestion of soil is accounted for separately in the food web model.

The BCF/BAF values used were based on the ratio between dry-weight soil and dry-weight earthworm tissue. Literature values based on the ratio between dry-weight soil and wet-weight earthworm tissue were converted to a dry-weight basis by dividing the wet-weight BCF/BAF by the estimated solids content for earthworms (16 percent [0.16]; USEPA, 1993). For inorganic chemicals without available measured BAFs or BCFs, an earthworm BAF of 1.0 was assumed. The soil-to-invertebrate (earthworm) BCFs/BAFs used in the SERA are shown in Table 8-7.

Small Mammals. Whole-body tissue concentrations in small mammals (shrews, voles, and/or mice) were estimated using one of two methodologies. For chemicals with literature-based soil-to-small mammal BAFs, the small mammal tissue concentration was estimated by multiplying the maximum measured surface soil concentration for each chemical by a chemical-specific soil-to-small mammal BAFs obtained from the literature. The BAF values used were based on the ratio between dry-weight soil and whole-body dry-weight tissue. Literature values based on the ratio between dry-weight soil and wet-weight tissue were converted to a dry-weight basis by dividing the wet-weight BAF by the estimated solids content for small mammals (32 percent [0.32]; USEPA, 1993).

BAFs reported in Sample et al. (1998b) were used to estimate whole-body tissue concentrations. BAFs for insectivores were used for shrews (or for general small mammals if insectivore values were unavailable), BAFs for voles were used for herbivores, and BAFs for mice were used for omnivores. General BAFs for small mammals were used when BAFs for specific receptor groups were not available. The small mammal BAFs used in the SERA are shown in Table 8-8.

For chemicals without soil-to-small mammal BAF values, an alternate approach was used to estimate whole-body tissue concentrations. Because most chemical exposure for small mammal species is via diet, it was assumed that the concentration of each chemical in the small mammal's tissues was equal to the chemical concentration in its diet, that is, a diet to whole-body BAF (wet-weight basis) of one was assumed. The diet to whole-body BAF value of one is expected to represent a conservative estimate of tissue concentrations for most chemicals. For example, a maximum BAF (wet weight) value of 1.0 was reported by Simmons and McKee (1992) for PCBs based on laboratory studies with white-footed mice. Menzie et al. (1992) reported BAF values (wet-weight) for DDT of 0.3 for voles and 0.2 for short-tailed shrews. Reported BAF (wet-weight) values for dioxin were only slightly above one (1.4) for the deer mouse (USEPA, 1990). Resulting tissue concentrations (wet-weight) were then converted to dry weight using an estimated solids content of 32 percent (see above).

Aquatic Plants. Tissue concentrations in the above-ground vegetative portion of aquatic plants were estimated using the same methodologies as described above for terrestrial plants except that maximum sediment (not soil) concentrations were used in the calculation.

Aquatic Invertebrates. Tissue concentrations in aquatic invertebrates were estimated by multiplying the maximum measured sediment concentration for each chemical by chemical-specific sediment-to-invertebrate BAFs obtained from the literature. The BAF values used were based on the ratio between dry-weight sediment and dry-weight invertebrate tissue. BAFs based on depurated analyses (sediment was purged from the gut of the organism prior to analysis) were given preference over undepurated analyses when selecting BAF values since direct ingestion of sediment is accounted for separately in the food web model.

Literature values based on the ratio between dry-weight sediment and wet-weight invertebrate tissue were converted to a dry-weight basis by dividing the wet-weight BAF by the estimated solids content for aquatic invertebrates (21 percent [0.21]; USEPA, 1993). For chemicals without literature based sediment-to-invertebrate BAFs, a BAF of 1.0 was assumed. The sediment-to-invertebrate BAFs used in the SERA are shown in Table 8-9.

Fish. Tissue concentrations in whole-body fish were estimated by multiplying the maximum measured sediment concentration for each chemical by chemical-specific sediment-to-fish BAFs obtained from the literature. The BAF values used were based on the ratio between dry-weight sediment and dry-weight fish tissue. Literature values based on the ratio between dry-weight sediment and wet-weight fish tissue were converted to a dry-weight basis by dividing the wet-weight BAF by the estimated solids content for fish (25 percent [0.25]; USEPA, 1993). For chemicals without literature based sediment-to-fish BAFs, a BAF of 1.0 was assumed. The sediment-to-fish BAFs used in the SERA are shown in Table 8-9.

8.2.3.5 Dietary Intakes

Dietary intakes for each receptor species were calculated using the following formula (modified from USEPA [1993]):

$$DI_x = \frac{[[\sum_i (FIR)(FC_{xi})(PDF_i)] + [(FIR)(SC_x)(PDS)] + [(WIR)(WC_x)]]}{BW}$$

where: DI_x = Dietary intake for chemical x (mg chemical/kg body weight/day)

FIR	=	Food ingestion rate (kg/day, dry-weight)
FC_{xi}	=	Concentration of chemical x in food item i (mg/kg, dry weight)
PDF_i	=	Proportion of diet composed of food item i (dry weight basis)
SC_x	=	Concentration of chemical x in soil/sediment (mg/kg, dry weight)
PDS	=	Proportion of diet composed of soil/sediment (dry weight basis)
WIR	=	Water ingestion rate (L/day)
WC_x	=	Concentration of chemical x in water (mg/l)
BW	=	Body weight (kg, wet weight)

A summary of the receptor-specific exposure parameters used for the above equation is provided in Table 8-10. Exposures were based on maximum ingestion rates and minimum body weights for each receptor. As discussed previously, water ingestion was only included for Sites 4 and 5/6 since these were the only sites with a potential source of fresh drinking water.

8.2.4 Screening-Level Risk Calculation

The screening-level risk calculation is the final step in a SERA. In this step, the maximum exposure concentrations (i.e., direct exposure to environmental media) or exposure doses (i.e., ingestion/dietary dosage for upper trophic level receptor species) are compared with

the corresponding screening values to derive screening risk estimates. The outcome of this step is a list of COPCs for each media-pathway-receptor combination evaluated.

The COPCs are selected using the HQ method. The HQs are calculated by dividing the estimated exposure concentration by the corresponding medium-specific screening value (direct exposure) or by dividing the exposure dose by the corresponding ingestion screening value (food web exposure). Chemicals with HQs greater than or equal to 1.0 are considered COPCs in the SERA and are further evaluated in the ERA. When HQs are less than 1.0 the chemicals are not considered COPCs and are eliminated from further consideration in the ERA. Chemicals without screening values were retained as COPCs in the SERA.

HQs equal to or exceeding 1.0 indicate the potential for risk. However, screening values and exposure estimates are derived using intentionally conservative assumptions such that HQs greater than or equal to 1.0 do not necessarily indicate that risks are present or impacts are occurring. Rather, it identifies chemical-pathway-receptor combinations requiring further evaluation. Following the same reasoning, HQs that are less than 1.0 indicate that risks are very unlikely, enabling a conclusion of no unacceptable risk to be reached with high confidence.

Chemicals (detected or not detected) that did not have screening values and chemicals that were not detected but had maximum reporting limits exceeding screening values were identified as COPCs in the SERA. Chemicals that were not detected and did not have screening values, though identified as COPCs in the SERA, were not further evaluated in Step 3A. Uncertainties associated with these compounds were discussed in the Uncertainty section at the end of Step 3A.

8.2.5 Refinement of Conservative Exposure Assumptions (Step 3A)

COPCs are identified in the SERA (i.e., Steps 1 and 2) using conservative exposure assumptions. If chemicals are shown to have the potential for posing ecological risk (i.e., HQs greater than or equal to 1.0) then they require further evaluation. According to Navy guidance (CNO, 1999), the baseline ERA is initiated in Step 3A. In this step, the conservative exposure assumptions are refined to be more environmentally realistic and the risk estimates are re-calculated using the conceptual models developed in Tier 1. The following sections discuss the refinements to the exposure assumptions and risk calculation conducted as part of Step 3A.

8.2.5.1 Exposure Assumption Refinements

The refined exposure assumptions and methods that were modified for the calculation of media-specific and food chain hazard quotients for Step 3A are listed below.

Average concentrations are used instead of maximum concentrations to evaluate potential impacts to terrestrial plants and terrestrial and aquatic invertebrates. While immobile invertebrates could be impacted by maximum concentrations, the invertebrate population as a whole will be exposed to a range of chemical concentrations and therefore the average concentration is a more realistic indicator of the overall potential for population- or community-level effect.

Average chemical concentrations are used instead of more conservative maximum concentrations to evaluate potential effects to individual avian and mammal receptors, because the average chemical concentration more accurately estimates exposure to these mobile receptors that are likely to forage over a large area.

Where sufficient data are available, mean BCF or BAFs replace the selected BCF or BAF used in the SERA. The refined soil-to-plant and soil-to-invertebrate BCFs/BAFs, soil-to-small mammal BAFs, and sediment-to-invertebrate and sediment-to-fish BCFs/BAFs are summarized in Tables 8-11, 8-12, and 8-13, respectively.

Midpoints of body weight and ingestion rate were used to develop exposure estimates, rather than minimum body weights and maximum ingestion rates because midpoint exposure parameters are more representative of a greater proportion of a population. The Step 3A refined exposure parameters are summarized in Table 8-14.

8.2.5.2 Refined Risk Calculations

Following refinement of the exposure assumptions, risks from direct and food web exposure were recalculated using the same HQ method as described in Section 8.2.4. In the SERA, however, chemicals in the food web models were identified as COPCs if the estimated dose to wildlife exceeded the NOAEL for a chemical. The dose that is protective to wildlife, however, is expected to fall between the NOAEL and the LOAEL. Both the NOAEL and LOAEL were used for comparison in Step 3A. However, chemicals were eliminated as COPCs if estimated wildlife exposure doses did not exceed the LOAEL because this dose is expected to be protective of the overall population, which is the assessment endpoint being evaluated.

Chemicals that were not detected but were retained as COPCs in the SERA because the maximum reporting limit exceeded the respective screening value were further evaluated in Step 3A by comparing the mean reporting limit to the screening value. Chemicals (nondetected) having mean reporting limits that exceeded screening values were discussed in the Uncertainty section at the end of Step 3A. Finally, chemicals that were detected but did not have screening values were retained as COPCs.

8.3 Chemical Concentrations and Risk Calculations (Steps 2 and 3A)

The following section summarizes chemical concentrations detected in soil, sediment, and surface water at each site. This section also presents the results of the SERA and BERA (Step 3A) risk calculations.

8.3.1 Site 3

8.3.1.1 Summary of Chemical Concentrations

Summaries of chemical concentrations detected in Site 3 soil, sediment, and surface water are presented in Tables 8-15, 8-16 and 8-17, respectively. These tables include a summary of the reporting limit range, frequency of detection, maximum concentration detected,

identification of sample with the maximum detected concentration, arithmetic mean concentration, and standard deviation of the mean.

8.3.1.2 Screening-Level Risk Calculations

The following sections summarize the outcome of the screening-level risk calculation. COPCs were identified for receptors via both direct and food web exposure and all receptors were consequently considered further in the Step 3A risk calculations. It should be noted, a number of the organic chemicals identified as COPCs were not detected but had maximum detection limits exceeding screening values, or were detected, but did not have medium-specific screening values.

8.3.1.3 Direct Exposure

The SERA (Step 2) indicated the potential inorganic and organic chemicals in soil, sediment, and surface water to adversely affect ecological receptors at Site 3 as a result of direct exposure. A summary of these COPCs is presented in Table 8-18 for soil, Table 8-19 for sediment, and Table 8-20 for surface water.

8.3.1.4 Food Web

Inorganic chemicals, pesticides/PCB mixtures, and SVOCs were identified as COPC for several higher trophic level avian and mammalian receptors. A summary of these COPCs is presented in Table 8-21.

8.3.1.5 Refined Risk Calculations (Step 3A)

Because COPCs were identified in the SERA, risk was recalculated for both direct and food web exposure using the Step 3A refined exposure assumptions. As discussed in Section 8.2.1.1, only soil will be further evaluated in Step 3A for Site 3 because viable aquatic habitats are not present on this site and sediment and surface water samples were screened at Site 3 only to evaluate these media as a potential source of chemicals to Blows Creek.

8.3.1.6 Direct Exposure

The mean concentrations of nine inorganic chemicals and 13 PAHs exceeded soil-screening levels in Step 3A. A summary of these chemicals is presented in Table 8-22. Those chemicals which were not detected, but with reporting limits above screening values and with a HQ greater than 1 have been identified as (YES) on this table. The pesticide Endosulfan I, three SVOCs (2-methylnapthalene, carbazole, and bis[2-ethylhexhexyl] phthalate), 2 VOCs (acetone and chloromethane) were identified as a COPCs in soil since they were detected but did not have screening values. Cyanide and seven additional SVOCs were not detected, but were identified as COPCs because the mean of their reporting limits exceeded screening values.

8.3.1.7 Food Web

Results of the revised food web exposure models (Table 8-23), which evaluate risk based on comparison of the revised exposure concentrations to the LOAEL, suggest that lead and zinc in surface soil could pose a risk to avian insectivores (represented by American woodcock).

8.3.2 Site 4

8.3.2.1 Summary of Chemical Concentrations

Summaries of chemical concentrations detected in Site 4 soil, sediment, and surface water are presented in Tables 8-24, 8-25, and 8-26, respectively. These tables include a summary of the reporting limit range, frequency of detection, maximum concentration detected, identification of sample with the maximum detected concentration, arithmetic mean, and standard deviation of the mean.

8.3.2.2 Screening-Level Risk Calculations

The following sections summarize the outcome of the screening-level risk calculation. COPCs were identified for receptors via both direct and food web exposure and all receptors were consequently considered further in the Step 3A risk calculations. It should be noted, a number of the organic chemicals identified as COPCs were not detected but had maximum detection limits exceeding screening values, or were detected, but did not have medium-specific screening values.

Direct Exposure. The SERA (Step 2) indicated the potential for inorganic and organic chemicals in soil, sediment, and surface water to adversely affect ecological receptors at Site 3 as a result of direct exposure. A summary of these COPCs is presented in Table 8-27 for soil, Table 8-28 for sediment, and Table 8-29 for surface water.

Food Web. Inorganic chemicals, pesticides/PCB mixtures, and SVOCs were identified as COPC for several higher trophic level avian and mammalian receptors. A summary of these COPCs is presented in Table 8-30.

8.3.2.3 Refined Risk Calculations (Step 3A)

Because COPCs were identified in the SERA, risk was recalculated for both direct and food web exposure using the Step 3A refined exposure assumptions. Presented below are summaries of the results of the risk calculations for both direct exposure (by media) and food chain effects.

8.3.2.4 Direct Exposure

Soil. The mean concentrations of nine inorganic chemicals, the PCB Aroclor-1260, and 14 PAHs exceeded soil-screening levels in Step 3A. A summary of these chemicals is presented in Table 8-31. Five SVOCs (2-methylnapthelene, butylbenylphthalate, carbazole, dibenzofuran and bis[2-ethylhexyl]phthalate) and two VOCs (acetone and 2-butanone) were identified as COPCs in soil since they were detected but did not have screening values. Cyanide and 14 additional SVOCs were not detected, but were identified as COPCs because the mean of one half their reporting limits exceeded screening values.

Sediment. The mean concentrations of ten inorganic chemicals, five pesticide/PCB compounds, and 11 PAHs exceeded screening values for sediments (Tables 8-32). Beryllium and thallium and three VOCs (acetone, carbon disulfide, and toluene) were identified as COPCs in sediment since they were detected but did not have screening values. Eleven pesticide/PCB compounds, 12 SVOCs, and one VOC were identified as COPCs because the mean of one half their reporting limit exceeded screening levels.

Surface Water. The mean concentrations of nine inorganic chemicals and the VOC carbon disulfide exceeded surface water screening values (Table 8-33). Twenty three pesticide/PCB compounds and 14 SVOCs were not detected, but were retained as COPCs since the mean of one half their reporting limits exceeded screening values.

Food Web. Results of the revised food web exposure models, which evaluate risk based on comparison of the revised exposure concentrations to the LOAEL, suggest that mercury in sediment could pose a risk to avian piscivores (represented by belted kingfisher) (Table 8-34).

8.3.3 Sites 5 and 6

8.3.3.1 Summary of Chemical Concentrations

Summaries of chemical concentrations detected in Site 5/6 soil, sediment, and surface water are presented in Tables 8-35, 8-36, and 8-37, respectively. These tables include a summary of the reporting limit range, frequency of detection, maximum concentration detected, identification of sample with the maximum detected concentration, arithmetic mean and standard deviation of the mean.

8.3.3.2 Screening-Level Risk Calculations

The following sections summarize the outcome of the screening-level risk calculation. COPCs were identified for receptors via both direct and food web exposure and all receptors were consequently considered further in the Step 3A risk calculations. It should be noted, a number of the organic chemicals identified as COPCs were not detected but had maximum detection limits exceeding screening values, or were detected, but did not have medium-specific screening values.

Direct Exposure. The SERA (Step 2) indicated the potential for inorganic and organic chemicals in soil, sediment, and surface water to adversely affect ecological receptors at Site 5/6 as a result of direct exposure. A summary of these COPCs is presented in Table 8-38 for soil, Table 8-39 for sediment, and Table 8-40 for surface water.

Food Web. Inorganic chemicals, pesticides/PCB mixtures, and SVOCs were identified as COPC for several higher trophic level avian and mammalian receptors. A summary of these COPCs is presented in Table 8-41.

8.3.3.3 Refined Risk Calculations (Step 3A)

Direct Exposure. ***Soil.*** The mean concentrations of ten inorganic chemicals, the pesticide compounds 4,4'-DDE and 4,4'-DDT, and 13 PAHs exceeded soil-screening levels in Step 3A. A summary of these chemicals is presented in Table 8-42. Five SVOCs (2,4-dinitrotoluene, 2,6-dinitrotoluene, 2-methylnapthelene, cabazole and bis[2-ethylhexyl]phthalate), two explosive compounds (2,4-dinitrotoluene and 2-amino-4,6-dinitrotoluene) and two VOCs (acetone and 2-butanone) were identified as COPCs in soil since they were detected but did not have screening values. Seven SVOCs were not detected, but were identified as COPCs because the mean of one half their reporting limits exceeded screening values.

Sediment. The mean concentrations of eight inorganic chemicals, four pesticide/PCB compounds, and 10 SVOCs exceeded screening values for sediments (Tables 8-43). The inorganic chemicals beryllium and thallium, the pesticide endrin aldehyde, the explosive

2,4-dinitrotoluene, and five VOCs were identified as COPCs in sediment since they were detected but did not have screening values. Twelve pesticide/PCB compounds and 13 SVOCs were identified as COPCs because the mean of one half their reporting limit exceeded screening levels.

Surface Water. The mean concentrations of ten inorganics and one VOC (carbon disulfide) exceeded screening values in surface water (Table 8-44). The SVOC 4-methylphenol was detected was identified as a COPC in surface water because it was detected but did not have screening value. Silver and 22 pesticide/PCB mixtures and 14 SVOCs were not detected, but were retained as COPCs since the mean of one half their reporting limits exceeded screening values.

Food Web. Results of the revised food web exposure models, which evaluate risk based on comparison of the revised exposure concentrations to the LOAEL, suggest that lead in surface soil could pose a risk to avian insectivores (represented by American woodcock), zinc in surface soil could also pose a risk to avian insectivores (represented by American woodcock), and mercury in sediment could pose a risk to avian piscivores (represented by belted kingfisher) (Table 8-45).

8.3.4 Summary of COPCs

Summaries of the COPCs resulting for direct exposure and food chain risk calculations at the completion of Step 3A are presented in Table 8-46 for Site 3, Table 8-47 for Site 4, and Table 8-48 for Site 5/6.

8.3.4.1 Uncertainties

Due to the need to make assumptions and extrapolations when estimating risk, there are uncertainties associated with risks estimated in this ERA. Because, however, conservative assumptions were used throughout the ERA, particularly in the SERA (Steps 1 and 2), these assumptions are more likely to result in the overestimation of potential risk.

- Detection Limits — Although some chemicals were not detected in site media, they were identified as COPCs because the instrument detection limit for that chemical exceeded applicable screening values (i.e., the maximum detection limit for the SERA, and half the mean detection limit for the BERA, Step 3A). The potential for risks associated with these chemicals cannot be fully evaluated and represents an uncertainty in the risk assessment.

  One notable group of chemicals associated with this uncertainty in this risk assessment are PAHs. Detection limits for PAHs in soils and sediments were elevated at a number of sample locations. Elevated detection limits not only result in a less accurate estimate of chemical concentration (as a result of censoring), but can also upwardly bias concentration (and risk) estimates when using a summary statistics (e.g., mean) for the calculation of risk.

- Nondetected Chemicals Exceeding Screening Values and Chemicals Without Screening Values — Nondetected chemicals with maximum detection limits exceeding screening values and nondetected chemicals without screening values were not identified for additional focused evaluation. There is some uncertainty associated with these

chemicals as it cannot be determined definitively that they do not occur onsite. However, based on the large number of samples collected from soils, sediment, and surface water and the bias of samples to potential source areas, it is considered unlikely that chemicals potentially posing a risk to ecological receptors would not have been accurately quantified in site media.

- Soil Sampling Depth—Chemicals concentrations were evaluated in soil samples collected from a depth of 0 to 6 inches because this best represents the depth at which most ecological receptors would be exposed to chemicals in soil. However, some potential receptors could be exposed to chemicals at greater depth if they burrow to subsurface soils. There is some potential for risks to have been underestimated to burrowing organisms if chemical concentrations are greater in subsurface soil.

  Dioxins/furans were analyzed for and detected in subsurface soil (depth of 6 to greater than 60 inches) samples collected from Sites 3 and 5/6 (see Section 5). Site 4 was not sampled for dioxins/furans because historic activities are unlikely cause dioxins/furans to be present at Site 4. Dioxin/furan samples were collected from waste material during trenching (see Section 2). The objective of this sampling event was to establish the presence/absence of dioxins/furans in source material. Dioxins were not analyzed for in surface soil or sediment. There is, accordingly, uncertainty associated with the presence of dioxins in these media. This uncertainty has the potential to underestimate risks primarily to upper trophic level species based on the potential for dioxins/furans to bioaccumulate in the food web.

- Sediment Screening Values—The surface water bodies associated with Sites 4 and 5/6 transition from freshwater in the upper reaches to brackish water in the area adjacent to Blows Creek. The lower of marine and freshwater sediment and surface water screening values were used in the ERA to evaluate the potential for adverse effects to aquatic life. Accordingly, there is the potential for risks to have been overestimated in freshwater habitats in the upper ditches if the marine screening value is lower than the freshwater screening value and is used in the assessment.

- Ingestion Screening Values—Toxicity data for many of the COPCs and surrogate receptor species were minimal, requiring the extrapolation of data from similar wildlife species or from laboratory studies with non-wildlife species (e.g., rats, mice, chicken, dog, etc.). The extrapolation of toxic effects in one species to those in another is characterized by a UF that is often the product of several others. Thus a benchmark value may be less than the concentration used in the actual literature studies. The uncertainties associated with toxicity extrapolation were minimized through the selection of the most appropriate test species for which suitable toxicity data were available. The factors considered in selecting a test species to represent a receptor species included taxonomic similarities, trophic level, foraging method, and similarity of diet.

Secondly, there are situations in which LOAEL or LD_{50} values are the only toxicity endpoints available from the literature. In these situations, UFs are applied for extrapolating/converting these values into NOAEL value. Extrapolating in such a manner may either over estimate or under estimate toxicity.

Finally, another form of uncertainty relates to the derivation of ingestion screening values applied to inorganic chemicals. Most of the toxicological studies on which the ingestion screening values for inorganic chemicals were based used soluble forms (such as salts) which exhibit higher bioavailability to receptors. Since the analytical samples on which site-specific exposure estimates were based measured total concentration, regardless of form, and these highly bioavailable forms are expected to compose only a fraction of the total concentration, this is likely to result in an overestimation of potential risks for these chemicals.

- Chemical Mixtures—Information on the ecotoxicological effects of chemical interactions is minimal, which required (as is standard for ecological risk assessments) that the chemicals be evaluated on a compound-by-compound basis during the comparison to screening value. This could result in an underestimation of risk (if there are additive or synergistic effects among chemicals) or an overestimation of risks (if there are antagonistic effects among chemicals).

- Surrogate Receptor Selection and Use—Specific receptor species (e.g., red-tailed hawk) or species groups (e.g., fish) were selected using criteria thought to best represent the ecological communities at these sites and to evaluate potential risks to larger ecological components (i.e., feeding guilds, such as piscivorous birds). Even though as many site-specific factors as possible are incorporated, not all existing species or habitat conditions can be considered. This represents an uncertainty in the risk assessment.

At Sites 3,4 and 5/6, several species of amphibians and reptiles have been observed or expected to exist on Annex land. Since the toxicity data are not very well developed for these wildlife groups, other vertebrate receptors with similar diets and habitat requirements were used for these sites to represent the broader ecological community.

- Food Web Exposure Modeling—Chemical concentrations in terrestrial and aquatic food items (plants, earthworms, small mammals, aquatic invertebrates, and fish) were modeled from measured media concentrations and were not directly measured. Use of the literature-derived exposure models and BAFs introduces some uncertainty into the resulting tissue concentration estimates. For example, it was conservatively assumed chemicals were bioavailable in the environment. Factors affecting bioavailability of contaminants for uptake by plants and invertebrates were not evaluated in the SERA or BERA. Therefore calculated exposure doses may be overestimated. The values selected and methodology employed were intended to provide a conservative (SERA) or reasonable (Step 3A) estimate of potential food web exposure concentrations.

Another source of uncertainty is the use of default assumptions for exposure parameters such as BCFs/BAFs. Although BCFs or BAFs for many bioaccumulative chemicals were readily available from the literature and were used in the ERA, the use of a default factor of 1.0 to estimate the concentration of some chemicals in prey items is a source of uncertainty and, in most cases, has the potential to overestimate risk.

- Wildlife Site Exposure Assumptions—Another source of this uncertainty at Sites 4 and 5/6 relates to exposure assumptions made when estimating potential risk to belted kingfisher. In the ERA, it was assumed belted kingfisher obtain all of their diet from the drainage ditches. This assumption, although appropriate for the SERA, is expected to

greatly overestimate potential exposure for several reasons. First, the drainages are small and are unlikely to support fish. They will support amphibians in the freshwater portions of the ditches and aquatic invertebrates. However, these food items are unlikely to comprise the total diet of a belted kingfisher. Further, better quality foraging habitat is present at many locations outside the influence of the site. The assumption that 100 percent of a belted kingfisher's diet will come from the ditches is accordingly expected to overestimate risk.

8.4 Problem Formulation Revision (Step 3B)

8.4.1 Detailed Evaluation of Step 3A COPCs

The following section further evaluates chemicals identified as COPCs at the conclusion of Step 3a by comparing site-related chemical concentrations to available reference concentrations, evaluating the bioavailability of selected COPCs, and characterizing the distribution of site-related chemicals.

8.4.1.1 Comparison of Site Soil to Reference Concentrations

Previous evaluations of potential risk did not account for the non site-related concentrations of chemicals in the environment. However, some inorganic chemicals occurring at concentrations above screening values for direct exposure comparisons, or indicating potential risk via the food web models, may reflect non site-related concentrations or naturally-occurring concentrations. If inorganic chemicals are present at naturally occurring concentrations, and the risk models indicate a potential risk, it is reasonable to assume that risks due to site-related impacts were overestimated by the methods employed. The overestimation of potential risk may reflect naturally elevated regional concentrations, in which case ecological communities would be expected to have adapted to these levels, or may reflect the conservative exposure or toxicity assumptions made in the ERA.

Reference (non site-impacted) surface soil data were collected during the St. Juliens Annex Background Soils Investigation (CH2M HILL, 2001). Inorganic chemical concentrations detected in surface soil from reference sample locations were compared to concentrations detected in soils collected from each site to determine if these compounds are present at concentrations exceeding those present in non site-impacted areas. Inorganic chemicals detected in surface soil were not considered to be a site-related risk and were not recommended for further evaluation if they were detected at concentrations less than those detected in the reference samples. Sediment and surface water samples were collected from Blows Creek, however, many of these samples were collected from potentially-impacted downgradient locations and were therefore not used for comparison to the sites. Blows Creek data will be considered in Section 8.4.6.

In addition to chemicals occurring at concentrations within the ranges of reference (background) concentrations, some chemicals present in soil may, at least in part, have originated from sources not related to the sites evaluated in this ERA. PAHs are ubiquitous in the environment (Eisler, 1987) and the presence of PAHs in soil does not necessarily indicate a site-related source. Accordingly, in this assessment, maximum PAH concentrations detected in site soils were compared to PAH concentrations detected in reference soils to help determine if these chemicals are site-related.

Dredge fill soil type soil was used for comparison. Although dredge fill soil will not represent chemical concentrations in pristine soils, it was selected for use in this comparison because it represents the dominant soil type in potentially site-impacted areas (see Section 8.1.2.3) and. Use of the dredge fill soil thus allows a differentiation to be made between chemicals resulting from site-related and non site-related activities. Maximum detected site concentrations were compared to maximum chemical concentrations detected at reference locations. It was conservatively assumed chemical concentrations were not elevated relative to non site-impacted areas if the maximum onsite concentrations did not exceed maximum detected reference concentrations.

Maximum concentrations of inorganic COPCs and PAH COPCs detected in site soils are compared to the maximum concentrations detected in reference locations in Table 8-49 for Site 3, Table 8-50 for Site 4, and Table 8-51 for Site 5/6. Among the inorganic chemicals identified as COPCs, the maximum detected aluminum concentrations at Sites 3, 4, and 5/6 did not exceed those detected in samples collected from non site-impacted areas. Maximum detected mercury concentrations at Sites 3 and 5/6 did not exceed those detected in non-site-impacted areas while the maximum detected mercury concentration at Site 4 (1.3 mg/kg) approximated the maximum reference concentration (1.2 mg/kg). All other inorganic COPCs were detected at concentrations exceeding detected reference concentrations. Maximum detected concentrations of all PAHs at Site 5/6, most PAHs (8 of 13) at Site 3, and half (7of 14) of the PAHs at Site 4 exceeded those detected in reference concentrations. Based on this comparison, it is concluded that aluminum and mercury are present at concentrations that are consistent with those detected in dredge fill soils from non site-impacted areas. Because the concentrations of these chemicals detected in site soils approximate those detected in non site-impacted areas, it is concluded the concentrations of these chemicals in surface soil are not site-related and that further evaluation of these chemicals as site-related COPCs is not warranted. No other inorganic chemicals could be eliminated from further consideration based on comparison to reference concentrations. PAHs in many cases exceed concentrations detected in reference samples. The detected concentrations of these compounds, coupled with historic site use information, suggests these compounds are site-related and warrant further consideration in the ERA.

8.4.1.2 Evaluation of Potential Toxicity of Chemicals in Sediment Based on Bioavailability and Total Organic Carbon

Sediment toxicity values were recalculated to account for the potential effect of TOC on chemical toxicity. The sediment toxicity values derived in this section use the approach presented in USEPA (1993), which accounts for the bioavailability of nonionic organic chemicals in sediment by accounting for the partitioning of nonionic organic chemicals between the organic component of sediment and pore water. This approach is based on the assumption that the bioavailable and potentially toxic fraction of a nonionic organic chemical in sediment is the fraction present in pore water.

The fraction of chemical present in pore water is a function of both a chemical's hydrophobicity and the organic carbon content of the sediment. Using the equations/ approach presented in USEPA (1996) and Jones et al. (1997), sediment toxicity values were determined by adjusting water quality screening values for a chemical by the sediment's organic carbon content and chemical's octanol-water partition coefficient (Kow), which characterizes the propensity for a chemical to adsorb to organic carbon in sediment. AWQC

(USEPA, 1999) or Tier II values from Suter & Tsao (1996) were used as water quality screening values to derive the carbon-adjusted sediment screening values. An average TOC of 4.2 percent for Site 3 sediment, 4.1 percent for Site 4 sediment, and 2.8 percent for Site 5/6 sediment (see Table 8-1), determined on sediment samples (0 to 6 inches) collected during the RI, was used to adjust the TOC-dependant toxicity values. Kow values were based primarily on recommended Kow values presented in USEPA (1995b).

The bioavailability-adjusted sediment toxicity values were compared to the mean concentrations of chemicals identified as COPCs during Step 3A. The results of these comparisons are summarized in Table 8-52 Site 3, 8-53 Site 4, 8-54 Site 5/6.

The results of this comparison indicate that organic carbon in site sediments may greatly reduce the potential for nonionic organic chemicals to adversely affect benthic organisms. Only one PAH and two VOCs in Site 3 sediment exceeded screening values when mean organic chemical concentrations were compared to TOC-adjusted values, two PAHs and one VOC in Site 4 sediment exceeded screening values when mean organic chemical concentrations were compared to TOC-adjusted values, and one pesticide, two PAHs, and two VOCs in Site 5 sediment exceeded screening values when mean organic chemicals were compared to TOC-adjusted values. Based on the limited number of chemicals exceeding the carbon-adjusted screening values and the very low frequency at which these chemicals exceed the screening values, it is concluded that the overall potential for organic chemicals in sediment to adversely affect benthic organisms is minimal, and that initial estimates of potential risk identified at the completion of Step 3A were overly conservative.

8.4.1.3 Spatial Trends of COPCs in Soil/Sediment

The following section provides a graphical presentation of the primary COPCs identified in the soils and drainage sediments of each site. This information is key to understanding the distribution of chemicals, which is necessary when evaluating the area/potential magnitude of a potential ecological risk, the movement of COPCs to offsite areas (e.g., transport via site-related drainages), and the focus and/or need for further site investigation.

Inorganic chemicals, PAHs, pesticides, and PCBs comprise the predominant groups of site-related COPCs in soils and sediments and are evaluated in this section. Because of the large number of PAHs in soils and sediments, five representative PAH COPCs were selected for graphical presentation. Surface water was not considered in this section based on the transient nature of this media.

8.4.1.4 Inorganic Chemical Concentrations in Soils and Sediments

Figures 8-4 and 8-5 depict the concentrations of inorganic chemicals identified as COPCs in surface soil and sediment, respectively. Although most of the inorganic COPCs were detected at elevated concentrations in soils throughout the sites, many had very isolated "hotspots" that had much higher chemical concentrations than in the surrounding areas. For example, the highest concentrations of copper (6,470 mg/kg), lead (7,210 mg/kg), and zinc (8,490 mg/kg), were detected in a sample from within the waste area at Site 5 (SJS05-SS01-00). Concentrations detected at these "hotspot" locations were typically an order of magnitude higher than detected at other sample locations (see Figure 8-4). The highest detected chromium concentration (680 mg/kg), which was detected in a sample from within the waste area (SJS04-SS05-000) collected from Site 4, was also much higher than chromium

concentrations detected at other sample locations. These "hotspots" likely reflect historic disposal locations and represent potential chemical source areas.

With the exception of mercury, concentrations of inorganic COPCs were consistently lower in drainage sediments than in soils. This trend likely reflects the initial disposal of wastes to upland areas, and the subsequent runoff of inorganic chemicals to the site-related drainages. Mercury did not follow this pattern of distribution. The highest mercury concentrations (up to 6.4 mg/kg) were detected in a couple sediment samples (SJS04-SD03-001 and SJS04-SD02-001) collected from a drainage ditch adjacent to Site 4 and Blows Creek. Mercury was detected at approximately 1 mg/kg or less in all other site-related sediment and soil samples.

8.4.1.5 Selected PAH Concentrations in Soils and Sediments.

Figures 8-6 and 8-7 depict the concentrations of selected PAHs in site soils and sediments, respectively. PAHs are widespread in the soils and sediments at Sites 3, 4, and 5/6. The highest mean concentrations were in Site 4 soils, with lower mean concentrations detected at Sites 3 and 5/6. As with inorganic chemicals, isolated PAH "hotspots" were detected in surface soils, with much lower concentrations in the surrounding areas (see Figure 8-6). These "hotspots" likely reflect historic disposal locations and represent potential chemical source areas.

PAH concentrations detected in the Site 3 and 4 soils are generally higher than in the sediments at these sites. As discussed for inorganic chemicals, this trend likely reflects the initial disposal of PAH-bearing wastes to upland areas, and the subsequent runoff of PAHs to the drainage sediments. This trend of higher PAH concentrations in soil than sediment was not observed in Site 5/6. The PAH concentrations detected in soils at Site 5/6 were highest west of the waste area adjacent to the perimeter road and were generally lower than the other sites, approximating concentrations detected in Site 5/6 sediment.

No spatial trends in PAH distribution were apparent within the site-related drainages. Factors (e.g., grain size, TOC) potentially influencing the distribution of chemicals in sediment are further evaluated in Section 8.4.4.

8.4.1.6 Pesticide and PCB Concentrations in Soils and Sediments.

Figures 8-8 and 8-9 depict the concentrations of Aroclor-1260 and the pesticide DDT and its breakdown products DDD, and DDE in site soils and sediments, respectively. Aroclor-1260 was detected at concentrations above screening toxicity values at only isolated locations in Site 4 soils (SJS04-SS08-000 and SJS04-SS05-000) within the limits of the landfill and at several locations in the drainage ditches adjacent to Site 4. Aroclor-1254 and 1260 were also detected at isolated locations in Site 3 soils and/or sediments. However, concentrations detected in Site 3 soils remained below screening values while viable aquatic habitats are not present on Site 3 because of the transient nature of surface water at this site. Accordingly, if adverse ecological effects are occurring, they would be localized to Site 4 soils and sediments. Based on the proximity of Site 4 to Blows Creek, there is potential for Aroclor-1260 to be transported to Blows Creek.

DDT, DDD, and DDE were detected at relatively low concentrations (averaging < 1 mg/kg) in soils and sediments throughout Sites 3, 4, and 5/6. The widespread distribution of DDT,

DDD, and DDE results from the historic application of this compound at the facility and not from disposal of this compound at the sites.

8.4.1.7 Influence of Grain Size and TOC on Chemical Distribution in Drainage Sediment

This section considers the relationship between physical factors (grain size and TOC) and COPC distribution in drainage sediments associated with Sites 4 and 5/6. The results of this analysis can be used to develop a better understanding of current chemical distribution and to help in predicting the fate of site-related compounds in the aquatic environment.

Grain size (as percent fines) and TOC were compared against COPC concentrations to determine if there is a relationship between these parameters and detected concentrations of each chemical. Because of the small number of samples analyzed for physical parameters, data from Sites 3, 4, and 5/6 samples were combined into a single grouping for the analysis of each chemical. It should be recognized, however, in many cases this resulted in a sample size of four or less. The resulting regressions for both TOC and grain size are presented in Appendix M and discussed below.

Based on the small sample size, it was not possible to determine definitively if there is a relationship between chemical concentration and TOC or grain size. This problem was particularly acute for organic chemicals, many of which were detected in only a few of the samples (e.g., Aroclor-1260) where TOC and/or grain size was analyzed. No relationships were apparent between TOC and COPC concentration. This apparent lack of relationship may simply be the result of the small sample size. Trends in some COPCs do suggest there may be a relationship between sediment grain size and the concentration of at least some chemicals in sediment. There may, for example, be a relationship between grain size and chemical concentration for lead and mercury (Figures 8-11 and 8-12). Although the data set for each chemical is not large enough to support a definitive conclusion about a particular chemical, data for these COPCs suggest there is a possible correlation between grain size and chemical concentration for at least some compounds, with an apparent trend in increasing chemical concentrations with increasing percentage of fine-grained sediments. Accordingly, physical characteristics may at least partially explain the distribution of chemicals in sediment. It is recommended that any further evaluation of sediment sampling activities in this watershed include additional samples collected for TOC and grain size analysis.

8.4.1.8 Evaluation of Sources of Chemical Contamination

The following section considers the relative importance of potential chemical sources and transport routes identified in the preliminary conceptual model. The transport of chemicals to sediment and surface water via surface soil runoff and groundwater discharge are the focus of the following discussion because they were identified in the conceptual model as the primary sources from which chemicals could be transported from site media to offsite locations. The following sections first consider each of these media as potential sources of chemicals to adjacent water bodies. This information will be used to further develop the conceptual model for Sites 3, 4, and 5/6.

Surface Soil as a Potential Source of Chemicals to Site Drainages. Surface soil is likely to be the primary source of chemicals to the site-related ditches. Several lines of evidence support this conclusion. First, the primary groups of COPCs in soil (inorganic chemicals, PAHs, and

PCBs) are the same as in sediment. Further, the highest concentrations of these chemicals were almost always detected in soil, which is consistent with soils being the source of these compounds. Finally, the proximity of the site soils to the drainage ditches makes runoff from surface soil a likely source of chemicals to the drainage ditches.

In a few isolated situations, soils may not be the primary source of chemicals to the site drainages. As discussed in Section 8.4.3.1, the highest mercury concentrations (up to 6.4 mg/kg) were detected in sediment samples (SJS04-SD03-001 and SJS04-SD02-001) collected from the drainage ditch adjacent to Site 4. Mercury was detected at approximately 1 mg/kg or less at all other samples collected from both sediments and soils. The lower concentrations detected in soil coupled with the large number of samples collected from this media suggests that surficial runoff may not be the primary source of mercury detected in this ditch. The pesticide 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane (DDT) and its breakdown products 1,1-dichloro-2,2-bis(p-choropheny1)ethane (DDD) and 1,1-dichloro-2,2-bis(chlorophenyl)ethylene (DDE) were detected at relatively low concentrations (averaging < 1 mg/kg) in both soils and sediments throughout Sites 3, 4, and 5/6. The ubiquitous distribution of DDT, DDD, and DDE is likely to reflect the historic and widespread application of this compound throughout the facility. DDT and its breakdown products is considered unlikely to be a site-related compound.

Groundwater as a Potential Source of Chemicals to Site Drainages. In addition to surface soil, groundwater may represent a potential source of chemicals to surface water and sediment in site drainages and to Blows Creek. As discussed in Section 8.2.1.1, groundwater is an incomplete exposure pathway for aquatic life. There is, however, the potential for groundwater to discharge to surface water and sediment (Section 4), at which point chemicals present in groundwater could adversely affect aquatic life. This section considers the potential for groundwater to be a source of chemicals to surface water and sediment. Chemicals associated with the Columbia Aquifer are the focus of this investigation because this aquifer discharges to the site-related drainages and Blows Creek (Section 4).

Chemical concentrations detected in groundwater samples from the Columbia Aquifer are summarized in Table 8-55 for Site 3, Table 8-56 for Site 4, and Table 8-57 for Site 5. The following sections evaluate the potential for groundwater from these sites to be a source of the chemicals detected in surface water and sediment.

The majority of inorganic chemicals identified as COPCs in surface water and sediment were also detected in groundwater. Groundwater discharges at least periodically to the site drainages and Blows Creek. If historic site activities have increased inorganic chemical concentrations to levels above those expected to naturally occur in groundwater, then groundwater may represent a source of inorganic chemicals to surface water and sediment. However, elevated concentrations of these inorganic chemicals were also detected in site soils. Based on the proximity of these media to one another, and the potential for chemicals to runoff from soil into sediment, it is considered likely that surface soils represent the primary source of chemicals to the drainages.

Limited organic chemicals were detected in groundwater: heptachlor and 4-methylphenol were detected each in one sample collected from Site 3 groundwater, carbon disulfide was detected in one sample collected from Site 4 groundwater, and 4,4'-DDT and 4-methyphenol were detected in one sample while di-n-butylphthalate was detected in two samples

collected from Site 5 groundwater. Available information suggests these organic chemicals have very limited potential to be discharging to surface water at concentrations that could adversely affect aquatic life. This conclusion is based in part on the low frequency of detection of these chemicals in both groundwater and, more importantly, in the potential receiving water bodies. Heptachlor, for example, was not detected in the surface water (Tables 8-17, 8-26, and 8-37) or sediments of ditches associated with any of the sites (Tables 8-16, 8-25, 8-36), 4-methyphenol was detected in only a single surface water sample from Site 5/6 but was not detected in any other sediment or surface water sample collected from the ditches, and di-n-octylphthalate was only detected in a single sample in Site 4 sediment and a single sample in Blows Creek surface water (see Appendix H). DDT was detected in sediment samples and some surface water samples collected from the site ditches and in sediment samples collected from Blows Creek. DDT was also detected in soils at all sites, which is likely to reflect the historic application of this pesticide. Historic application and runoff from soils, and not groundwater discharge, is likely to be the primary source of DDT compounds in sediment and surface water.

Carbon disulfide was detected in sediment and surface water samples collected from all ditches and in sediment samples collected from Blows Creek. Carbon disulfide was not detected in surface soil, which is expected because it is a volatile compound and would readily volatilize from this media. Accordingly, surficial runoff would not represent a source of this compound to surface water and sediment. Carbon disulfide was only detected in groundwater at Site 4; the source of carbon disulfide in surface water is unknown and may represent an analytical artifact.

8.4.1.9 Preliminary Evaluation of Risks to Blows Creek

There is the potential for chemicals from Sites 3, 4, and/or 5/6 to be transported via the site drainages to Blows Creek. The potential for adverse effects to aquatic life within the ditches is limited based on the minimal aquatic habitat provided by the drainages. However, if chemicals reach the tidally-influenced portions of the drainages (immediately adjacent to the main Blows Creek channel) and/or the main Blows Creek channel, a broad range of aquatic species could be exposed to site-related chemicals. This section preliminarily evaluates sediment and surface water chemical analytical data collected from Blows Creek to determine if chemical concentrations are high enough to potentially adversely affect ecological receptors in this water body. The types of chemicals detected in Blows Creek are also compared to those detected in Sites 3, 4, and 5/6 to determine if they are likely to be site-related. This evaluation should only be considered a preliminary indication of potential site-related effects on Blows Creek for two reasons. First, only a limited number of samples are available to characterize chemical concentrations in Blows Creek. More importantly, there are other potential chemical sources to Blows Creek besides Sites 3, 4, and 5/6, including both Annex-related (e.g., AOC 1) and non facility-related sources (e.g., migration of chemicals from the Elizabeth River with tidal flux).

Sediment and surface water data collected from locations in Blows Creek in April 1999 (Appendix H) were used to determine if chemicals in these media could be adversely affecting potential ecological receptors. Data were screened for potential risks to benthic invertebrates from exposure to chemicals in sediment, to aquatic life from exposure to chemicals in surface water, and to aquatic-based wildlife (raccoon, muskrat, mink, belted kingfisher) from exposure to chemicals that have accumulated in food from sediment and

surface water. Risks were calculated for both Steps 2 (maximum) and 3 (mean) exposure scenarios using the same assumptions that were used to calculate Site 3, 4, and 5/6 risk estimates (Section 8.2). The following sections summarize results of the risk calculations using both Step 2 and 3 exposure assumptions. There is also some potential for chemicals originating from site-related sources to be transported to the Southern Branch of the Elizabeth River. However, this section focuses on the potential for transport to Blows Creek based on the data currently available and the greater potential (based on proximity to the site-related sources) for chemicals to reach the sediments and surface water of this water body.

8.4.1.10 Direct Exposure (Sediment)

HQs for chemicals in sediment are summarized in Table 8-58 for the Step 2 model assumptions and Table 8-59 for the Step 3 model assumptions. The mean concentrations (Step 3 comparisons) of nine inorganic chemicals, the pesticide compounds DDT and DDE, and one PAH exceeded screening values for sediments (Tables 8-59). The inorganic chemical beryllium, the SVOC bis(2-chloroethoxy)methane, and four VOCs (2-butanone, acetone, carbon disulfide, ethylbenzene, and toluene) were identified as COPCs in sediment because they were detected but did not have screening values. The mean of one half the reporting limit of 14 pesticide/PCB compounds and 20 SVOCs exceeded screening levels.

Chemicals with HQs greater than or equal to one are generally consistent with those identified as COPCs in the sediment of one or more site drainage. For example, inorganic chemicals with HQs greater than or equal to one are the same as chemicals identified as COPCs in Site 3, 4, and/or 5/6 drainage. The pesticide DDT and its breakdown products and PAHs were also identified as COPCs in the site drainages. It is therefore concluded there is the possibility that Sites 3, 4, and/or 5/6 have contributed to the chemicals present in Blows Creek. The viability/importance of this potential transport pathway may accordingly warrant further consideration.

Direct Exposure (Surface Water).HQs for chemicals in surface water are summarized in Table 8-60 for the Step 2 model and Table 8-61 for the Step 3 model. The mean concentrations (Step 3 comparisons) of six inorganic chemicals exceeded screening values for surface water (Tables 8-61). The mean of one half the reporting limit of silver and 13 SVOCs exceeded screening levels.

All of the inorganic chemicals with HQs greater than or equal to one are the same as chemicals identified as COPCs in Site 3, 4, and/or 5/6 drainage. It is therefore concluded there is the possibility that Sites 3, 4, and/or 5/6 have contributed to the chemicals present in Blows Creek. The viability/importance of this potential transport pathway accordingly warrants further consideration.

8.4.1.11 Food Web (Aquatic).

HQs for aquatic food web models are summarized in Table 8-62 for the Step 2 model and Table 8-63 for the Step 3 model. Results for the Step 3 model suggest there is the potential for adverse effects to the belted kingfisher from the presence of mercury in sediment. It should be noted, however, the maximum detected mercury concentrations in sediment (up to 0.69 mg/kg) are low and fall within the range of mercury concentrations detected in reference soils (see Section 8.4.1).

8.4.1.12 Risk Summary and Conclusions

The following sections briefly summarize risks and conclusions for the Step 1 though 3 ERA. Conclusions are summarized separately for terrestrial and aquatic receptors.

8.4.1.13 Terrestrial Receptors

The ERA indicates the potential for adverse effects to lower trophic-level receptors (plants and soil invertebrates) from the presence of chemicals (primarily inorganic chemical and PAHs) in soils at Sites 3, 4, and 5/6. The ERA also indicates the potential for adverse effects to avian and mammalian insectivores from lead and zinc in Site 3 and Site 5/6 soils. However, presumptive remedies/remedial activities currently planned for these sites will either eliminate the potential exposure of terrestrial receptors to chemicals in surface soil by placing a soil cover over contaminated surface soils, and/or reduce chemical concentrations and potential risk by the direct removal of site-impacted surface soils. Based upon these planned presumptive remedies/remedial activities, further evaluation of ecological risks from chemicals in surface soil is not warranted.

8.4.1.14 Aquatic Receptors

Chemicals are present in drainage sediments at each site at concentrations exceeding screening values. Inorganic chemicals, pesticides, and PAHs are the predominant chemicals exceeding screening values. As discussed in Section 8.4.2, however, many of the organic chemicals in drainage sediments are likely to be complexed with organic carbon and not bioavailable (or toxic) to benthic organisms. Furthermore, as presented in a general discussion in Section 8.1.2.2 and in site-specific discussions in Section 8.1.2.3, the drainages above the area of tidal influence provide very little (Sites 4 and 5/6) or no (Site 3) viable habitat for aquatic species.

Finally, presumptive remedies/remedial activities currently planned for the drainages in the potential site source area will either eliminate the potential exposure of aquatic life to chemicals in sediment by placing a cover over contaminated sediments, and/or reduce chemical concentrations and potential risk by direct removal of site-impacted sediments.

It is therefore concluded that further evaluation of the drainages above tidal influence is not warranted.

There is the potential for a much greater diversity of aquatic life to be exposed to chemicals in sediment if they are transported to the tidally-influenced portions of the drainages immediately adjacent to Blows Creek and to the main channel of Blows Creek where a much greater diversity of aquatic species could be supported. Further evaluation of the potential for adverse effects to aquatic life in sediments of the tidally-influenced drainages to Blows Creek and in the main Blows Creek channel (as a result of chemical transport from Sites 3, 4, and 5/6) is accordingly recommended. This evaluation should include further consideration of the elevated mercury concentrations (greater than 6 mg/kg) detected in the Site 4 drainage sediments adjacent to Blows Creek.

Chemicals present in surface water (primarily inorganic chemicals) may also have limited potential to adversely affect aquatic life. The presumptive remedies/remedial activities currently planned for the potential source areas and upland drainages will largely address potential risks to aquatic life by eliminating the potential site-related sources of chemicals

detected in surface water. Further consideration of this potential exposure pathway in the tidally-influenced portion of the drainages and Blows Creek is warranted. It is, however, recommended that additional ecological investigations emphasize the evaluation of sediment. This conclusion is based on the transient nature of surface water and the observation that sediment is likely to represent the primary source of chemicals to surface water once presumptive site remedies are completed.

Step 3A risk calculations indicated the potential for adverse effects to avian piscivores from mercury in drainage sediments at Sites 4 and 5/6. Avian piscivores are, however, expected to spend most of their time foraging in the higher quality aquatic habitats provided by Blows Creek. Currently available data suggests a very limited potential for chemicals in Blows Creek to adversely affect aquatic life, however, only limited samples have been collected from Blows Creek. It is accordingly recommended that further evaluation of this potential exposure pathway focus on the characterization of chemical concentrations in Blows Creek sediment, which would be the repository for most potentially bioaccumulative chemicals.

As discussed in Section 8.2.1.4, avian species were considered a surrogate indicator of the potential for adverse effects to reptiles while aquatic life was considered a surrogate indicator of the potential for adverse effects to amphibians. Based on the potential for adverse effects to avian piscivores from the presence of chemicals in the tidally-influence drainages to Blows Creek and in the main Blows Creek channel, it is concluded there is the potential for adverse effects to reptiles foraging on aquatic life in this portion of the Blows Creek channel. This potential receptor/exposure pathway accordingly warrants further evaluation in the ERA. There is some indication of the potential for adverse effects to aquatic life from the presence of chemicals in surface water and sediment and it might also be concluded there is some potential for adverse effects to amphibians from the presence of chemicals in sediment and surface water. However, as discussed above for aquatic life, presumptive remedies/remedial activities currently planned for the drainage sediments in the potential site source area will either eliminate the potential exposure of amphibians to chemicals in these media by placing a cover over contaminated sediments/soils, and/or reduce chemical concentrations and potential risk by direct removal of site-impacted sediments/soils. Further evaluation of the drainages above tidal influence is therefore not warranted. However, amphibians are generally intolerant of prolonged exposure to saline environments (Ferraro et al. 1993, Hart et al. 1991). It is accordingly considered unlikely that amphibians would occur throughout much of the tidally-influenced portions of Blows Creek and amphibians were not identified as receptors for further evaluation in the ERA.

8.4.2 Conceptual Model Revision

In this section the screening problem formulation is revised and focused to better define the key chemical-pathway-receptor combinations identified in the Step 3A evaluation and in the additional evaluations presented in the preceding section. This revised problem formulation develops a revised conceptual model and includes a discussion of exposure pathways, assessment endpoints, and risk hypothesis/questions and serves as a basis for developing the necessary site-specific studies (Step 4) to further characterize potential ecological risks.

8.4.2.1 Complete Exposure Pathways

Historic site activities have resulted in the presence of chemicals in soils at concentrations that could represent a potential risk to terrestrial wildlife. However, presumptive remedies/remedial activities currently planned for these sites will be designed to either eliminate or reduce potential risks to ecological receptors, by either placing a soil cover over contaminated surface soils (eliminating a potential exposure pathway) and/or by reducing chemical concentrations in by soil via soil removal. These potential exposure pathways will accordingly not be further evaluated in the ERA.

Surficial runoff and soil leaching during storm events, potential groundwater discharge, and historic aerial deposition are all pathways by which chemicals (primarily inorganic chemicals and PAHs) are likely to have been released into the site drainage sediments and to Blows Creek sediments. It is also possible that some chemicals released from site-related sources have been transported via Blows Creek to the Southern Branch of the Elizabeth River.

As discussed in Sections 8.1.2.2 and 8.1.2.3, the site drainages contain a limited amount of water and are expected to provide minimal aquatic habitat. Accordingly, potential exposure pathways are complete primarily for chemicals reaching the tidally-influenced portion of the site drainages and the main Blows Creek channel and possibly downgradient locations Benthic invertebrates in this area could be exposed to chemicals by direct contact with chemicals in sediment and sediment pore water and by the ingestion of sediment. Aquatic-based terrestrial wildlife and reptiles also could be exposed to bioaccumulative chemicals (if present in Blows Creek sediment) by ingestion of prey (e.g., fish). Further, surface water may contain chemicals that could adversely affect aquatic life. However, following the remediation of soils (planned as part of a presumptive remedy for the sites), sediment is expected to be the primary source of chemicals to surface water. Based on this consideration and the transient nature of surface water, it is recommended that further evaluation of the Blows Creek aquatic habitat consider both sediment and surface water, but emphasize the evaluation of sediment as a potential risk to aquatic life. This further evaluation should also emphasize the evaluation of Blows Creek. However, trends in data collected from Blows Creek will also be used to determine the extent to which site-related chemicals are being transported to the Southern Branch of the Elizabeth River.

8.4.2.2 Assessment Endpoints

Assessment endpoints are intended to focus the risk assessment on particular receptors of the ecosystem that could be adversely affected by contaminants from the site. Based on conclusions drawn from the refined risk assessment models, the assessment endpoints chosen for Sites 3, 4, and 5/6 are as follows:

- *Benthic invertebrate community survival and reproduction in Blows Creek* – Benthic invertebrates serve as a prey base for many aquatic species. Blows Creek will support fewer fish and other aquatic animals if chemicals transported from the sites are limiting the survival and growth of the benthic invertebrate community. Benthic invertebrates also play an important role in the processing and breakdown of organic matter in aquatic systems. However, the role of benthic invertebrates as a forage base in Blows Creek will be the primary focus of this assessment endpoint, as it is an assessment endpoint that can be evaluated with greater accuracy.

- *Water column-dwelling aquatic life (fish) survival and reproduction in Blows Creek* – Water column-dwelling species occupy a number of trophic levels in the aquatic food web, ranging from primary producers (e.g., phytoplankton) to upper trophic-level aquatic predators (e.g., some fish species). The viability of the overall aquatic community is dependant in many ways on the aquatic species represented by this group. Blows Creek will support fewer fish and other water column-dwelling aquatic animals if chemicals transported from the sites are present in Blows Creek surface water at concentrations limiting the survival and growth of this community. The survival and reproduction of fish in Blows Creek was selected as the primary focus of this assessment endpoint, as it can be evaluated with accuracy based on data available in the scientific literature. Further, fish represent several different trophic-levels in the aquatic community and the viability of fish populations is important to the overall viability of an aquatic community. *Avian piscivore population survival and reproduction in Blows Creek* – Avian piscivores represent higher trophic-level predators that could be exposed to chemicals that have accumulated in prey if chemicals are transported to Blows Creek. These chemicals could reduce the growth and survival of avian piscivores and adversely affect the viability of these populations. Avian piscivore populations were selected as a focal point of evaluation because the limited data available for Blows Creek suggests some potential for adverse effects to this receptor. However, because only limited data were collected from Blows Creek, the potential for adverse effect to all aquatic-based wildlife considered in this ERA should also be screened if additional data are collected from this water body. Because avian piscivores were identified as surrogates for reptiles, the potential for adverse effects to reptiles from exposure to chemicals accumulated by potential prey items in Blows Creek was also selected for further evaluation.

8.4.2.3 Risk Hypotheses/Questions

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 judgement of risk assessors. The risk hypotheses/questions associated with the assessment endpoints are:

- Are chemicals originating from Sites 3, 4, and /or 5/6 present in Blows Creek sediment at high enough concentrations to impair benthic infaunal and epifaunal invertebrate communities to the extent that their function as a prey base for aquatic predators is adversely affected?
- Are chemicals originating from Sites 3, 4, and /or 5/6 present in Blows Creek surface water at high enough concentrations to impair water column-dwelling aquatic life (represented by fish) to the extent that their function (as both aquatic predators and prey) is adversely affected?
- Are bioaccumulative chemicals originating from Sites 3, 4, and/or 5/6 present in Blows Creek sediment at high enough concentrations to represent a potential risk to avian piscivores, other aquatic-based wildlife, or reptiles foraging in this water body?

The risk assessment will also initially consider the potential for chemicals originating from Sites 3, 4, and/or 5/6 to reach the Southern Branch of the Elizabeth River at levels that are

high enough to adversely affect the receptors identified above for additional evaluation in the ERA.

8.5 References

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SECTION 9

Conclusions

9.1 Nature and Extent of Contamination

The following conclusions regarding the nature and extent of potential contamination have been derived from the data collected at Sites 3, 4, 5, and 6.

9.1.1 Site 3

The extent of waste at Site 3 was determined visually during trenching activities in 2001, and the extent of contamination is based both on the visual extent of waste and analytical results of media sampling. Burnt soils (friable black silty sand) and the presence of construction debris and minor scrap ordnance characterize the waste at Site 3. Waste debris consisted of construction related material including wires, ceramics, brass, glass, and wood. Debris was generally located within the first 2 ft and burnt/stained soils were identified to a depth of no more than 2.5 ft below ground. Based on the results of the trenching activities, the boundaries of Site 3 waste were determined to be limited to a two acre area along the gravel road that transects the site. Sample analytical data were evaluated with respect to background and risk screening criteria.

Constituents in surface and subsurface soils reflective of potential impacts from Site 3 were metals, PAHs, and dioxins. The highest concentrations of metals exceeding background UTLs are limited to the waste area and a potential "hot spot" outside the waste in surface soil at SJS03-SS15. Central-tendency comparisons to dredge fill background show metals concentrations in Site 3 soils were similar to background. Statistically elevated over background, the PAHs anthracene and phenanthrene in surface soil were limited to the waste area and in subsurface soil were below risk screening criteria, which suggests that the PAHs are not very mobile. Elevated TPH (diesel range) is limited to samples within the waste.

In shallow groundwater only iron and manganese were consistently detected in samples above screening criteria and maximum background, including upgradient of the site. The presence of total thallium above the MCL in shallow groundwater (SJS03-MW06S) was not confirmed by the duplicate sample. There were no MCL exceedances in deep groundwater in 1999 samples. Based on constituent concentrations detected in groundwater and the existence of a laterally extensive hydraulic aquitard (Yorktown Confining Unit), deep groundwater does not appear to have been impacted at Site 3.

In sediment, several metals and pesticides exceeded the soil background UTL, and pose a potential risk based on human health and ecological screening. The greatest concentrations of metals in sediment were near the Site 3 waste boundary (SJS03-SD02 and SJS03-SD08). PCB aroclor-1260 was present near the waste (SJS03-SD02 and SJS03-SD06) above ecological screening criteria. 4,4'-DDE was present in sediment in both the eastern and western drainage ditches. Although exceeding ecological screening values, PAHs in sediment were below background and reported at estimated concentrations below quantitation limits.

In surface water, several metals and pesticides pose a potential risk based on human health and ecological screening. Of significance is the elevated concentrations of metals at SJS03-SW01,on the north side of the perimeter road northeast of Site 3. This location (SJS03-SW01) is not connected to the drainage ditch near the southeast waste boundary and would not receive runoff from Site 3 except during significant storms or floods. The greatest concentrations of metals in surface water were in the eastern drainage ditch (SJS03-SW08) and the greatest concentrations of pesticides in surface water were in the western drainage ditch (SJS03-SW03).

9.1.2 Site 4

Surface and subsurface soils contained several inorganic compounds elevated above background (UTLs central-tendency). These were antimony, copper, lead, nickel, and zinc in surface soil and antimony, arsenic, barium, beryllium, copper, iron, lead, manganese, mercury, vanadium, and zinc in subsurface soil. The surface soils also contained PAHs and pesticides/PCBs. However, none of the pesticides indicated a statistical difference from the background data based on central-tendency population comparisons, and all pesticide UTL exceedances occurred within the limits of waste. The most significant PCB detection is aroclor-1260 at 6,300 μg/kg in sample SJS04-SS08 within the waste. In general, these potential site contaminants were restricted to the soils located within the limits of waste. The soil sample locations along the north-southwest perimeter, adjacent to the aerial extent of waste, indicated elevated concentrations of metals in surface and subsurface soils.

In the Columbia and Upper Yorktown Aquifers, several total and dissolved metals were detected above tap water RBCs and maximum background value. Of these, only iron and manganese were consistently detected in samples from both shallow and deep monitoring wells above screening criteria and background. The highest concentrations were upgradient (Site 3) of the site. Based on constituent concentrations detected in groundwater and the existence of a laterally extensive hydraulic aquitard (Yorktown Confining Unit), deep groundwater does not appear to have been impacted at Site 4.

In sediment, several metals and PAHs pose a potential risk based on human health and ecological screening. Of significance is mercury in the eastern drainage ditch sediment sample SJS04-SD03 at 6.4 mg/kg. Although exceeding ecological screening criteria, most PAHs, with the exception of SJS04-SD04, were reported at estimated concentrations below quantitation limits.

In surface water, several metals and carbon disulfide exceeded screening criteria. Of significance is the elevated concentration of metals in surface water sample SJS04-SW04, including a total lead concentration of 746 μg/l.

In general, similar concentrations of constituents found in Site 4 groundwater, surface water and sediment were found in the upgradient Site 3 groundwater, surface water and sediment.

9.1.3 Site 5

The extent of waste at Site 5 was determined visually during trenching activities in 2001, and the extent of contamination is based both on the visual extent of waste and analytical results of media sampling. Burnt soils (friable black silty sand) and the presence of

construction debris and minor ordnance characterize the waste at Site 5. Two spent ordnance were found at Site 5 and included a spent percussion primer and a Mark 7 cartridge case. Waste debris consisted of construction related material including wires, ceramics, brass, glass, and wood. Debris was generally located within the first 16" and burnt/stained soils were identified to a depth of no more than 26" below ground. Based on the results of the trenching activities, the boundaries of Site 5 were adjusted to extend farther to the north. A sample of waste was analyzed for TCLP (metals and organic) and was found to be non-hazardous. Sample analytical data were evaluated with respect to background and risk screening criteria.

In soils, metals, explosives, and dioxins reflected potential contamination within the limits of waste. The metals in soil most indicative of site-related activities were characterized by samples within the northern portion of the waste area and included, barium, copper, lead, and zinc. Outside the waste boundary arsenic, barium, lead, chromium, and zinc were elevated in surface soil in localized areas: arsenic northeast (SJS05-SS11) and southwest (SJS05-SS09 and SJS05-SS32) of the waste area, lead southeast (SJS05-SS03, SJS05-SS05, SJS05-SS07, and SJS05-SS14) of the waste area, and antimony, barium, chromium, lead, and zinc south (SJS05-SS19) of the waste area. There was not widespread metals contamination in subsurface soil at Site 5. Pesticides were most frequently detected in soils west of Site 5 along the perimeter road and near the drop tower to the southeast of the waste area with no definitive pattern to indicate that these compounds are related to the waste.

In the Columbia Aquifer, total and dissolved beryllium, cadmium, and lead exceed the MCL in one downgradient sample, SJS05-MW03S. Total and dissolved iron and manganese were elevated in samples from all shallow wells. A few VOCs and SVOCs were infrequently detected at low estimated concentrations in groundwater below screening criteria. In deep groundwater (Yorktown Aquifer) RDX was reported for the 1999 sample from SJS05-MW01D located within the waste.

In sediment, metals and pesticides were elevated in localized areas of the drainage ditch and the low marsh area east of Site 5. Although present in some sediment samples, PAH concentrations were similar to Blows Creek reference concentrations.

In surface water, metals were elevated in the marsh area east of Site 5. Sample SJS05-SW05 is significant with arsenic, copper, iron, lead, manganese, nickel, and zinc at concentrations that exceeded the maximum concentration of the reference samples by an order of magnitude as well as screening criteria.

9.1.4 Site 6

The results of the trenching activities indicated no visual signs of stained/burned soils at Site 6. With the exception of minor amounts of concrete and a small ordnance item (M3 initiator switch) in the top 6 in., no debris, waste, or burned/stained soils were observed in the test pits. The extent of contamination is based both on the visual extent of waste and analytical results of media sampling.

Site 6 was investigated as part of Site 5. Groundwater, surface water, and sediment samples were not collected at Site 6.

Constituents in surface soil reflective of potential impacts from Site 6 are the metals barium and zinc, present at an order of magnitude greater than the background UTL and statistically elevated over the background population. Only barium also exceeded the adjusted residential soil RBC and both compounds exceed the BTAG soil flora/fauna screening values.

9.2 Contaminant Fate and Transport

Waste materials and impacted soil, sediment, surface water and groundwater are sources for contaminant migration and transport at the sites. The principal mechanisms for transport of constituents from the waste areas is from surface water runoff and erosion resulting in potential leaching and dissolution of constituents from soil, as well as physical transport to the drainage ditches where suspended particulates settle to sediment.

Based on the distribution of potential site-related constituents in site media, other potential but less prominent mechanisms for transport and migration are: (1) infiltrating precipitation and flow through the vadose zone resulting in the leaching of constituents from soil to the groundwater system, followed by groundwater discharge to low-lying marsh areas and Blows Creek, and seasonally to the upland drainage ditches, (2) infiltration of surface water in upland drainage ditches during low water-table conditions through the vadose zone resulting in the leaching of constituents from sediment to the groundwater system, (3) suspension and dissolution of constituents from sediment to surface water and transport of surface water and sediment to Blows Creek, and (4) in the southeastern portions of Site 4 it is likely that the water table intersects the waste resulting in potential transport of COIs to the groundwater, and during high water-table conditions groundwater may come in contact with the waste at Sites 3, 5, and 6 and discharge to the upland drainage ditches. Because the sites are vegetated and volatile compounds are not prevalent in site media, wind erosion and volatilization to the atmosphere are not pathways of concern at the sites.

The following summarizes the key elements for the fate and transport of potential site-related constituents at Sites 3, 4, 5, and 6:

9.2.1 Site 3

Surface water runoff and erosion can potentially transport metals, SVOCs, pesticides, and PCBs present in soil to the upland drainage ditches at Site 3. Their presence in sediment suggest physical transport from runoff at the southeast extent of the waste area. Although present, SVOCs, pesticides, and PCBs are not prevalent at high concentrations in site soils, and they do not readily dissolve in water but adsorb very strongly to soil and sediment; there is little to no impact on surface water or groundwater from these compounds. Dioxins in subsurface soil within the waste have little potential to migrate as they are relatively insoluble and adsorb strongly to subsurface soil. Metals, either suspended or dissolved in surface water, may migrate to the south within the drainage ditches to Blows Creek. It is also possible that constituents in sediment may migrate within the eastern drainage ditch to the south, adjacent to and merging with runoff from Site 4, to discharge at Blows Creek.

The presence of some metals, in particular iron and manganese, in the Columbia Aquifer above screening criteria and/or maximum background suggests potential infiltration of precipitation through the vadose zone and leaching from soil to the groundwater system.

Although the waste and site soils may contribute to the concentrations of iron and manganese in shallow groundwater, elevated iron and manganese in groundwater upgradient of Site 3 indicate contributions from offsite. The Columbia Aquifer may be a source of dissolved iron and manganese to the Upper Yorktown Aquifer. Metals in shallow groundwater may also be transported through groundwater discharge to Blows Creek and low-lying marsh areas of the creek.

9.2.2 Site 4

Surface water runoff and erosion can potentially transport metals, SVOCs, pesticides, and PCBs present in soil to the upland drainage ditch at Site 4 and the wetland marsh area in the southwest portion of the site. Their presence in sediment suggest physical transport from runoff across the waste area. Although present, SVOCs and pesticides, are not prevalent at significantly high concentrations above background in site soils, and they do not readily dissolve in water but adsorb very strongly to soil and sediment; there is little to no impact on surface water or groundwater from these compounds.

PCBs were detected in a surface soil sample at high concentrations within the waste. Low concentrations of arcolor-1260 in the eastern drainage ditch sediment likely reflects transport of adsorbed PCBs to soil by surface runoff. Metals, either suspended or dissolved in surface water, may migrate to the south in surface water and sediment within the drainage ditch and to the southwest marsh area of Blows Creek. Significantly elevated mercury found in one sediment sample from the eastern drainage ditch may have resulted from transport by surface runoff, however mercury concentrations in all surface soil samples is low and below background concentrations.

The presence of some metals, in particular iron and manganese, in the Columbia Aquifer above screening criteria and/or maximum background suggests potential infiltration of precipitation through the vadose zone and leaching from soil to the groundwater system. Although the waste and site soils may contribute to the concentrations of iron and manganese in shallow groundwater, elevated iron and manganese in groundwater upgradient of Site 4 (Site 3 and offsite) indicate contributions to groundwater other than Site 4. The Columbia Aquifer may be a source of dissolved iron and manganese to the Upper Yorktown Aquifer. Metals in shallow groundwater may also be transported through groundwater discharge to Blows Creek and low-lying marsh areas of the creek. The southern extent of Site 4 is expected to be affected by tidal influx from Blows Creek and the Southern Branch of the Elizabeth River resulting in an exchange of constituents (surface water, sediment, and groundwater) migrating between the southern extent of Site 4 and Blows Creek.

9.2.3 Site 5

Surface water runoff and erosion can potentially transport metals, SVOCs, pesticides, and explosives (2,4-dinitrotoluene) present in soil to the upland drainage swale at Site 5 and to the phragmites marsh area east and southeast of the site. The presence of metals, SVOCs, and pesticides in sediment suggest physical transport from runoff across the waste area. Explosives adsorbed to surface soil do not appear to have migrated from the site as evidenced by the absence of explosive compounds in subsurface soil, sediment, surface

water, or shallow groundwater. Dioxins in subsurface soil within the waste also have little potential to migrate as they are relatively insoluble and adsorb strongly to subsurface soil.

Although present, SVOCs and pesticides, are not prevalent at significantly high concentrations above background in site soils, and they do not readily dissolve in water but adsorb very strongly to soil and sediment; there is little impact on surface water or groundwater from these compounds.

Metals either suspended or dissolved in surface water runoff may migrate to the south within the upland drainage swale and east-southeast to the phragmites marsh area and subsequently to Blows Creek. Significantly elevated metals were present in one surface water sample from the phragmites marsh area east of Site 5 that may have resulted from dissolution and transport by surface runoff, or analysis of an extremely turbid sample. Metals in surface water downstream of this location were much lower as were metals in the co-located sediment sample at this location.

The presence of some metals, in particular iron and manganese, in the Columbia Aquifer above screening criteria and/or maximum background suggests potential infiltration of precipitation through the vadose zone and leaching from soil to the groundwater system. Although the waste and site soils may contribute to the concentrations of iron and manganese in shallow groundwater, elevated iron and manganese in groundwater upgradient of Site 5 (Site 3 and offsite) indicate contributions to groundwater other than Site 5. The Columbia Aquifer may be a source of dissolved iron and manganese to the Upper Yorktown Aquifer. Metals in shallow groundwater may also be transported through groundwater discharge to Blows Creek and low-lying phragmites marsh areas east of the site. The explosive RDX was detected in the Upper Yorktown Aquifer in the 1999 sample from MW01D collected within the waste. The absence of RDX in any other media sample, including shallow groundwater, suggest the transport mechanism may have been from well installation through the waste. Further evaluation of Site 5 groundwater may be considered to confirm possible RDX contamination.

9.2.4 Site 6

Surface water runoff and erosion can potentially transport metals, and pesticides present in soil at Site 6 to the phragmites marsh area southwest of the site. The area is grasses with mixed forest between the site and the marsh area and metals concentrations in soil were not significantly elevated. Transport of metals through surface runoff and erosion is expected to be minimal.

9.3 Baseline Human Health Risk Assessment

A baseline HHRA was conducted to evaluate the potential human health risks associated with the presence of site-related soil, (surface and subsurface soil combined), surface water, sediment, deep groundwater, and shallow groundwater contamination at Site 3, Site 4, and Sites 5 and 6 at the SJCA. The baseline risk assessment was conducted to characterize the current and potential future human health risks at each site if no additional remediation is implemented. Total potential risks are summarized below for current/future adult and adolescent trespassers, current adult, child, and lifetime residents, future adult, child, and

lifetime residents, future adult construction workers, and future adult other workers for each site.

9.3.1 All Sites

- No hazards or risks above USEPA target levels (noncarcinogenic hazard of 1 and carcinogenic risk range of 10^{-6} to 10^{-4}) based on industrial use of any of the sites.
- Hazards and risks above USEPA target levels exist if deep groundwater beneath the sites is used as residential potable water supply and/or the sites are used for future residential development.
- Concentrations of site-related constituents in deep groundwater downgradient of the sites are expected to be less than those onsite, and therefore, downgradient uses of groundwater would result in much lower risks than those calculated at the sites.

9.3.2 Site 3

- The noncarcinogenic hazards to current and future adult and child residents who use the deep groundwater beneath Site 3 as a potable water supply exceed USEPA's target, primarily based on ingestion of manganese and arsenic in deep groundwater.
- The noncarcinogenic hazards associated with potable use of the deep groundwater also exceed USEPA's target, associated with ingestion of thallium. However, thallium was only detected in a 1997 sample from the upgradient well and was not detected in the subsequent sampling rounds.
- Future use for residential development would also result in a carcinogenic risk above USEPA's target based on contact with arsenic in the deep groundwater, soil, and sediment.
- The noncarcinogenic hazard to the future child resident based on arsenic and iron in the soil, and antimony and iron in the sediment also exceeds USEPA's target hazard.

9.3.3 Site 4

- The carcinogenic risk associated with use of the deep groundwater as a potable residential water supply exceeds USEPA's target risk range, mainly associated with arsenic and a smaller contribution from bis(2-ethylhexyl)phthalate and chloroform. Bis(2-ethylhexyl)phthalate and chloroform were only detected in deep groundwater in 1997 and not in subsequent sampling events, and these common lab contaminants may reflect artifacts of the analysis process.
- The noncarcinogenic hazards associated with potable use of the groundwater also exceed USEPA's target hazard, associated with ingestion of arsenic, iron, and manganese.
- Future residential development would result in a carcinogenic risk slightly above USEPA's target risk range due to arsenic in the soil and the use of groundwater as a potable water supply.
- The noncarcinogenic hazard to a child resident exposed to the arsenic and iron in the soil and iron in the sediment exceeds USEPA's target hazard level.

9.3.4 Sites 5 and 6

- Current carcinogenic risks are within or below USEPA's target risk range of for all media for all exposure scenarios.
- Future residential use of the site may result in a carcinogenic risk slightly above USEPA's target risk range associated with the combined exposure to arsenic in the deep groundwater, the soil, and the sediment.
- Although chloroform was also identified as a combined exposure carcinogenic risk in deep groundwater for future residential use, chloroform was only detected in 1997 and was not detected in the subsequent sampling rounds. Additionally, chloroform is a common potential lab contaminant and it is suspected that the 1997 sample results reflect artifacts of the sampling and analysis process.
- Potable use of deep groundwater would result in noncarcinogenic hazards in exceedance of USEPA's target HI for adult and child residents.
- The HI exceedances are primarily attributable to the ingestion pathway due to the presence of antimony, arsenic, iron, and manganese in deep groundwater for adult and child residents.
- Future residential development would result in exceedance of USEPA's target noncarcinogenic hazard to the child resident, primarily attributable to incidental ingestion of arsenic and iron in the soil, and incidental ingestion of and dermal contact with arsenic and iron in the sediment.

9.4 Screening Ecological Risk Assessment and Baseline Ecological Risk Assessment Step 3

The following conclusions regarding potential ecological risk have been derived from the data collected at 3, 4, 5, and 6.

- The ERA indicates the potential for adverse effects to:
  - Lower trophic-level receptors (plants and soil invertebrates) from the presence of chemicals (primarily inorganic chemical and PAHs) in soils at Sites 3, 4, and 5/6; and,
  - Avian and mammalian vermivores from lead and zinc in Site 3 and Site 5/6 (soils.
- Chemicals mainly inorganics, pesticides, and PAHs present in drainage sediments at all sites are present at concentrations that could potentially adversely affect aquatic life. The drainages (above the area of tidal influence) provide very little (Sites 4 and 5/6) or no (Site 3) viable habitat for aquatic species based on the limited surface water present within them. A broader range of aquatic species could be exposed to chemicals if they are transported via the site-related drainages to Blows Creek, where a much greater diversity of aquatic species is expected to occur based on habitat present in this water body.

- Chemicals present in surface water (primarily inorganic chemicals) may also have limited potential to adversely affect aquatic life. However, as with sediment, a broader range of aquatic species could be exposed to chemicals if they are transported via the site-related drainages to Blows Creek, where a variety of aquatic species could be exposed to chemicals in surface water or following deposition to sediment.
- Step 3A risk calculations indicated the potential for adverse effects to avian piscivores from mercury in drainage sediments at Sites 4 and 5/6. Avian piscivores are, however, expected to spend most of their time foraging in the higher quality aquatic habitats provided by Blows Creek. Available data suggests a very limited potential for chemicals in Blows Creek to adversely affect aquatic life, however, only limited samples have been collected from Blows Creek and further evaluation of this potential exposure pathway is needed.

9.5 Risk Management

The findings of the RI activities, including site characterizations, extent of contamination, fate and transport of contaminants, and risks identified in the human health and ecological risk assessments, provide the basis for evaluating potential remedial alternatives for the protection of human health and the environment. Risk management is an essential consideration in assessing remedial alternatives protective of human health and the environment, and necessitates an understanding of the uncertainties inherent in the risk assessment process, uncertainties in the identification of site-related contaminant releases with regard to naturally occurring compounds, anthropogenic compounds, and compounds typically reported in environmental media that are common artifacts of the sampling and analytical process. This section addresses uncertainties and issues that warrant consideration as part of management of site risks and provides a preface to the consideration of presumptive remedies for the sites. This discussion is not intended to identify in detail the uncertainty associated with every risk driver compound/media pathway/receptor, but to provide some perspective on the factors that may be incorporated into risk management and the remedial alternatives screening process that will be detailed in the feasibility study (FS) for the sites.

9.5.1 Human Health Risk Management

In identifying risks, the HHRA does not take into account background concentrations, and does not include a detailed analysis of the spatial distribution of constituent concentrations, or an evaluation of the circumstances of maximum concentrations dominating a 95-percent UCL used in determining exposure concentration. In partnership, the Navy, USEPA and VDEQ will include this type of evaluation in the risk management process. Risk management considerations for human health at the sites are discussed below.

9.5.1.1 Site 3

Concurrent with the completion of this RI, the SJCA Partnering Team (Navy, USEPA, and VDEQ) developed an EE/CA for a removal action at Site 3. The selected alternative consists of the complete removal of waste and debris at Site 3, the removal of soil posing a potential

risk outside the waste area (SJS03-SS15), and the removal of surface sediment in the upland drainage ditches.

Soil. Human health risk drivers for soil (surface and subsurface combined) are arsenic and iron. Arsenic and iron are elevated above background UTLs at two surface (SJS03-SS09 and SJS03-SS17) and subsurface (SJS03-SB09 and SJS03-SB17) soil locations within the waste area. Arsenic and iron concentrations in samples outside the limits of waste are below the background UTLs with the exception of the iron concentration (61,800 mg/kg) in sample SJS03-SS15. Additionally, there is no statistical difference in arsenic and iron concentrations between site and background based on population (site) to population (background) statistical comparisons. Risk associated with soil within the waste and at SJS03-SS15 will be mitigated by the proposed removal action.

Groundwater. No human health risk drivers were identified for the Columbia Aquifer groundwater. Human health risk drivers for the deeper Upper Yorktown Aquifer are arsenic, manganese, and thallium. Arsenic was only detected in one unfiltered sample in the upgradient well SJS03-MW01D in May 1999 and the concentration was below the MCL. Arsenic was not detected in any of the filtered samples. Total and dissolved manganese were detected in samples from both deep wells at concentrations below the tap water RBC. Total thallium exceeded the tap water RBC and MCL in a 1997 sample from the upgradient well but was not detected in the subsequent sampling rounds. The Navy, EPA, and VDEQ agreed risk management of groundwater is warranted with no further action.

Sediment. Antimony, arsenic, and iron in sediment were identified as human health risk drivers. Antimony was detected in samples SJS03-SD06 and SJS03-SD08 at the southeast extent of waste and the concentrations were above the background UTL. The concentration of antimony in SJS03-SD08 also exceeded the adjusted residential RBC; however, antimony was not detected in the duplicate of this sample. Arsenic and iron were detected in all seven Site 3 sediment samples. Arsenic concentrations only exceeded the background UTL in SJS03-SD08. Iron concentrations only exceeded the adjusted residential RBC and background UTL in two samples (SJS03-SD04 and SJS03-SD08). Additionally, there is no statistical difference in antimony, arsenic, and iron concentrations between site sediment and background soil based on population (site) to population (background) statistical comparisons. Risk associated with exposure to sediment and potential transport and migration to Blows Creek will be mitigated through the selected removal action alternative addressed in the EE/CA for Site 3.

Surface Water. There were no human health risk drivers associated with surface water.

9.5.1.2 Site 4

A presumptive remedy consisting of a minimum 2-ft soil cover over Site 4 is currently being considered by the SJCA Partnering Team. Risks associated with constituents in site media will be addressed in the FS for Site 4.

Soil. Human health risk drivers for soil (surface and subsurface combined) are associated with exposure to arsenic and iron. Arsenic is elevated above the background UTL at two subsurface soil sample locations, SJS04-SB02 and SJS04-SB06, within the waste area and one location peripheral to the waste (SJS04-SB07). Iron is elevated at one surface soil sample location (SJS04-SS11) in the waste area and two locations (SJS04-SB01 and SJS04-SB07)

peripheral to the waste area. There is no statistical difference in arsenic and iron concentrations between site and background based on population (site) to population (background) statistical comparisons. Risk associated with arsenic and iron will be considered during evaluation of remedial alternatives in the FS.

Groundwater. No human health risk drivers were identified for the Columbia Aquifer groundwater. The primary human health risk drivers for the deeper Yorktown Aquifer are arsenic, iron, and manganese. Total and dissolved arsenic were detected in all samples collected from SJS04-MW03D; however, the concentrations did not exceed the MCL. Total and dissolved iron and manganese were detected in all samples from both SJS04-MW01D and SJS04-MW03D and exceeded the respective tap water RBC and maximum background in all samples.

Bis(2-ethylhexyl)phthalate and chloroform were also identified as deep groundwater risk drivers. Bis(2-ethylhexyl)phthalate was only detected at SJS04-MW03D in November 1997 but was not detected in the previous or subsequent sampling rounds. Chloroform was detected in the July 1997 samples from both wells, SJS04-MW01D and SJS04-MW02D, at concentrations below the MCL, and was not detected in either samples in the two subsequent sampling events conducted. Bis(2-ethylhexyl)phthalate and chloroform are known potential lab contaminants and it is suspected that the samples reflect artifacts of the analysis process. The SJCA Partnering Team will consider risk management of bis(2-ethylhexyl)phthalate and chloroform in the Yorktown Aquifer.

Sediment. Iron was identified as a human health risk driver in sediment. Iron was detected in all nine sediment samples and the concentrations exceeded the adjusted residential RBC in five samples. Human health risks associated with iron in sediment will be managed through an evaluation of the remedial alternatives in the FS.

Surface Water. There were no human health risk drivers associated with surface water.

9.5.1.3 Sites 5 and 6

Presumptive remedies currently under consideration for Site 5 by the SJCA Partnering Team consist of soil cover and/or removal of waste/soil/sediment posing potential risk. Risks associated with Site 5 will be addressed in the FS for the site. Because Site 6 is a very small area where remnants of the caged pit are believed buried, the SJCA Partnering Team agreed that complete removal of the caged pit and associated potential risk to soil at Site 6 was warranted. Site 6 is included in the EE/CA with Site 3 and removal of Site 6 was completed in the summer of 2002.

Soil. Human health risk drivers in soil are arsenic and iron. At Site 5, arsenic concentrations are elevated above the background UTLs in surface soil to the east and west of the waste area. Site 5 iron concentrations exceeded the background UTLs in the surface and subsurface soil within the waste area and to the east and west of the waste. There is no statistical difference in arsenic and iron concentrations between site and background based on population (site) to population (background) statistical comparisons. However, based on comparison with background UTLs, risk associated with arsenic and iron in soil will be considered during evaluation of remedial alternatives.

Groundwater. No human health risk drivers were identified for the shallow Columbia Aquifer. Human health risk drivers for the deep groundwater in the Upper Yorktown Aquifer are antimony, arsenic, iron, manganese, and chloroform. Total antimony was detected in two samples collected from SJS05-MW02D at concentrations below the MCL and tap water RBC. Total arsenic was only detected in July 1997 from SJS05-MW02D and was not detected in its corresponding filtered sample or in the two subsequent sampling rounds. The detected concentration of arsenic was below the MCL.

Total and dissolved iron and manganese were detected in multiple rounds from all three wells at concentrations that exceeded the respective tap water RBCs. In the 1999 sampling, all iron and manganese concentrations were below the maximum background concentration.

Chloroform was also identified as a deep groundwater risk driver, however, a review of the data shows that chloroform was detected in two July 1997 samples from SJS05-MW01D and SJS05-MW02D but was not detected in the subsequent sampling rounds. Additionally, chloroform is a known potential lab contaminant and it is suspected that the July 1997 sample results reflect artifacts of the sampling and analysis process.

The SJCA Partnering Team will consider risk management of metals and chloroform in the Yorktown Aquifer at Site 5/6.

Sediment. Arsenic and iron were identified as human health risk drivers in sediment. Arsenic was detected in five of the seven sediment samples at concentrations exceeding the adjusted residential RBC. Iron was detected in four sediment samples at concentrations that exceeded the adjusted residential RBC. Human health risks associated with arsenic and iron in sediment will be managed through an evaluation of the remedial alternatives in the FS.

Surface Water. There were no human health risk drivers associated with surface water.

9.5.2 Ecological Risk Management

The ERA evaluated the potential for adverse effects to ecological receptors using both SERA (Step 2) and BERA (Step 3A) scenarios. The ERA also considered the following factors when evaluating and interpreting the risk results:

- Inorganic and PAH concentrations in site soils compared to those in reference samples;
- Chemical bioavailability in sediment;
- Chemical distribution in site soil and sediment;
- Influence of grain size and TOC on chemical distribution in sediment;
- Potential chemical sources to site drainages; and,
- Potential risks to ecological receptors in Blows Creek.

The following risk management recommendations are based on conclusions made in the ERA and risk model results as well as the additional considerations above and presumptive remedies for surface soils and upland drainages at the sites:

- Further investigation of potential risks to terrestrial receptors from the presence of COPCs in soil is not recommended based on remediation/presumptive remedies currently planned for the Sites.

- Further evaluation of the potential for adverse effects to aquatic life in Blows Creek is recommended as a result of historical potential chemical transport from Sites 3, 4, and 5/6 (via the site-related drainages) to Blows Creek sediment and surface water. This evaluation should include further characterization of the elevated mercury concentrations (6 mg/kg) detected in the lower portion of the eastern Site 4 drainage ditch sediments adjacent to Blows Creek. Further evaluation of the potential for adverse effects to aquatic life in the upland drainage ditches is not recommended based on the minimal habitat provided by these drainages.

- Further evaluation of the potential for adverse effects to avian piscivores foraging in Blows Creek may be warranted, based primarily on the potential for mercury in drainage sediments at Sites 4 and 5/6 to have been transported to Blows Creek. Although available chemical analytical data for Blows Creek suggests little potential for mercury or other chemicals to adversely affect avian piscivores or other wildlife foraging in this aquatic habitat, only limited chemical analytical data are currently available for Blows Creek and further evaluation of this potential exposure pathway is needed before more definitive conclusions regarding risk can be made.

9.5.3 Risk Management Summary

Figures 9-1 through 9-10 illustrate the elements of risk management (background concentrations and spatial distribution of constituent concentrations) applied to the quantitative HHRA and ERA The figures show the human health and ecological risk drivercompounds that were detected in site media at concentrations greater than background UTLs. Risk driver compounds detected at concentrations below screening criteria, or that do not have screening criteria are not shown on the summary figures.

Risk management considerations by the SJCA Partnering Team inlcude:

- Risk management of vanadium copper, and lead in Site 3 surface soil outside the limits of waste and "hot spot" SJS03-SS15.

- Risk management of arsenic, iron, and manganese in deep groundwater at Sites 3 and 4, and antimony, arsenic, iron, and manganese in deep groundwater at Site 5.

- Risk management of chloroform and bis(2-ethylhexyl)phthalate in deep groundwater at Sites 4 and 5/6, detected in 1997 samples but not detected in subsequent sampling events.

Remedies under consideration by the SJCA Partnering Team include removal and/or soil cover to address potential risk from exposure to surface soil and upland ditch sediment. Mitigation of risk through remedial actions for surface soil and upland ditch sediment will also eliminate concern for continued transport of potential contaminants to Blows Creek via the upland ditches. The SJCA Partnering Team may consider additional soil sampling at Sites 3 and 5 in support of further evaluating remedial alternatives. A BERA for Blows Creek will be conducted in FY03 to identify potential risk associated with poossible historical contributions to Blows Creek via transport from the sites in upland drainages. Because surface water is transient at Sites 3 through 6 and the upland ditches provide minimal ecological habitat, there is no significant risk to human health and the environment from direct exposure to surface water.