Tennessee Valley Authority
Regulatory Submittal for Kingston Fossil Plant

Documents submitted
Kingston Fly Ash Recovery Project Non-Time-Critical Removal Action Embayment/River System Engineering Evaluation/Cost Analysis (EE/CA) Report

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Kingston Ash Recovery Project
Non-Time Critical Removal Action
River System
Engineering Evaluation/Cost Analysis (EE/CA)

Prepared by:
Tennessee Valley Authority

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00	River System EE/CA for TVA Review	May 21, 2012
01	River System EE/CA for Regulatory Review	June 15, 2012
02	River System EE/CA for Public Review	August 6, 2012

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List of Acronyms

ARAP	Aquatic Resources Alteration Permit
ARAR	Applicable or Relevant and Appropriate Requirement
AVS	acid volatile sulfide
BERA	Baseline Ecological Risk Assessment
BHHRA	Baseline Human Health Risk Assessment
BSFR	Bulk Survey for Release
CAP	Corrective Action Plan
CB	cement-bentonite
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulation
cfs	cubic foot per second
cm	centimeter
COC	constituent of concern
COEC	constituent of ecological concern
COPC	constituent of potential concern
COPEC	constituent of potential ecological concern
CRM	Clinch River Mile
CSB	confined sediment basin
cy	cubic yard
DO	dissolved oxygen
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EE/CA	Engineering Evaluation/Cost Analysis
EMWMF	Environmental Management and Waste Management Facility
EPA	U.S. Environmental Protection Agency
ERDC	Engineering Research and Development Center
ERDCWES	ERDC Waterways Experimentation Station
ERM	Emory River Mile
ESTCP	Environmental Security Technology Certification Program
ºF	degree Fahrenheit
FR	Federal Register
Frontier	Frontier Global Sciences, Inc.
ft	foot
ft^3	cubic foot
Geosyntec	Geosyntec Consultants, Inc.
GP	Geoprobe®
HI	hazard index
HQ	hazard quotient
Jacobs	Jacobs Engineering Group Inc.
KIF	Kingston Fossil Plant
LOAEL	lowest-observed-adverse-effect levels
LOE	line of evidence
LOEC	lowest observed effect concentration
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm	millimeter
MNR	monitored natural recovery
msl	mean sea level

MW	monitoring well
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOAEL	no-observed-adverse-effect level
NOEC	no observed effect concentration
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance
ORP	oxidation-reduction potential
OSC	On-Scene Coordinator
OSHA	Occupational Safety and Health Act
Pa	pascal
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
pCi/g	picocuries per gram
PLM	polarized light microscopy
PPE	personal protective equipment
PPRTV	Provisional Peer Reviewed Toxicity Value
PWS	Perimeter Wall Stabilization
RAO	removal action objective
RG	remediation goal
SAP	Sampling and Analysis Plan
SEM	simultaneously extracted metal
SLERA	Screening-Level Ecological Risk Assessment
TCA	Tennessee Code Annotated
TCLP	Toxicity Characteristic Leaching Procedure
TDEC	Tennessee Department of Environment and Conservation
TDS	total dissolved solid
TM	Technical Memorandum
TME	tissue monitoring endpoint
TRM	Tennessee River Mile
TSS	total suspended solids
TVA	Tennessee Valley Authority
TWP	temporary well point
TWQC	Tennessee Water Quality Criteria
TWRA	Tennessee Wildlife Resources Agency
UCL	upper confidence limit

EXECUTIVE SUMMARY

This Engineering Evaluation/Cost Analysis (EE/CA) evaluates alternatives for restoration of the river system impacted by the released fly ash at the Tennessee Valley Authority (TVA) Kingston Fossil Plant Release Site (the "Site") in Roane County, Tennessee.

On Monday, December 22, 2008, a coal ash release occurred at TVA's Kingston plant, allowing a large amount of ash to escape from an onsite Dredge Cell into the Swan Pond Embayment and the adjoining Emory River. On January 12, 2009, the Tennessee Department of Environment and Conservation issued a Commissioner's Order, Case No. OGC09-0001, requiring that action be taken to respond to the emergency under Tennessee Code Annotated §69-3-109(b)(1), the Water Quality Control Act. On May 11, 2009, an Administrative Order and Agreement on Consent was signed between the U.S. Environmental Protection Agency (EPA) and TVA providing the regulatory framework for the restoration. The restoration work is being conducted under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and, more specifically, under the removal program.

TVA undertook time-critical actions to achieve short-term strategic Site objectives defined in the EPA Order. These actions included hydraulic and mechanical dredging of ash from the Emory River, mechanical excavation of ash from the Swan Pond Embayment, dewatering and processing of the recovered ash, loading of the dewatered ash into railcars, transport of the ash via rail offsite, and ultimate disposal of the ash at the Arrowhead Landfill in Perry County, Alabama. Time-critical dredging was completed in June 2010 and offsite disposal was completed in December 2010.

A Work Plan for performing non-time-critical removal actions at the Site recommended that two EE/CAs be prepared, one for the embayment/Dredge Cell area and the other for residual ash in the river. The EE/CA for the embayment/Dredge Cell area was approved by EPA in January 2010. Non-time-critical removal actions are currently underway and include excavation of ash from the Swan Pond Embayment, dry-stacking the ash in an onsite Ash Landfill, and final closure of the Ash Landfill.

The Work Plan also recommended that the EE/CA for the river system be prepared at a later date, following further sampling and analysis of biotic and abiotic media, and assessment of potential human health and ecological risks for the river system. A Sampling and Analysis Plan for the river system was prepared in May 2010 to define the required sampling and analysis. Results of that sampling and analysis are presented in this EE/CA.

The purpose of this EE/CA is to describe the objectives of the removal action in the river system, and to describe and evaluate available alternatives for restoration of areas having residual fly ash. This EE/CA has been prepared in accordance with EPA's *Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA.*

Site Conditions. Failure of the Dredge Cell dike released about 5.4 million cubic yards (cy) of coal ash. Approximately 2.4 million cy of that ash filled the Swan Pond Embayment, and the remaining 3.0 million cy entered the Emory River. Time-critical dredging of the Emory River removed approximately 3.5 million cy of released ash and sediment, but approximately 532,000 cy of ash was estimated to remain in the river system, as described in the EPA-approved On-Scene Coordinator Report. Current estimates based on 2010 sampling provide similar results; approximately 510,000 cy of ash deposits greater than 0.5 ft thick are estimated to remain in the river system. The ash is composed of fine silica particles similar to sand. Trace amounts of metals and radionuclides occur naturally in the coal and remain in the ash after coal combustion.

The Emory River drains a watershed area of approximately 865 square miles with average flow rates between 700 and 1,300 cubic feet per second. The affected reach of Watts Bar Reservoir extends upstream to above Harriman. Normal summer pool within Watts Bar Reservoir is maintained between 740 and 741 ft above mean sea level (msl); normal winter pool is maintained between 735 and 737 ft msl. During low flow conditions in the Emory River, backflow of water from the Clinch River up the Emory River can occur.

For purposes of sampling and analysis, the river system was divided into 10 different reaches: three upstream (reference) reaches, three downstream reaches in the Emory River, and two downstream reaches in each of the Clinch and Tennessee Rivers. The area most affected by the ash release extends from Emory River Mile 1.5 to 3.5 in Emory River Reach B.

The Emory, Clinch, and Tennessee Rivers are waters of the state classified for the following uses: domestic water supply, industrial water supply, fish and aquatic life, recreation, irrigation, livestock watering and wildlife, and navigation.

Nature and Extent of Contamination. Samples of cell ash, sediment, surface water, groundwater, and biota have been collected and analyzed for metals, organic chemicals, radionuclides, and other parameters. Metals, primarily arsenic and selenium, have been the focus of this monitoring, since they contribute most to potential ecological risk. Arsenic is present in the cell ash at an average concentration of 74.5 milligrams per kilogram (mg/kg); selenium is present in the cell ash at an average concentration of 7.89 mg/kg.

Nearly 70 samples of seasonally-exposed sediment were collected near the shoreline in the Emory and Clinch River reaches. Average arsenic concentrations in seasonally-exposed sediment varied between 14.3 and 19.2 mg/kg in Emory and Clinch River reaches. Average concentrations of selenium, when detected, were near the detection limit, ranging from 1.77 to 2.45 mg/kg in the downstream reaches.

More than 80 samples of submerged sediment were collected from the river bottom from the 10 river reaches. Average arsenic concentrations in submerged sediment were highest in the lower Emory River, at 25.0 mg/kg, and declined to an average of 12.1 mg/kg in the Tennessee River. Average concentrations of selenium, when detected, were highest in the Emory River at 5.16 mg/kg, then declined to non-detect in the Tennessee River sediment.

Surface water samples were collected during an 8-week period in September and October 2010, from both mid-depth and epibenthic (near the bottom of the river) zones. More than 80 mid-depth surface water samples were analyzed from 11 stations located in the Emory, Clinch, and Tennessee Rivers. Average arsenic concentrations in mid-depth surface water were highest in the Emory River at 0.0020 milligrams per liter (mg/L), then declined to near reference values in the Tennessee River. Arsenic in epibenthic surface water in the Emory River was higher than mid-depth surface water, varying between 0.0030 and 0.0037 mg/L. Selenium was detected infrequently and at low concentrations near reference values in surface water samples. No constituent in either mid-depth or epibenthic surface water in downstream reaches exceeded Tennessee Water Quality Criteria (TWQC). Arsenic, lead, and mercury concentrations exceeded TWQC infrequently during storm event sampling.

Groundwater samples were collected between September and October 2010 from a series of 8 permanent monitoring wells, 6 temporary well points, and 11 Geoprobe® locations in and around the Ash Landfill. Arsenic concentrations in permanent monitoring wells were less than the TWQC maximum contaminant level of 0.010 mg/L with a maximum of 0.002 mg/L in one well. Arsenic concentrations were much higher in temporary well points in the alluvium beneath the Dredge Cell, with a maximum of 0.594 mg/L; in the cell ash porewater, arsenic concentrations were as high as 0.915 mg/L. Selenium was not detected in any of the permanent monitoring wells or temporary well points; in the cell ash porewater, selenium concentrations ranged from 0.00035 to 0.0196 mg/L. Results of groundwater modeling simulations predict that after 100 years, concentrations of arsenic and selenium will change little over time, primarily a result of sorption, reduction in recharge due to capping, and reduction in lateral groundwater movement due to the construction of a perimeter wall around the Ash Landfill.

Samples of plants and animals were analyzed for evaluation of bioaccumulation and food web modeling in the ecological risk assessment. In addition, results of toxicity testing of sediment and surface water and surveys of fish and benthic invertebrate communities were used as additional lines of evidence (LOE) in evaluating ecological risks.

Baseline Human Health Risk Assessment. A Baseline Human Health Risk Assessment was completed to develop quantitative and qualitative estimates of potential cancer risks and non-cancer hazards for human receptors exposed to environmental media impacted by ash remaining in the river system. The risk analysis was based on analytical data collected from seasonally-exposed sediment, surface water, and fish filet sampling. The risk assessment was conducted in accordance with EPA *Risk Assessment Guidance for Superfund* protocols.

Cancer risk estimates for a resident exposed to surface water slightly exceeded EPA's target risk range. The highest cancer risk (2E-04) was calculated for a resident adult drinking untreated surface water directly from Watts Bar Reservoir. However, there is high uncertainty in this risk estimate because it is driven by detection of radium-228 in a single sample. In addition, this scenario assumes that the resident draws water directly from the river for household use without filtration or treatment, by-passing the available public water supply or installation of a groundwater well. This exposure pathway is unlikely. Therefore, the risks due to surface water ingestion are unlikely. The highest noncancer Hazard Index (HI) was calculated to be 1; however, the HI for individual constituents was less than 1. Potential noncancer effects of these constituents impact different target organs and additivity of effects is not likely to occur. Therefore, no removal action is warranted for protection of a resident.

Cancer risk estimates for a recreator (swimmer/beachcomber) exposed to seasonally-exposed sediment or surface water did not exceed the target risk range for any receptor (adult or adolescent). The highest calculated risk in any river reach was 3.E-05 for an adult recreator exposed to sediment. Similarly, noncancer hazard estimates for recreator exposure to seasonally-exposed sediment or surface water did not exceed the HI threshold of 1 for any receptor (adult or adolescent). The highest calculated HI was 0.3 for the adolescent recreator.

Cancer risk estimates for recreators from fish consumption exceeded the target risk range in most river reaches. These cancer risk estimates ranged from 6.E-05 to a high of 7.E-04 for adult consumption of catfish in Emory River Reach C. These cancer risks are driven by arsenic, various pesticides, and polychlorinated biphenyls (PCBs) in fish. Potential cancer risks from arsenic are at the lower end of EPA's target risk range (i.e., 1E-06 to 1E-04). Pesticides and PCBs are legacy constituents in the river system that are not ash-related. For this reason, although there is potential unacceptable cancer risk due to ingestion of fish, these risks are associated with legacy contaminants in the river system and not ash-related. There is no unacceptable cancer risk to people eating fish as a result of residual ash in the river.

Noncancer hazard estimates for recreators exceeded the HI threshold of 1 for fish consumption in most river reaches. The highest calculated HI was 46 for child consumption of bass in Emory River Reach C. While constituents contributing to these noncancer hazards varied by type of fish and reach of the river, only mercury and PCBs had individual hazard quotients equal to or greater than 1. The noncancer effects of other constituents are based on impacts to different target organs, and additivity of effects is not likely to occur. PCBs and mercury are legacy constituents in the river system and not ash-related. Although there is potential unacceptable noncancer hazard due to ingestion of fish, these hazards are associated with legacy contaminants in the river system and not ash-related. There is no unacceptable noncancer hazard to people eating fish as a result of residual ash in the river. Therefore, no removal action is warranted for protection of a recreator.

Ecological Risk Assessment. A Baseline Ecological Risk Assessment was conducted to evaluate potential risks to aquatic and riparian (shoreline) ecological receptors exposed to environmental media impacted by ash remaining in the river system. The risk analysis followed an 8-step process in accordance with EPA's *Ecological Risk Assessment Guidance for Superfund* protocols.

Receptor groups evaluated included the benthic invertebrate and fish communities, aquatic- or riparian-feeding bird and mammal populations, aerial-feeding bird and mammal populations, amphibians, reptiles, and aquatic plant communities. Each receptor group was evaluated using multiple endpoints and multiple LOE. Potential risks were then characterized using a weight-of-evidence approach. More than one LOE was used to demonstrate whether ash-related constituents could cause adverse effects. Primary evidence included comparison of effects values to measured constituent concentrations in environmental media, prey, or the organism's tissue; results of toxicity tests; and site-specific biological community surveys. Secondary evidence included health metrics (such as liver enzyme levels in fish and mammals, organ dysfunction, or increased frequency of lesions in fish).

Benthic invertebrates (e.g., mayflies or snails) were considered to be at moderate risk in the Emory River and low risk in the Clinch River due to biouptake of arsenic and selenium in ash-contaminated sediment. Riparian-feeding birds (e.g., killdeer) that feed on benthic invertebrates in ash-impacted areas of the river system were considered at low risk due to biouptake of arsenic and selenium in their diet (larval mayflies and snails). Aerial-feeding birds (e.g., tree swallows) were also considered to be at low risk due to biouptake of selenium in their diet (adult mayflies). Risk management actions were recommended for these receptor groups; potential removal actions are evaluated in this EE/CA.

Other ecological receptor groups were considered to be at low to negligible risk. These include fish, fish-eating birds, mammals, amphibians, reptiles, and aquatic plant communities. No further actions were recommended for protection of these receptor groups.

Removal Action Objectives. Results of the human health and ecological risk assessments indicate no unacceptable risk to human health and relatively low potential risk to ecological receptors due to exposure to naturally-occurring metals and radionuclides in the ash-contaminated sediments. A removal action is needed to mitigate the threat or potential threat to environment. The following are the specific Removal Action Objectives (RAOs):

- Protect benthic invertebrate populations in Watts Bar Reservoir from adverse affects due to arsenic and selenium in ash-contaminated sediment;
- Protect riparian-feeding bird (killdeer) and aerial-feeding bird (tree swallow) populations from adverse affects due to uptake of arsenic and selenium in ash-contaminated sediment through their diet (benthic invertebrates);
- Restore the ecological function and recreational use of the river system to pre-release conditions;
- Dispose of waste streams from the removal action in accordance with Applicable or Relevant and Appropriate Requirements (ARARs).

Development of Alternatives. EPA guidance identifies major remedial approaches or alternatives available for managing risks from contaminated sediment to assist in making risk management decisions. These approaches include monitored natural recovery, institutional controls, in-situ capping, in-situ treatment, and dredging/excavation. Given site-specific conditions and presence of metals, monitored natural recovery, in-situ capping, and dredging with subsequent disposal are applicable technologies for this Site.

A limited number of alternatives has been developed. These alternatives are intended to represent a range of possibilities for restoration of the river, with distinctly different advantages and disadvantages, so that tradeoffs between them can be clearly defined and evaluated. The following alternatives have been developed:

- Alternative 1: Monitored Natural Recovery.
- Alternative 2: In-situ Capping. Two subalternatives were evaluated; one (Alternative 2a) would cap virtually all areas of ash deposits, and the other (Alternative 2b) would cap areas of ash deposits subject to scouring.
- Alternative 3: Dredging. Two subalternatives were evaluated; one (Alternative 3a) would dredge virtually all areas of ash deposits, and the other (Alternative 3b) would dredge areas of greater ecological significance.

Evaluation of Alternatives. The relative performance of each alternative has been evaluated with respect to its effectiveness, implementability, and cost. The purpose of this comparative analysis is to highlight the advantages and disadvantages of each alternative relative to one another so that key tradeoffs that would affect the remedy selection can be identified.

Effectiveness. Each alternative would meet RAOs and would be protective of both human health and the environment, although Alternatives 2 and 3 would initially cause short-term impacts to the benthic community to be protected. Under Alternative 1, scour and sedimentation processes would result in mixing of ash and natural sediments within the upper 6 inches of sediment; percentage of ash, concentrations of arsenic and selenium, and biouptake by benthic invertebrates would therefore decline. Under Alternative 2, capping of ash deposits greater than 6 inches in thickness would eliminate direct contact with much of the exposed ash deposits and would reduce potential scour during flood events. Under Alternative 3, removal of ash deposits greater than 1 ft in thickness would reduce the total volume of ash in the river system by 80% and reduce the area extent of residual ash deposits by half. There is considerable uncertainty in the prediction of future mass transport and rate of concentration decline for the three alternatives.

Each of the alternatives would comply with ARARs. Natural recovery of the rivers would gradually restore waters of the state for fish and aquatic wildlife and recreation in compliance with chemical-specific ARARs. Under Alternative 1, no location- or action-specific ARARs would be invoked because only monitoring activities would be conducted within the rivers. Under Alternatives 2 and 3, capping and dredging would involve activities within the floodplain, invoking location-specific ARARs. Capping under Alternative 2 could impact flood elevations, requiring further hydrologic analysis. Management of dredged spoils under Alternative 3 would invoke action-specific ARARs regarding site preparation, construction, excavation, and waste characterization, storage and disposal activities.

Each of the alternatives would be effective over the long term, although in differing ways and to differing degrees. Monitored Natural Recovery (MNR) under Alternative 1 would rely on permanent and irreversible processes of scour and sedimentation to gradually eliminate direct contact of benthic invertebrates with arsenic and selenium in the ash and biouptake from ash-contaminated sediment to riparian- and aerial-feeding birds. The alternative would be effective in naturally establishing a mixed ash and sediment cover; although severe storm flow events could expose underlying ash deposits, the natural cover would become reestablished. As a result, RAOs may not be fully achieved for nearly 30 years. Under Alternative 2, biota exposure in capped areas would be eliminated following cap placement. The cap protection would be effective so long as the cap materials remain in place; however, effectiveness of the cap would be limited if a severe storm flow event were to occur. Under Alternative 3, removing the ash from the river system would effectively reduce biota exposure. Dredging would be effective in removing large quantities of retrievable ash while minimizing the disturbance of native sediment; however, residual ash lenses about 1 ft in thickness would likely remain over half of the dredged area. Over-dredging of native sediment would be particularly undesirable in the lower Emory and Clinch Rivers due to the presence of cesium-137, PCBs, polynuclear aromatic hydrocarbons, mercury, and other legacy contaminants in underlying sediments that are not related to the ash release.

Short-term impacts are not likely under Alternative 1, since there would be no construction in the river. Alternative 1 would therefore be consistent with an existing DOE Record of Decision for the Clinch River, which established that the sediment not be removed because there is more risk from removing it than leaving it in place due to high rates of sediment resuspension and impacts to the benthic invertebrate population.

Short-term impacts would be much greater under both Alternatives 2 and 3. Placing cap material under Alternative 2 would smother existing benthic invertebrate communities and dredging under Alternative 3 would virtually eliminate existing benthic invertebrate communities. Benthic invertebrate communities were found to rebound quickly following the time-critical dredging activities (within one year), so similar rapid rebound would be expected for Alternative 3. Rebound in capped areas (Alternative 2) may be inhibited by the cap itself, which would discourage burrowing and provide a poor substrate. Placement of cap materials (Alternative 2) or dredging (Alternative 3) could result in short-term turbidity impacts on water quality. Sediment resuspension could increase potential exposure of benthic organisms to sediments containing legacy constituents (cesium-137, PCBs, and mercury). Impacts on the public during construction would be negligible and would not require closing of the river to recreational boaters nor pose unacceptable risk to the public during swimming, fishing, or other recreational use of the river.

Alternative 2 would involve hauling up to 161,000 cy of cap materials, resulting in estimated transportation risks of less than one truck accident, with no injuries or fatalities. Alternative 3 would involve hauling up to 440,000 cy of waste materials, resulting in nearly 2.4 million trip miles and estimated transportation risks of two potential truck accidents, with no injuries or fatalities. Various disposal options would affect these short-term risk estimates. Short-term risks to workers would be greatest under Alternative 3 due to the greater amount of material handling.

Implementability. The alternatives would be implementable using conventional technologies. Alternative 1 would be implementable immediately, since no construction would be required. Long-term operations and maintenance (O&M) activities would include routine monitoring of sediment and biota, fate and transport modeling, and residual risk evaluation for a period of up to 30 years. Alternative 2 would be implementable within 18 to 22 months. Implementation would require particular care in placement of the cap materials to limit turbidity and to place the cap to a uniform thin layer underwater. Alternative 3 would be implementable within 25 months for Alternative 3a and 11 months for Alternative 3b; however, significant challenges would be anticipated. Dredging in shallow water areas would be complicated by the need to coordinate dredging with fluctuations in reservoir levels. Properties of the fine-grained ash would complicate ash dewatering particularly during periods of prolonged inclement weather. The greatest difficulty in implementing Alternative 3 would be the availability of suitable capacity of disposal facilities due to potential cesium-137 contamination in the ash. Regulatory and/or public opposition to use of a particular disposal facility would complicate implementability of disposal options.

Long-term O&M would be greatest under Alternative 2. In addition to monitoring, O&M would include routine inspection and surveying of the cap to verify it remains in place, and repair of the cap as required.

Cost. There are no estimated capital costs for Alternative 1 because there would be no active construction. Capital costs for Alternative 2 are moderate ($31.9 million for Alternative 2a and $25.9 million for Alternative 2b). Capital costs are highest for Alternative 3 ($169.4 million for Alternative 3a and $73.7 million for Alternative 3b) due to the high cost of transport and disposal of large volumes of material. Capital costs for Alternative 3 are highly dependent on the ultimate disposal location, which results in considerable uncertainty.

Annual O&M costs are comparable for the alternatives, since the O&M activities for sediment and biota monitoring are much the same. Estimated annual O&M costs range between $0.5 million/year (2012 dollars) for Alternatives 1 and 3 to $0.7 million/year for Alternative 2. Alternative 2 O&M costs are greater due to cap maintenance activities. Other monitoring for supplemental investigation of fish bioaccumulation, fish community surveys, or sediment toxicity testing may be conducted for up to 5 years to confirm trends. Costs of other monitoring are estimated at $0.3 million/year.

Present worth costs, which reflect combined capital, annual O&M, and other monitoring costs, are highly dependent on the duration of MNR. This time frame is uncertain due to the considerable uncertainty in the prediction of future mass transport and rate of concentration decline. A monitoring period of 30 years has been used in evaluating present worth costs. Total present worth costs are estimated to be $10.0 million for Alternative 1, $44.8 million for Alternative 2a, $38.7 million for Alternative 2b, $179.1 million for Alternative 3a, and $83.4 million for Alternative 3b.

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1. INTRODUCTION

This Engineering Evaluation/Cost Analysis (EE/CA) evaluates alternatives for restoration of the river system impacted by the released ash at the Tennessee Valley Authority (TVA) Kingston Fossil Plant Release Site (the "Site") in Roane County, Tennessee (Figure 1).

On December 22, 2008, approximately 5.4 million cubic yards (cy) of ash material were released into the Swan Pond Embayment and adjacent Emory River. In response to this release, TVA undertook immediate response actions and worked in close coordination with the U.S. Environmental Protection Agency (EPA), Tennessee Department of Environment and Conservation (TDEC), and other agencies to provide for the safety of area residents, to contain released ash and minimize its downriver migration, and to monitor and assess air and water quality. On January 12, 2009, TDEC issued a Commissioner's Order to TVA requiring the comprehensive assessment, cleanup and restoration of areas impacted by the release (TDEC 2009). On May 11, 2009, an Administrative Order and Agreement on Consent (EPA Order) was signed between EPA and TVA providing the regulatory framework for the removal actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (EPA 2009). TVA undertook time-critical actions to achieve short-term strategic Site objectives defined in the EPA Order. These actions included hydraulic and mechanical dredging of ash from the Emory River, mechanical excavation of ash from the Swan Pond Embayment, dewatering and processing of the recovered ash, loading of the dewatered ash into railcars, transport of the ash via rail offsite, and ultimate disposal of the ash at the Arrowhead Landfill in Perry County, Alabama. Other related actions included cenosphere removal, air monitoring and dust control, surface water monitoring, storm water management, dike stability evaluations and stabilization, and construction of a test embankment to demonstrate the constructability of dry ash stacking.

In accordance with Section IX.30 of the EPA Order, a Work Plan for performing one or more EE/CAs for non-time-critical removal actions at the Site was prepared. That Work Plan (Jacobs 2010a) recommended that two EE/CAs be prepared, one for the embayment/Dredge Cell area and the other for residual ash in the river. The EE/CA for the embayment/Dredge Cell area was approved by EPA in January 2010 (Jacobs 2010a). Non-time-critical removal actions are currently underway and include excavation of ash from the Swan Pond Embayment, dry-stacking the ash in an onsite Ash Landfill, and final closure of the Ash Landfill.

The Work Plan also recommended that the EE/CA for the river system be prepared at a later date, following further sampling and analysis of biotic and abiotic media, and assessment of potential human health and ecological risks for the river system. A Sampling and Analysis Plan (SAP) for the river system was prepared in May 2010 to define the required sampling and analysis (Jacobs 2010d). Results of that sampling and analysis are presented in this EE/CA.

The purpose of this EE/CA is to describe the objectives of the removal action in the river system, describe and evaluate available alternatives for restoration of areas having residual ash, and identify the recommended action. This EE/CA has been prepared in accordance with EPA's *Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA* (EPA 1993). The EE/CA is organized as follows:

- Section 1, Introduction, describes the Site and previous actions taken at the Site.
- Section 2, Nature and Extent of Contamination, summarizes available data used to characterize the Site and surrounding areas.
- Section 3, Summary of the Risk Evaluations, describes briefly the assessments that have been done to evaluate potential human health and ecological risks.

- Section 4, Removal Action Objectives (RAOs), identifies the scope, goals, and objectives of the non-time-critical removal action for the river system and summarizes Applicable or Relevant and Appropriate Requirements (ARARs).

- Section 5, Removal Action Alternatives, identifies applicable technologies and develops alternatives for restoration of the river system.

- Section 6, Analysis of Alternatives, presents an individual analysis of the alternatives based on effectiveness, implementability, and cost, followed by a comparative analysis to identify trade-offs between alternatives.

- Section 7, Recommended Removal Action Alternative, identifies the removal action alternative that best satisfies the evaluation criteria.

- Figures are located at the end of the document, attached.

- Appendices are also located at the end of the document. In particular, the appendices include the analytical data, detailed ARARs, and cost estimates in support of this EE/CA.

1.1 SITE DESCRIPTION

1.1.1 Site Location and History

The Kingston plant is located just off Swan Pond Road in Harriman, Roane County, Tennessee, near the city of Kingston (Figure 1). Construction of the plant began in 1951 and was completed in 1955. The plant typically generates 10 billion kilowatt-hours of electric power each year, enough to supply the needs of about 670,000 homes in the Tennessee Valley. The plant consumes approximately 14,000 tons of coal per day when operating at full power (nine coal-fired units).

Ash material is a by-product of burning pulverized coal in fossil fuel power generation plants. The Kingston plant can produce about 1,000 dry tons, or approximately 1,200 cy of ash per day when operating at full power. Ash material consists of both bottom ash and fly ash. Bottom ash is a coarse-grained material that is carried out of the bottom of the plant's production furnaces. Fly ash is a fine powdery material that is removed from the plant's exhaust stream by electrostatic precipitators. Prior to the release, the bottom ash and fly ash were then sluiced as a water-based slurry to an Ash Pond for settling. The ash was then dredged from the Ash Pond and piped to long-term unlined storage ponds, also known as dredge cells.

The dredge cells were permitted by TDEC on September 26, 2000, as a Class II Solid Waste Landfill under state regulations. The three permitted dredge cells (Cells 1, 2, and 3) that failed during the release (referred to as the Dredge Cell) covered approximately 127 acres and stored approximately 16.2 million cy of both fly and bottom ash at the time of the release. A fourth permitted dredge cell (referred to as the Lateral Expansion area, or Cell 4) was being constructed at the time in the northern half of the Ash Pond. Together, the Ash Pond and Lateral Expansion area covered approximately 120 acres and contained approximately 4.0 million cy of ash at the time of the release (Jacobs 2010b). The Dredge Cell, Ash Pond, and Lateral Expansion areas therefore contained a combined total of approximately 20 million cy.

Ash is also present in other areas of the Kingston plant, having been generated from historical ash processing operations. The Ball Field is a triangular-shaped area located immediately north of the plant and south of the Dredge Cell; the Ball Field was one of the first ash settling pond areas at the Kingston plant, and has at least 40 ft of underlying ash deposits (Figure 2). The area was later used for metals treatment ponds, and for community use as a soccer field and baseball diamond prior to the release. A larger ash settling pond was constructed in 1961, after the Ball Field had been filled with ash and capped. The new ash settling pond consists of the Lateral Expansion, Stilling Pond and Ash Pond areas (Figure 2). The intermediate dike separating the Ash Pond and Stilling Pond was installed between 1976 and 1984. The Lateral Expansion remained part of the Ash Pond until 2008 when TDEC permitted the northern half of the Ash Pond as a storage area. The Stilling Pond is a triangular-shaped area located immediately east of the Ash Pond and Lateral Expansion area; the Stilling Pond is used for final treatment of plant wastewaters prior to discharge under the Kingston plant's National Pollutant Discharge Elimination System (NPDES) permit; the Stilling Pond also has approximately 40 ft of underlying ash deposits. Quantities of ash present in the Ball Field and Stilling Pond areas are estimated to be less than 5 million cy. The Dredge Cell, Ash Pond, Lateral Expansion, Ball Field, and Stilling Pond areas therefore contained a combined total of approximately 24 million cy.

The ash material contains naturally-occurring metals and radionuclides that are hazardous substances as defined by CERCLA Section 101(14). Coal, in its natural state, contains various inorganic constituents that can be concentrated and retained in the ash after burning the coal for power production. The specific chemical composition of fly ash depends on the source of the coal. The plant mostly uses eastern bituminous coal but also has used coal from Illinois and blends low-sulfur Western coal to reduce emissions. Ash is primarily composed of fine silica particles. Oxides of silicon, aluminum, iron, and calcium, chemically combined in an amorphous form, comprise 95 to 99% of fly ash. Ash contains variable amounts of magnesium, titanium, sulfur, sodium, and potassium. Ash also contains trace amounts (less than 1%) of other constituents that occur naturally in coal, such as arsenic, barium, beryllium, boron, copper, lead, mercury, nickel, selenium, thallium, vanadium, and zinc (TVA 2009a). In addition, ash contains naturally-occurring radionuclides, such as isotopes of uranium and thorium, their short-lived daughter products (such as radium), and potassium-40. Analytical data for ash and naturally-occurring soils in the region are discussed in Section 2.

The released ash extended through several miles of riverways. Initially, the ash may have traveled upriver as far as Emory River Mile (ERM) 5.75 and as far downriver as Tennessee River Mile (TRM) 564. During the time-critical removal action, further downriver migration of ash occurred into the Clinch and Tennessee Rivers in response to large rainfall and high river flow events. Dredging of the Emory River during the time-critical removal action removed approximately 3,511,000 cy of released ash and sediment, but not all ash was retrieved. Approximately 532,000 cy of ash was estimated to remain in the river system, as described in the EPA-approved On-Scene Coordinator (OSC) Report (Jacobs 2011b).

1.1.2 Demographics

Roane County had a total population of 54,181 in 2010. The county is primarily rural, with about 60% of the population living outside of incorporated cities and towns. The nearest cities include Kingston (population 5,934) approximately 2 miles southeast of the Kingston plant, Harriman (population 6,350) 3 miles northwest, and Rockwood (population 5,562) 10 miles southwest.

Per the EPA Order, the "Site" is defined as those areas of the Kingston plant where waste material has been deposited, stored, disposed of, or placed or has migrated or otherwise come to be located. Most of the 300 acres directly affected by the release was TVA property, although 40 non-TVA owned properties, constituting a total of 8 acres, were affected. TVA has since purchased most of the affected properties and others in the area that may be affected by response actions.

1.1.3 Climate

Climate in the region surrounding Kingston, Tennessee is warm during summer when average daily temperatures tend to be in the 70's and cold during winter when temperatures tend to be in the 30's. The warmest month of the year is July with an average maximum temperature of 87 degrees Fahrenheit (ºF), while the coldest month of the year is January with an average minimum temperature of 25 ºF. Temperature variations between night and day tend to be moderate during summer with a difference that can reach 23 ºF, and moderate during winter with an average difference of 22 ºF.

The annual average precipitation at Kingston is 53.23 inches. Rainfall is fairly evenly distributed throughout the year. The wettest months of the year occur between November and April, with highest average monthly precipitation in March of 5.70 inches. The driest months of the year occur in August through October (National Weather Service 2006).

1.1.4 Topography

The Kingston plant and the area affected by the ash release lie within the Valley and Ridge physiographic province, a region characterized by narrow, subparallel ridges and valleys trending northeast-southwest. Topography varies from elevations of 1,000 to 1,100 ft mean sea level (msl) on the tops of the ridges to 737 ft msl at Watts Bar Reservoir. Early maps of the area indicate the ash storage area was formerly a seasonal backwater or flood plain of the Emory River. The backwater was likely subject to periodic flooding; the Emory River floodplain elevations before construction of the Kingston plant varied between approximately 725 and 735 ft msl (based on a 1924 topographic survey). Bottom elevation of the pre-release embayment area varies between 735 and 737 ft msl. After the release, ash and intermixed soil filled much of the embayment to depths of more than 20 ft; ash has been removed from much of the embayment area to pre-release elevations. Within the former Dredge Cell, ash is being dry-stacked as part of the construction of the Ash Landfill; following the non-time-critical removal action, elevations at the top of the Ash Landfill are planned to vary between 765 and 790 ft msl.

1.1.5 Surface Water Hydrology

The Kingston plant is located on the Emory River close to the confluence of the Clinch and Tennessee Rivers. The Emory River at the Kingston plant is impounded by Watts Bar Dam. Watts Bar Dam was built in 1942 across the Tennessee River at river mile marker 529.9, which subsequently caused the Emory River to back up and flood shallow land that is now covered by the Ball Field, Dredge Cell, Ash Pond, Lateral Expansion, and Stilling Pond. Swan Pond Embayment was created as a shallow backwater area of the Emory River due to this damming. The Emory River originates upstream on the Cumberland Plateau and its flows into Watts Bar Reservoir are not controlled. Flows in the nearby Clinch River arm of Watts Bar Reservoir are controlled by Melton Hill Dam.

The Emory River drains a watershed area of approximately 865 square miles with average flow rates between 700 and 1,300 cubic ft per second. The affected reach of Watts Bar Reservoir transitions from the upstream riverine (riverlike) reaches of the Emory River to the more lacustrine (lakelike) conditions found in the impounded portions of the backwaters of Watts Bar Reservoir. The reservoir pool extends upstream to above Harriman (ERM 11.0). In accordance with the TVA Watts Bar Operating Guide, normal summer pool within Watts Bar Reservoir is maintained between 740 and 741 ft msl; normal winter pool is maintained between 735 and 737 ft msl.

During low flow conditions in the Emory River, backflow of water from the Clinch River up the Emory River can occur, particularly when cooling water is being removed from the Intake Channel during power generation operations at the Kingston plant. During SAP sampling between June 26 and November 15, 2010, the Emory River experienced low flow conditions with flows ranging between 9.4 and 1,570 cubic feet per second (cfs) (average 188 cfs). During this time, backflow of Clinch River water up the Emory River was observed based on hardness measurements taken of surface water samples collected from the Emory River. Reverse flow was observed as far upriver as ERM 8.0 based on hardness measurements. This reverse flow could also carry ash-related constituents upstream in the Emory River, as discussed in Section 2.5.3.

The area most affected by the ash release extends from ERM 1.5 to 3.5. Prior to the release, the 100-year flood elevations for this reach of the Emory River varied from elevation 747.6 ft msl at ERM 1.5 to elevation 749.4 ft msl at ERM 3.5. At the Swan Pond Embayment, located at ERM 2.2, the 100-year flood elevation was approximately 748 ft msl. Modeling of flood frequency and hydrologic analysis was conducted following the time-critical removal action. Results of that modeling indicate that predicted water surface elevations for the 100-year flood in the Emory River are equal to or less than those prior to the release (Aquaveo 2011).

The Emory, Clinch, and Tennessee Rivers are waters of the state. "Waters of the State" are defined by T.C.A. §69-3-103(33) and are classified by the Tennessee Water Quality Control (TWQC) Board for suitable uses. The three rivers have been classified for the following uses: domestic water supply, industrial water supply, fish and aquatic life, recreation, irrigation, livestock watering and wildlife, and navigation. The Watts Bar Reservoir is the source of drinking water for the city of Kingston and several municipalities further downstream.

1.1.6 Geology

The controlling structural feature of the region is a series of northeast-striking thrust faults which have forced older rocks from the southeast over younger units. Bedrock units of the Rome Formation, the Lower Conasauga Group, and the Knox Group occur beneath the affected area in northeast-trending bands (Figure 3). These units generally dip to the southeast at angles averaging 45 to 50 degrees.

Alluvial and/or residual deposits generally cover bedrock, and form a blanket separating ash deposits from underlying bedrock. Alluvium (sand, silt, and/or clay) is generally limited to the natural (pre-reservoir) floodplains of the Emory River and its tributaries. Thickness of the alluvial deposits beneath the ash disposal areas ranges up to 65 ft, but thickness is unknown in areas offsite. Residuum (clayey soil derived from the weathering of the underlying bedrock) is expected to cover the remaining upland areas within the region, but data regarding its thickness offsite is currently unavailable.

Bedrock beneath most of the ash-affected area is represented by the Lower Conasauga Group and Rome formation. The Lower Conasauga Group primarily consists of shale with interbedded siltstone, limestone, and conglomerate, and is locally of low water-producing capacity. The Rome formation consists of interbedded shale, sandstone, and siltstone, and is a poor water producer. The primary water-bearing units of the region are the limestone and dolomite members of the Knox Group and the Maynardville formation (Upper Conasauga). The Knox Group includes several relatively pure, thick-bedded limestone and dolomite members susceptible to karst development, as evidenced by the sinkholes shown on Figure 3. The only ash-affected areas overlying the Knox Group include the stream bank margins along Swan Pond Embayment.

1.1.7 Hydrogeology

Groundwater within the region is derived from infiltration of precipitation through the soil overburden. Direct recharge to bedrock aquifers by storm runoff through sinkholes may also occur in areas underlain by karst bedrock. Shallow groundwater movement is generally from upland areas to adjacent stream valleys with groundwater ultimately discharging to streams and springs (Figure 4). The occurrence of numerous springs along the Emory River and within the Swan Pond Embayment indicates the former Dredge Cell lies within a regional groundwater discharge area. Limited stream recharge of shallow groundwater could occur during periods of rapid rise in reservoir elevation causing temporary reversal of groundwater hydraulic gradients. It is likely that shallow groundwater originating on the former Dredge Cell area discharges to the Emory River.

In a groundwater discharge setting, deeper bedrock wells should have higher hydraulic head (higher groundwater elevation) than shallower wells, creating an upward vertical gradient. To evaluate the vertical gradient, water levels and/or piezometric data were collected from paired wells/piezometers in and around the Ash Landfill during July 2010 (Jacobs 2011d). Results showed mostly upward vertical gradients at the foot of Pine Ridge and along the plant Intake Channel, yet mostly downward gradients over much of the Dredge Cell. Water levels in the Dredge Cell are influenced by the adjacent Ash Pond and Stilling Pond and by legacy effects of former Dredge Cell wet-sluicing operations. Ash within the relic portion of the Dredge Cell has retained a nearly saturated moisture content, raising the piezometric levels and resulting in the downward gradients. Results of groundwater modeling indicated that groundwater elevations near the Emory River are higher in the bedrock than in shallower deposits; namely, that there is an upward gradient to the river. This modeling supports the expectation of discharge conditions to the river system.

Available water supply data indicate that the water-supply wells and springs in the locality are situated upgradient of ash-affected land bordering streams. Consequently, any ash-related constituents entering shallow groundwater beneath affected areas would be transported a short distance to local streams without encountering wells or springs. There are no water-supply wells downgradient of the ash, between the ash and the reservoir.

Relevant hydrostratigraphic units underlying the former Dredge Cell include, in descending stratigraphic order, ash deposits, alluvial clay, alluvial sand, and Conasauga Group shale bedrock. Residuum, fill soils, and the Conasauga Group shale bedrock underlie areas southwest of the Ball Field. Residuum and the Rome formation shale bedrock underlie Pine Ridge. Small-scale geologic structures, such as bedding fractures and solution features, provide pathways for groundwater flow and are a major factor in the likely groundwater movement through the Conasauga Group shale. Although shallow bedrock is highly weathered, fractured, and permeable, the fracture aperture width and frequency generally decrease with depth, restricting the depth of active groundwater flow.

Several field investigation activities were conducted under the SAP to collect additional site-specific hydrogeologic data. These included drilling and logging of boreholes, geochemical and geotechnical testing, installing wells, measuring water levels, and aquifer testing. These data were used to evaluate hydrostratigraphy, groundwater flow rates, and geochemical attenuation, and to support the development of a three-dimensional groundwater flow model.

Three new permanent monitoring wells (MWs) (GW-01,-02, and -03) and six new temporary well points (TWPs) (TWP-04, -05, -06, -24, -25, and -26) were installed under the SAP. A combination of hollow stem auger and rotosonic drilling methods were used to install the boreholes, permanent MWs, and TWPs. The locations of permanent MWs and TWPs, both pre-existing and those installed under the SAP, are shown in Figure 5. The temporary well planned in residuum at location TWP-22 was not installed because bedrock was encountered at shallow depth. Direct push technology (Geoprobe® [GP]) was utilized to collect samples of porewater in contact with ash. Porewater samples were collected within the Dredge Cell, Lateral Expansion area, and Ball Field area at a total of 11 GP locations (GP-7 through GP-21, and GP-23) (Figure 5). Several proposed GP locations were not sampled because they were in pond areas where the Geoprobe® rig could not be safely mobilized; samples at proposed locations GP-17, GP-

19, GP-20, and GP-21 were therefore eliminated. The boring logs and well construction diagrams for the MWs, TWPs, and GPs are contained in the Groundwater Sampling Technical Memorandum (TM) (Jacobs 2012e).

Field sampling activities under the SAP began on September 23, 2010 and concluded on October 21, 2010. Aquifer testing included water level measurements, hydraulic head measurements, borehole flowmeter measurements, and aquifer (slug) tests. Additional aquifer testing for characteristics such as porosity, hydraulic conductivity, and geochemical parameters was conducted at selected monitoring locations. TVA Engineering Services tested the nine new wells and TWPs, five existing wells, and three previously installed piezometers to determine in-situ hydraulic conductivity and groundwater flow characteristics using pumping, slug, and electromagnetic borehole flowmeter techniques in single well and multiple well tests. Laboratory-based hydraulic conductivity tests were conducted on undisturbed samples to further define hydrogeologic properties. The results of this testing are presented in the Groundwater TM (Jacobs 2012e).

Groundwater levels from 180 wells and piezometers were collected during a single, site-wide water level measurement event performed between July 28 and 30, 2010. These data were supplemented by surface water level measurements at 34 locations. Water level data were grouped according to hydrostratigraphic unit (i.e., ash, fill, residuum, alluvial sand, alluvial clay, and bedrock) and plots of the potentiometric surface were constructed. Figure 6 shows the potentiometric surface for the ash and shallow soils from the July 2010 sampling event. These data served as a baseline for comparison to the predicted potentiometric surface based on groundwater modeling of future, post-closure conditions (Section 1.3.6). The water level measurements are reported in the Groundwater Modeling Report (Jacobs 2011d).

As shown in Figure 6, groundwater gradients in areas of the Ball Field, Ash Pond, and Stilling Pond indicate an easterly groundwater flow toward the Emory River and Intake Channel. Groundwater gradients in the northern portion of the former Dredge Cell indicate a northerly flow to the Swan Pond Embayment. In the southwestern portion of the former Dredge Cell, shallow groundwater elevations are highest (near 766 ft msl); groundwater gradients in this area indicate a pseudoradial configuration.

1.1.8 Ecology

The following summary of ecological conditions and immediate impacts from the release have been summarized largely from Section 2.1.6, Natural Resources, of the *Corrective Action Plan (CAP) for the TVA Kingston Fossil Plant Ash Release* (TVA 2009b), the SAP (Jacobs 2010d), and the Baseline Ecological Risk Assessment (BERA) (Arcadis 2012). The CAP was a requirement of the TDEC Commissioners Order. Existing information from various TVA and Tennessee Wildlife Resources Agency (TWRA) projects and surveys were used to develop an estimate of the aquatic community prior to the release. These included TVA fish and benthic surveys conducted as part of the TVA Reservoir Vital Signs Monitoring Program; TVA fish, mussel, wetlands, and avian surveys conducted in support of permit requirements and National Environmental Policy Act assessments for the plant and other TVA projects in the vicinity, and TWRA fish and mussel surveys and creel data.

Fish and Aquatic Life

TVA has systematically monitored the ecological conditions of its reservoirs since 1990 as part of the Vital Signs Monitoring Program. The fish assemblage in the Clinch River in Watts Bar Reservoir has consistently rated “good” on a “Good—Fair—Poor” evaluation system that incorporates several different fish community measures. Lower scores were reported in 2007 related to drought conditions that continued into 2008. The quality of the Watts Bar Reservoir sport fishery has consistently rated at or above the valley-wide average.

A total of 43 species of fish were caught during a TVA fish sampling effort in 2009; the predominant species included bluegill, redear sunfish, channel catfish, largemouth bass, and gizzard shad. Two federal- and state-listed, threatened fish species potentially occur within Watts Bar Reservoir: the snail darter and the spotfin chub. In addition, the blue sucker is also state-listed as threatened, and the tangerine darter, flame chub, and Tennessee dace have been identified by the state of Tennessee as species in need of management.

Prior to the ash release, the mussel fauna in the Emory River near the plant had been substantially altered by the impoundment of Watts Bar Reservoir, by impacts from mining in the headwaters, and by municipal and industrial wastewater discharges further upriver (Yorkley 2005). Six mussel species (giant floater, fragile papershell, pistolgrip, pimpleback, wartyback, and three-horn wartyback) and a common aquatic snail (horn snail) were found in a pre-release survey of this area. All of these species, except pistolgrip, are generally tolerant of reservoir conditions and could have been expected to occur in the area affected by the ash release in small numbers due to the low dissolved oxygen (DO) conditions that occasionally develop in summer in the impounded part of the Emory River. Eight species of mussels and one species of aquatic snail are federal- and state-listed as endangered. In addition, the state identified the pyramid pigtoe mussel as a species in need of management.

Reservoir bottom sediments provide habitat for a variety of aquatic worms and the larval form of many aquatic insects. The abundance and diversity depend on factors such as the physical properties of the sediments, presence or absence of DO in the overlying water, and abundance of food. In an area such as the Emory River arm of Watts Bar Reservoir, mayfly and caddisfly larvae, and a variety of midges and chironomids, among other benthic fauna would be expected to occur.

During the release, fish in the area were stranded on adjacent shorelines and experienced physical trauma due to the ash, debris, and high levels of suspended solids in the water. Approximately 200 to 300 dead fish (including threadfin shad, freshwater drum, smallmouth buffalo, largemouth bass, and sunfish) were observed immediately following the release, most on stream banks where they were stranded by the initial surge of water. Bottom-dwelling animals (mussels, snails, insects, crayfish, etc.) in areas where large amounts (>0.5 ft) of ash were deposited were likely unable to escape the release and were smothered by ash deposits. TVA fish community and benthic community assessments conducted in 2009 and 2010 indicated that fish and benthic invertebrates were present in numbers and conditions typically observed for similar water bodies. Subsequent surveys continue to confirm that the release appears to have had minimal impacts on the numbers and species of aquatic organisms present (Jacobs 2011b). Results of fish and benthic community assessments are further discussed in the BERA.

Wetlands

Wetland habitats in the vicinity of the plant have been monitored as part of a larger study associated with the *2004 TVA Reservoir Operations Study and Environmental Impact Statement* (TDEC 2004). There are two wetland study plots within the Swan Pond Embayment area north of the Dredge Cell. Baseline data were collected on these plots in 2004 and 2006. One scrub-shrub and one forested wetland plot were part of the original Reservoir Operations Study design. The Swan Pond Embayment plots were chosen because they were high quality wetland plots on TVA land, which ensured long-term access to these plots.

Wetland areas in the Swan Pond Embayment prior to the ash release were typically associated with shoreline margins, in floodplains of tributary streams, small islands, and at the heads of reservoir coves. These wetlands included a mix of forested, shrub, and/or herbaceous vegetation depending on the land use. National Wetland Inventory maps show narrow fringe wetlands along the shorelines of Swan Pond Embayment, and three small island wetlands.

Wetland areas along the Emory and Clinch Rivers are also generally limited to narrow fringe wetlands. This is due to the approximately 5 ft variation in water elevation between winter and summer pool levels and the relatively steep topography along much of the shoreline, which limits the areas where soils remain saturated. Exceptions typically are located near shallow inlets fed by springs or small tributaries. The reservoir shorelines are sparsely populated with small beds of emergent vegetation located below the summer pool level. Wetland plants along the summer pool shoreline also are limited in distributions primarily along points and islands. These fringe wetlands appear to be comprised primarily of rushes or cattails.

The ash release eliminated the wetlands (including three small island wetlands) in the Swan Pond Embayment; some of these wetlands were heavily used by waterfowl and shorebirds. Approximately 2.5 acres of wetlands were affected by the ash release. Restoration of these wetland areas is currently underway as part of the non-time-critical removal action for the Swan Pond Embayment.

Other Ecological Habitat Types

Other ecological habitats, largely riparian interfaces between upland (terrestrial) habitats and the aquatic habitats (reservoir and river tributaries) were present in the area prior to the release. Riparian habitats along the Emory, Clinch, and Tennessee Rivers are varied in nature and include mature deciduous (or mixed) forests, scrub/shrub, mixed herbaceous vegetation, rock or concrete retaining walls, and manicured lawns. These riparian zones can be important habitats for a variety of wildlife species. Riparian zones were identified by using a 25-yard wide buffer of pre-release hydrology along the shoreline. Approximately 55 acres of riparian zone habitat was estimated prior to the release that may have been affected by the release.

Much of the riparian zone adjacent to the former Dredge Cell consisted of short grasses and a thin marginal strip of trees along the shorelines. This habitat and the residential grasses offered minimal wildlife benefits. Forested habitat along the embayment, east of the former Dredge Cell represented better wildlife habitat. A large mudflat was also present in Watts Bar Reservoir prior to the release. This mudflat was exposed when reservoir levels were reduced during winter months. Four islands were present near the former Dredge Cell and Ash Pond. One island was used by a colony of great blue herons and black-crowned night-herons. The islands also provided nesting habitat for Canada geese.

Terrestrial plant and animal communities in the Ash Pond area have been greatly altered by Kingston plant operations. The dominant plant communities consist of a variety of wetland species in and on the fringe of the ash settling ponds and at the outer base of the dikes. The former Dredge Cells contained very little vegetation. The dikes were mostly vegetated with a mixture of common, weedy, native and nonnative grasses, and herbs. A band of riparian trees and shrubs, including sycamore, willow, boxelder, and alder occurred along much of the outer edge adjacent to the reservoir. Similar riparian vegetation occurred along other parts of the shoreline of Swan Pond Embayment and on the islands in the embayment. Other affected areas of the reservoir shoreline were landscaped, suburban lawns or oak-hickory forest.

The Ash Pond, Stilling Pond, Swan Pond Embayment, and the adjacent Emory River have been heavily used by Canada geese, wood ducks, great blue and green herons, great egrets, belted kingfishers, osprey, and double-crested cormorants. A variety of songbirds, semiaquatic mammals, turtles, and water snakes have also been abundant in the riparian vegetation along the shoreline. Ospreys are common in the area, often nesting on natural and man-made structures on and around the plant properties. Heron colonies also occur near the plant; the closest is approximately 0.3 mile upstream and in direct line of sight of the affected area. A second colony including great blue herons and double-crested cormorants occurs just downstream of the junction of the Emory and Clinch Rivers.

Numerous bird species use the riparian and wetland habitats along the reservoir (Arcadis 2012). Common species include resident populations, wading shorebirds and migratory species. Some neotropic migrant species, such as killdeer and semipalmated plover, are commonly found within the reservoir area, as well as waterfowl species, such as mallard, American black duck, hooded merganser, resident Canada goose, and wood duck. There are also other water/wading birds, such as pied-billed and various tern and gull species. Piscivorous birds, such as double-crested cormorant, great blue heron, black-crowned night-heron, and osprey are common and nest along the river. One federal-listed protected species, the bald eagle, is present within the reservoir area, and one state-listed endangered species, Bachman's sparrow, is present. Four state-listed species in need of management are also found, including bald eagle, barn owl, least bitten, and sharp-shinned hawk.

The reservoir area supports a number of mammal species in the riparian, wetland, and aquatic habitat types. Common mammals seeking food and cover in these habitats include white-tailed deer, eastern mole, eastern cottontail rabbit, groundhog, gray fox, and coyote, along with others. One federal- and state-listed endangered species, the gray bat, is present. Additionally, the eastern small-footed bat, southeastern shrew, and southern bog lemming are state-listed as species in need of management.

The reservoir area also supports a number of amphibian and reptile species, such as bullfrog, green frog, eastern narrow-mouth toad, Fowler's toad, northern water snake, common snapping turtle, painted turtles, and red-eared slider. While there are no federal-listed amphibian or reptile species in this area, a number of state-listed species are present, including the Berry cave salamander and northern pine snake. In addition, the eastern hellbender, four-toed salamander, and eastern slender glass lizard are species listed by the state as in need of management.

Various species of wildlife may have been affected by the release, as several wetland and riparian habitats used by these species were destroyed or greatly modified. Samples of mammals, spring breeding frogs and aquatic turtles, and bird resources demonstrate that these organisms remain in the area. Low levels of immediate wildlife mortality were associated with the ash release. A great blue heron carcass was found at the Site by the U.S. Fish and Wildlife Service. The specimen exhibited a broken leg and may have died from injuries related to the release. A small colony of great blue heron located on an island near the release remained intact. The settling ponds used by shorebirds and waterfowl were not affected by the release; however, ash removal operations reduced shorebird and waterfowl activity at the ponds.

Riparian habitat types were impacted by the release; their overall acreage was changed by the release and by removal actions. The marginal strip of forest habitat was heavily impacted. The North Embayment area was largely filled by ash and has been replaced by a narrow stream corridor with a riparian zone consisting of grasses, rip-rap and other erosion control measures. These areas offer little wildlife benefit. A small slough north of the Dredge Cell, referred to as Church Slough, and the East Embayment area have been cleared of ash and have vegetation regrowth and wildlife activity. The island with the large heron colony remains intact and ash removal operations have not disturbed heron reproduction. Osprey and Canada geese also continue to breed in proximity to the Site. Tree swallow colonies continue to produce viable eggs and hatchlings. Restoration of these riparian zones is currently underway as part of the non-time-critical removal action for the Swan Pond Embayment.

1.2 PREVIOUS REMOVAL ACTIONS

Immediately following the ash release, an Incident Command Center was established and emergency measures were implemented to ensure safety of people in the area, contain and evaluate the damage, and plan for recovery of the ash. Several routine monitoring programs were put in place to monitor river water, drinking water, and air quality. Road, railroads, and utilities were repaired and replaced. Dikes and weirs, both on land and in the water, were constructed to control the ash movement. Dust control activities were implemented and are ongoing. Storm water management systems, such as clean water diversion ditches and ash water collection and settling basins, were constructed.

Time-critical removal actions began immediately following issuance of the EPA Order on May 11, 2009, and an Action Memorandum was approved on August 4, 2009, for removing the ash from the river under the time-critical removal action (TVA 2009c). The purpose of removing the ash from the river was to limit the potential for future ash migration and to prevent upstream flooding in the event of a large rainfall. Actions included hydraulic and mechanical dredging of ash from the river, mechanical excavation of ash from the Swan Pond Embayment, dewatering and processing of the recovered ash (including water management), loading of the dewatered ash into railcars, transport of the ash via rail offsite, and ultimate disposal of the ash at the Arrowhead Landfill in Perry County, Alabama. Other related actions included cenosphere removal, air monitoring and dust control, surface water monitoring, storm water management, dike stability evaluations and stabilization, and construction of a test embankment to demonstrate the constructability of dry ash stacking. Dredging associated with the time-critical removal action was completed in June 2010, and offsite disposal was completed in December 2010. Details of the removal actions, their effectiveness, difficulties encountered, and costs incurred are described in the EPA-approved OSC Report (Jacobs 2011b).

On May 18, 2010, an Action Memorandum was approved for removing ash from the Swan Pond Embayment under a non-time-critical removal action (Jacobs 2010c). The purpose of this non-time-critical removal action was to restore the embayment to pre-release conditions and to close the former Dredge Cell in accordance with Tennessee Solid Waste Rule 1200-1-7. The decision was made to remove ash from the embayment using primarily land-based equipment, then process and dispose of the ash in an onsite Ash Landfill (Figure 7). Other related actions include Perimeter Wall Stabilization (PWS) around the former Dredge Cell and Ash Pond to contain the ash within the Ash Landfill, final cap and cover to close the landfill, and restoration of the aquatic and riparian habitats within the embayment. The non-time-critical removal action is ongoing and is anticipated to be complete by October 2014. Key features of the former Dredge Cell and Ash Pond area are shown in Figure 7.

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2. NATURE AND EXTENT OF CONTAMINATION

This section presents a summary of the sampling conducted in accordance with the EPA-approved SAP (Jacobs 2010d). This sampling addressed multiple abiotic and biotic media, including ash deposits, seasonally-exposed sediment, submerged sediment, sediment porewater, surface water, groundwater, benthic invertebrates, fish, wildlife, and aquatic vegetation. This section summarizes abiotic media only; results of sampling of biotic media is presented in the BHHRA and BERA. Table 2-1 presents a cross-walk describing where each sampled media is presented.

Table 2-1 Crosswalk of Sampled Media and Where the Results are Presented

Sampled Medium	Where Results are Presented		
	EE/CA	BHHRA	BERA
Ash Deposits	✓		
Seasonally-Exposed Sediment	✓		
Submerged Sediment	✓		
Sediment Porewater	✓		
Surface Water	✓		
Groundwater	✓		
Benthic Invertebrates			✓
Fish - filets		✓	
Fish - nonfilets			✓
Birds			✓
Mammals			✓
Amphibians			✓
Reptiles			✓
Aquatic Vegetation			✓

Notes:
EE/CA = Engineering Evaluation / Cost Analysis
BHHRA = Baseline Human Health Risk Assessment (Jacobs 2012, Appendix H)
BERA = Baseline Ecological Risk Assessment (Arcadis 2012, Appendix I)

Sampling was planned within different sections or reaches of the river system, as shown on Figure 8. These ten reaches are described below.

- Reference locations upstream of ERM 6.0: This reach consists of reference “background” locations in the Emory River where ash deposition was not found in prior sampling.
- Emory Reach C (ERM 3.5 to 6.0): This reach consists of impacted locations upstream of the primary time-critical removal action (Phase 1) dredging operations.
- Emory Reach B (ERM 1.5 to 3.5): This reach consists of sections of the channel that were dredged in a series of “grids” during the primary time-critical removal action. This reach also includes sections of the river outside of the dredged channel.
- Emory Reach A (ERM 0.0 to 1.5): This reach consists of impacted locations downstream of the primary dredging operations. Time-critical dredging was not conducted in this reach due to the presence of cesium-137 in the underlying sediment (Jacobs 2011b).
- Intake Channel: This reach consists of the Kingston plant intake channel from the skimmer wall to the plant intakes.

- Reference locations upstream of Clinch River Mile (CRM) 4.5: This reach consists of reference “background” locations in the Clinch River where ash deposition was not found in prior sampling.
- Clinch Reach B (CRM 3.0 to 4.5): This reach consists of impacted locations in the Clinch River downstream of the primary dredging operations, yet upstream of the Kingston plant discharge.
- Clinch Reach A (CRM 0.0 to 3.0): This reach consists of impacted locations in the Clinch River, downstream of the Kingston plant discharge.
- Tennessee Reach B (TRM 566 to 568): This reach consists of potentially impacted locations in the Tennessee River, downstream of the confluence with the Clinch River.
- Tennessee Reach A (TRM 550 to 566): This reach consists of downstream Tennessee River locations where deposition of ash from storm event transport has been predicted to occur (Jacobs 2011b).

Samples of abiotic and biotic media collected from each of these reaches were analyzed for various constituents. Naturally-occurring metals (e.g., arsenic or selenium) and naturally-occurring radionuclides (e.g., radium-226 or thorium-228) are present within the ash and were the primary constituents of interest. Legacy constituents, (e.g., polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, mercury, or cesium-137), although not present within the ash, may be present in the river system from other historical sources. Analytical results for these constituents are presented in the corresponding TMs and in the consolidated database (Appendices A through H). To focus the discussion of nature and extent of contamination, an approach was developed that would highlight the primary constituents related to ash in abiotic media. Primary ash-related constituents (for purposes of discussion of extent of contamination) were identified as having the following characteristics:

- Naturally-occurring metal or radionuclide (not a legacy constituent);
- Mean concentration greater than 2 times the mean in reference media;
- Frequently detected in Site media; and
- Not an essential nutrient.

Using these characteristics, the mean concentrations of naturally-occurring inorganic (metal) and radiological constituents detected in cell ash samples were compared to the mean concentrations reported for reference soil to identify an initial set of ash-related constituents. Arsenic, barium, beryllium, boron, calcium, chromium, copper, nickel, potassium, selenium, sodium, thallium, vanadium, potassium-40, radium-226, thorium-230, thorium-234, and uranium-238 were identified as having a mean concentration greater than 2 times the mean in reference media. Of these, thallium was infrequently detected (14% of the samples) at levels near the detection limit, and calcium, potassium, and sodium are essential nutrients, and are therefore not considered contaminants. The resulting ash-related constituents that were evaluated for nature and extent of contamination in abiotic media are listed in Table 2-2.

Of these, arsenic and selenium are of primary interest due to their potential ecological toxicity (Section 3.2). Arsenic was present in each of the abiotic media at concentrations at least twice its average reference value. Selenium was detected in all but the mid-depth surface water at an average at least twice its average reference value. These two constituents represent the primary ash-related constituents in the river system, and are discussed in greater detail in the following sections on the nature and extent of contamination.

Table 2-2 Ash-Related Constituents Evaluated

Ash-Related Constituents	Submerged Sediment	Seasonally Exposed Sediment	Epibenthic Surface Water	Mid-Depth Surface Water
Arsenic	X	X	X	X
Barium	X	X		
Beryllium				
Boron	X	X		
Chromium		X	X	
Copper	X	X	X	X
Nickel		X	X	
Selenium	X	X	X*	
Vanadium	X	X	X*	X*
Potassium-40	X	X		
Radium-226	X	X		X
Thorium-230	X	X		X
Thorium-234	X	X		
Uranium-238	X	X	X	

Notes:
X = average detected concentration greater than twice average reference concentration in associated medium.
X* = constituent not detected in any reference sample, but detected in samples from downstream reaches.

2.1 ASH DEPOSITS

For estimating the volume and distribution of residual ash deposits, the depth, thickness, areal extent, and degree of mixing or layering was investigated by sampling using vibracore techniques. Two methods were used to distinguish ash from non-ash sediment: (1) visual observations, where the gray ash can be readily differentiated from the natural brown river sediment, and (2) polarized light microscopy (PLM), which provides a quantifiable estimate of the proportion of ash in a sample of sediment. The PLM views mineral specimens under a polarized light, which exhibit colorations when subjected to polarized light filters. When these filters are crossed, characteristics of the mineral specimen can be compared to known characteristics in mineral charts for an accurate identification of the mineral, in this case, ash.

A total of 268 vibracores were sampled. In general, samples were taken on a regular grid layout, at mid-channel, and both left and right of the channel (Plate 1). Sampling frequency was greater in those reaches where ash deposition from the ash release was greatest and decreased upstream and downstream from those reaches. Results of the vibracore sampling, including visual descriptions of the ash or sediment, thickness, and any depositional layering; photographs; and coring logs are included in the Ash Deposits, Submerged Sediment, and Seasonally-Exposed Sediment Sampling TM (Jacobs 2012j). Results of PLM analyses, both field and confirmatory laboratory analyses, are shown on the vibracore sampling logs.

Plate 1 depicts the locations where ash was found to be present, based on interpretations of results of vibracore sampling and bathymetric survey information. Interpreted thicknesses and extent of ash are shown. The ash deposits depicted on Plate 1 incorporate prior interpretations of the extent of ash remaining following dredging, as presented in the EPA-approved OSC Report (Jacobs 2011b). A sample was interpreted as representing an ash deposit if the corresponding field or laboratory PLM analysis reported an estimated 50% or greater proportion of the sample to be ash grains. Only ash deposits greater than 0.5 ft in thickness are depicted. Estimated areas of ash deposits and estimated volumes of ash remaining in each reach of the river system are listed in Table 2-3.

The maximum thickness of ash deposits as measured in the vibracore samples was 4.2 ft in Emory River Reach B. There is uncertainty in the ash deposit thickness in Emory River Reach B at the location of the former Weir 1, which was removed during the time-critical removal action. Concurrence forms developed at the completion of time-critical dredging reported that the remaining material could not be further excavated or sampled due to encountering hard material (refusal). Yet the subsurface bathymetry would suggest that portions of that area are as much as 10 ft higher than historical river channel bathymetry. Because additional sediment information could not be obtained from that area, the original interpretation from the time-critical removal action OSC Report is shown on the figures.

Ash deposits are more extensive in Emory River Reach A than in other reaches, in part because time-critical dredging was not conducted below ERM 1.8 due to the presence of legacy constituents (cesium-137) in the sediment. Thicknesses of the residual ash deposits decrease with distance downstream, as evident in Plate 1. Ash deposits greater than 1 ft in thickness were encountered as far downstream as CRM 1.5; thinner ash deposits were encountered in vibracore samples as far downstream as CRM 1.0. No ash deposits (greater than 50% ash and at least 0.5 ft thick) were encountered in the vibracore sampling in the Tennessee River.

Table 2-3 Summary of Thickness, Area, and Volume of Ash Deposits in the River Reaches

River Reach	No. of Samples	No. of Samples with > 0.5 ft Ash	Maximum Thickness of Ash (ft)	Mean Thickness of Ash (ft)	Area of Deposits with >0.5 ft Ash (sf)	Volume of Deposits with >0.5 ft Ash (cy)
Emory River						
Reach ER-R	11	0	<0.5	<0.5	0	0
Reach ER-C	35	3	1.3	1.0	390,000	17,000
Reach ER-B	69	20	4.2	1.9	3,780,000	247,000
Reach ER-A	45	10	2.8	1.4	2,870,000	169,000
Clinch River						
Reach CR-R	3	0	<0.5	<0.5	0	0
Reach CR-B	40*	12*	2.6	1.5	1,580,000	72,000
Reach CR-A	36	1	0.5	<0.5	90,000	5,000
Tennessee River						
Reach TR-R	3	0	<0.5	<0.5	0	0
Reach TR-B	14	0	<0.5	<0.5	0	0
Reach TR-A	12	0	<0.5	<0.5	0	0
TOTAL	**268**	**46**	**4.2**	**--**	**8,710,000**	**510,000**

Notes:
* Includes sample CRM_A01, located at boundary of Reach CR_B.
For definitions, see the Acronyms section.

The total volume of measurable ash deposits estimated to remain in the river system is 510,000 cy based on the SAP sampling and interpretation described above. This is similar to the volume estimated to remain in the river system following the time-critical removal action of 532,000 cy, as reported in the OSC Report (TVA 2011). The difference is attributable to the additional SAP sampling, and to the ash/sediment scour, deposition, and mixing processes that have been taking place in the river system since the end of the time-critical removal action.

2.1.1 Constituent Concentrations in Ash Deposits

Between December 2008 and September 2010, TVA, TDEC, and EPA performed ash sampling in the former Dredge Cell, referred to as the "cell ash" (Jacobs 2011b). Table 2-4 presents the range of concentrations of naturally-occurring metals and radioisotopes found in TVA cell ash sampling; TDEC and EPA sampling showed similar results. The mean concentration of naturally-occurring inorganic (metal) and radiological constituents detected in cell ash samples were compared to the average concentrations reported for reference regional soil (Jacobs 2010d). It should be noted that ash is not natural soil, and therefore direct comparisons to "background" concentrations cannot be made. These comparisons are only meant to provide a framework for recognizing differences or similarities between the ash constituents and those found in typical regional soils. Ash-related constituents were identified as those detected in more than half the samples and whose mean concentration was more than twice that for typical regional soil. The following analytes are identified as ash-related constituents: arsenic, barium, beryllium, boron, chromium, copper, nickel, selenium, vanadium, zinc, and naturally-occurring radionuclides, specifically isotopes of uranium and thorium, their short-lived daughter products, and potassium-40. These ash-related constituents are naturally-occurring elements that are concentrated in the ash through the coal combustion process at the Kingston plant. They are widely distributed in the natural environment.

Table 2-4 Summary Statistics for Cell Ash

Analyte	Units	Regional Average Surface Soil Concentration	Cell Ash			
			Minimum Detected Result	Maximum Detected Result	Average Detected Result	Frequency of Detection
Aluminum	mg/kg	13,776	13,500	45,200	25,746	28 / 28
Antimony	mg/kg	0.54	ND	ND	ND	0 / 28
Arsenic	mg/kg	19.0	28.6	166	74.5	28 / 28
Barium	mg/kg	69.5	331	1,410	763.7	28 / 28
Beryllium	mg/kg	0.9	3.47	9.6	5.935	28 / 28
Boron	mg/kg	11.5	35.9	212	95	28 / 28
Cadmium	mg/kg	0.3	ND	ND	ND	0 / 28
Calcium	mg/kg	1,813	3,300	30,900	11,566	28 / 28
Chromium	mg/kg	21.2	27.9	66.0	45.2	28 / 28
Cobalt	mg/kg	12.3	13.1	29.7	20.6	25 / 28
Copper	mg/kg	19.9	44.3	102.0	70.3	28 / 28
Iron	mg/kg	23,639	9,840	39,700	18,884	28 / 28
Lead	mg/kg	31.6	17.5	46.0	29.4	28 / 28
Magnesium	mg/kg	1,920	1,040	6,120	2,828	28 / 28
Manganese	mg/kg	938	50	196	87	28 / 28
Mercury	mg/kg	0.130	0.136	0.209	0.167	3 / 11
Molybdenum	mg/kg	2.62	ND	ND	ND	0 / 28
Nickel	mg/kg	14.71	26.30	57.10	41.21	28 / 28
Potassium	mg/kg	1,268	2290	7,040	3897	28 / 28
Selenium	mg/kg	2.44	2.64	17.80	7.89	27 / 28
Silver	mg/kg	0.59	ND	ND	ND	0 / 28
Sodium	mg/kg	288	335	1790	801	28 / 28

Table 2-4 Summary Statistics for Cell Ash (continued)

Analyte	Units	Regional Average Surface Soil Concentration	Cell Ash			
			Minimum Detected Result	Maximum Detected Result	Average Detected Result	Frequency of Detection
Thallium	mg/kg	0.29	2.65	3.80	3.06	4 / 28
Vanadium	mg/kg	34.06	70.10	163.00	112.90	28 / 28
Zinc	mg/kg	51.04	34.80	91.10	58.26	28 / 28
Potassium-40	pCi/g	6.75	20.81	32.42	27.06	12 / 12
Radium-226	pCi/g	1.14	3.36	6.42	5.40	12 / 12
Thorium-228	pCi/g	1.08	0.41	1.46	0.76	12 / 12
Thorium-230	pCi/g	0.75	0.94	3.99	2.20	12 / 12
Thorium-232	pCi/g	2.54	0.32	1.82	0.99	12 / 12
Thorium-234	pCi/g	2.19	5.97	11.27	7.97	11 / 12
Uranium-234	pCi/g	1.21	0.82	2.51	1.79	12 / 12
Uranium-235	pCi/g	0.63	0.04	0.18	0.12	12 / 12
Uranium-238	pCi/g	0.85	0.87	2.33	1.78	12 / 12

Notes:
ND = not detected
Results are reported on a dry-weight basis.
For additional definitions, see the Acronyms section.

Primary ash-related constituents (arsenic and selenium) are contributors to ecological risk (Section 3.2), have been found above reference concentrations in multiple media during this investigation, and are representative of the nature and extent of ash-related contamination at the Site (Table 2-2). Detected arsenic concentrations in cell ash samples ranged from 28.6 to 166 mg/kg, with an average of 74.5 mg/kg. Maximum arsenic levels for soils typical of the Roane County region range from 0.2 to 655 mg/kg, averaging 19.0 mg/kg. While arsenic concentrations are in a range similar to those of typical regional soil, average arsenic levels in the cell ash are nearly four times higher than the average for regional soil.

Selenium was detected in nearly all of the cell ash samples. Selenium concentrations ranged from 2.64 to 17.8 mg/kg, with an average of 7.89 mg/kg. Selenium concentrations for typical regional soils range from 0.105 to 5.3 mg/kg, averaging 2.4 mg/kg. Average levels in the cell ash were more than three times higher than the average for regional soil.

2.2 SEASONALLY-EXPOSED SEDIMENT

Seasonally-exposed sediment refers to the sediment that becomes exposed on the river banks during the times that the reservoir levels are low (i.e., winter months December to April). These sediments are submerged during the remainder of the year in shallow water near the river bank. People may be exposed to these sediments during recreational activities (e.g., beachcombing); exposure while swimming or wading is not expected to be significant, since the sediment is washed off by the overlying water. Aquatic plants as well as aquatic- or riparian-feeding birds and mammals may be exposed to these sediments in shallow water along the shoreline. Benthic fish and invertebrates may be exposed to these shallow sediments when the reservoir is at the summer pool level.

A systematic visual survey of the banks of the Emory River was conducted in 2010 to check for evidence of ash when the reservoir is at winter pool level. Results of that survey are reported in the *Time-Critical*

Removal Action Completion Report for River System Phase II Nature and Extent of Ash Investigation (TVA 2010). Based on that survey, the spatial extent of any visually distinct ash was estimated and mapped.

Sixty-nine samples of seasonally-exposed sediment were collected between December 14, 2010 and January 25, 2011. Samples were collected using new, decontaminated, 2-1/2-inch diameter by 18-inch length acrylic core tubes. Samples were collected by manual hand-coring, as reported in the Ash Deposits, Submerged Sediment, and Seasonally-Exposed Sediment Sampling TM (Jacobs 2012j). In general, samples were taken randomly along each shoreline (right and left bank), regardless of particle make-up (proportion of ash to native sediment). Sample locations were adjusted based on results of the visual survey to bias the sampling towards depositional areas or visible ash and thereby result in conservative estimates of risk for both human and ecological receptors. Sample locations within different reaches of the river system are shown on Figures 9 and 10. Seasonally-exposed sediment samples were collected from the Emory and Clinch Rivers, but not from the Tennessee River, per the SAP. Reference samples were collected from upstream locations only in the Emory River.

Samples were visually described for presence and thickness of ash and any depositional layering. Field PLM estimates of percentage of ash were included in the sediment description and recorded in a field logbook. Confirmatory laboratory PLM estimates were made on 10% of the total samples as quality control. Samples were also analyzed in an offsite analytical laboratory for naturally-occurring metals and radionuclides. In order to estimate potential effects of legacy constituents, 25% of the samples were analyzed for legacy constituents, including PAHs, PCBs, and pesticides. Because of their impact on constituent migration and/or toxicity, 25% of the samples were also analyzed for chemical speciation for arsenic, mercury, selenium, and chromium.

2.2.1 Constituent Concentrations in Seasonally-Exposed Sediment

Analytical results for seasonally-exposed sediments in each river reach are presented in Appendix A. The nature of potential ash-related contamination in seasonally exposed sediment was evaluated by comparing the average concentrations of constituents in the designated river reaches to those measured in the Emory River reference reach. Reference sediment samples were not collected for the Clinch River; therefore, constituent concentrations were compared to the Emory River reference reach. This comparison must be viewed cautiously because of potential differences between soil and sediment types in the upper watershed areas and presence of contaminant sources along the Clinch River. Concentrations were compared to screening criteria in the human health and ecological risk assessments (Jacobs 2012a and Arcadis 2012). Results of seasonally-exposed sediment sampling for arsenic and selenium are depicted on Figures 9 and 10, respectively.

The maximum detected concentration of arsenic was 82.6 mg/kg in Clinch River Reach B. Average arsenic concentrations in Emory River Reaches A and B and Clinch River Reaches A and B were 4 to 5 times higher than the average reference concentration. Average concentrations of arsenic in these downstream reaches ranged from 14.3 to 19.2 mg/kg, compared to the average reference concentration of 3.4 mg/kg.

The maximum detected concentration of selenium was 3.64 mg/kg in Emory River Reach B. Selenium was not detected in Emory River reference reach samples; therefore, direct comparisons cannot be made for selenium. In downstream reaches, selenium was infrequently detected; frequency of detection was somewhat greater in Emory River Reach B (3 of 18 samples) and Emory River Reach A (3 of 12 samples). Average concentrations of selenium, when detected, were near the detection limit, ranging from 1.77 to 2.45 mg/kg in the downstream reaches.

Other ash-related constituents (as identified in Table 2-2) also exceeded reference concentrations. Average concentrations of barium, boron, chromium, copper, nickel, vanadium, potassium-40, radium-226, thorium-230/234, and uranium-238 in at least one Emory or Clinch River reach were greater than twice the average concentrations measured in Emory River reference reach samples. Boron was detected in the majority of samples in all reaches except Emory River Reach C. Average copper concentrations in Emory River Reaches A and B and Clinch River Reaches A and B were 3 to 4 times higher than the average reference concentration. Average vanadium concentrations in Emory River Reaches A and B and Clinch River Reaches A and B were 2 to 4 times higher than the average reference concentration. The other constituents were infrequently detected, and when detected had concentrations only slightly above the detection limit. Beryllium, while identified as an ash-related constituent, was detected at an average concentration less than twice its average reference concentration.

Average concentrations of aluminum, cobalt, iron, lead, magnesium, manganese, strontium, zinc, and cesium-137, while not identified as ash-related constituents in Table 2-2, were greater than twice the average concentrations in reference reach samples. Antimony, mercury, and thallium were detected in multiple river reach samples but were not detected in reference samples; therefore, direct comparisons cannot be made for these constituents. Of particular note is cesium-137, which was detected at an average concentration more than 20 times its average reference concentration in the Emory River. Cesium-137 is a legacy contaminant historically released from the U.S. Department of Energy (DOE) Oak Ridge Reservation, and is not related to the ash release. The maximum concentration of cesium-137 was 2.84 picocuries per gram (pCi/g) in Clinch River Reach A; cesium-137 was also detected at levels more than 10 times reference in Emory River Reach A and Clinch River Reach B.

Other legacy constituents (PAHs, PCBs, and pesticides) were detected in nearly all river reaches including the Emory River reference reach, and are therefore likely from an upstream source. PAHs were highest in Emory River Reach B, at a maximum of 1.112 mg/kg (total sum of PAHs). Total PCBs (predominantly PCB-1254 and PCB-1260 isomers) were highest in Clinch River Reach B, at a maximum of 25.0 mg/kg. Pesticides were infrequently detected; the highest detected concentration was in a sample taken within Emory River Reach A, at a maximum of 0.036 mg/kg (gamma-chlordane in a single sample).

Seasonally-exposed sediment samples were submitted to Frontier Global Sciences, Inc. (Frontier) for speciation of arsenic [inorganic arsenic (arsenate, arsenite) and organic arsenic], selenium [inorganic selenium (selenate, selenite) and organic selenium], and mercury (inorganic, and methyl). Figure 11 shows the concentrations of the various species expressed as a percentage of the total concentration of the metal. Arsenic species were primarily in the biologically available inorganic form, consisting mostly of more mobile arsenate species and suggesting greater oxidizing conditions than in submerged sediment. Selenium species were primarily in a biologically-available organic form. The smaller inorganic selenium fraction consisted completely of the less mobile selenite. These results are consistent with a study performed at the U.S. Army Corps of Engineers Engineering Research and Development Center (ERDC) Environmental Laboratory (ERDC 2009). Mercury species were almost 100% inorganic; methylmercury constituted less than 2% of the total mercury. The high percentage of inorganic mercury suggests that mercury is largely immobile and not biologically available.

2.2.2 Spatial Trends in Seasonally-Exposed Sediment

The extent of potential ash-related contamination was evaluated based on the distribution of the primary ash-related constituents (arsenic and selenium). Concentrations of these constituents are lowest in Emory River Reach C, just upstream of the ash release. Concentrations of arsenic and selenium are higher in downstream reaches of both the Emory and Clinch Rivers. Spatial distribution of these constituents is depicted in Figure 12, which plots the range of minimum-maximum concentrations and the average detected concentrations progressively downriver.

Average arsenic concentrations show a slight increasing trend in downgradient reaches. In Emory River Reach C, concentrations are similar to the Emory River reference reach, averaging 3.0 mg/kg. Concentrations are sharply higher beginning in Emory River Reach B (in the area of the ash release), averaging 16.0 mg/kg, and increase only slightly in downstream reaches, to an average of 19.2 mg/kg in Clinch River Reach A.

Selenium was undetected in Emory River Reach C, similar to the reference reach. Selenium was detected in Emory River Reach B, and greatest in Emory River Reach A at an average concentration of 2.45 mg/kg. Concentrations decline downstream in the Clinch River, and were undetected at Clinch River Reach A. Because selenium was detected so infrequently and at such low concentrations in the Emory and Clinch River samples, this trend should be viewed with caution.

2.2.3 Conclusions for Seasonally-Exposed Sediment

Several ash-related constituents (including arsenic and selenium) and legacy constituents (cesium-137, PCBs, pesticides, and PAHs) were detected in seasonally-exposed sediment at concentrations exceeding reference concentrations. This medium was therefore evaluated further in the BHHRA and BERA (Section 3). Seasonally-exposed sediment was not identified in the BHHRA as a pathway contributing to risk to human receptors, but was identified in the BERA as a pathway contributing to potential risks to benthic invertebrates in the riparian zone and insectivorous birds that feed on them. A removal action has been recommended to manage those potential risks.

2.3 SUBMERGED SEDIMENT

Submerged sediment refers to the sediment that is below water year round. For the human health risk assessment, recreators would use the river system during summer pool months only, so there is no human exposure to continually submerged sediments. For ecological receptors, the BERA used a weight-of-evidence process to characterize the magnitude and likelihood of risk. The primary lines of evidence (LOE) included: (1) constituent concentrations compared to sediment effects values, (2) laboratory bioassays, and (3) biosurveys of benthic invertebrate communities. These LOE are discussed in the following subsections.

Samples of submerged sediment were collected concurrently with ash deposit samples. In general, samples were selected randomly from among the ash deposit samples recovered regardless of particle make-up (ash/native sediment proportion). Because ecological exposures would occur in the upper 6 inches of submerged sediment, sample specimens were chosen from the upper 6 inches of the vibracore sample. A total of 81 submerged sediment samples were collected, as reported in the Ash Deposits, Submerged Sediment, and Seasonally-Exposed Sediment Sampling TM (Jacobs 2012j). Sample locations within different reaches of the river system are shown on Figures 13 and 14.

Samples were analyzed in an offsite analytical laboratory for naturally-occurring metals and radionuclides, legacy constituents (PAHs, PCBs, and pesticides), chemical speciation for arsenic, mercury, selenium, and chromium; acid volatile sulfides (AVS); and simultaneously extracted metals (SEM).

2.3.1 Constituent Concentrations in Submerged Sediment

Analytical results for submerged sediments in each river reach are presented in Appendix B. The nature of potential ash-related contamination in submerged sediment was evaluated by comparing the average concentrations of constituents in the designated river reaches to those measured in their respective reference reach. Reference sediment samples were collected from upstream locations in the Emory, Clinch, and Tennessee Rivers. Concentrations were compared to screening criteria in the BERA (Arcadis 2012). Results of submerged sediment sampling for arsenic and selenium are depicted on Figures 13 and 14, respectively.

The maximum detected concentration of arsenic was 89.5 mg/kg in Emory River Reach B. Average arsenic concentrations in all river reaches except the Tennessee River Reach A were between 2 and 6 times higher than the respective average reference concentration. Arsenic concentrations varied considerably in Emory River Reaches B and C, but were relatively consistent in Emory River Reach A and Clinch River Reaches A and B. Average concentrations of arsenic in downstream reaches ranged from 12.1 to 25 mg/kg, compared to the average reference concentrations of 4.0 to 6.5 mg/kg. These values are approximately 3 to 6 times less than those for cell ash; detected arsenic concentrations in cell ash samples ranged from 28.6 to 166 mg/kg, with an average of 74.5 mg/kg.

The maximum detected concentration of selenium was 5.16 mg/kg in Emory River Reach C. However, selenium detections were sporadic and variable. Selenium was detected in only 1 of 9 Emory River Reach C samples, yet was detected in all 12 Emory River Reach A samples. Selenium was not detected in any of the reference reach samples; therefore, direct comparisons to reference concentrations cannot be made for selenium. Average detected concentrations of selenium in downstream reaches (excluding the one sample from Emory River Reach C) ranged from 2.1 to 3.4 mg/kg. These values are approximately three times less than those for cell ash; selenium was detected in all cell ash samples at concentrations ranging from 2.64 to 17.8 mg/kg, with an average of 7.89 mg/kg.

Other ash-related constituents (as identified in Table 2-2) also exceeded reference concentrations in submerged sediment. Average copper concentrations in downstream river reaches were 2 to 4 times higher than the respective average reference concentrations, except for Emory River Reach C, which was near the average reference concentration. Average vanadium concentrations in Emory River Reaches A and B and Clinch River Reaches A and B were 2 to 3 times higher than the respective average reference concentrations. Average concentrations of barium, beryllium, boron, potassium-40, radium-226, thorium-230 and -234, and uranium-238 were more than two times greater in at least one river reach than the average concentrations measured in their respective reference reach samples. Chromium and nickel, while identified as ash-related constituents, were detected at average concentrations less than twice their respective average reference concentrations.

Average concentrations of aluminum, mercury, strontium, cesium-137, radium-228, and isotopes of lead, thorium, and uranium, which have not been identified as ash-related constituents in Table 2-2, were also more than two times greater in at least one river reach than their respective average reference concentrations. Because average concentrations in Clinch and/or Tennessee River reference samples were also much higher for these constituents, they are likely related to legacy contamination from upstream sources in those rivers. One exception is strontium, which had average concentrations 5 to 10 times greater in the Emory and Clinch River reaches than either of the reference reach samples, and may therefore be ash related.

Cesium-137, a byproduct of nuclear fission, is of interest because it may affect waste disposal options. Waste materials containing detectable cesium-137 could not be disposed of in a traditional Subtitle D solid waste landfill, but would need to be disposed of in a waste disposal facility permitted to accept low-level radioactive waste. Cesium-137 is not ash-related, but is a legacy constituent from former DOE operations on the Oak Ridge Reservation. Maximum cesium-137 radioactivity measured in submerged sediment samples collected under the SAP was 3.7 pCi/g. However, activities as high as 17.57 pCi/g were measured in samples collected during the time-critical removal action at a depth approximately 1 ft below the river bottom. Dredged materials containing cesium-137 would therefore be considered low level radioactive waste. Figure 15 depicts sampling locations where cesium-137 was detected in submerged sediment. In general, cesium-137 was detected in nearly all samples downstream of Emory River Reach B; namely, the plant Intake Channel, Emory River Reach A, and Clinch River Reaches A and B.

Radium-228, a daughter decay product of thorium-232, is a contributor to human health risk in surface water (Jacobs 2012a). Maximum radium-228 was 3.0 pCi/g in the plant Intake Channel; however, average concentrations of radium-228 were similar throughout the river system, varying between 1.68 and 2.19 pCi/g, with the higher average concentrations in the Tennessee River. Therefore, radium-228 may be from a source within Watts Bar Reservoir unrelated to the ash release.

Legacy constituents were detected in all river reaches, including the reference reaches. PAHs were highest in the Emory River reference reach, at a concentration of 0.807 mg/kg (total PAHs). PCBs were highest in Emory River Reach C (at a maximum concentration of 0.0556 mg/kg total PCBs), but were found at similar levels in both the Emory and Clinch River reference reaches (at concentrations of 0.0268 and 0.0414 mg/kg total PCBs, respectively). Pesticides were sporadically detected across all river reaches. The highest detected concentration was in a sample taken within Tennessee River Reach A, at a maximum of 0.1325 mg/kg total pesticides, but pesticides were also found at similar levels in both the Emory and Clinch River reference samples (at concentrations of 0.0654 and 0.0618 mg/kg total pesticides, respectively).

Submerged sediment samples were submitted to Frontier for speciation of arsenic, selenium, and mercury. Figure 11 shows the concentrations of the various species expressed as a percentage of the total concentration of the metal. Arsenic species were primarily in an inorganic form consisting of approximately equal percentages of arsenate and arsenite. Selenium species were primarily in the biologically available organic form. The smaller inorganic selenium fraction consisted completely of the less mobile selenite. The presence of arsenite and selenite in submerged sediment suggests anoxia and thus reducing conditions in the sediment. These results are consistent with a study performed at the U.S. Army Corps of Engineers ERDC Environmental Laboratory (ERDC 2009). Mercury species were almost 100% inorganic. Methylmercury constituted 1 to 2% of the total mercury. The high percentage of inorganic mercury suggests that mercury is largely immobile and not biologically available.

2.3.2 Spatial Trends in Submerged Sediment

The extent of potential ash-related contamination in submerged sediment was evaluated based on the distribution of the primary ash-related constituents (arsenic and selenium). Spatial distribution trends of these constituents are depicted in Figure 16, which plots the range of minimum-maximum concentrations and average detected concentrations progressively downriver.

Average arsenic concentrations show an increasing trend downstream in the Emory River, then gradually decreasing further downstream in the Clinch and Tennessee Rivers. The average concentration of arsenic was greatest in Emory River Reach A, at 25.0 mg/kg. Concentrations then decline to an average of 12.1 mg/kg in Tennessee River Reach A. Arsenic concentrations were relatively variable in Emory River Reaches B and C, which may be a result of the dredging activities in these reaches.

Average detected selenium concentrations show a continually decreasing trend downstream. Selenium was undetected in the Emory River reference reach, then sharply higher in Emory River Reach C, although this is due to a single detection out of nine samples. Average selenium concentrations continue to decline further downstream, and were undetected at Tennessee River Reach A. Because selenium was detected so infrequently and at such low concentrations in submerged sediment samples, this trend should be viewed with caution. In considering percentage of detection, selenium was detected most frequently in Emory River Reach A (12 of 12 samples), then diminished downstream, being detected in 8 of 12 Clinch River Reach A samples and 2 of 4 Tennessee River Reach B samples.

2.3.3 Comparison of Ash Content to Submerged Sediment Concentrations

Detected concentrations in submerged sediment samples were compared to percent ash content as reported by the offsite laboratory using PLM. Only samples where both percent ash and constituent concentrations were available were used in this analysis, with some modification. Samples from reference sediment locations were assigned an ash content value of 1%, to reflect the lack of ash at reference locations. Cell ash samples were also used in this analysis, and assigned an ash content value of 99%, to reflect the nature of ash within the former Dredge Cell. Samples in which a constituent was not detected were assigned a constituent concentration equal to the detection limit, to reflect the low concentrations at those locations. A linear correlation was evaluated, to reflect the range of constituent concentrations for a range of ash content varying from 1% to 99% ash. In this way, the y-intercept (0% ash) reflects an average reference background concentration of the constituent in submerged sediment; the 100% intercept reflects the constituent concentrations in cell ash; with a straight-line interpretation between the two.

Results of ash content to submerged sediment concentrations are shown on Figure 17. In general, constituent concentrations increase as the percent ash content increases, as would be expected. Scatter in the correlation is also expected, since percent ash content estimates using PLM are not precise and constituent concentrations, particularly at higher concentrations in the cell ash, vary over a wide range. Arsenic shows moderately good correlation. Selenium shows good correlation; however, most selenium concentrations in sediment are less than would be expected with a straight-line interpretation between reference values and cell ash, suggesting that some of the selenium may have been released from the ash portion to surface water rather than retained in the ash portion in the sediment.

2.3.4 Laboratory Bioassays in Submerged Sediment

A second LOE for evaluating potential ecological risk involved evaluating the results of laboratory bioassays (toxicity testing) in which benthic invertebrate and larval fish species were exposed to sediment samples in the laboratory and effects on their growth and survivability was observed. The purpose of this testing was to estimate the bioavailability and risk relative to the presence of ash-related constituents. Reference bioassay tests were used as laboratory controls for comparison with toxic effects due to exposure to ash-related constituents.

Sediment toxicity tests were conducted on site-related sediments from the Emory and Clinch Rivers. Sediment samples for bioassay testing were collected from locations representative of the range of ash and substrate types that exist in the river, with an equal number of samples in each river. Sediment samples were collected from eight representative locations within the Emory River and two reference locations upstream on the Emory River, and from eight representative locations and two reference locations on the Clinch River, for a total of 20 samples. Bioassay testing was also performed on a sample of ash taken from the Swan Pond Embayment. Samples were collected of the upper 6 inches of sediment using Ponar/Peterson sampling devices. Approximately three to five grab samples were taken from each location and composited to create a test sample. Sample locations within different reaches of the river system and corresponding results are presented in the Sediment Bioassay and Porewater Sampling TM (Jacobs 2012l).

Each composite sediment ("bulk sediment") sample used in the toxicity tests was analyzed for metals; naturally-occurring radionuclides; legacy constituents (PAHs, PCB, and pesticides); AVS/SEM; total organic carbon content; grain size; speciation of arsenic, mercury, selenium, and chromium; and for sequentially extracted metals. Average concentrations of constituents detected in bulk sediment samples collected from Clinch River Reach A and B and Emory River Reach A were less than 2 times the average concentrations in submerged sediment for a specific reach, suggesting that the bulk sediment samples were representative of the sediment present in the reach. However, in Emory River Reach B, several metals, including arsenic, had average concentrations greater than 2 times the average concentrations in submerged sediment. Therefore, the bulk sediment samples may not be representative of the reach and sediment bioassay results may overestimate average effects within that reach.

Bioassay testing was done using three indicator species and a combination of short-term chronic and longer duration tests, in accordance with EPA and American Society for Testing and Materials toxicity testing protocols. Bioassay 7-day tests were conducted for *Ceriodaphnia dubia* (water column filter feeders), 10-day and 28-day tests were conducted for *Hyalella azteca* (amphipods living on or in sediment), and 10-day and approximately 28-day (emergence) tests for *Chironomus dilutus* (larval midges that burrow in the sediment prior to emerging). The reference control sediment used in these tests was a 50:50 composite of the two reference samples of each river.

C. dubia were exposed to 8 site sediment samples and one reference from each river. Exposures were short-term chronic, and included 6 dilutions for each sediment sample using reference sediment as the diluent. *H. azteca* and *C. dilutus* were exposed to 8 site sediment samples and one reference from each river at 100% sediment (no dilution) in short-term (screening) testing. Longer-term testing was conducted on 4 sediment samples, with up to 3 having caused a lethal or sublethal effect in the 10-day tests and at least one from among those having caused no effect. The long-term *H. azteca* 28-day and *C. dilutus* partial life cycle test exposures consisted of 4 sediment samples with 6 dilutions of each sample. Because of delayed emergence, *C. dilutus* tests were extended beyond the planned 28-day testing period.

Endpoints measured were: (1) survival, (2) biomass (weight of organisms surviving at the end of the test divided by the initial number of organisms), and (3) emergence (the percentage of midges that emerged from the water from each tested sediment sample). Endpoints represented a statistically significant difference relative to observed effects in the reference samples. Results are summarized in Table 2-5.

Observed effects on survival and biomass were greater in the Emory River than in the Clinch River. Site sediment collected from ERM 2.5 and 3.5 contained the greatest percentage of ash at 88 and 64%, respectively, and caused the greatest reductions in survival, biomass and emergence. Measurable effects on survival and/or biomass and emergence also occurred, at a lesser extent, for the other Emory River samples. Minimal effects were measured in the Clinch River samples, with CRM 1.5 producing the greatest decrease in *C. dilutus* survival and emergence and *H. azteca* biomass during the long-term tests. Effects observed in long-term tests at CRM 1.5 were suspected to result from higher copper concentrations in the sediment. Results suggest that the average percentage of ash in a sediment sample that may cause an observed effect of survival of 25% of the test organisms was approximately 40 to 50% (37% ash for midges and 52% ash for amphipods).

Table 2-5 Summary of Laboratory Bioassay Results in Submerged Sediment

Type of Test	Species	Endpoint	Emory River Mile (% Reduction)							
			ERM 0.5	**ERM 0.8**	**ERM 1.0**	**ERM 2.5**	**ERM 3.0**	**ERM 3.5**	**ERM 4.0**	**ERM 5.5**
Short-term	*C. dubia*	Survival, Reproduction	NS	NS	NS	NS	NS	NS	NS	NS
Screening 10-day	*C. dilutus*	Survival	-1%	4%	1%	**29%**	-1%	**11%**	-1%	-1%
		Biomass	**25%**	**17%**	5%	**58%**	**19%**	**40%**	**23%**	**14%**
	H. azteca	Survival	1%	-1%	5%	**49%**	**48%**	**73%**	7%	**21%**
		Biomass	13%	0%	1%	**71%**	**56%**	**81%**	**22%**	**44%**
Long-term	*C. dilutus*	Survival (20 day)	4%	—	6%	**49%**	—	6%	—	—
		Biomass (20 day)	**43%**	—	**32%**	**68%**	—	**53%**	—	—
		Survival PLC	**38%**	—	**50%**	**72%**	—	**66%**	—	—
		Emergence PLC	**38%**	—	**50%**	**72%**	—	**66%**	—	—
	H. azteca	Survival	5%	—	—	**55%**	—	**38%**	—	0%
		Biomass	**31%**	—	—	**78%**	—	**60%**	—	**29%**
% Ash			43%	49%	42%	88%	53%	64%	1%	26%
Arsenic concentration (mg/kg)			21.8	31.7	29.4	77.7	48.9	63.3	9.25	19
Selenium concentration (mg/kg)			3.1	4.27	3.76	4.56	3.97	3.86	2.57	1.95

Type of Test	Species	Endpoint	Clinch River Mile (% Reduction)							
			CRM 0.0	**CRM 1.5**	**CRM 2.0**	**CRM 2.5**	**CRM 3.0**	**CRM 3.5**	**CRM 4.0**	**CRM 4.5**
Short-term	*C. dubia*	Survival, Reproduction	NS	NS	NS	NS	NS	NS	NS	NS
Screening 10-day	*C. dilutus*	Survival	0%	10%	3%	1%	1%	0%	8%	3%
		Biomass	-5%	1%	**15%**	-9%	-15%	-5%	**34%**	4%
	H. azteca	Survival	-5%	-4%	-5%	-5%	-1%	-4%	8%	-5%
		Biomass	-3%	**20%**	11%	14%	13%	7%	14%	15%
Long-term	*C. dilutus*	Survival (20 day)	—	-2%	2%	—	-7%	—	-2%	—
		Biomass (20 day)	—	-22%	-18%	—	-22%	—	-8%	—
		Survival PLC	—	**32%**	5%	—	3%	—	23%	—
		Emergence PLC	—	**32%**	5%	—	7%	—	23%	—
	H. azteca	Survival	—	1%		-4%	-7%	—	—	-7%
		Biomass	—	**31%**	—	14%	12%	—	—	**-32%**
% Ash			24%	22%	41%	20%	32%	28%	39%	34%
Arsenic concentration (mg/kg)			32.5	18.7	19.9	21.7	29.6	26.1	19.2	45.1
Selenium concentration (mg/kg)			4.06	3.75	2.60	2.78	3.22	2.88	2.84	3.39

Notes:

Shading denotes statistically significant differences relative to the reference.
NS = observed effects not statistically significant different relative to reference
PLC = partial life cycle, covers the lifespan of chironomids in the sediment prior to emergence.
— = samples not tested

2.3.5 Biosurveys of Benthic Invertebrate Communities

A third LOE for evaluating potential ecological risk in submerged sediment included community surveys of benthic invertebrates upstream and downstream in the Emory, Clinch, and Tennessee Rivers. These community surveys are presented in the BERA (Arcadis 2012).

2.3.6 Conclusions for Submerged Sediment

Several ash-related constituents (including arsenic and selenium) and legacy constituents (cesium-137, PCBs, pesticides, and PAHs) were detected in submerged sediment at concentrations exceeding reference concentrations. This medium was therefore evaluated further in the BHHRA and BERA (Section 3). Submerged sediment was not identified in the BHHRA as a pathway contributing to risk to human receptors, but was identified in the BERA as a pathway contributing to potential risks to benthic invertebrates and insectivorous birds that feed on them. A removal action has been recommended to manage those potential risks.

2.4 SEDIMENT POREWATER

Sediment porewater refers to the interstitial water present between grains of sediment that is the primary source of exposure to aquatic plants and benthic invertebrates (particularly burrowing organisms) near the base of the food chain. The purpose of evaluating sediment porewater separately from whole sediment is to understand the factors involved in desorption of constituents from the ash/sediment and toxicity of the chemical constituents apart from any physical effects of ash on benthic growth. The objective of porewater sampling was to collect sediment interstitial water, not incidentally collected surface water.

Sediment porewater samples were collected at locations in the Emory and Clinch Rivers from affected areas downstream of the ash release, as well as locations upstream unaffected by the ash release (reference areas). Sediment porewater samples were collected from the same locations as ash deposit and/or submerged sediment samples. Figures 18 and 19 show locations of the sediment porewater samples.

Sediment porewater sampling was conducted in the Clinch River from February 14 through 16, 2011 and in the Emory River from May 26 through 31, 2011. Sediment samples were collected from the upper four inches of sediment, a depth considered appropriate for evaluating benthic invertebrate exposures. Multiple sample specimens were collected to provide the volume of sample necessary for laboratory analysis. Samples were collected using a Wildco Box Core dredge sampler with a decontaminated acrylic liner; conditions at CRM 6.5, CRM 7.5, and ERM 5.5 required that the samples be collected manually.

The porewater samples were not exposed to air during sampling and were extracted from the sediment at an offsite laboratory under an inert atmosphere. Sediment porewater samples were analyzed for total metals and mercury, dissolved metals and mercury, radionuclides, hardness, major ions (chloride, sulfate), alkalinity, DO, pH, ORP, specific conductivity, and arsenic and selenium speciation. Speciation analyses were not conducted for the porewater sample from location ERM 0.8 because there was insufficient sample volume. The sediment from which the porewater was taken, referred to as residual sediment samples, were analyzed for total metals, mercury, and radionuclides and arsenic and selenium speciation. The residual sediment samples were used to evaluate the proportion of ash-related constituents within the sediment fraction, as compared to the extracted porewater fraction.

Two reference locations were sampled in the Emory River (at locations ERM 10.0 and 8.0) and in the Clinch River (at locations CRM 7.5 and 6.5). The two porewater reference samples were then composited at the analytical laboratory, resulting in one reference sample each for the Emory and Clinch Rivers. Likewise, residual sediment samples from the reference locations were composited prior to analysis, resulting in one reference sample each for the Emory and Clinch Rivers. A total of 17 sediment porewater and residual sediment samples were analyzed.

2.4.1 Constituent Concentrations in Sediment Porewater

Analytical results for sediment porewater in each river reach are presented in Appendix C. The nature of potential ash-related contamination in sediment porewater was evaluated by comparing the average concentrations of constituents in the designated river reaches to those measured in their respective reference reach. Concentrations were compared to screening criteria in the BERA. Results of sediment porewater sampling for arsenic and selenium are depicted on Figures 18 and 19, respectively.

The maximum detected concentration of arsenic was 0.564 milligrams per liter (mg/L) from location ERM 2.5 (Emory River Reach B), which is more than 153 times higher than the reference concentration in the Emory River of 0.00368 mg/L. Arsenic concentrations in 14 of 15 remaining downstream porewater samples were more than twice their respective reference concentrations. Exceptions included samples from locations ERM 5.5 (Emory River Reach C), and CRM 1.5 (Clinch River Reach A) where arsenic concentrations were less than twice the respective reference concentration.

Selenium was not detected in either of the reference porewater samples, but was detected at downstream locations. The maximum detected concentration of selenium was 0.00097 mg/L at ERM 2.5 (Emory River Reach B).

Copper was detected at concentrations more than twice the reference concentration in 3 of 8 downstream samples in the Emory River and all 8 downstream samples in the Clinch River. The maximum detected concentration of copper was 0.0079 mg/L at CRM 3.0 (Clinch River Reach B), which is more than 10 times higher than the reference concentration in the Clinch River of 0.00077 mg/L. Boron was the only other ash-related constituent (Section 1.3.1) that was found at an average concentration more than twice the respective reference concentration in sediment porewater. Boron was detected at a maximum concentration of 1.06 mg/L from location ERM 2.5 (Emory River Reach B); the average boron concentration in Emory River Reach B was 35 times higher than the reference concentration. Vanadium was not detected in either of the reference porewater samples, but was detected at several downstream locations.

Molybdenum, while not identified as an ash-related constituent, was also more than two times greater than the respective reference concentration at 5 of 7 locations in the Emory River and 7 of 8 locations in the Clinch River. The maximum concentration of molybdenum was 0.234 mg/L from location ERM 2.5; the average molybdenum concentration in Emory River Reach B was more than 266 times higher than the reference sample concentration. Lead was detected at concentrations more than twice the reference concentration in 5 of 8 Clinch River downstream locations. The maximum concentration of lead was 0.0105 mg/L at location CRM 3.0, about 18 times the reference sample concentration.

Porewater samples were submitted to Frontier for speciation of arsenic [inorganic arsenic (arsenate, arsenite) and organic arsenic] and selenium [inorganic selenium (selenate, selenite) and organic selenium]. Figure 11 shows the concentrations of the various species expressed as a percentage of the total concentration of the metal. Arsenic species were primarily in an inorganic form consisting mostly of arsenite. Selenium species were primarily organic selenium. The smaller inorganic form consisted completely of selenite. The presence of arsenite and selenite in porewater suggests anoxia and thus reducing conditions in sediment.

Concentrations were compared to TWQC for domestic water supply, for protection of fish and aquatic life, and for recreational use (water and organisms criteria), in accordance with TDEC Rule 1200-04-03. TWQC are not directly applicable to sediment porewater, but are useful in indicating potential constituent contributions to epibenthic surface water and potential exposure by benthic organisms. In sediment porewater, 13 of 17 samples (dissolved analysis) exceeded the arsenic TWQC for drinking water supply and recreational use (water and organisms criteria) of 0.010 mg/L, and one of those samples exceeded the arsenic TWQC for protection of fish and aquatic life of 0.15 mg/L. Three samples exceeded the lead TWQC for drinking water supply of 0.005 mg/L and four samples exceeded the lead TWQC for protection of fish and aquatic life of 0.0025 mg/L.

Only one sample was analyzed for total metals; in that sample, total arsenic and lead exceeded the TWQC for drinking water supply; total cadmium, copper, and lead exceeded the TWQC for protection of fish and aquatic life; and total arsenic and thallium exceeded the TWQC for recreational use (water and organisms criteria).

2.4.2 Spatial Trends in Sediment Porewater

The extent of potential ash-related contamination in sediment porewater was evaluated based on the distribution of the primary ash-related constituents (arsenic and selenium). Spatial distribution of these constituents is depicted in Figure 20, which plots average detected concentrations in each reach progressively downriver.

Average dissolved arsenic concentrations show little discernable trend. Detected concentrations were near the detection limit in the Emory River reference reach and Reach C, then rose sharply in Emory River Reach B. However, this is primarily due to the one abnormally high concentration of 0.564 mg/L at ERM 2.5. Concentrations in all other samples in the downstream reaches were less than 0.104 mg/L. Average detected concentrations decline in Emory River Reach C to 0.079 mg/L, and in the Clinch River to less than 0.027 mg/L.

Average dissolved selenium concentrations imply an increasing trend; however, because selenium was detected so infrequently and at such low concentrations in sediment porewater samples, this trend should be viewed with caution. Selenium was not detected in either the Emory River reference reach or Emory River Reach C, but rose sharply in Emory River Reach B due to a single detection at 0.00097 mg/L. Average detected concentrations of dissolved selenium in the remaining downstream reaches were less than 0.00058 mg/L.

2.4.3 Residual Sediment

Residual sediment is the sediment from which the porewater was extracted. Residual sediment was analyzed to evaluate the proportion of ash-related constituents within the sediment fraction, as compared to the extracted porewater fraction.

While not always directly correlative on a constituent-by-constituent basis, the overall trends between sediment porewater and residual sediment results are similar. Arsenic concentrations in both porewater and residual sediment rose sharply at Emory River Reach B, primarily due to one abnormally high concentration at ERM 2.5, and declined in reaches further downstream. The maximum arsenic concentration of 82.7 mg/kg in residual sediment at location ERM 2.5 (Reach B) was about 21 times the reference concentration. Selenium concentrations imply an increasing trend, with a sharp increase at Emory River Reach B, however, selenium has been infrequently detected and at such low concentrations that trends should be viewed cautiously. The maximum detected selenium concentration of 5.11 mg/kg in residual sediment was at location ERM 2.5 (Reach B); selenium was not detected in the reference sample.

Concentrations of these constituents in sediment porewater are generally in equilibrium with those in their respective residual sediment. One measure of comparison is the ratio of the average porewater concentration in a given reach to the average residual sediment concentration. For arsenic, this ratio ranges roughly from 0.001 to 0.002 kg/L; selenium from 0.00015 to 0.0002 kg/L.

Other ash-related constituents, including barium, boron, copper, nickel, and vanadium were more than twice their reference concentrations in residual sediment. Boron, copper, and vanadium concentrations were also much higher than reference in porewater. Copper concentrations in both media show a continually increasing trend downstream. The maximum copper concentration of 55.5 mg/kg in residual sediment in Clinch River Reach A was about 12 times the reference concentration. Vanadium concentrations also imply an increasing trend, although values are more variable in porewater than in residual sediment. The maximum vanadium concentration of 77.0 mg/kg in residual sediment was in Emory River Reach B, yet average concentrations further downstream in the Clinch River were higher than average concentrations in the Emory River reaches. Barium and nickel concentrations were similar to their reference concentrations in porewater, which would suggest that these constituents in residual sediment are not migrating into the porewater. Strontium was also greater than twice the reference concentration.

Concentrations in residual sediment were also compared to those in submerged sediment. As would be expected, average concentrations are similar.

2.4.4 Conclusions for Sediment Porewater

Several ash-related constituents (including arsenic and selenium) were detected in sediment porewater at concentrations exceeding reference concentrations. Arsenic and lead exceeded TWQC in several samples. This medium was therefore evaluated further in the BERA (Section 3). Sediment porewater was not identified as a discrete pathway contributing to risk. No removal action has been recommended to manage this pathway.

2.5 SURFACE WATER

Surface water refers to the conditions in the river following completion of dredging. For the human health risk assessment, people may be exposed to surface water if they use the river system for recreation or as an untreated drinking water source. For the ecological risk assessment, aquatic biota may be directly exposed to surface water, and birds and mammals that inhabit or forage in the river system may be exposed to surface water in their diet. The BERA used a weight-of-evidence process to characterize the magnitude and likelihood of risk to ecological receptors. The primary LOE included: (1) constituent concentrations compared to water quality criteria for protection of aquatic life, (2) laboratory bioassays, and (3) biosurveys of fish communities. These LOE are discussed in the following subsections.

Surface water samples were collected at fixed monitoring locations in the Emory, Clinch, and Tennessee Rivers. TVA had established 10 fixed stations that were monitored during the time-critical removal action. These locations were adjusted during the non-time-critical sampling to correlate with approximate locations of submerged sediment samples and with historical TVA fish health and bioaccumulation study locations and to provide representative measurement of water quality evenly distributed across the study area. An additional sample location was added at ERM 0.3 at the request of the EPA OSC for the time-critical removal action.

Surface water samples were collected at two discrete depth intervals using a peristaltic pump. One sample was collected at each location at mid-depth for use in evaluating human, fish, and wildlife exposures. The second sample was collected approximately 1.5 ft above the bottom for use in evaluating epibenthic water for bottom-dwelling organisms. When thermal stratification of the water column was detected, samples were collected at mid-depth in the epilimnion, mid-depth in the hypolimnion, and at the epibenthic depth. Sample locations for chemical analysis of constituent concentrations in surface water are shown on Figures 21 and 22, and summarized below:

- Upstream reference monitoring locations: A total of three reference locations were sampled at ERM 8.0, CRM 6.0, and TRM 568.5. The locations of these fixed stations were adjusted to correlate with approximate locations of reference sediment samples. Historical TVA fish health and bioaccumulation studies have established upstream reference ranges at roughly ERM 8.0 and CRM 6.0; therefore, the reference monitoring stations were reset to these locations.

- Within the Emory River, a total of five locations were sampled at ERM 0.3, 1.0, 2.0, 3.0, and 4.0. Previously, TVA had established four fixed station-monitoring locations at ERM 0.1, 1.75, 2.1, and 4.0, whereas fish studies had historically been conducted at about ERM 0.9 and 2.0. The fixed monitoring stations were reset to ERM 0.3, 1.0, 2.0, 3.0, and 4.0 to provide representative measurement of water quality across the Site. Locations were adjusted to correlate with approximate locations of submerged sediment samples.

- Within the Clinch River, two locations were sampled at CRM 2.0 and 3.5. Previously, TVA had established three fixed station monitoring locations at CRM 0.0, 2.0, and 4.0, whereas fish studies had been conducted at about CRM 1.5. The fixed monitoring stations were reset to CRM 2.0 and 3.5 to provide a representative measurement of water quality across the Clinch River reaches; these locations were adjusted to correlate with locations of submerged sediment samples.

- Within the Tennessee River, one location was sampled at TRM 566.0. TVA had previously established a fixed station-monitoring location at TRM 563.5; this fixed monitoring station was reset to TRM 566.0 to correlate with locations of submerged sediment samples.

A total of 207 samples were collected, as reported in the Surface Water Sampling TM (Jacobs 2012b). Surface water sampling began on August 31, 2010 and concluded on October 21, 2010; samples were collected weekly over this 8-week period at each sampling location and depth. Water-quality parameters (temperature, DO as mg/L, DO as percent saturation, specific conductance, turbidity, pH, and ORP) were measured in the field at each sampling location using a HACH® Hydrolab® DS5x.

Surface water samples were analyzed for the following constituents: total and dissolved metals, hardness as calcium carbonate, total suspended solids (TSS), total dissolved solids (TDS), and dissolved organic carbon. Twenty-five percent of the surface water samples were randomly selected to also include the following analysis: radionuclides (potassium-40, radium-226/228, isotopic thorium, isotopic uranium, cesium-137, cobalt-60), and speciation of dissolved metals.

2.5.1 Constituent Concentrations in Mid-Depth Surface Water

Analytical results for surface water in each river reach are presented in Appendix D. The nature of potential ash-related contamination in surface water was evaluated by comparing the average concentrations of constituents in mid-depth surface water samples from the designated river reaches to those measured in the reference reach samples. Analytical results for mid-depth surface water in each river reach are presented in Appendix D-1. When thermal stratification resulted in collecting both an epilimnion and a hypolimnion sample, the maximum concentration was selected for evaluation of mid-depth surface water. Concentrations were compared to screening criteria in the BERA. Results of mid-depth surface water sampling for arsenic and selenium are depicted on Figures 21 and 22, respectively.

Concentrations were compared to TWQC for domestic water supply, for protection of fish and aquatic life, and for recreational use (water and organisms criteria), in accordance with TDEC Rule 1200-04-03. In mid-depth surface water only one sample result exceeded a single criterion. The sample from the reference location CRM 6.0 (10/19/2010) detected dissolved mercury at a concentration of 0.002 mg/L, which is greater than the TWQC for recreational use of 0.0005 mg/L). Therefore, no surface water sample in downstream reaches exceeded TWQC.

The maximum detected concentration of total arsenic was 0.00278 mg/L in Emory River Reach B (at ERM 2.0 on 10/5/2010). Average arsenic concentrations in Emory River Reaches B and C were nearly three times higher than their respective average reference concentrations. Average arsenic concentrations in these two reaches were 0.0020 mg/L, compared to the average reference concentrations of 0.0007 mg/L for the Emory River. Average concentrations in all other reaches, including Clinch and Tennessee River reaches, were less than 0.013 mg/L.

The maximum detected total selenium concentration was 0.00093 mg/L in Emory River Reach A (at ERM 1.0 on 10/12/2010). Selenium was detected infrequently, and at concentrations near the detection level. The average detected selenium concentrations in downstream reaches ranged from 0.00036 to 0.00050 mg/L, compared to average concentrations in Emory, Clinch, and Tennessee reference reach samples that ranged from 0.00038 to 0.00043 mg/L. Selenium was therefore found at concentrations similar to reference concentrations.

Copper and vanadium were also more than twice as high as respective reference concentrations. Average copper concentrations in Emory River Reaches A and B were two to three times higher than the respective average reference concentration. Vanadium was not detected in reference reach samples in either the Emory or Clinch Rivers, yet was detected in downstream reaches of the Emory, Clinch, and Tennessee Rivers at average concentrations ranging from 0.0013 mg/L to 0.0020 mg/L.

No other ash-related constituent (Section 1.3.1) nor other analyte had an average concentration greater than 2 times the average in reference reach samples. Sampling for legacy constituents in mid-depth surface water was limited to radionuclides. The legacy radionuclides (cesium-137 and cobalt-60) were not detected in any surface water sample.

Manganese is of interest because it contributes to potential noncancer risk due to ingestion of surface water by a resident child (Section 3.1). The maximum concentration of total manganese was 0.225 mg/L in Emory River Reach C. However, the average concentration of manganese in Emory River Reach C was 0.132 mg/L, similar to the average in the reference reach of 0.094 mg/L. Total manganese in all other reaches was less than 0.060 mg/L. Therefore, the presence of manganese in surface water is likely from natural sources within the Emory River or from sources further upstream, and not related to the ash release.

Radium-228 is also of interest because it contributes to potential cancer risk due to ingestion of surface water by a resident (Section 3.1). Radium-228 was detected in a single sample in Emory River Reach C at an activity of 3.77 pCi/L; radium-228 was not detected in any other reach, including the reference reach. The presence and source of radium-228 in surface water is uncertain, in part due to the relatively small number of surface water samples analyzed for radium-228 (a total of 22 samples). Radium-228 was detected in submerged sediment samples at activities greater than the reference sample. It was also detected in cell ash samples.

Mid-depth surface water samples were submitted to Frontier for speciation of arsenic and selenium. Figure 11 shows the concentrations of the various species expressed as a percentage of the total concentration of the metal. Arsenic species were primarily in an inorganic form, although the percentage of organic arsenic is much greater than in sediment or sediment porewater. The inorganic arsenic consisted mostly of arsenate, suggesting oxidizing conditions. Selenium species were primarily organic selenium. The inorganic form consisted completely of selenate. These arsenic results are consistent with a study performed at the U.S. Army Corps of Engineers ERDC Environmental Laboratory (ERDC 2009). However, the presence of selenate is not consistent with the results of that study.

2.5.2 Spatial Trends in Surface Water

Spatial trends in the concentrations of the primary ash-related constituents in mid-depth surface water were evaluated for the 8-week sampling period following completion of dredging. The concentrations of some ash-related constituents were elevated in the area of the ash release relative to the Emory and Clinch River reference reaches. Figures 21 and 21 show the average concentrations of total arsenic and total selenium at each of the surface water sampling locations. Spatial distribution of these constituents is depicted in Figure 23, which plots average detected concentrations in each reach progressively downriver.

Average total arsenic concentrations in surface water were highest in the river reaches where time-critical dredging had been performed. Detected concentrations were near the detection limit in the Emory River reference reach, then rose sharply in Emory River Reach C and B to an average of 0.0020 mg/L. Concentrations then declined in samples from the river reaches further downstream to return to background concentrations. A slight increasing trend in Clinch River Reach A (CRM 2.0) may be due to discharge of condenser cooling water obtained from the plant Intake Channel. The average detected concentration in the Tennessee River was 0.0008 mg/L, similar to the average concentrations in all three reference reaches.

Average total selenium concentrations exhibit no discernable trend; however, selenium was detected infrequently and at low concentrations in surface water samples and any trend should be viewed with caution. Selenium was not detected in any samples in Emory River Reach C (ERM 4.0) or in the Tennessee River (TRM 566.0), but was detected in at about half of the samples in the other reaches. When detected, selenium concentrations ranged from slightly above the detection limit to approximately three times the detection limit, and averaged 0.0004 to 0.0005 mg/L, similar to the few detections in reference reaches (which averaged 0.0004 mg/L).

2.5.3 Temporal Trends in Surface Water

Temporal trends in the concentrations of ash-related constituents in Emory River mid-depth surface water samples were evaluated for the time period September 2009 through October 2010. Temporal trends have been influenced by several key factors, which should be considered when evaluating those trends. First, dredging operations were conducted within the Emory River under the time-critical removal action between September 2009 and June 2010. Second, sampling under the SAP was conducted during an 8-week post-dredging sampling period, between August and October 2010, at which time the Watts Bar Reservoir was at summer pool elevation and the Kingston plant was operating, drawing water into its cooling water system from the plant Intake Channel. This may contribute to backflow from the Clinch River into the Emory River. Lastly, drought conditions persisted during the period between August and October 2010, resulting in very low flow in the Emory River. This may contribute to stagnant or sluggish flow in the lower Emory River, combined with backflow from the Clinch River.

Figure 24 displays the monthly average concentrations of arsenic and selenium in mid-depth surface water in the Emory River over time. The monthly average total arsenic concentrations exhibit a general trend of decreasing concentrations as dredging activities ended, particularly in Emory River Reaches A and B. Concentrations in upstream reaches (Emory River reference reach and Reach C) do not exhibit any definitive trend, as concentrations generally remain uniform over time. It should be noted that sampling locations changed over time within each river reach. Temporal trends in the Emory River Reach reference reach are represented by sampling at stations ERM 8.0 and 12.0; Emory River Reach C by stations ERM 4.0; Emory River Reach B by stations ERM 1.0 and 2.1; and Emory River Reach A by stations ERM 0.1 and 0.3. As such, these interpretations should be viewed with caution.

Average monthly total arsenic concentrations in the area of the ash release (Emory River Reach B) averaged 0.0035 mg/L during dredging operations, peaking in May 2010 at 0.0055 mg/L, then declined to approximately 0.0018 mg/L following completion of dredging (Figure 24). A similar trend is seen in the downstream sample locations (Emory River Reach A) where the average monthly arsenic concentration averaged approximately 0.0023 during dredging, then declined to approximately 0.0010 mg/L following dredging. The average arsenic concentration in upstream sample locations (Emory River Reach C) exhibit an increasing trend following completion of dredging with average concentrations rising from 0.0007 mg/L during dredging to approximately 0.0019 mg/L following dredging. As previously stated, this trend may be due to the low flow in the Emory River combined with backflow from the Clinch River, resulting in higher concentrations upstream. Average monthly concentrations in the Emory River reference reach remained relatively uniform throughout the sampling period.

There are no discernable temporal trends in total selenium concentrations over time, because selenium was infrequently detected and when detected, was at concentrations near the detection limit. Average total selenium concentrations in the area of the ash release remained relatively uniform between the detection limit (0.00033 mg/L) and approximately 0.0005 mg/L (Figure 24). Selenium was not detected in any of the Emory River reference reach samples.

2.5.4 Comparison of Epibenthic to Mid-depth Surface Water Concentrations

Epibenthic surface water samples were collected within 1.5 ft of the bottom and, therefore, may provide an indication of constituents that are being released from the sediments or residual ash and may be more indicative of ecological exposure to bottom-dwelling organisms. Analytical results for epibenthic surface water in each river reach are presented in Appendix D-2. Average concentrations of detected constituents in mid-depth surface water samples were compared to those measured in epibenthic surface water samples to identify any differences in concentrations or spatial trends. Epibenthic surface water samples were only collected during the SAP sampling event (August to October 2010), and therefore, temporal trends cannot be evaluated for epibenthic surface water.

Concentrations were compared to TWQC for domestic water supply, for protection of fish and aquatic life, and for recreational use (water and organisms criteria), in accordance with TDEC Rule 1200-04-03. No sample exceeded TWQC in epibenthic surface water.

Arsenic concentrations were highest in Emory River Reaches B and C, with a maximum of 0.00638 mg/L and average concentrations of 0.0037 and 0.0030 mg/L, respectively. Spatial trends for arsenic in epibenthic surface water were therefore similar to those in mid-depth surface water (Figure 25). Average concentrations of total arsenic in epibenthic surface water samples were slightly higher (less than twice) than those of mid-depth surface water samples in 6 river reaches and slightly lower in three river reaches, indicating no apparent trend. The ratio of average arsenic concentration in epibenthic compared to mid-depth samples ranged from 0.8 to 1.8, indicating that the concentrations were similar.

Selenium was infrequently detected in downstream reaches, and when detected was near the detection limit. Therefore, general trends should be viewed with caution. Selenium concentrations were similar to those in mid-depth surface water at a maximum of 0.00093 mg/L, and exhibited no spatial trend (Figure 25). The ratio of average selenium concentrations in epibenthic surface water samples to mid-depth samples ranged between 0.8 and 1.2 at all locations where selenium was detected in both samples. Selenium was detected in the mid-depth surface water samples but not in the epibenthic samples at the

Emory River reference location. Conversely, selenium was detected in the epibenthic surface water samples but not in the mid-depth samples at the Tennessee River sample locations.

Copper was the only other ash-related constituent in epibenthic surface water samples whose average concentrations exceeded 2 times the average concentrations in respective reference reaches. Copper concentrations were higher in Emory River Reaches B and C, and Clinch River Reach A, downstream of the cooling water discharge from the Kingston plant. Chromium and nickel only slightly exceeded 2 times reference in a single individual reach.

Aluminum, while not identified as an ash-related constituent (Section 2.3.1), was found at concentrations more than 6 times higher than its average reference concentration in epibenthic surface water. The maximum aluminum concentration (1.22 mg/L) was found in Emory River Reach B. The average concentrations of aluminum in Emory River Reaches B and C were 0.73 and 0.44 mg/L, respectively, compared to average reference concentration of 0.12 mg/L in the Emory River. This is in contrast to aluminum concentrations in mid-depth surface water, which were similar to reference concentrations, suggesting that aluminum may have been released from sediments on the river bottom to the epibenthic surface water zone. Iron and lead, also not ash-related constituents, only slightly exceeded 2 times reference in a single individual reach in epibenthic surface water and are therefore not of concern.

Manganese, also not an ash-related constituent, is of interest in sediment porewater because it contributes to potential noncancer risk due to ingestion of mid-depth surface water (Section 3.1). The average concentrations of manganese in epibenthic samples were similar to those in the reference reach. However, when compared to mid-depth samples, concentrations of manganese in epibenthic samples are more than 2 times higher than those in mid-depth samples in several reaches. As with aluminum, this may suggest that manganese may have been released from sediments on the river bottom to the epibenthic surface water zone.

Epibenthic surface water samples were submitted to Frontier for speciation of arsenic and selenium. Figure 11 shows the concentrations of the various species expressed as a percentage of the total concentration of the metal. Arsenic species were primarily in an inorganic form, similar to mid-depth surface water, although the percentage of organic arsenic was much greater than in sediment or sediment porewater. The inorganic arsenic consisted mostly of arsenate, suggesting oxidizing conditions. Selenium species were primarily organic selenium. The inorganic form consisted completely of selenate. These arsenic results are consistent with a study performed at the U.S. Army Corps of Engineers ERDC Environmental Laboratory (ERDC 2009). However, the presence of selenate is not consistent with the results of that study.

2.5.5 Comparison of Total to Dissolved Concentrations in Surface Water

Average detected total constituent concentrations in mid-depth surface water samples were compared to average detected dissolved constituent concentrations to evaluate the potential for particle-bound transport (Figure 26). The ratio of dissolved concentrations to total concentrations was approximately one for most constituents (including selenium and copper), indicating that most of the constituent is present in dissolved phase in mid-depth surface water. Several ash-related constituents, including arsenic, nickel, and vanadium, had ratios of 1.3 to 1.5, indicating a slight affinity to suspended particulates. Other constituents that are not identified as ash-related constituents (Section 2.1) exhibited strong affinity to suspended particles. Manganese had a ratio of total: dissolved of more than 10. Aluminum was detected in only 2 dissolved phase samples, yet was frequently detected in total phase samples at concentrations more than 3 times the detection limit. Similarly, iron was detected in only five dissolved phase samples, yet was frequently detected in total phase samples. Therefore, aluminum, iron, and manganese are predominantly associated with suspended particulates whereas most other constituents, when detected, are largely present in the dissolved phase.

Comparison of total to dissolved concentrations in epibenthic surface water samples were similar to those for mid-depth surface water (Figure 27). The ratio of dissolved concentrations to total concentrations was approximately one for most constituents (including selenium), indicating that most of the constituent is present in dissolved phase in epibenthic surface water. Several ash-related constituents, including arsenic, copper, nickel, and vanadium had ratios of 1.6 to 2.0, indicating an affinity to suspended particulates. Manganese had a ratio of only 1.3, which is much lower than in mid-depth surface water, indicating that manganese in epibenthic surface water was present predominantly in dissolved phase, with a slight affinity to suspended particulates. Aluminum was not detected in any dissolved phase samples, yet was frequently detected in total phase samples at concentrations more than 6 times the detection limit. Similarly, iron was detected in only 7 dissolved phase samples, yet was frequently detected in total phase samples. Therefore, aluminum and iron are predominantly associated with suspended particulates whereas most other constituents, when detected, are largely present in the dissolved phase.

2.5.6 Rainfall Event Monitoring

Rainfall event sampling was conducted in the Emory, Clinch, and Tennessee Rivers during the time-critical removal action to monitor the potential downriver migration of ash. Rainfall event sampling in the river system was triggered when cumulative rainfall exceeded 1.0 inch at the Kingston plant or if flow in the river exceeded 5,000 cfs as measured at the Oakdale, Tennessee, gauging station. The objective was to conduct sampling of the storm flow in the river within 24 hours of the rainfall event being triggered. Manual monitoring of surface water quality following a rainfall event was performed at 10 fixed locations. In December 2009, TVA placed an automated Isco sampling platform at ERM 0.5 to monitor surface water quality during peak flow without endangering sampling personnel.

During the non-time critical sampling period, rain event sampling in the river system consisted of the collection of 24-hour composite surface water samples at three fixed locations on the Emory River and two fixed locations on the Clinch River during heavy local rain events and/or high Emory River flows. Samples were collected using remotely-triggered automated samplers and were analyzed for TSS and ash-related metals. Sampling was triggered by 24-hour rainfall $\geq$ 1.0 inch at the Kingston plant meteorological station or flows $\geq$10,000 cfs at the Oakdale, Tennessee gauging station.

Analytical results for non-time critical surface water samples collected during rainfall event monitoring are generally similar to routine (non-rainfall event) sampling. No more than two exceedances of water quality criteria (less than 2% of the total number of samples) were recorded for arsenic, lead, mercury, and thallium in the various stretches of river, including reference background locations.

In general, average metal concentrations in rainfall event samples were less than 2 times greater than non-rainfall event samples; upriver concentrations increased during rainfall events as much as downriver samples. These results suggest that residual ash had minimal impact on water quality during rainfall events.

Concentrations were compared to TWQC for domestic water supply, for protection of fish and aquatic life, and for recreational use (water and organisms criteria), in accordance with TDEC Rule 1200-04-03. A rainfall event on 11/30/10 resulted in a peak Emory River flow of 57,100 cfs and a daily average flow of 22,600 cfs measured at the Oakdale gauging station (Figure 28). Arsenic concentrations were near or above the TWQC for drinking water supply and recreational use at ERM 2.0 (0.0099 mg/L), ERM 0.3 (0.0096 mg/L), and CRM 2.5 (0.0125 mg/L). Lead also exceeded the TWQC for recreational use in the samples from ERM 2.0 and CRM 2.5 on 12/1/10. The only other exceedances of the TWQC during the evaluation period were for mercury measured in samples collected on 03/01/11 from CRM 4.6 and CRM 2.5. Mercury is a legacy constituent associated with historical releases from DOE's Oak Ridge Reservation. Because mercury exceedances were observed only in the Clinch River, and both upstream and downstream of the Emory River confluence, there is no reason to believe that these water quality exceedances for mercury were related to the release.

2.5.7 Laboratory Bioassays in Surface Water

A second LOE for evaluating potential ecological risk involved evaluating the results of laboratory bioassays (toxicity testing) in which benthic invertebrates and larval fish species were exposed to surface water samples in the laboratory and effects on their growth and survivability were observed. The purpose of this testing was to estimate the bioavailability and risk relative to the presence of ash-related constituents. Reference bioassay tests were used as laboratory controls for comparison with toxic effects due to exposure to ash-related constituents.

Surface water was collected in the fall of 2010 from the Emory River in order to determine if the water from the vicinity of the ash release was toxic to aquatic organisms. A reference location (ERM 8.0) and near-site samples (ERM 1.0, 2.0, 3.0, and 4.0) were used to conduct surface water toxicity tests for *C. dubia* (water flea) and *Pimephales promelas* (fathead minnow). The tests included dilutions for each sample and endpoints consisted of a no observed effect concentration (NOEC), a lowest observed effect concentration (LOEC), and an IC_{25} (concentration that inhibits 25% of organisms) for the measured endpoint.

Toxicity tests for the fathead minnow and water flea were standard laboratory short-term (approximately 7 days), chronic tests. There were no effects on fathead minnow growth or survival and no effects on water flea reproduction or survival. As a result, the NOEC, LOEC, and IC_{25} were determined to be greater than or equal to 100% water for all locations tested.

2.5.8 Biosurveys of Fish Communities

A third LOE for evaluating potential ecological risk in surface water included community surveys of fish upstream and downstream in the Emory, Clinch, and Tennessee Rivers. These community surveys are presented in the BERA (Arcadis 2012).

2.5.9 Conclusions for Surface Water

Several ash-related constituents (including arsenic) were detected in surface water at concentrations exceeding reference concentrations. No constituent in either mid-depth or epibenthic surface water in downstream reaches exceeded TWQC. Arsenic, lead, and mercury concentrations exceeded TWQC infrequently during storm event sampling. This medium was evaluated further in the BHHRA and BERA (Section 3). Surface water was not identified as a pathway contributing to risk to either human or ecological receptors. No removal action has been recommended to manage this pathway.

2.6 GROUNDWATER

This section describes existing and predicted post-closure groundwater quality conditions at the former Dredge Cell (Ash Landfill), including temporal changes in the distribution and concentrations of ash-related constituents of concern (COCs) and groundwater modeling of future contaminant migration and flux to surface water.

Groundwater sampling and analysis was conducted in accordance with the SAP (Jacobs 2010d), and as described in the Groundwater TM (Jacobs 2012e). Groundwater samples were collected from 8 permanent MWs and 6 TWPs, and porewater from 11 GP locations to define aqueous-phase concentrations of ash-related constituents. Groundwater samples were collected from bedrock (upgradient wells GW-01 and GW-03, and paired wells TWP-24, -25, and -26), residuum (upgradient wells AD-1 and GW-02, and downgradient wells AD-2 and AD-3) and alluvium (paired wells TWP-04, -05, and -06, and downgradient wells 6AR and 22). Samples were analyzed for metals including mercury, radionuclides, major and minor ions, ammonia-N, TSS and TDS, and field parameters. Major and minor ions included chloride, fluoride, sulfate, and nitrate-nitrite. Field parameters included pH, ORP, DO, specific conductivity, and temperature. Analytical results included dissolved analysis for metals and radionuclides. In addition, analytical results for wells 6AR, 22, and the TWPs included total analysis for metals, and results for wells AD-1, -2, and -3 included total analysis for both metals and radionuclides.

Compliance monitoring of the permanent wells in the Dredge Cell and Ash Pond area is being conducted in accordance with the Kingston plant's operating permit No. IDL 73-0094 (TDEC 2006). As a permitted industrial waste landfill, the Dredge Cell is subject to TDEC Rule 1200-01-07 for Solid Waste Processing and Disposal. These standards set methods, the suite of analysis, and frequencies of sampling for monitoring of groundwater. Historically, unfiltered groundwater samples have been collected semiannually from at least four monitoring wells associated with the Dredge Cell, and analyzed for the 17 inorganic constituents listed in Appendix I of the TDEC Rule 1200-1-7-.04.

The pre-release Dredge Cell/Ash Pond compliance monitoring network consisted of wells 4B, 6A, 13B, and 16A. Compliance wells 4B and 16A were destroyed in the ash release in December 2008. For compliance monitoring purposes, well 4B was replaced by existing well 22, which previously was sampled only for general water chemistry as part of a National Environmental Policy Act commitment. Groundwater samples were not analyzed for radionuclides during compliance monitoring. Monitoring of well 16A was replaced by monitoring of the new upgradient permanent well AD-1, which was installed in the Ball Field area in the spring of 2009 along with permanent wells AD-2 and AD-3. Former compliance well 6A was destroyed during routine plant operations in August 2009, and was replaced by well 6AR. Compliance well 13B was destroyed by routine plant operations in December 2009 and was replaced by monitoring of the existing well AD-3. Currently, groundwater monitoring of the Dredge Cell area is accomplished through sampling of wells AD-1, AD-2, AD-3, 6AR, and 22. Figure 29 shows the location of compliance monitoring wells.

2.6.1 Baseline 2010 Groundwater Quality Conditions

Groundwater data collected under the SAP during the September-October 2010 sampling event from permanent MWs, TWPs, and GP locations are presented in Appendix E and summarized in the Groundwater Sampling TM (Jacobs 2012e). The data for the permanent MWs and the TWPs represent groundwater conditions. Data from the GP locations represent porewater in direct contact with ash. The GP boreholes were advanced in 3 to 4 ft increments until a saturated zone suitable for sampling was reached; the GP location was then offset 2 ft and a stainless steel "Screen Point 15" was used for sample collection.

Results are summarized in Table 2-6 for dissolved analysis in both groundwater and cell porewater for the September-October 2010 sampling event. Results are also presented in Appendix E and in the Groundwater TM (Jacobs 2012e).

Table 2-6 Summary of Groundwater and Cell Porewater Data

Analyte	Units	Groundwater MCL / [Exceedances]	No. of Detections / Samples	Detection Limit Range	Max. Detected Result	Min. Detected Result	Mean of Detected Results	Location of Max. Detected Result
GROUNDWATER DATA								
Aluminum	mg/L	0.05 [4]	4 / 14	0.05 / 0.05	1.18	0.114	0.61	TWP26
Antimony	mg/L	0.006	3 / 14	0.00033 / 0.00033	0.00063	0.00035	0.00046	TWP04
Arsenic	mg/L	0.01 [3]	10 / 14	0.00033 / 0.00033	0.594	0.00037	0.074	TWP04
Barium	mg/L	2	14 / 14	--	0.544	0.027	0.136	TWP25
Beryllium	mg/L	0.004	1 / 14	0.00033 / 0.00033	0.00066	0.00066	0.00066	6AR
Boron	mg/L	--	14 / 14	--	2.75	0.0228	0.86	TWP04
Cadmium	mg/L	0.005	1 / 14	0.00033 / 0.00033	0.00237	0.00237	0.00237	6AR
Chromium	mg/L	0.1	5 / 14	0.00033 / 0.0005	0.00154	0.00033	0.00069	GW01
Cobalt	mg/L	--	8 / 14	0.00033 / 0.00033	0.0939	0.00034	0.0148	6AR
Copper	mg/L	1.3	2 / 14	0.00033 / 0.00033	0.00072	0.00034	0.00053	GW01
Iron	mg/L	0.3 [6]	8 / 14	0.025 / 0.025	52.3	0.051	8.68	TWP06
Lead	mg/L	0.005	0 / 14	0.00033 / 0.0005	ND	ND	ND	--
Magnesium	mg/L	--	12 / 14	0.25 / 0.25	47.2	0.639	12.6	TWP04
Manganese	mg/L	0.05 [11]	12 / 14	0.00033 / 0.00154	31.1	0.00104	4.7	6AR
Mercury	mg/L	0.002	0 / 14	0.00015 / 0.0002	ND	ND	ND	--
Molybdenum	mg/L	--	8 / 14	0.00033 / 0.00127	0.61	0.00033	0.13	TWP04
Nickel	mg/L	0.1	6 / 14	0.00033 / 0.001	0.0397	0.00105	0.0079	6AR
Selenium	mg/L	0.05	0 / 14	0.00033 / 0.00033	ND	ND	ND	--
Silver	mg/L	0.1	0 / 14	0.00033 / 0.00033	ND	ND	ND	--
Strontium	mg/L	--	14 / 14	--	3.4	0.115	0.67	TWP04
Thallium	mg/L	0.002	1 / 14	0.0005 / 0.00065	0.00058	0.00058	0.00058	22
Vanadium	mg/L	--	3 / 14	0.001 / 0.001	0.00834	0.00263	0.0060	GW01
Zinc	mg/L	5	2 / 14	0.0083 / 0.0083	0.0333	0.013	0.023	6AR
Actinium-228	pCi/L	--	0 / 14	12.2 / 17.3	ND	ND	ND	--
Americium-241	pCi/L	--	0 / 14	11.6 / 31.9	ND	ND	ND	--
Bismuth-214	pCi/L	--	12 / 14	5.95 / 15.4	86.1	17.7	44.6	AD2
Cesium-137	pCi/L	--	0 / 14	2.98 / 4.23	ND	ND	ND	--
Cobalt-60	pCi/L	--	0 / 14	3.25 / 4.27	ND	ND	ND	--
Lead-212	pCi/L	--	0 / 14	6.5 / 8.96	ND	ND	ND	--
Lead-214	pCi/L	--	12 / 14	6.02 / 16.7	91.8	12.4	47.0	AD2
Potassium-40	pCi/L	--	0 / 14	26.4 / 57.7	ND	ND	ND	--
Radium-226	pCi/L	--	8 / 14	0.216 / 0.645	1.58	0.283	0.85	GW02
Radium-228	pCi/L	--	1 / 14	0.5 / 1.41	0.843	0.843	0.84	22
Thallium-208	pCi/L	--	0 / 14	3.46 / 4.57	ND	ND	ND	--
Thorium-228	pCi/L	--	0 / 14	0.0324 / 0.138	ND	ND	ND	--
Thorium-230	pCi/L	--	2 / 14	0.0236 / 0.102	0.0944	0.0778	0.086	TWP25
Thorium-232	pCi/L	--	0 / 14	0.0379 / 0.111	ND	ND	ND	--
Thorium-234	pCi/L	--	0 / 14	126 / 270	ND	ND	ND	--
Uranium-234	pCi/L	--	5 / 14	0.0565 / 0.171	1.01	0.0923	0.50	TWP04
Uranium-235	pCi/L	--	0 / 14	0.0531 / 0.145	ND	ND	ND	--
Uranium-238	pCi/L	--	7 / 14	0.0355 / 0.133	0.849	0.0709	0.33	TWP04

Table 2-6 Summary of Groundwater and Cell Porewater Data (continued)

Analyte	Units	Groundwater MCL / [Exceedances]	No. of Detections / Samples	Detection Limit Range	Max. Detected Result	Min. Detected Result	Mean of Detected Results	Location of Max. Detected Result
CELL POREWATER								
Aluminum	mg/L	0.05 [5]	5 / 11	0.05 / 0.05	57.1	0.064	11.6	GP18
Antimony	mg/L	0.006 [2]	10 / 11	0.00033 / 0.00033	0.0225	0.00068	0.0041	GP13
Arsenic	mg/L	0.01 [9]	11 / 11	--	0.915	0.00393	0.30	GP12
Barium	mg/L	2 [1]	11 / 11	--	6.8	0.0271	0.69	GP18
Beryllium	mg/L	0.004	0 / 11	0.00033 / 0.00033	ND	ND	ND	--
Boron	mg/L	--	11 / 11	--	12.2	1.2	4.27	GP18
Cadmium	mg/L	0.005	0 / 11	0.00033 / 0.00033	ND	ND	ND	--
Chromium	mg/L	0.1	8 / 11	0.00033 / 0.00033	0.00051	0.00033	0.00040	GP13
Cobalt	mg/L	--	9 / 11	0.00033 / 0.00033	0.00423	0.00035	0.0025	GP08
Copper	mg/L	1.3	4 / 11	0.00033 / 0.00033	0.0093	0.00041	0.0029	GP18
Iron	mg/L	0.3 [7]	8 / 11	0.025 / 0.025	126	0.0351	49.1	GP08
Lead	mg/L	0.005	1 / 11	0.00033 / 0.00033	0.00033	0.00033	0.00033	GP18
Magnesium	mg/L	--	10 / 11	0.25 / 0.25	68.8	18	40.9	GP15
Manganese	mg/L	0.05 [10]	10 / 11	0.00033 / 0.00033	4.47	0.136	1.96	GP10
Mercury	mg/L	0.002	0 / 10	0.00015 / 0.00015	ND	ND	ND	--
Molybdenum	mg/L	--	11 / 11	--	3.01	0.0074	0.51	GP15
Nickel	mg/L	0.1	11 / 11	--	0.0691	0.00046	0.026	GP07
Selenium	mg/L	0.05	7 / 11	0.00033 / 0.00033	0.0196	0.00035	0.0056	GP18
Silver	mg/L	0.1	0 / 11	0.00033 / 0.00033	ND	ND	ND	--
Strontium	mg/L	--	11 / 11	--	15.8	1.84	4.38	GP18
Thallium	mg/L	0.002	6 / 11	0.0005 / 0.0005	0.00178	0.00051	0.00088	GP13
Vanadium	mg/L	--	9 / 11	0.001 / 0.001	0.15	0.001	0.025	GP13
Zinc	mg/L	5	6 / 11	0.0083 / 0.0083	0.745	0.0996	0.337	GP08
Actinium-228	pCi/L	--	0 / 10	12.5 / 15.1	ND	ND	ND	--
Americium-241	pCi/L	--	0 / 10	10.5 / 23.7	ND	ND	ND	--
Bismuth-214	pCi/L	--	4 / 10	6.01 / 8.8	24.7	9.24	15.7	GP10
Cesium-137	pCi/L	--	0 / 10	2.87 / 3.73	ND	ND	ND	--
Cobalt-60	pCi/L	--	0 / 10	2.8 / 3.73	ND	ND	ND	--
Lead-212	pCi/L	--	0 / 10	5.89 / 8.67	ND	ND	ND	--
Lead-214	pCi/L	--	1 / 10	6.53 / 17.4	19.8	19.8	19.8	GP10
Potassium-40	pCi/L	--	1 / 10	26.2 / 56.3	91	59.7	91	GP10
Radium-226	pCi/L	--	3 / 10	0.346 / 0.707	2.28	0.617	1.25	GP18
Radium-228	pCi/L	--	2 / 10	0.508 / 1.22	3.74	0.773	2.26	GP18
Thallium-208	pCi/L	--	0 / 10	3.16 / 4.49	ND	ND	ND	--
Thorium-228	pCi/L	--	1 / 10	0.0433 / 0.152	0.298	0.298	0.298	GP18
Thorium-230	pCi/L	--	1 / 10	0.0283 / 0.113	0.185	0.185	0.185	GP18
Thorium-232	pCi/L	--	0 / 10	0.0334 / 0.106	ND	ND	ND	--
Thorium-234	pCi/L	--	0 / 10	112 / 223	ND	ND	ND	--
Uranium-234	pCi/L	--	10 / 10	--	6	0.225	1.62	GP11
Uranium-235	pCi/L	--	2 / 10	0.0702 / 0.13	0.347	0.304	0.33	GP15
Uranium-238	pCi/L	--	10 / 10	--	6.45	0.341	1.64	GP11

Notes:

MCL = Maximum Contaminant Level; lead value from TDEC Rule 1200-4-3.03(1) General Water Quality Criteria for Domestic Water Supply.
All values are dissolved (filtered) results.
ND = not detected.
For additional definitions, see the Acronyms section.

Concentrations of ash-related constituents in groundwater were compared to corresponding maximum contaminant levels (MCLs) for analytes for which MCLs are available, per TWQC for Domestic Water Supplies, Rule 1200-4-3.03(1)(j). For the September to October 2010 sampling event, primary MCLs were not exceeded for any constituent in permanent MWs. Dissolved arsenic exceeded its primary MCL of 0.010 mg/L in three TWPs in alluvium, with concentrations of 0.594 mg/L, 0.119 mg/L, and 0.0173 mg/L in TWP 04, 05 and 06, respectively. Figure 29 shows the distribution of arsenic in alluvium for the September to October 2010 sampling event. Secondary MCLs were exceeded in dissolved analyses for aluminum, manganese, sulfate, and TDS in both permanent MWs and TWPs, and iron exceeded its secondary MCL in permanent MWs. Other ash-related constituents (copper, selenium, and vanadium) did not exceed primary nor secondary MCLs. Only five wells were sampled for total analysis in the September to October 2010 sampling event (Wells 22, 6AR, AD-1, AD-2, and AD-3). Secondary MCLs were exceeded in total analyses for aluminum, manganese, and iron. Results for total analyses are presented in Appendix E for these five wells.

Groundwater in the ash disposal area was also evaluated by comparing concentrations of ash-related constituents in the downgradient permanent MWs (22, 6AR, AD-2, and AD-3) to those detected in the upgradient permanent MWs (AD-1, GW-01, GW-02, GW-03) for the Ash Landfill area. Antimony, beryllium, cadmium, total chromium, lead, mercury, thallium, vanadium, and zinc were not detected in upgradient well samples but were detected at concentrations near the detection limit in downgradient wells. Average concentrations of aluminum, arsenic, barium, boron, cobalt, iron, magnesium, manganese, molybdenum, nickel, and strontium, detected in one or more downgradient wells were greater than twice the average concentrations measured in upgradient wells. The maximum concentration of dissolved radium-226 (a constituent evaluated in fate and transport modeling) was 1.58 pCi/L in upgradient well GW-02, suggesting a natural upgradient source of radium-226.

Dissolved arsenic was higher in upgradient well GW-1 (0.00254 mg/L) than in any of the downgradient permanent MWs. However, dissolved arsenic was much higher in the downgradient TWPs, at a maximum of 0.594 mg/L in alluvium and 0.0272 mg/L in bedrock. Dissolved arsenic reported for well 22 was 0.00072 mg/L, greater than for total arsenic, so results should be viewed with caution. Total arsenic concentration exceeded two times the upgradient concentration (0.0004 mg/L in well AD-1) only in downgradient well AD-2 (0.00149 mg/L). Total arsenic was not detected in wells 22 or 6AR in the 2010 sampling event. Total and dissolved selenium were not detected in any upgradient or downgradient well.

Concentrations of ash-related constituents were higher in cell porewater samples from the GP locations than those found in groundwater from wells. Detected concentrations of dissolved arsenic ranged from 0.00393 to 0.915 mg/L; dissolved selenium from 0.00035 to 0.0196 mg/L. These concentrations are as much as 50 times higher than those in groundwater, suggesting that the porewater in contact with cell ash may serve as a potential source of constituent migration to groundwater. Other constituents, including aluminum, antimony, barium, and zinc, had dissolved concentrations in cell porewater more than 10 times higher than those in groundwater.

2.6.2 Temporal Groundwater Trends

Arsenic is the only ash-related contaminant that has been detected above a primary MCL, and exceedances have been detected in two downgradient wells 6A and AD-2. Table 2-7 shows arsenic concentration trends in downgradient groundwater MWs beginning with the December 1999 sampling event. Wells AD-1, AD-2, and AD-3 were first sampled during the June 2009 sampling event. Well 22 had not been sampled for aqueous phase constituents (including arsenic) until June 2009, after a nearby well (well 4B) was destroyed in the December 2008 ash release.

Table 2-7 Temporal Trends in Arsenic Concentration in Downgradient Groundwater

Well Number:		KIF-13B	KIF-16A	KIF-22	KIF-4B	KIF 6A/6AR	KIF-AD2	KIF-AD3
Well Depth:		71-81 ft	52-62 ft	14-49 ft	19-24 ft	50-55 ft	14-24 ft	9-14 ft
Sample Date	**Unit**							
12/06-07/1999	mg/L	<0.001	<0.001	NA	<0.001	<0.001	NA	NA
12/14/2000	mg/L	<0.001	<0.001	NA	0.002	0.003	NA	NA
06/28/2001	mg/L	<0.001	<0.001	NA	<0.001	<0.001	NA	NA
12/31/2001	mg/L	<0.001	<0.001	NA	0.0042	**0.011**	NA	NA
06/28/2002	mg/L	0.002	<0.001	NA	<0.001	0.008	NA	NA
01/08/2003	mg/L	<0.001	0.006	NA	0.004	0.006	NA	NA
06/16-17/2003	mg/L	<0.001	<0.001	NA	<0.001	<0.001	NA	NA
09/02/2003	mg/L	0.0002	0.0009	NA	0.0012	**0.0115**	NA	NA
12/29/2003	mg/L	<0.001	0.0006	NA	0.0004	0.005	NA	NA
03/10/2004	mg/L	<0.001	0.0005	NA	0.002	0.0057	NA	NA
06/07/2004	mg/L	0.001	0.002	NA	0.004	**0.011**	NA	NA
09/14-16/2004	mg/L	0.002	0.002	NA	0.001	**0.013**	NA	NA
12/08/2004	mg/L	<0.001	<0.001	NA	0.005	**0.014**	NA	NA
03/15-17/2005	mg/L	<0.001	0.001	NA	0.003	0.006	NA	NA
05/31-6/01/2005	mg/L	<0.001	0.001	NA	0.001	0.004	NA	NA
12/13/2005	mg/L	<0.001	0.001	NA	<0.001	0.005	NA	NA
06/06/2006	mg/L	<0.001	<0.001	NA	<0.001	0.003	NA	NA
12/12-15/2006	mg/L	<0.001	0.001	NA	0.001	0.004	NA	NA
06/05/2007	mg/L	0.0013	0.0011	NA	0.0016	0.0064	NA	NA
12/03-04/2007	mg/L	<0.001	<0.001	NA	0.0018	<0.005	NA	NA
06/02/2008	mg/L	0.0011	0.0014	NA	0.0017	0.0063	NA	NA
12/01-02/2008	mg/L	0.0011	0.0014	NA	<0.001	**0.011**	NA	NA
02/11/2009	mg/L	NA	NA	NA	NA	<0.005	NA	NA
06/10-11/2009	mg/L	0.00326	NA	<0.002	NA	0.00646	**0.0297**	0.00205
7/23/2009	mg/L	NA	NA	NA	NA	NA	**0.014**	NA
9/14-15/2009	mg/L	0.00089	NA	0.00052	NA	0.00038	0.00709	0.00074
10/13-19/2009	mg/L	0.00062	NA	NA	NA	NA	0.00922	0.00059
11/16-17/2009	mg/L	0.00348	NA	NA	NA	NA	0.00397	0.00048
12/14-17/2009	mg/L	0.00239	NA	<0.00033	NA	<0.00033	0.00376	<0.00033
1/12-13/2010	mg/L	NA	NA	NA	NA	NA	0.00509	<0.00033
2/17/2010	mg/L	NA	NA	NA	NA	NA	0.00438	<0.00033
3/8-11/2010	mg/L	NA	NA	0.00045	NA	0.00045	0.00254	<0.00033
4/12-19/2010	mg/L	NA	NA	<0.00033	NA	<0.00033	0.00221	<0.00033
5/11/2010	mg/L	NA	NA	NA	NA	NA	0.00391	0.00034
6/14-16/2010	mg/L	NA	NA	0.00042	NA	0.00046	0.00272	<0.00033
7/12-13/2010	mg/L	NA	NA	NA	NA	NA	0.00243	0.00038
9/22-29/2010	mg/L	NA	NA	0.00072	NA	<0.00033	0.00167	0.0005
12/15-17/2010	mg/L	NA	NA	<0.00033	NA	<0.00033	0.00334	<0.00033
3/7/2011	mg/L	NA	NA	NA	NA	NA	0.00159	<0.00033
6/27-29/2011	mg/L	NA	NA	0.00068	NA	0.00062	0.0044	<0.00033
9/27-28/2011	mg/L	NA	NA	NA	NA	NA	0.00139	<0.00033
12/5-7/2011	mg/L	NA	NA	<0.00033	NA	<0.00033	0.00098	<0.00033
3/19-20/2012	mg/L	NA	NA	NA	NA	NA	0.00143	<0.00033

Notes:

Bold font indicates value exceeds reference criterion for arsenic (0.010 mg/L).

Values are higher of dissolved and/or total results.

NA = not analyzed on this date.

The highest levels of arsenic have been reported in well AD-2, with concentrations of 0.0297 and 0.0142 mg/L (total) for the June and July 2009 sampling events, respectively (Figure 30). Total arsenic concentrations in well 6A have exceeded the MCL of 0.010 mg/L for five sampling events, with a maximum concentration of 0.014 mg/L for the December 2004 event. The last exceedance for well 6A was in December 2008. Well 6AR, installed to replace well 6A after its destruction in August 2009, was sampled beginning September 2009. Arsenic results for well 6AR have not exceeded the MCL in any sampling event. Fluctuations in arsenic concentrations in wells AD-2 and 6A/6AR are over a relatively narrow range and do not indicate either an increasing or a decreasing trend.

Trends for selenium are similar to those of arsenic. Fluctuations in concentrations in downgradient wells are over a relatively narrow range and do not indicate either an increasing or decreasing trend.

2.6.3 Groundwater Modeling and Results

Groundwater fate and transport modeling was conducted to predict future groundwater flux and contaminant concentrations following closure of the Ash Landfill. Because there is no man-made liner beneath the Dredge Cell or Ash Pond and because groundwater discharges only a short distance to Watts Bar Reservoir, the flux of constituents in groundwater could conceivably impact the river system. Results of groundwater flow modeling indicated that groundwater in contact with the ash in the closed Ash Landfill would be transported with shallow groundwater to the Emory River and Swan Pond Embayment. Fate and transport modeling was then conducted to predict flux and contaminant concentrations at these discharge locations. The modeling results were in turn used to evaluate potential long-term risks to ecological receptors in the reservoir exposed to surface water or sediment porewater. Details of the modeling effort are presented in *Kingston Ash Recovery Project Groundwater Flow and Transport Model Report* (Jacobs 2011d).

A comprehensive three-dimensional groundwater flow model was developed in Visual MODFLOW and calibrated to summer 2010 and winter 2012 conditions to refine the hydrogeologic parameters that would in turn be used to develop a second model representing future (closed) conditions. Eight model layers were defined based on lithology; the top 5 layers represented ash, layers 6 and 7 represented the alluvial clay and sand beneath the Ash Landfill area, and layer 8 represented the Conasauga Group shale. Hydraulic properties were assigned to the layers based on previous investigations and hydraulic conductivity testing conducted under the SAP. Recharge rates were assigned to the model based on studies at the nearby Oak Ridge Reservation, which has similar geological setting, and as calculated using the HELP model.

The model representing future (closed) conditions was constructed based on conceptual Ash Landfill design, finished topography, surface drainages and surface bodies, and other engineering features that may impact the groundwater and surface movement. Future conditions assumed that the Ash Landfill would be closed and both the Ball Field and Stilling Pond areas would be leveled and capped. It was further assumed that the Swan Pond Embayment channel would be restored to its pre-failure location and topography.

The engineered components of the closed Ash Landfill were assumed to consist of stacked ash, a PWS system, and a final cover system. Stacked ash would cover the footprint of the former Dredge Cell and Ash Pond. The PWS would be constructed to bedrock to stabilize the foundation beneath the dikes around the perimeter of the closed Ash Landfill. The final cover system would consist of a flexible membrane liner with a 2-ft vegetative soil cover above the liner. The landfill surface would be sloped at 2 to 5% and the top elevation will range from 760 to slightly above 790 ft msl. The flow model predicted groundwater flow directions beneath the closed Ash Landfill to be radial in each formation, with overall flow generally from Pine Ridge toward the Emory River. In the Ball Field area, flow is southeasterly toward the plant Intake Channel. Reduction in recharge from capping of the Ash Landfill area produced a striking difference (lowering) in the potentiometric surface relative to that observed in 2010 (Figure 31). The predicted steady-state groundwater flux under closed conditions was 1,963 ft^3/d (10.2 gpm) to the Emory River, 1,931 ft^3/d (10.0 gpm) to the Swan Pond Embayment, and 1,259 ft^3/d (6.5 gpm) to the Intake Channel.

The constituents identified in the SAP for transport modeling were arsenic, mercury, chromium, selenium, radium-226, and thorium-228. Before detailed modeling calculations were performed, further evaluation was performed by Geosyntec Consultants, Inc., (Geosyntec) to assess their potential occurrence and mobility in groundwater (Geosyntec 2011). That evaluation concluded that mercury, chromium, selenium, and thorium-228 are subject to natural attenuation mechanisms such as adsorption, ion-exchange, and chemical precipitation, or occur at negligible concentrations such that transport modeling would be unwarranted. However, selenium was considered further due to its potential for bio-magnification by aquatic organisms (Geosyntec 2011). Therefore, arsenic, selenium, and radium-226 were carried forward in groundwater fate and transport modeling.

Initial conditions for the transport model were based on constituent concentrations and distributions from the 2010 sampling event. Constituent concentrations in the alluvial clay and sand were identified collectively as an “alluvium” aquifer, as it was not possible to distinguish analytical results between them. Background concentrations were used to infill active model cells outside of the Ash Landfill area where field data were absent.

Fate and transport modeling was conducted using MT3DMS for periods of 30 and 100 years into the future. The predicted mass flux for a given constituent depends on the initial contaminant concentrations and distributions, mass alignment with hydraulic gradients, and travel distance to surface water bodies. Transport predictions indicated slightly more arsenic mass flux entering the Emory River after 100 years relative to Swan Pond Embayment or plant Intake Channel; however, the differences in mass flux between modeling scenarios were small. Similarly, transport predictions showed slightly more selenium and radium-226 mass entering the Emory River segment.

Based on modeling simulations, arsenic, selenium and radium-226 showed little change over time, with the concentration distributions remaining nearly stationary. This is primarily a result of sorption, reduction in recharge due to capping, and reduction in lateral groundwater movement due to the PWS. The predicted spatial distribution of arsenic over time showed minor increase in concentrations laterally from the ash source toward receiving streams. The highest arsenic concentration predicted to enter the Emory River was 0.00127 mg/L, to enter Swan Pond Embayment was 0.0135 mg/L, and to enter the plant Intake Channel was 0.0314 mg/L at 100 years. These concentrations are therefore expected to exceed the MCL for arsenic (0.010 mg/L) and to exceed TWQC for recreational use (water and organisms criteria) for arsenic (0.010 mg/L), but to be less than the TWQC for protection of fish and aquatic life for arsenic (0.150 mg/L). Arsenic contributions to receiving streams were primarily associated with shallow groundwater (model layers 4 and 5) that coincides with the lower portion of the ash fill. Predicted arsenic distribution at 100 years is depicted on Figure 32. Concentrations of arsenic in the river system are not expected to exceed 0.010 mg/L due to dilution and dispersion of constituents in surface water.

Predicted spatial distribution of selenium over time showed reductions below detection limits (0.00033 mg/L) in certain portions of the aquifer and minimal vertical transport from ash into alluvium. The highest selenium concentration predicted to enter the Emory River was 0.00096 mg/L, to enter Swan Pond Embayment was 0.00039 mg/L, and to enter the plant Intake Channel was 0.00107 mg/L at 100 years. These concentrations are therefore not expected to exceed either the MCL for selenium (0.050 mg/L), nor the TWQC for protection of fish and aquatic life for selenium (0.005 mg/L). Selenium contributions to receiving streams were associated with deeper geologic media, including alluvium and bedrock.

Predicted concentrations of radium-226 exhibited little change over time. The highest radium-226 concentration predicted to enter the Emory River was 9.31E-10 mg/L (0.92 pCi/L), to enter Swan Pond Creek was 8.97E-10 mg/L (0.89 pCi/L), and to enter the plant Intake Channel was 9.25E-10 mg/L (0.91 pCi/L) at 30 years. These concentrations are therefore not expected to exceed the MCL for combined radium-226/radium-228 (5 pCi/L). With increasing time, radium-226 concentrations are predicted to be reduced to below background concentrations in certain upgradient portions of the aquifer.

2.6.4 Conclusions for Groundwater

Several ash-related constituents (including arsenic) were detected in groundwater at concentrations exceeding reference concentrations. Arsenic in groundwater exceeded its MCL on two occasions in one well in 2009, but has not exceeded its MCL in subsequent monitoring. Groundwater was evaluated in the EE/CA for the Embayment and Dredge Cell (Jacobs 2010a) and a removal action is currently underway to manage potential risks at the Ash Landfill. Groundwater fate and transport modeling has predicted that groundwater will migrate from the Ash Landfill to the surrounding water bodies at concentrations that could conceivably impact the river system. This pathway was therefore evaluated further in the BERA (Section 3). Groundwater transport to sediment porewater and subsequently to the surface water column in the river was not determined to be a significant pathway contributing to ecological exposures. No removal action has been recommended to manage this pathway.

2.7 BIOTA

Sampling of biota included benthic invertebrate bioaccumulation and community surveys, fish tissue bioaccumulation and community surveys, and sampling of wildlife (birds, raccoons, amphibian, and turtles). Vegetation sampling included emergent and shoreline vegetation and periphyton. Results of that sampling are evaluated in the BHHRA (Jacobs 2012) and BERA (Arcadis 2012).

Results of the BHHRA (Section 3) indicated potential cancer risk and noncancer hazard to recreators due to fish consumption. However, risk drivers were legacy constituents in the river system (PCBs and mercury) that are unrelated to the ash release. Therefore no removal action has been recommended to manage this pathway.

Results of the BERA (Section 3) indicated moderate risk to benthic invertebrates exposed to ash-contaminated sediment and low risk to insectivorous birds through biouptake in their diet. Although ash-related constituents were found in other biota (fish, raccoons, amphibians, turtles, and aquatic vegetation) at concentrations exceeding reference concentrations, results of the BERA (Section 3) did not identify risk to those receptors. Therefore, a removal action has been recommended to manage potential risks only to benthic invertebrates and the birds that feed on them.

2.8 SUMMARY OF NATURE AND EXTENT OF CONTAMINATION

Samples of cell ash, sediment, surface water, groundwater, and biota were collected and analyzed for metals, organic chemicals, radionuclides, and other parameters. Metals, primarily arsenic and selenium, have been the focus of this monitoring, since they contribute most to potential ecological risk. Arsenic and selenium are present in the cell ash at concentrations more than twice the average concentration in typical regional soils, and indicate that the ash may be a source of these constituents in other environmental media.

Arsenic and selenium are also present in seasonally-exposed sediment, submerged sediment, sediment porewater, surface water (both mid-depth and epibenthic), and groundwater at concentrations more than twice the average concentration in their respective reference samples. These environmental media have therefore been further evaluated in the BHHRA and BERA, as summarized in Section 3.

Samples of plants and animals were analyzed for evaluation of bioaccumulation and food web modeling in the ecological risk assessment. In addition, results of toxicity testing of sediment and surface water and surveys of fish and benthic invertebrate communities were used as additional LOEs in evaluating ecological risks.

2.9 SUMMARY OF CONTAMINANT FATE AND TRANSPORT

Constituents within the ash may be transported through the environment through both physical processes (sediment deposition and transport, scouring/re-suspension of sediment/ash mixtures and transport by storm events, or groundwater transport) and physico-chemical processes (dissolution/leaching of constituents into the water column, or immobilization/sorption of constituents to sediment particles). Direct contact of benthic invertebrates with consituents in the ash and biouptake from ash-contaminated sediment to riparian- and aerial-feeding birds may also occur.

2.9.1 Scour and Sediment Transport

Scour and sedimentation processes result in mixing of ash and natural sediments. The ERDCWES has performed baseline fate and transport modeling of the Emory and Clinch Rivers sediment (ERDCWES 2012). Flume testing was performed using ash, native sediment, and ash-sediment mixes to provide model input data on critical shear stress and bed scour (erosion rates). The model was established to represent how the river system would respond to periodic floods and low flow periods. Modeling was conducted using a two-dimensional adaptive hydraulics numerical model developed at ERDCWES. The model performed a simulation of sediment transport over a 30-year timeframe, using actual river flows and flood events as recorded for the years 1978 to 2008. Within that time, a total of 13 flood events with river flows ranging from 60,000 to 170,000 cfs were recorded, and used in the simulation. Results of that modeling indicate that over the long term natural sediment dynamic processes yield decreasing proportions of ash and decreasing concentrations of arsenic and selenium in sediment in the Emory and Clinch Rivers. Natural sedimentation and scour processes would likely produce a layer of mixed ash and sediment approximately 6 inches thick over a period of 10 to 15 years in depositional side channel areas. This mixed ash/sediment layer has been observed in vibracore sampling performed in 2009 and 2010, confirming the model predictions.

The modeling also showed that periodic severe storm flow events (greater than a 10-year recurrence interval) would be expected to result in scouring portions of this natural cover, particularly in the main channel as well as some of the side channel deposits. The bulk of the residual ash would be transported downstream and out of the lower Emory and Clinch Rivers. Following such severe storm flow events, deeper sediments with potentially higher levels of ash and ash-related constituents could become exposed. However, the model predicted that ash and natural sediment mixtures would deposit in side channel areas of the Emory and Clinch Rivers, and that the natural cover of mixed ash/sediment would redevelop. Deposition rates in the Emory and Clinch Rivers averaged about 0.5 inch per year over the 30-year simulation.

The model predicted the percentage of ash in the ash/sediment side channel deposits would gradually decrease over time with mixing and redeposition throughout the river system. Based on the model predictions, ash/sediment mixtures would contain less than 50% ash in approximately 10 years, and would continue to decline thereafter. This mixture of ash and sediment has been observed in vibracore sampling performed in 2009 and 2010, confirming the model predictions. In addition, chemical (binding) processes contribute to metals immobilization. Concentrations of metals within the upper 6 inches of submerged sediments would reduce over time as ash-contaminated sediment becomes blended with or covered by the natural sediment load within the river system.

2.9.2 Groundwater Transport

Groundwater transport processes could conceivable result in discharge of contaminants from groundwater below the closed Ash Landfill to the adjacent river system. As discussed in Section 2.6.3, groundwater fate and transport modeling was conducted to predict future groundwater flux and contaminant concentrations following closure of the Ash Landfill (Jacobs 2011d). Results of that modeling indicated that groundwater in contact with the ash in the closed Ash Landfill would be transported with shallow groundwater to the Emory River and Swan Pond Embayment.

A comprehensive three-dimensional groundwater flow model was developed in Visual MODFLOW. The model was constructed to represent future (closed) conditions based on conceptual Ash Landfill design and restoration of the Swan Pond Embayment to its pre-failure topography. The flow model predicted groundwater flow directions beneath the closed Ash Landfill to be radial in each formation, with overall flow generally from Pine Ridge toward the Emory River. The predicted steady-state groundwater flux under closed conditions was 1,963 ft^3/d (10.2 gpm) to the Emory River, 1,931 ft^3/d (10.0 gpm) to the Swan Pond Embayment, and 1,259 ft^3/d (6.5 gpm) to the Intake Channel.

Fate and transport modeling was conducted using MT3DMS for periods of 30 and 100 years into the future. Arsenic, selenium, and radium-226 were carried forward in groundwater fate and transport modeling. Other constituents (e.g., mercury, chromium, or thorium-228) are subject to natural attenuation mechanisms, such as adsorption, ion-exchange, and chemical precipitation that limit their transport. Based on modeling simulations, arsenic, selenium, and radium-226 showed little change over time, with the concentration distributions remaining nearly stationary. This is primarily a result of sorption, reduction in recharge due to capping, and reduction in lateral groundwater movement due to the PWS.

The BERA evaluated the contributions of groundwater to concentrations of selenium and arsenic in the river system using different diffusion coefficients. Modeled potential fluxes of groundwater for 30 or 100 years indicated no potential exceedances of TWQC. Consequently, groundwater transport to sediment porewater and subsequently to the surface water column in the river was not determined to be a significant pathway contributing to ecological exposures.

2.9.3 Dissolution/Leaching/Dispersion

Dissolution (leaching) of constituents could result in transport of constituents from ash/sediment into the water column. Dissolution and dispersion process are evident in comparison of constituent concentrations in sediment porewater, epibenthic surface water, and mid-depth surface water. For example, average concentrations of arsenic in sediment porewater are as much as 150 times larger than those in epibenthic surface water. Similar trends cannot be seen for selenium, since detected concentrations of selenium are near the detection limit. As discussed in Section 2.5.4, constituent concentrations in mid-depth surface water are similar to those in epibenthic surface water, indicating that once the dissolved constituents enter the river system, they become rapidly dispersed in the water column.

2.9.4 Adsorption

Adsorption is the process through which a constituent is removed from the water column onto the surface of ash/sediment particles. As such, adsorption is a reversal of the dissolution (leaching) process; the two processes act in equilibrium, depending on changes in water chemistry and sediment characteristics. As discussed in Section 2.3.3, comparison of ash content to submerged sediment concentrations show that constituent concentrations increase as the percent ash content increases, as would be expected. Arsenic shows moderately good correlation, and suggest that arsenic tends to remain adsorbed to the ash particles in the river system. Selenium concentrations in sediment are less than would be expected, suggesting that selenium may be more readily dissolved from the ash to surface water rather than remaining adsorbed to the ash particles.

2.9.5 Biouptake and Bioaccumulation

Biouptake is the process through which constituents in the ash or other environmental media accumulate in plant or animal tissue through ingestion or direct content. Higher concentrations of constituents in benthic invertebrates, fish, birds, and other biota than in their respective reference reaches suggest that bioaccumulation is occurring or has occurred at the Site. Biouptake is generally proportional to the constituent concentration in sediment; site-specific bioaccumulation factors have been used in the BERA to estimate ecological risks due to exposure to ash-related constituents in environmental media. The BERA also used dietary exposure models to estimate biouptake through the food web.

3. SUMMARY OF THE RISK EVALUATIONS

This section summarizes the results of the Baseline Human Health Risk Assessment (BHHRA) and the BERA (Arcadis 2012).

3.1 BASELINE HUMAN HEALTH RISK ASSESSMENT

A BHHRA was completed to develop quantitative and qualitative estimates of potential cancer risks and non-cancer hazards for human receptors exposed to environmental media impacted by ash remaining in the river system. The risk analysis was based on analytical data collected from seasonally-exposed sediment, surface water, and fish filet sampling. The risk assessment was conducted in accordance with EPA *Risk Assessment Guidance for Superfund* protocols. Methods and details of the human health risk evaluation are presented in *Kingston Fly Ash Recovery Project Non-Time Critical Removal Action for the River System, Baseline Human Health Risk Assessment* (Jacobs 2012a).

3.1.1 Data Evaluation

Data from samples collected by TVA during the 2010 sampling events were used in the quantitative risk assessment. Analytical data were reviewed to ensure that data of acceptable quality and quantity were used in the risk assessment. Uncertainty was evaluated by reviewing such aspects as the sources of the data, consistency in data collection methods and handling, analytical methods and detection limits, data quality indicators (precision, accuracy, representativeness, comparability, and completeness), and data qualifiers.

Constituents of potential concern (COPCs) are chemicals that are potentially Site-related and whose data are of sufficient quality for use in the quantitative risk assessment. These chemicals may contribute to human health risk and are carried through the risk assessment process. Trace metals and radionuclides are commonly found in fly ash as byproducts of coal combustion. Ten metals (arsenic, chromium, copper, lead, mercury, nickel, selenium, thallium, vanadium, and zinc) and naturally-occurring radionuclides (potassium, radium, thorium, and uranium) are constituents of interest in ash. Background screening was not used to eliminate COPCs; rather, background was used in the uncertainty analysis to place the risk estimates in context with local or regional concentrations. As a result, all detected constituents were carried through the BHHRA as COPCs.

Exposure point concentrations were determined and chemical intakes calculated for the various exposure pathways identified for the Site. Because potential receptors were assumed to move randomly across the Site spending equivalent amounts of time in each location, contact with a contaminated medium over time was represented by the average concentration of a detected analyte. To ensure that the estimate of the average (or mean) is conservative and not underestimated, EPA recommends using an upper confidence limit on the mean (UCL) as an estimate for the exposure point concentration (e.g., the 95% UCL). The UCL is a statistical number calculated to represent the mean concentration with a high percent confidence that the true arithmetic mean concentration will be less than the UCL. The high level of confidence (e.g., 95%) is used to compensate for the uncertainty involved in representing site conditions with a finite number of samples. When limited data are available or when the data are extremely variable, the UCL can be greater than the highest detected concentration. Therefore, the exposure point concentration represents the UCL or the maximum detected concentration, whichever is smaller.

Essential nutrients (i.e., calcium, chloride, iodine, magnesium, phosphorus, potassium, and sodium) are an integral part of the human food supply and are often added to foods as supplements. Essential nutrients were eliminated as COPCs because maximum detected concentrations were less than recommended dietary intake values.

3.1.2 Exposure Assessment

The exposure scenarios evaluated in the BHHRA were for potential current and future receptors, which may include residents or recreators. Residents (child or adult) may be exposed to surface water if they were to draw their drinking water directly from the river for household use without filtration or treatment. Recreators (adolescent or adult) could become exposed to surface water while swimming during the summer, to ash-impacted sediment while beachcombing during the winter when Watts Bar Reservoir is at low winter pool, and to fish filets while consuming fish. Detailed equations used to quantify exposures are provided in the BHHRA (Jacobs 2012a). Groundwater as a drinking water source was evaluated as part of the EE/CA for the Embayment and Dredge Cell (Jacobs 2010a) and is not part of this river system EE/CA.

3.1.3 Toxicity Assessment

Toxicity is defined as the ability of a chemical to induce adverse effects in biological systems. The toxicity assessment weighs available evidence regarding the potential for a chemical to cause adverse effects in exposed individuals (hazard identification), and provides an estimate of the relationship between exposure to the chemical and the likelihood of adverse effects (dose-response assessment).

The BHHRA used EPA-derived toxicity values. There are two types of toxicity values: cancer slope factors for evaluating carcinogenic (cancer) effects and reference doses for evaluating noncarcinogenic (noncancer) effects. Slope factors and reference doses used in the risk assessment were obtained from the latest version of the regional screening levels tables which follows EPA’s three-tiered hierarchy (EPA 2003). Details of the evaluation of carcinogenicity, noncarcinogenic effects, dermal toxicity, and target organ toxicity are presented in the BHHRA (Jacobs 2012a).

3.1.4 Risk Characterization

Risk characterization integrates the results of the exposure and toxicity assessments to estimate potential cancer risks and noncancer hazards. Cancer risk is expressed in terms of the probability that an individual will contract cancer over a lifetime of exposure and is referred to as Incremental Lifetime Cancer Risk (ILCR). The ILCR is the potential increased probability that an individual may develop cancer due to exposure to Site-related constituents. Chemical-specific and radionuclide-specific risks are then summed to determine the total cancer risk associated with each exposure route. Risks for each exposure route are then summed to estimate a total risk for an individual receptor exposed through more than one route. The calculated cancer risk estimates are compared to the target risk range specified in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) of 1E-06 to 1E-04, or 1 in 1 million to 1 in 10,000 exposed persons developing cancer. ILCRs below 1E-06 are considered acceptable. ILCRs above 1E-04 are considered unacceptable.

Noncancer hazards are expressed in terms of hazard quotients (HQs) and hazard indexes (HIs). An HQ is calculated for each chemical for each exposure route by dividing the exposure dose by the chemical-specific reference dose. An HI is calculated for each exposure route by summing the HQs. HIs for each exposure route and media are summed to derive a total HI for each scenario. An HI greater than 1 has been defined as the level of concern for potential adverse noncancer health effects (EPA 1989).

COCs are COPCs that significantly contribute to a pathway in an exposure scenario for a receptor that either (a) exceeds a 1E-04 cumulative cancer risk; or (b) exceeds a noncancer HI of 1. Chemicals are not considered to be significant contributors to risk and, therefore, are not COCs if their individual ILCR contribution is less than 1E-06 and their individual noncarcinogenic HQ is less than 0.1.

Detailed calculations of cancer risk and noncancer hazard estimates are presented in the BHHRA (Jacobs 2012a). Table 3-1 summarizes the risk characterization results.

Table 3-1 BHHRA Risk Characterization Results

Receptor	Medium	Incremental Lifetime Cancer Risk (ILCR)		Noncarcinogenic Hazard Index (HI)	
		Min	Max	Min	Max
Recreator - Adult	Seasonally-Exposed Sediment	5.E-06	3.E-05	0.02	0.2
	Surface Water	5.E-08	9.E-07	0.003	0.01
	Fish (All species)	7.E-05	**7.E-04**	0.7	**10.**
Recreator - Adolescent	Seasonally-Exposed Sediment	2.E-06	1.E-05	0.04	0.3
	Surface Water	5.E-08	9.E-07	0.004	0.02
Recreator - Child	Fish	6.E-05	**7.E-04**	**3.**	**46.**
Resident - Adult	Surface Water	9.E-06	**2.E-04**	0.1	0.5
Resident - Child	Surface Water	5.E-06	4.E-05	0.3	1.

Notes:
Bold font indicates ILCR exceeds target risk range or HI exceeds threshold.
Min = minimum calculated value for any downstream river reach
Max = maximum calculated value for any downstream river reach

Resident Scenarios

Cancer risk estimates for a resident exposed to surface water slightly exceeded the target risk range. The highest cancer risk (2E-04) was calculated for a resident adult drinking untreated surface water directly from Watts Bar Reservoir. The cancer risk estimates are driven by ingestion of radium-228 in Emory River Reach C. However, there is high uncertainty in this risk estimate because it is driven by detection of radium-228 in a single sample. In addition, this scenario assumes that the resident draws water directly from the river for household use without filtration or treatment, by-passing the available public water supply or installation of a groundwater well. This exposure pathway is unlikely. Therefore, the risks due to surface water ingestion are unlikely. Potential cancer risks for arsenic were within EPA's target risk range (1E-06 to 1E-04); therefore, there are no COCs for residential use of surface water.

Noncancer hazard estimates for resident exposed to surface water ranged from 0.1 to 0.5 for the adult and 0.3 to 1 for the child. Only the child hazard index for Emory River Reach C exceeded unity. However, the HI for individual constituents did not exceed unity and potential noncancer effects of these constituents impact different target organs. Because additivity of effect is not likely to occur, there are no COCs for residential use of surface water due to noncancer effects. Therefore, no removal action is warranted for protection of a resident.

Recreator Scenarios

Cancer risk estimates for recreator exposed to seasonally-exposed sediment or surface water did not exceed the target risk range for any receptor (adult or adolescent). The highest calculated risk in any river reach was 3.E-05 for an adult recreator (beachcomber) exposed to sediment.

Similarly, noncancer hazard estimates for recreator exposed to seasonally-exposed sediment or surface water did not exceed the HI threshold of 1 for any receptor (adult or adolescent). The highest calculated HI was 0.3 for the adolescent recreator (beachcomber).

Cancer risk estimates for recreators from fish consumption exceeded the target risk range in most river reaches. These cancer risk estimates ranged from 6.E-05 to a high of 7.E-04 for adult consumption of catfish in Emory River Reach C. COCs for these fish species include arsenic, various pesticides, and PCBs. Of these, only PCBs had cancer risk estimates equal to or greater than 1E-04. Arsenic in fish filet samples was evaluated using data for detected inorganic arsenic species (arsenite). Arsenic speciation data demonstrates that for the majority of samples arsenic is in the less toxic organic form. Potential cancer risks from arsenic are at the lower end of EPA's target risk range (i.e., 1E-06 to 1E-04). Pesticides and PCBs are legacy constituents in the river system that are not ash-related.

Noncancer hazard estimates for recreators exceeded the HI threshold of 1 for fish consumption in most river reaches. The highest calculated HI was 46 for child consumption of bass in Emory River Reach C. While noncancer COCs varied by type of fish and reach of the river, only mercury and PCBs had individual hazard quotients equal to or greater than 1. The noncancer effects of other COCs are based on impacts to different target organs, and additivity of effects is not likely to occur. PCBs and mercury are legacy constituents in the river system that are not ash-related. Although there is potential unacceptable noncancer hazard due to ingestion of fish, these hazards are associated with legacy contaminants in the river system and not ash-related. There is no unacceptable noncancer hazard to people eating fish as a result of residual ash in the river. Therefore, no removal action is warranted for protection of a recreator.

3.2 BASELINE ECOLOGICAL RISK EVALUATION

A BERA was conducted to evaluate potential risks to ecological receptors exposed to environmental media impacted by ash remaining in the river system. The BERA followed an 8-step process in accordance with EPA's *Ecological Risk Assessment Guidance for Superfund* protocols. Methods and details of the BERA are presented in the *Baseline Ecological Risk Assessment* (Arcadis 2012).

A Screening-Level Ecological Risk Assessment (SLERA) was conducted in 2009, and was presented in the EE/CA Work Plan (Jacobs 2009). The SLERA indicated the possibility of adverse effects on ecological receptors exposed to constituents of potential ecological concern (COPECs) in ash (as sediment) or surface water, and concluded that a BERA was warranted for the river system.

3.2.1 Assessment Endpoints

Assessment endpoints include important ecological resources that, if damaged, could impact the ability of the ecosystem to function. Assessment endpoints are selected based on the ecosystem, communities, or ecological functions; COPECs present; the extent and magnitude of contamination; mechanisms of toxicity; and potential exposure pathways. The BERA identified assessment endpoints for the river system as the maintenance and reproduction of balanced communities or populations of the following receptor groups:

- Benthic invertebrate communities
- Fish communities (pelagic and benthic)
- Aquatic- and riparian-feeding bird populations (including piscivorous, insectivorous, omnivorous, and herbivorous birds)
- Aquatic- and riparian-feeding mammal populations (including piscivorous, omnivorous, and herbivorous mammals)
- Aerial- feeding bird populations (insectivorous)
- Aerial-feeding mammal populations (insectivorous)
- Aquatic- and riparian-feeding amphibians and reptiles
- Aquatic plant communities

The ecological conceptual model identified several potential exposure pathways for ecological receptors that may come into contact with ash-related constituents. These pathways include direct contact with ambient media (sediment, porewater, or surface water), ingestion of constituents in food items or surface water, and incidental ingestion of ambient media (sediment or porewater). Inhalation and dermal contact were eliminated as pathways warranting explicit evaluation in the BERA.

3.2.2 Measurement Endpoints

A measurement endpoint is a measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint and can include both measures of exposure and measures of effect. The measurement endpoints become the LOE that are used to conduct the risk characterization. The BERA selected the following measurement endpoints for each receptor:

- Benthic invertebrates: Benthic invertebrate community metrics (e.g., relative abundance and diversity), literature-derived toxicity data, short-term to partial life cycle toxicity texts for sediment and surface water (e.g., survival, reproduction, and biomass), constituent concentrations in mayfly and snail tissue, and constituent concentrations in environmental media (surface water, sediment, and porewater).
- Fish: Fish community metrics (species abundance and diversity), early lifecycle toxicity tests (e.g., survival and growth), fish reproductive studies (e.g., production of viable eggs), fish health studies (e.g., ovary status and condition factors), fish health metrics (e.g., liver enzymes), constituent concentrations in fish tissue, and constituent concentrations in surface water (total and dissolved).
- Aquatic- and riparian-feeding birds: Egg health metrics (e.g., weight and size), constituent concentrations in heron and osprey eggs, literature-derived toxicity data or toxicity reference values (TRV) for bird growth, reproduction, or embryonic effects, modeled dietary doses, and constituent concentrations in environmental media (surface water, sediment, and tissue of dietary items).
- Aerial-feeding birds: Egg or nestling health metrics (e.g., weight and size), productivity metrics (e.g., clutch size, hatchling success, nestling survival), constituent concentrations in eggs, eggshells, and nestlings, literature-derived toxicity dietary doses or TRVs for bird growth, reproduction, or embryonic effects, modeled dietary doses, and constituent concentrations in environmental media (e.g., surface water and tissue of dietary items).
- Aquatic- and riparian-feeding mammals: Health metrics in raccoons (e.g., blood count and plasma biochemistry), constituent concentrations in raccoon tissue, literature-derived toxicity dietary doses or TRVs for mammals, modeled dietary doses, and constituent concentrations in environmental media (e.g., surface water, sediment, and tissue of dietary items).
- Aerial-feeding mammals: literature-derived toxicity dietary doses or TRVs for mammals, modeled dietary doses, and constituent concentrations in environmental media (e.g., surface water and tissue of dietary items).
- Aquatic- and riparian-feeding amphibians and reptiles: Constituent concentrations in tissue, health metrics of exposure (e.g., constituent concentrations in blood), literature-derived toxicity data, community survey data, and constituent concentrations in environmental media (e.g., surface water and sediment).
- Aquatic vegetation: Constituent concentrations in aquatic vegetation (emergent and shoreline) and periphyton, literature-derived toxicity data, and constituent concentrations in environmental media (surface water, sediment, and porewater).

3.2.3 Risk Characterization

Because each receptor group was evaluated using multiple endpoints and multiple LOE, a weight-of-evidence approach was used to characterize risk. More than one LOE was used to demonstrate whether ash-related constituents could cause adverse effects on an assessment endpoint. Primary LOEs included literature-derived effects values compared to measured constituent concentrations in environmental media, prey, or the organism's tissue; results of toxicity tests; and site-specific biological community surveys. Secondary LOEs included health metrics, such as liver enzyme levels in fish and mammals, organ dysfunction, and increased frequency of histopathological lesions in fish.

Comparison of measured constituent concentrations to effects values provides a quantification of potential risk. HQs are derived by dividing the constituent concentration by an appropriate effects value. An HQ>1 indicates a potential effect for the species, exposure pathway, and measured effects level. Several different effects levels were used for comparison, including a TRV, a "No-Observed-Adverse-Effect Level" (NOAEL), or a "Lowest-Observed-Adverse-Effect Level" (LOAEL). The NOAEL is the highest exposure level at which there are no biologically significant increases in the frequency or severity of adverse effect between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered adverse or precursors of adverse effects. The LOAEL is the lowest exposure level at which there are biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group. The NOAEL is lower, and therefore more conservative in its protectiveness, than the LOAEL.

The weight-of-evidence approach first characterized risk based on each individual LOE, then based on the entire body of evidence. Risks were characterized by estimating the magnitude and likelihood of potential effects, the evidence of causality, and relevance of the data to the assessment endpoints. These four attributes were synthesized together by assigning a relative weight, estimating the potential risk, assigning a level of confidence in that risk determination, and identifying the constituents most likely to be associated with the estimated effects. Spatial distribution, temporal variations, and data quality were considered in estimating risks. The weight-of-evidence approach is qualitative, based on professional judgment in assigning relative criteria (low, moderate, high) to the attributes and risk estimates. The risk characterization results in a determination of the level of risk to each assessment endpoint and the corresponding Constituents of Ecological Concern (COECs), which are the constituents determined to pose a risk.

The following subsections briefly summarize the risks by receptor, identifying those for which risk management appears to be warranted. The weight-of-evidence risk characterization for each receptor is summarized in Table 3-2, along with the risk management recommendations.

Fish

Risks to fish are expected to be low due to the lack of population-level impairment from the fish community studies and lack of effects from the fish toxicity testing. The fish community survey results suggest that there has been no ecologically significant impairment to the fish communities; similar patterns in community metrics were observed before and after the ash release and extend throughout Watts Bar Reservoir. The fish toxicity tests did not elicit significant effects on survival or growth of tested species, which is consistent with the fish community surveys.

Table 3-2 BERA Risk Characterization Results

Receptor	Potential Risk	Confidence in Risk Determination	Risk Management Recommended	COECs
Benthic Invertebrates	Moderate (Emory River) Low (Clinch River)	High	**Yes**	As, Se
Fish	Negligible	Moderate	No	--
Aquatic- and Riparian-Feeding Birds				
Piscivore - Heron, Osprey	Negligible	Moderate	No	--
Insectivore - Killdeer	Low	Moderate	**Yes**	As, Se
Omnivore - Mallard	Low	Moderate	No	--
Herbivore - Wood Duck	Negligible	Moderate	No	--
Aerial-Feeding Birds Insectivore - Tree Swallow	Low	Moderate	**Yes**	Se
Aquatic- and Riparian-Feeding Mammals				
Piscivore - Mink	Low	Moderate	No	--
Omnivore - Raccoon	Low	Low	No	--
Herbivore - Muskrat	Low	High	No	--
Aerial-Feeding Mammals Insectivore - Gray Bat	Low	Low	No	--
Amphibians	Low	Moderate	No	--
Reptiles	Low	Moderate	No	--
Aquatic Vegetation	Low	Moderate	No	--

Notes:
Bold font indicates risk management is recommended.
As = Arsenic; Se = selenium

Fish reproduction studies provided no conclusive evidence of adverse impacts on the reproductive condition of female largemouth bass or redear sunfish. Ovarian development was delayed in bluegill in the 2009 breeding season; however, this was most likely due to habitat alterations and food web disruptions and was not observed in the 2010 breeding season. Fish health studies also provided no conclusive evidence of ecologically significant health effects in sentinel fish species.

The comparison of fish tissue data to TRVs indicated several exceedances; however, similar exceedances were observed in fish from reference areas. The highly conservative nature of the screening values provides weak evidence that effects to fish populations could actually occur. Comparison of surface water chemistry data to water quality benchmarks indicated few exceedances.

Therefore, significant risks to fish are not expected. No risk management actions were recommended in the BERA for the protection of fish.

Benthic Invertebrates

Benthic invertebrates are considered to be at moderate risk in the Emory River and low risk in the Clinch River. These risks are associated with ash-related constituents, primarily arsenic, in ash-contaminated sediment. This conclusion is based on the observation of statistically significant reductions in growth and biomass in toxicity tests with Emory River sediment. The majority of statistically significant effects were sub-lethal (i.e., reductions in growth, biomass, or emergence), indicating that effects are not likely to be immediate or severe, but could result in long-term impacts to the population over time. This evidence is augmented by finding that ash-related constituent concentrations are present in benthic tissue, sediment, and porewater at concentrations potentially associated with adverse effects. Snail and mayfly tissue concentrations indicate that arsenic, and to some degree selenium, may be bio-accumulating. Sediment concentrations indicate that ash-related constituents may pose a low risk based on exceedances of conservative benchmarks. Porewater concentrations indicate that ash-related constituents may pose a low risk based on exceedances of ambient water quality criteria.

Benthic invertebrate community survey results did not support this conclusion. The survey provided no substantive evidence that the community composition has been negatively impacted. Macroinvertebrate density and taxa richness in the immediate area of the ash release were similar to or even greater than other locations in the river system. The data did not indicate a trend of decreasing macroinvertebrate abundance or decreasing richness. Combined, these results showed no obvious patterns of persistent adverse impacts from the ash release and differences are likely the result of habitat variation. The community composition was strongly correlated with substrate type rather than ash-related constituents. Despite this contrary evidence, it is possible that over time reductions in growth and biomass could result in a measurable impact on reproduction or community structure. For this reason, risk management actions were recommended in the BERA for the protection of the benthic invertebrate community.

Aquatic- and Riparian-Feeding Birds

Aquatic- and riparian-feeding bird species (as represented by the killdeer) that feed on benthic invertebrates in ash-impacted areas of the river system are considered at low risk based on dietary exposure models using benthic invertebrate tissue concentrations. The refined-analysis HQs for NOAELs and LOAELs ranged from 1 to 3 for arsenic and 1 to 5 for selenium, respectively. Results of the probabilistic dietary exposure model suggested a low probability (i.e., 5 to 24%) of HQs exceeding 1 for arsenic and selenium. Dietary exposure models were the only direct LOE available for estimating risks to killdeer.

Risks to other aquatic- and riparian-feeding bird species (as represented by the great blue heron, osprey, and wood duck) are considered to be negligible. Clutch size and egg biometrics for heron and osprey provided no substantive evidence of impacts on their populations. Concentrations of ash-related constituents in heron and osprey egg tissues were not significantly elevated above reference concentrations. Dietary exposure estimates for mallards suggested low risk. The refined-analysis HQs for NOAELs were based on conservative laboratory studies, resulting in a HQ only slightly above 1. Using less conservative assumptions, the probability of the selenium HQ exceeding 1 for mallards in the probabilistic model is essentially 0 percent, as vegetation in the mallard's diet dilutes the dose of selenium that comes from consumption of invertebrates.

Risk management actions were recommended in the BERA only for the aquatic- and riparian-feeding insectivorous birds (killdeer) in the lower reaches of the Emory and Clinch Rivers.

Aerial-Feeding Birds

Aerial-feeding insectivorous bird species (as represented by the tree swallow) that feed on aerial insects in ash-impacted areas of the river system are considered at low risk based on site-specific reproductive measures and results of the dietary exposure model. Reproductive measures showed a small reduction in female fledglings produced per nesting female relative to reference locations. This measure integrated other measures of tree swallow reproductive success, specifically clutch size, hatching success, and nestling survival. Dietary exposure estimates for tree swallow suggested that ash-related selenium may pose a risk, as HQs for NOAELs and LOAELs ranged from 2 to 5.

Results of the probabilistic dietary exposure model suggested a low probability (i.e., 10 to 30%) of HQs exceeding 1. These estimates were based on using the literature-based selenium benchmark for the mallard; HQs would be well below 1 if the literature-based selenium benchmark for the red-wing blackbird were to be used. The red-winged blackbird has a diet during the breeding season similar to that of the tree swallow and may also be similar in sensitivity to selenium. Despite this uncertainty, risk management actions were recommended in the BERA for the aerial-feeding insectivorous birds (tree swallow) in the lower reaches of the Emory and Clinch Rivers.

Aquatic- and Riparian-Feeding Mammals

Aquatic- and riparian-feeding mammal species (as represented by the raccoon, mink, and muskrat) that feed on fish and benthic invertebrates in ash-impacted areas of the river system are not considered to be at risk. Although a low risk may exist from aluminum exposures in some ash-impacted reaches, the uncertainties in the risk estimates led to moderate confidence in the risk determination. Not all fish and invertebrate data, upon which the risk estimate was based, were collected after dredging. Aluminum has not been shown to be strongly related to the ash deposits, and was present in reference locations in the Tennessee River at concentrations greater than those in either the Emory or Clinch Rivers. Tissue and health metrics for the raccoon suggested moderate and low risk, respectively, with low confidence; aluminum in raccoon hair samples was not significantly higher than in reference animals and may not be associated with adverse effects of aluminum bioaccumulation or reproduction. Much uncertainty exists around aluminum risk with few toxicity studies on growth effects upon which the TRV was based. Effects of ash-related constituents on reproduction were not measured in raccoons. For these reasons, no risk management actions were recommended in the BERA for the protection of aquatic- or riparian-feeding mammals.

Aerial-Feeding Mammals

Aerial-feeding mammal species (as represented by the gray bat) that feed on aerial insects in ash-impacted areas of the river system are not considered to be at risk. Although a low risk may exist from selenium exposures in some ash-impacted reaches, the uncertainties in the risk estimates led to low confidence in the risk determination. Dietary exposure models were the only direct LOE available for estimating risks to the gray bat. Refined-analysis HQs for selenium exceeded 1, but the effects value was based on reduced growth of laboratory animals and is very conservative. The probabilistic dietary model indicated that the probability of selenium HQs exceeding 1 for gray bats was near 0%. This suggested that bat populations are likely not at risk of decline. Literature-derived field studies of effects of selenium on mammal populations showed no clear adverse effects, but were limited and uncertain. For these reasons, no risk management actions were recommended in the BERA for the protection of aerial-feeding mammals.

Amphibians and Reptiles

Amphibian populations are considered to be at low risk from exposure to ash-related constituents, based on the low concentrations of constituents relative to effects values. The risk evaluation used a combination of conservative and central tendency estimates, which likely resulted in a significant overestimation of potential risk. Amphibian tissue concentrations suggested that constituents pose low risk; refined-analysis HQs were less than 1 for ash-related constituents. Tissue benchmarks were not available for selenium or strontium; however, the mean concentrations of selenium and strontium in amphibian whole body tissue were variable and lacked a clear trend of bioaccumulation over time. Surface water concentrations for ash-related constituents were below water quality screening levels and amphibian-specific literature-derived TRVs. Mean sediment HQs for arsenic were less than 3 when compared with chronic sediment TRVs, but were below 1 when compared to amphibian-specific literature-derived TRVs. For these reasons, ash-related constituents are not likely to pose substantial risk, and no risk management actions were recommended in the BERA for the protection of amphibians.

Reptile populations are also considered to be at low risk from exposure to ash-related constituents, based on the low concentrations of constituents relative to effects values. The risk evaluation used a combination of conservative and central tendency estimates, which likely resulted in a significant overestimation of potential risk. Turtle community survey results indicated a lack of adverse impacts on reptile populations. Species richness and relative abundance did not appear to be affected. No significant anomalies or diseases were observed in examination of turtle health. Turtle tissue concentrations indicated potential bioaccumulation of selenium and strontium relative to reference; however, no adverse effects were correlated with such concentrations in the literature. Surface water concentrations for ash-related constituents were below water quality screening levels. Mean sediment HQs for arsenic were as high as 3 in the lower Emory and Clinch Rivers, but the generic sediment screening-level values are designed for the protection of benthic invertebrates and likely overestimate the potential risk to turtles. For these reasons, ash-related constituents are not likely to pose substantial risk, and no risk management actions were recommended in the BERA for the protection of reptiles.

Aquatic Vegetation

Aquatic vegetation is considered to be at low risk from exposure to ash-related constituents. Concentrations of constituents in periphyton and aquatic vegetation tissue were given the most weight in the estimation of risks, because they require the least extrapolation from measured concentrations to relevant exposures. Periphyton tissue concentrations in downstream reaches were significantly different for arsenic, copper, and strontium compared to the reference location; however, tissue concentrations of these COPECs were not expected to pose unacceptable risk to the periphyton communities based on a comparison of tissue concentrations to available literature effects values. Shoreline and emergent vegetation tissue concentrations were not significantly greater than reference.

The risk evaluation for aquatic vegetation used a combination of conservative and central tendency estimates, which likely resulted in a significant overestimation of potential risk. Maximum surface water concentrations of aluminum, mercury, and lead exceeded conservative water quality screening levels, but comparison with additional literature-derived effects values identified no exceedances. Porewater concentrations of arsenic exceeded aqueous screening values, but further evaluations determined that risks were unlikely, based on differences in bioavailability in situ relative to synthetic laboratory water used for the toxicity study reported in the literature. Maximum sediment concentrations of arsenic, cobalt, and copper were marginally above conservative screening values, and average concentrations were comparable to these screening values. Manganese concentrations in sediment exceeded the soil screening value, but manganese was also found in reference samples at higher concentrations, which suggests that manganese may be related to naturally-occurring levels or legacy metals contamination in the river system. For these reasons, ash-related constituents are not likely to pose substantial risk, and no risk management actions were recommended in the BERA for the protection of aquatic vegetation.

4. REMOVAL ACTION OBJECTIVES

This section identifies the scope, goals, and objectives for the non-time-critical removal action for the river system.

4.1 SCOPE AND PURPOSE

The scope of the removal action is to fulfill mid-term strategic objectives for the Site, as defined in the Order (EPA 2009), for the river system. The first mid-term objective is to remove any remaining coal ash from the Emory River and the area east of Dike 2, to the maximum extent practicable, as determined by EPA in consultation with TDEC and TVA, pending further Site assessment. This EE/CA report satisfies the requirement for a comprehensive assessment of the Site and evaluation of alternatives to address the residual ash remaining after the previous removal actions have been completed.

The second mid-term objective as defined in the EPA Order is to remove the coal ash from impacted surface soils to the maximum extent practicable, as determined by EPA in consultation with TDEC and TVA, pending further Site assessment. The non-time-critical removal action for the embayment and Dredge Cell is already being implemented to satisfy this objective.

The final two mid-term objectives are to restore area waters impacted by the coal ash release in accordance with the required jurisdictional assessment, and to ensure proper disposal of all coal ash material recovered during these efforts. The scope of the non-time critical removal action decision for the river system includes remediation of any residual contamination in the Emory, Clinch, or Tennessee Rivers, as well as the associated Swan Pond Embayment and plant Intake Channel. Not only will the final condition of these geographic areas be decided, but disposal locations of any material removed will be part of the decision. Ultimately, the decision for the river system will center on the following question:

- In what condition should the various parts of the river system be left?

The removal action is to remove the ash and restore the river system to pre-release conditions. The BERA provided information to satisfy the requirements for a Jurisdictional Assessment, including maps of the Site prior to the release and following the non-time-critical removal action, areas/species/habitat impacted, habitat restoration, and similar elements for the impacted area. The information supporting the Jurisdictional Assessment is provided in the BERA (Arcadis 2012).

4.2 GOALS AND OBJECTIVES

Results of the human health and ecological risk assessments indicate no unacceptable risk to human health and relatively low potential risk to ecological receptors due to exposure to naturally-occurring metals in the ash-contaminated sediment. A removal action is needed to mitigate the threat or potential threat to the environment. The following are the specific RAOs:

- Protect benthic invertebrate populations in Watts Bar Reservoir from adverse effects due to arsenic and selenium in ash-contaminated sediment;
- Protect riparian-feeding bird (killdeer) and aerial-feeding bird (tree swallow) populations from adverse effects due to uptake of arsenic and selenium in ash-contaminated sediment through their diet (benthic invertebrates);
- Restore the ecological function and recreational use of the river system to pre-release conditions;
- Dispose of waste streams from the removal action in accordance with ARARs.

Remediation goals (RGs) are media-specific cleanup goals for a selected remedial action that set targets for meeting primary ecological endpoints. RGs are also called "remediation levels." Tissue Monitoring Endpoints (TMEs) are media-specific levels in biota tissue samples that set targets for meeting primary ecological endpoints through monitoring. RGs and TMEs are established in the EE/CA based on cost, technical feasibility, community acceptance, uncertainty in the BERA, schedule, and other risk management considerations. RGs and TMEs can be qualitative statements or numerical values expressed as concentrations of a chemical in an environmental medium. Achieving the RG/TMs in the removal action should result in residual contamination levels that are protective of human health and the environment.

Low levels of risk were reported in the BERA for affected areas of the lower Emory and Clinch Rivers for benthic invertebrates and invertebrate-feeding birds. Selenium and arsenic were the risk drivers and are the only COECs. Uncertainties regarding risk conclusions were relatively high, and assessment parameters were chosen to provide conservative (high) risk estimates. The sources of risks identified in the BERA are sediment-driven exposures of benthic invertebrates and invertebrate-feeding birds (killdeer, tree swallow). The RG/TMEs are media-specific endpoints representing particular monitoring targets and are directly related to each category of elevated risk identified in the BERA.

Options considered in developing appropriate RGs for monitoring of residual risks in the river system include adverse effect levels and equivalent reference concentrations. For benthic invertebrates, threshold effect concentrations were established for arsenic and selenium in sediment based on results of toxicity testing. For the two test species used in the toxicity testing (*H. azteca and C. dilutus*), threshold effects were determined via dilution series bioassays, which varied the proportion of ash in the test specimen. Results of this toxicity testing have suggested statistically significant reductions in sensitive endpoints (survival, emergence, or biomass) could occur when percent ash in the sediment is greater than about 40 to 50%. Threshold effect concentrations were calculated based on average IC_{25} values, which are an estimate of the effect concentration that caused a 25% reduction in sensitive endpoints in the toxicity testing. Arsenic and selenium concentrations at this observed effect level are the threshold effect concentrations established for benthic invertebrates.

For killdeer and tree swallows, dietary exposure risks were calculated, yielding NOAEL and LOAEL thresholds. The NOAEL is the highest exposure level at which there are no biologically significant increases in the frequency or severity of adverse effect between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered adverse or precursors of adverse effects. The LOAEL is the lowest exposure level at which there are biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group. The NOAEL is lower, and therefore more conservative in its protectiveness, than the LOAEL. These are the threshold effect concentrations established for killdeer and tree swallows.

For killdeer and tree swallows, TMEs were established for use in monitoring effects in those bird species due to biouptake of arsenic and selenium in ash-contaminated sediment through their diet (benthic and aerial invertebrates, respectively). TMEs are risk-based concentrations in tissue that result in HQs equal to one. A range of TMEs were developed based on the NOAEL and LOAEL values as selected in the BERA and assuming that 100% of the diet consists of invertebrates from the Site. Because killdeer can also be directly exposed to sediment through incidental sediment ingestion, dietary intake was accounted for by assuming a sediment concentration equal to the upper range of the sediment RGs. Derivation of the TMEs for the protection of birds are presented in Appendix L.

Equivalent reference concentrations from upstream locations in the Emory, Clinch, and Tennessee Rivers have also been considered. Because concentrations vary in environmental media, an equivalent reference concentration is taken as twice the average reference concentration. This is consistent with EPA Region 4

Risk Assessment Bulletin (EPA 2000) which recommends that for naturally-occurring inorganics the onsite maximum detected concentration be compared to two times the average site-specific background concentration. A chemical is not of potential concern if it is less than two times the average background level.

Selection of appropriate RG/TMEs for monitoring of residual risks in the river system then considered these options of threshold effect concentrations and equivalent reference concentrations. Table 4-1 lists the options considered in selecting appropriate RGs and TMEs. The following paragraphs describe the rationale for selection of appropriate RGs for sediment monitoring and TMEs for biota monitoring.

Table 4-1 Selection of Remedial Goals and Tissue Monitoring Endpoints

Remedial Goal Options					
Receptor / Exposure Pathway	**Wet or Dry Weight**	**Equivalent Reference Concentration**	**Threshold Effect Concentration**		**Selected Remedial Goal Range**
			IC_{25} (Midge)	**IC_{25}(Amphipod)**	
Benthic Invertebrates					
Arsenic concentration in sediment	Dry	8.0	29	41	29 - 41
Selenium concentration in sediment	Dry	3.0	2.8	3.2	3.0 - 3.2
Tissue Monitoring Endpoint Options					
Receptor / Exposure Pathway	**Wet or Dry Weight**	**Equivalent Reference Concentration**	**Threshold Effect Concentration**		**Selected Tissue Monitoring Endpoint Range**
			NOAEL	**LOAEL**	
Killdeer					
Arsenic concentration in diet (larval mayfly)	Dry	8.4	34	81	34 - 81
Selenium concentration in diet (larval mayfly)	Dry	7.1	2.3	5.0	7
Tree Swallow					
Selenium concentration in diet (adult mayfly)	Dry	7.0	1.6	2.8	7

Note: All units in mg/kg.

Benthic invertebrates. Benthic invertebrate risks are due to uptake of metals from sediment. Threshold effect concentrations for both arsenic and selenium are equal to or greater than the equivalent reference concentration, and are therefore selected as appropriate RGs. For sediment, the range of RGs for arsenic is 29 to 41 mg/kg, and the range of RGs for selenium is 3.0 to 3.2 mg/kg, whenever ash content comprises more than 50% of the sample.

Riparian-feeding birds (killdeer). Riparian-feeding bird dietary risks are due to uptake of arsenic and selenium from sediment through larval insects. For arsenic in larval insects (mayflies), the NOAEL and LOAEL concentrations are greater than the equivalent reference concentration; the range of TMEs for arsenic is 34 to 81 mg/kg. For selenium in larval insects, both the NOAEL and LOAEL concentrations are much lower than equivalent reference concentrations. For this reason, the selenium TME is selected as twice the average concentration at the Emory and Clinch River reference locations (7 mg/kg), which is an appropriate TME for monitoring reduction in risks equivalent to reference.

Aerial-feeding birds (tree swallow). Aerial-feeding bird dietary risks are due to uptake of selenium from sediment through adult insects. For selenium in adult insects (mayflies), both the NOAEL and LOAEL concentrations are much lower than equivalent reference concentrations. For this reason, the selenium TME is selected as twice the average concentration at the Emory and Clinch River reference locations (7 mg/kg) which is an appropriate TME for monitoring reduction in risks equivalent to reference.

4.3 IDENTIFICATION OF APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

CERCLA Section 121 specifies that actions for cleanup of hazardous substances must comply with requirements or standards under federal or more stringent state environmental laws that are applicable or relevant and appropriate to the hazardous substances or particular circumstances at a site. Removal actions conducted under CERCLA are required to attain these ARARs to the extent practicable, considering the exigencies of the situation. This river system cleanup action is being conducted as a non-time-critical removal action. A list of ARARs is provided in Appendix F.

The terms defined below are used.

- Applicable requirements are “those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site” (40 CFR 300.5).

- Relevant and appropriate requirements are “those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting law that, while not applicable to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site” (40 CFR 300.5).

- In the absence of federal or state-promulgated regulations, there are many criteria, advisories, guidance values, and proposed standards that are not legally binding but can serve as useful guidance for setting protective cleanup levels. These are not potential ARARs but are “to-be-considered” guidance [40 CFR 300.400(g)(13)].

CERCLA onsite response actions must comply with only the substantive requirements of a regulation to obtain federal, state, or local permits [CERCLA Sect. 121(e)]. To ensure that CERCLA response actions proceed as rapidly as possible, EPA has reaffirmed this position in the final National Oil and Hazardous NCP (Title 55, Federal Register (FR), Part 8756, March 8, 1990). Substantive requirements pertain directly to the actions or conditions at a site, while administrative requirements facilitate their implementation. ARARs are typically divided into three groups: (1) chemical-specific; (2) location-specific; and (3) action-specific.

- Chemical-specific requirements set health or risk-based concentration limits or discharge limitations in various environmental media for specific hazardous substances, pollutants, or contaminants (55 FR 8741, March 8, 1990). These requirements generally set protective cleanup levels for the contaminants of concern in the designated media or otherwise indicate a safe level of discharge that may be incorporated when considering a specific remedial activity. The anticipated chemical-specific ARARs identified include drinking water standards and the applicable surface water quality standards for the stream's designated use.

- Location-specific requirements establish restrictions on permissible concentrations of hazardous substances or establish requirements for how activities will be conducted because they are in special locations (wetlands, floodplains). Those location-specific requirements for this action are associated primarily with wetlands and floodplains.

- Action-specific ARARs include operation, performance, and design requirements or limitations based on the waste types, media, and response actions.

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5. REMOVAL ACTION ALTERNATIVES

5.1 TECHNOLOGY IDENTIFICATION

This section identifies the applicable technologies based on site-specific conditions and contaminants. The EE/CA technology identification process is focused only on those technologies that have proven to be effective at similar sites. Technologies were identified from multiple sources, including *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005), and *Implementation Guide for Assessing and Managing Contaminated Sediment at Navy Facilities* (NAVFAC 2005).

EPA does not identify a presumptive remedy for any contaminated sediment site. There are typically three major approaches that can be taken to reduce risk from contaminated sediment: monitored natural recovery (MNR), in-situ capping, and sediment removal by dredging or excavation. Hybrid approaches may combine these three. A fourth approach, in-situ treatment, may be considered, especially in combination with in-situ caps. Additionally, some form of institutional controls will generally be part of contaminated sediment remedy.

Table 5-1 presents results of the technology screening for submerged sediment source material, including an effectiveness, implementability, and cost evaluation. MNR, in-situ capping, and dredging with subsequent land disposal are retained for use in developing alternatives. Institutional controls, such as fish advisories, signage, and dredging restrictions may be used in conjunction with these technologies, but would not be effective as a stand-alone technology. In-situ treatment, such as reactive caps or enhanced biodegradation, would not apply to the metals-contaminated sediment at this Site. Other technologies are not considered cost-effective nor implementable for treatment of metal-contaminated submerged sediment at the Site.

CERCLA expresses a preference for treatment over containment (capping) or land disposal to address the principal threat at a site. Innovative technologies should be used when they clearly offer superior treatment performance and implementability, lesser impacts, or lower costs than demonstrated technologies. Removal actions cannot conform entirely to these requirements because of site-related time constraints, so that only the most qualified and proven technologies should be considered (EPA1993). MNR, in-situ capping, and dredging are proven technologies.

Various process options were evaluated for the retained technologies, as summarized below.

Monitored Natural Recovery

MNR would reduce the risk of exposure by benthic invertebrates through natural processes of mixing, scouring/redeposition, and sedimentation within Watts Bar Reservoir. Securing effective contaminant source control is a fundamental requirement of selecting MNR as a remedy. At the Site, the contaminant source is the former Dredge Cell and Ash Pond, which will be effectively contained following closure of the Ash Landfill as part of the ongoing non-time-critical removal action.

MNR is a knowledge-based technology applicable at sites where metals bioavailability and immobilization processes are understood. Three knowledge components are necessary for MNR: (1) a conceptual model reflecting processes known to contribute to metals immobilization; (2) site-specific understanding of immobilization processes; and (3) a data acquisition (monitoring) program going forward.

Table 5-1 Identification and Screening of Technologies

Technology	Effectiveness	Implementability	Cost	Retained for Evaluation
Institutional Controls Fish advisory, signs, dredging restrictions	Not effective as stand-alone technology; not effective for ecological receptors.	Readily implemented onsite; not implementable offsite.	Low	Yes
Monitored Natural Recovery Monitoring of active attenuation processes in sediment and biota for reduction in effects	Effective over the long-term as natural processes of scour, sedimentation, and mixing occur in-stream.	Readily implemented, proven at the Site.	Low	Yes
In-Situ Capping (Containment) Sand, gravel, clay cap/cover	Effective for direct contact and reducing scour depending on cover type.	Readily implemented, proven.	Medium	Yes
Dredging Dredge, dewater, haul, dispose onsite or offsite	Effective for removing contaminants from the Site; offsite protectiveness depends on proper disposal.	Readily implemented, proven. Offsite disposal availability depends on quantities and nature of waste material.	Medium – High; Costly with large volumes	Yes
In-situ Treatment Reactive caps Enhanced biodegradation	Effective for organic constituents; not applicable to metals.	Specialized expertise required. Innovative technology.	Low – Medium	No
Phytoremediation Plant uptake of constituents	Potentially effective for removing contaminants from seasonally-exposed sediment, but with higher uncertainty. Not effective for submerged sediment	Not proven, demonstration pilot test likely needed. Implementable depending on plant stock availability.	Medium	No
Separation Screen/sieve large soil fractions	Not effective since material is relatively homogenous in size; removal of large fraction would not change volume/mass.	Readily implementable, requires greater material handling and dust control.	Medium	No
Soil Washing/Soil Flushing Wash/flush constituents out of sediment	Innovative; not effective for homogenous material with low contaminant mass; removal of large fraction would not change volume/mass.	Not proven, demonstration pilot test likely needed. Requires specialty equipment/vendor with lower availability.	High; high energy demand and water treatment	No
Immobilization / Stabilization Mix chemical with sediment to make constituents less mobile	Effective for metals/radionuclides in sediment; not cost-effective for ash material with low contaminant mass.	Readily implementable, requires greater material handling and dust control; adds volume/mass of stabilization agent (cement, polymer) requiring disposal.	Medium – High	No

At the Site, both physical (sediment deposition and transport) and chemical (binding) immobilization processes contribute to metals immobilization. Concentrations of arsenic and selenium within the upper 6 inches of submerged sediments would reduce over time as ash-contaminated sediment becomes blended with or covered by the natural sediment load within the river system. Monitoring of constituent concentrations in sediment and population effects in benthic invertebrates are well-demonstrated technologies that have been used at the Site during prior investigations. Costs are generally less expensive than other technologies.

Several types of monitoring options could be used. Monitoring of abiotic media could include further sampling of whole sediment to analyze for substrate (sediment) ash content and metals concentrations. Monitoring of other media, such as porewater, surface water, or groundwater is not carried forward in this EE/CA, as those media do not contribute to ecological risk. Monitoring of biota could include benthic community surveys, and benthic bioaccumulation (metals concentrations in benthic invertebrates. Toxicity testing of residual sediment is not carried forward in this EE/CA, as the selected RGs for sediment are based on effects observed in prior toxicity testing.

<u>In-Situ Capping</u>

In-Situ Capping would reduce the risk of exposure by benthic invertebrates through engineered barriers that would minimize resuspension and migration of contaminants and the likelihood of direct exposure. Long-term protection would require continued maintenance. While in-situ capping would reduce contaminant exposure, it is not considered treatment. In-situ capping systems are commercially available, demonstrated technologies that use standard construction equipment and labor and readily-available materials. However, underwater placement of capping materials is difficult. Costs are generally less expensive than most forms of treatment, although costs are highly dependent on the area of ash contamination to be covered and site-specific hydrology.

Several types of capping systems could be used. Natural soil materials are appropriate in minimizing direct contact by benthic invertebrates and ash-contaminated sediment. Finer-grained materials (sand, silt, or clay) would provide for burrowing habitat for larvae and mussels, but would be more prone to scour. Gravel materials would be less prone to scour, but would not provide appropriate burrowing habitat. Man-made geosynthetic covers are not considered appropriate for underwater application. Traditional sediment caps are designed to resist scour, biointrusion, and inaccuracies in placement, which may add excess fill to compensate for these mechanisms. Thin caps can provide suitable performance when combined with MNR, while avoiding excess fill placement in the river system. Therefore, a thin granular cap option is carried forward in this EE/CA as a representative type of in-situ capping system for use in developing alternatives.

<u>Dredging</u>

Dredging would achieve long-term protectiveness by removing and properly disposing of the ash-contaminated sediment. While dredging would reduce the volume of material onsite, it is not considered treatment and the ash portion of the sediment would remain essentially unchanged. Dredging systems are implementable, using standard construction equipment and labor that have been used at the Site during the time-critical removal action. Costs of dredging are reasonable for small to medium volumes of contaminated material, but may become very high for large volumes.

Several types of dredging systems could be used. Hydraulic dredging is appropriate in excavating ash from shallower water conditions; mechanical dredging is appropriate in removing debris or from deeper water conditions. Within the river system, both hydraulic and mechanical dredging may be cost effective, and are carried forward in this EE/CA as representative types of dredging systems for use in developing alternatives. Other excavation techniques would be used as appropriate depending on actual conditions encountered during dredging.

Various options were considered for dewatering of dredged sediment. A self-contained barge-mounted unit would be appealing so as to reduce the need for land-based operations. However, no such unit could be identified. Land-based dewatering systems, such as filter presses, hydrocyclones, geocells, and similar systems were evaluated and tested during the time-critical removal action. However, these systems would have limited capacity and effectiveness, since they are able to dewater only to about 60% solids, requiring additional dewatering. Mechanical systems would be subject to equipment malfunction and downtime. Therefore, a gravity settling dewatering system, similar to that used during the time-critical removal action, was selected as a representative process option for further evaluation of dredged sediment dewatering in this EE/CA.

Disposal

Disposal would achieve protectiveness by transporting materials from the Site, and subsequently placing them in an acceptable waste management facility. The degree of protectiveness and reduction in mobility of contaminants is dependent on the specific constituents in the excavated material and the waste management practices at the disposal facility. Because the ash material is not a listed nor characteristic hazardous waste, disposal may occur within a permitted solid waste landfill. However, the presence of legacy constituents, such as cesium-137, may restrict disposal options. Cesium-137 is not ash-related, but is a legacy constituent from former DOE operations on the Oak Ridge Reservation. Maximum cesium-137 radioactivity measured in submerged sediment samples collected under the SAP was 3.7 pCi/g. However, activities as high as 17.57 pCi/g were measured in samples collected during the time-critical removal action in the lower reaches of the Emory River and in the Clinch River Any dredge spoils from these areas would be considered low level radioactive waste. Special measures may be required to protect workers and residents during material handling and transport. Costs of disposal, as with excavation, are typically higher for large volumes and are also higher for long transportation distances.

Onsite disposal within the former Dredge Cell or Gypsum Pond was considered, but not carried forward due to the potential presence of cesium-137 and due to limited onsite capacity. Onsite disposal of cesium-137 contaminated ash and sediment in a new landfill with capacity to accept the low-level radioactive waste material would require considerable time to locate a suitable site, obtain required permits, design, and construct. Potential regulatory agency and public concerns regarding siting such a facility locally would impose considerable administrative difficulties. Therefore, onsite disposal was not carried forward.

Offsite disposal facilities could include appropriate commercial, permitted landfills, such as the Energy Solutions Landfill in Clive, Utah. Because the cesium-137 is a DOE legacy constituent, offsite disposal could also include DOE’s Environmental Management and Waste Management Facility (EMWMF) in Anderson County, Tennessee. Transportation could occur by rail to Utah or truck hauling to Anderson County. Because each of these types of disposal are appropriate for consideration at the Site, they are both retained for use in developing alternatives, and evaluated further in this EE/CA.

5.2 DEVELOPMENT OF ALTERNATIVES

In this section, technologies retained from Section 3.1 are combined, as applicable, to form alternatives to meet the RAOs. A limited number of alternatives are developed. These alternatives are intended to represent a range of possibilities for restoration of the river system, with distinctly different advantages and disadvantages, so that tradeoffs between them can be clearly defined and evaluated.

The following alternatives have been developed; detailed descriptions are presented in Sections 5.2.1 through 5.2.3:

- **Alternative 1:** MNR. Alternative 1 would monitor the sediment and affected biota over time, to demonstrate that recovery is occurring as expected. Modeling would be used to evaluate the rate of scour or sedimentation. Sampling and analysis would be used to monitor the natural processes and concentrations of contaminants in sediment and biota to see if recovery is occurring at the expected rate.

- **Alternative 2:** In-Situ Capping and MNR. Alternative 2 would place a thin granular layer (nominally 6 inches thick) over the ash-contaminated sediment to contain the sediment and to reduce biouptake of metal contaminants through the food web. MNR would be implemented to demonstrate that recovery is occurring as expected. Approximately 200 acres would be capped. A subalternative was developed that would place the thin granular layer only over areas of ash deposits that are subject to scour, approximately 160 acres.

- **Alternative 3:** Dredging and MNR. Residual ash deposits (approximately 440,000 cy) would be removed from the river and processed to reduce its water content. Processed ash would be loaded into trucks for shipment to Anderson County for disposal in a permitted solid waste landfill, or could be loaded onto railcars for shipment to Clive, Utah. MNR would be implemented to demonstrate that recovery is occurring as expected. A subalternative was developed that would dredge only shallower water areas that are of greater ecological significance (approximately 160,000 cy).

5.2.1 Alternative 1: Monitored Natural Recovery

The actions under this alternative are designed to evaluate the natural processes of sedimentation and scouring/redeposition to achieve RAOs over time. Given the relatively low levels of risk, objectives for monitoring the natural recovery of the river system would be to confirm that risks associated with the ash release remain low and that ash-related metals concentrations decline with time.

An adaptive monitoring and management framework would be followed. Adaptive methodologies incorporate decision points where causal effects of changed conditions are explored as an integral component of the process. Adaptive methodologies would provide opportunities for effective response to unexpected monitoring results, and would provide objective decision points regarding continuation or termination of specific monitoring program components. A key component of the adaptive management process would be sediment dynamic modeling, as has been performed by ERDC Waterways Experimentation Station (ERDCWES). Results of sediment and biota monitoring would be used in conjunction with results of sediment transport modeling to evaluate the rate of decline in concentrations, locations of ash or sediment deposition, effectiveness of mixing, or to evaluate whether contingent response actions or additional data gathering would be warranted.

The major components of this alternative are listed in Table 5-2 and the monitoring locations are illustrated on Figure 33. Six representative monitoring transects would be sampled in the Emory and Clinch Rivers (at approximately ERM 1.0, ERM 2.0, ERM 3.0, ERM 4.0, CRM 3.0, and CRM 4.0), and one monitoring transect would be sampled at a reference location. Actual locations of the monitoring transects and types and frequencies of sampling would be identified through a data quality objectives process with participation by TVA, EPA, and TDEC. Because the alternative would involve no construction, it would be implemented immediately.

Table 5-2 Summary of Actions for Alternative 1, Monitored Natural Recovery

Action	Summary
Monitoring of Sediment	Sample sediment from 7 transects annually for up to 30 years and analyze samples for ash content and concentrations of arsenic and selenium in the sediment.
Monitoring of Biota	Sample benthic invertebrates (mayflies and mayfly larvae) from 7 transects annually for up to 30 years and analyze samples for arsenic and selenium.
Monitoring of Effects	Survey benthic populations for abundance and diversity at 7 transects in the river system annually for up to 30 years and evaluate results for benthic community health.
Modeling of Sediment Transport	Evaluate monitoring results against predicted rates of natural recovery. Update modeling every 5 years for up to 30 years to evaluate mixing and recovery rates.

Monitoring of Sediment

Three discrete samples of sediment would be collected from each of the seven monitoring transects. Samples would be taken using vibracore sampling techniques to determine depth of any ash deposit that may be present. Samples of sediment would be selected from the top 6 inches of the vibracore sample for analysis of percent ash content and of arsenic and selenium concentrations. Sampling would be conducted once per year for up to 30 years.

Monitoring of Biota

Monitoring would involve collection of benthic invertebrate adult emergent and larval insect (mayfly) body burden data for use in dietary risk calculations. Three composite samples of adult mayflies and three composite samples of larval mayflies would be collected from the area surrounding each monitoring transect. Samples of mayfly whole body would be analyzed for arsenic and selenium. Sampling would be conducted once per year for up to 30 years. Other monitoring may include supplemental investigation of fish bioaccumulation of arsenic or selenium for up to 5 years to confirm declining trends in whole body fish.

Monitoring of Effects

Monitoring would involve collection of benthic invertebrate community structure data for evaluation of abundance and diversity. Up to ten discrete samples would be collected from each of the seven monitoring transects. Sampling would be conducted once per year for up to 30 years. Other monitoring may include supplemental fish community surveys or sediment toxicity testing for up to 5 years to confirm trends.

Each year, a monitoring report would be prepared, documenting any changes in the sediment and biota analytical results or the invertebrate community structure. Risk evaluations would be conducted to compare invertebrate-feeding bird risk parameters (invertebrate community abundance and diversity, mayfly body burdens) relative to those derived for reference locations and to those documented in the baseline.

Modeling of Sediment Transport

Monitoring results would be compared against predicted rates of natural recovery, in particular, the predicted rate of reduction in ash content and the predicted rate of reduction in arsenic and selenium concentrations. The sediment fate and transport modeling would be updated every 5 years for 30 years to evaluate ash/sediment mixing and recovery rates, using updated bathymetry and ash deposit locations.

Modeling could also be used to evaluate sediment transport impacts following significant storm flow events.

Five-Year Remedy Reviews

Monitoring will be conducted annually for 30 years, with remedy reviews conducted every 5 years. At each 5-year review, the monitoring data will be evaluated. Based on the results of that evaluation, the sampling scope, locations, and/or frequency may be adjusted appropriately.

5.2.2 Alternative 2: In-Situ Capping and MNR

The actions under this alternative are designed to minimize exposure by benthic invertebrates to ash-contaminated sediment through capping of ash deposits in the river. Two subalternatives (2a and 2b) were developed to evaluate full capping and optimized (targeted) capping options. MNR would also be used to evaluate the natural processes of sedimentation and scouring/redeposition to achieve RAOs over time, both in capped and uncapped areas. The major components of this alternative are listed in Table 5-3 and the end-state of the alternative is illustrated on Figures 34 and 35.

Table 5-3 Summary of Actions for Alternative 2, In-Situ Capping and MNR

Action	Summary
Infrastructure	Upgrade a two-acre temporary dock area to stage, process, and load the cap materials.
Cap Placement	Cover the ash deposits with 6 inches of gravel. Two subalternatives, 2a and 2b, have been developed. Alternative 2a would fully cap all ash deposits (200 acres); Alternative 2b would optimize capping by capping only ash deposits subject to scour (160 acres).
Cap Maintenance	Maintain cap thickness in areas where scour exposes underlying ash deposits.
Monitoring of Capping Operations	Sample surface water upstream and downstream of active capping operations. Sample imported materials for grain size distribution.
Monitoring of Sediment	Sample cap and/or sediment from 7 transects annually for up to 30 years and analyze samples for sediment deposition and cap thickness.
Monitoring of Biota	Sample benthic invertebrates (mayflies and mayfly larvae) from 7 transects annually for up to years and analyze samples for arsenic and selenium.
Monitoring of Effects	Survey benthic populations for abundance and diversity at 7 transects in the river system annually for up to 30 years and evaluate results for benthic community health.
Modeling of Sediment Transport	Evaluate cap scour and deposition relative to predicted modeling results. Evaluate monitoring results against predicted rates of natural recovery.
Institutional Controls	Restrict river traffic around active capping operations. Restrict dredging activities in capped areas.
Operations and Maintenance	Conduct routine inspection, repair, and replacement of cap materials; conduct annual bathymetric survey of capped areas.

Infrastructure

A temporary docking facility would be built at the Kingston plant, such as at the South Dock near the TVA plant outfall in the Clinch River, or on the Stilling Pond peninsula near the Skimmer Wall. The facility would be about 2 acres in size and used to stage, process, and load the cap materials. The facility would also be used for access to barges (e.g., for repairs), service vehicles and transport vehicles.

Cap Placement

Approximately 200 acres of identifiable ash deposits are present in the Emory River and upper Clinch River. An identifiable ash deposit is considered an area where the ash content in a sediment sample constitutes more than 50% of the sediment and where the deposit is present in a layer at least 6 inches thick. Figures 34 and 35 show the distribution of identifiable ash deposits and area to be capped.

Sediment containing less than 50% ash content, as determined by PLM analysis of sediment grab samples, has been shown to have minimal effect on benthic invertebrate test organisms based on results of sediment toxicity testing. A determination of >50 and <50% is a practical determination that can be made in the field based on field PLM analysis and confirmed by fixed-base laboratory PLM analysis. Therefore, the 50% ash content has been selected as the appropriate target for capping of identifiable ash deposits.

Ash-contaminated sediment deposits that are less than 6 inches thick, as determined by vibracore sampling of the sediment, will have minimal effect on benthic invertebrates because the organisms typically burrow at least 6 inches into the sediment. A determination of sediment thickness to within an accuracy of ±6 inches is a practical determination that can be made readily in the field using conventional sampling techniques. Therefore, the 6-inch thickness has been selected as the appropriate target for capping of identifiable ash deposits.

The ERDCWES has performed baseline fate and transport modeling of bed shear to determine the grain size needed for the cap material in each area of the Emory River and upper Clinch River to protect the cap from scour. In general, greater bed shear, and therefore greater scour potential, is expected in the main thalweg or center channel of the river; lesser bed shear, and therefore lesser scour potential, is expected in the inside curves of riverbends or former oxbows, where natural sediment deposition typically occurs. Results of that modeling (ERDCWES 2012) indicate the following:

- Grain size of the cap material would be at least 7 millimeters (mm) (1/4-inch) size in areas where the predicted bed shear is less than 5 pascals (Pa). This is a small gravel ("pea-gravel") size material.
- Grain size of the cap material would be at least 25-mm (1-inch) size in areas where the predicted bed shear is greater than 5 Pa. This is a medium gravel size material, similar to road base aggregate.

Under this alternative, a relatively thin layer (6 inches) of the granular material described above would be placed over all areas where ash is present in an identifiable deposit (>50% and >6 inches). The granular cap material would be obtained from local commercial quarries, and hauled to the Site by truck. The cap material would be off-loaded at the temporary docking facility. The cap material would then be placed using a "Broadcast Capping System" in which the material is first fed into a hopper and slurried via submerged pipeline to a spreader barge. The spreader barge would then broadcast the capping materials above the water surface using the full water column to buffer the impact of descending sand or gravel. Silt curtains would be used to mitigate the suspension of fines associated with sediment resuspension. Alternatively, the cap material could be loaded onto barges for transport to the point of placement in the river. In such case, a conventional excavator would be used to offload the barge and spread the cap material in a relatively thin layer. The average production rate is estimated at approximately 45 cy/hour placement, or around 1,800 cy/week, equivalent to a cap area of 2.2 acres/week. Cap thickness would be determined through a combination of techniques, including river bottom bathymetric survey, vibracore sampling, and calculation of total material volume spread.

Alternative 2a would fully cap areas of identifiable ash deposits. Figure 34 shows areas of capping using 1/4-inch and 1-inch material, based on the ERDCWES bed shear modeling. The area that would be capped using 1/4-inch material is estimated at 150 acres and the area that would be capped using 1-inch material is estimated at 50 acres. As such, this alternative would place nearly 121,000 cy of 1/4-inch material, and 40,000 cy of 1-inch material.

Targeted Capping

Alternative 2b would target capping within specific areas of the river system to maximize capping effectiveness in reducing scour while minimizing short-term adverse impacts. The ERDCWES flume testing and fate and transport modeling of bed shear indicated that the critical bed shear for native ash/sediment mixtures is approximately 1.6 Pa. Areas where bed shear is less than 1.6 Pa would be resistant to scour during storm events; these areas are typically located near shore where biological activity is most abundant. Targeted capping would therefore avoid capping in those areas, which would limit disturbance to ecological resources. As a result, the area that would be capped using 1/4-inch material would be 110 acres, while the area that would be capped using 1-inch material would remain the same (50 acres). Figure 35 shows the areas to be capped under Alternative 2b. As such, this alternative would place nearly 89,000 cy of 1/4-inch material, and 40,000 cy of 1-inch material.

Monitoring of Capping Operations

Monitoring during construction would include routine surface water sampling. Routine surface water monitoring would be conducted upstream and downstream of active capping operations to check for turbidity and TSS on a daily basis. Imported materials would be routinely analyzed for grain size distribution to verify required grain size.

Monitoring of Sediment

Three discrete samples of sediment would be collected from each of seven monitoring transects. Samples would be taken using vibracore sampling techniques to determine depth of any sedimentation on top of the cap or scour into the cap that may have occurred. No chemical analysis of samples taken from the cap material would be required; samples of mixed ash and sediment would be analyzed for arsenic and selenium. Sampling would be conducted once per year for up to 30 years until results show that concentrations of arsenic and selenium in sediment have declined to below sediment RGs. For cost estimating purposes, 30 years of monitoring has been assumed.

Monitoring of Biota

Monitoring would involve collection of benthic invertebrate adult emergent and larval insect (mayfly) body burden data for use in dietary risk calculations. Three composite samples of mayflies would be collected from the area surrounding each monitoring transect. Samples of mayfly whole body would be analyzed for arsenic and selenium. Sampling would be conducted once per year for up to 30 years until results show that concentrations of arsenic and selenium in biota have declined to below TMEs. Similar to sediment monitoring, for cost estimating purposes, 30 years of monitoring has been assumed.

Monitoring of Effects

Monitoring would involve collection of benthic invertebrate community structure data for evaluation of abundance and diversity. Up to ten discrete samples would be collected from each of the seven monitoring transects. Sampling would be conducted once per year for up to 30 years. Similar to sediment and biota monitoring, for cost estimating purposes, 30 years of community surveys has been assumed.

Each year, a monitoring report would be prepared, documenting any changes in the sediment/cap thickness and biota analytical results or the invertebrate community structure. Risk evaluations would be conducted to compare invertebrate-feeding bird risk parameters (invertebrate community abundance and diversity, mayfly body burdens) relative to those derived for reference locations and to those documented in the baseline.

Modeling of Sediment Transport

Monitoring results would be compared against predicted rates of natural recovery, in particular, the predicted rate of reduction in arsenic and selenium concentrations in biota. In addition, the rates of sediment deposition or cap scour would be evaluated relative to predicted modeling results.

Institutional Controls

To protect safety of workers and public during cap placement, river use restrictions and no wake zones would be established in portions of the river where active cap placement operations are occurring. Such restrictions would be removed once the cap is placed. Longer-term institutional controls would include restrictions on dredging within the Emory River to avoid damage to the capped areas. Restrictions on dredging already exist in the Clinch River, in accordance with DOE's Watts Bar Reservoir Record of Decision, to avoid disturbance of legacy contaminants.

Operation and Maintenance (O&M)

Routine inspection, repair, and replacement of cap materials; would continue throughout the 30-year post-remediation O&M period. A bathymetric survey of the capped areas would also be done annually to identify areas of potential scour. For cost estimating purposes, it has been assumed that 1% of the capped area would need to be repaired or replaced on average each year.

5.2.3 Alternative 3: Dredging and MNR

The actions under this alternative are designed to remove the ash-contaminated sediment to the extent practicable and dispose of the dredged material offsite. Two subalternatives (3a and 3b) were developed to evaluate full dredging and optimized (targeted) dredging options. MNR would also be used to evaluate the natural processes of sedimentation and scouring/redeposition to achieve RAOs over time, both in dredged and undredged areas. The major components of this alternative are listed in Table 5-4 and the end-state of the alternative is illustrated on Figures 36 and 37.

Table 5-4 Summary of Actions for Alternative 3, Dredging and MNR

Action	Summary
Infrastructure	Construct or install areas for drying ash, for offloading barges, and for loading of trucks.
Dredging	Remove ash deposits in the river system using hydraulic and/or mechanical dredges. Two subalternatives, 3a and 3b have been developed. Alternative 3a would dredge virtually all areas of ash deposits (440,000 cy); Alternative 3b would dredge only targeted shallower water areas of particular ecological significance (160,000 cy).
Dewatering	Separate solids from the dredge spoils using gravity settling ponds. Dry the solids suitable for offsite shipment using windrows.
Disposal	Load and haul dried ash/sediment to permitted solid waste landfills.

Table 5-4 Summary of Actions for Alternative 3, Dredging and MNR (continued)

Action	Summary
Monitoring of Dredging Operations	Sample air quality around land-based facilities. Sample surface water upstream and downstream of active dredging operations. Sample waste material prior to waste shipment offsite.
Monitoring of Sediment	Sample sediment from 7 transects annually for up to 30 years and analyze samples for ash content and concentrations of arsenic and selenium in the sediment.
Monitoring of Biota	Sample benthic invertebrates (mayflies and mayfly larva) from 7 transects annually for up to 30 years and analyze samples for arsenic and selenium.
Monitoring of Toxic Effects	Survey benthic populations for abundance and diversity at 7 transects in the river system annually for up to 30 years and evaluate results for benthic community health.
Modeling of Sediment Transport	Evaluate monitoring results against predicted rates of natural recovery. Update modeling every 5 years for up to 30 years to evaluate mixing and recovery rates.
Institutional Controls	Restrict river traffic around active dredging operations.

Infrastructure

Prior to dredging, infrastructure improvements would be built to support the subsequent dredging, dewatering, and offsite shipment of ash/sediment.

- A docking station would be constructed on the Emory River on the east end of the Gypsum Pond peninsula, or other suitable location. Floating docks about 50 ft wide would be anchored to the river bottom and gangways/ramps installed to allow operating vehicles to access the dock. The docking station would allow access for barges to be hydraulically offloaded and for support boats.

- A dewatering facility would be constructed on a 15-acre area on the peninsula. The facility would be lined and underdrained to collect water from the dewatering operations. The liner would consist of a 12-inch compacted clay liner covered with a geosynthetic flexible membrane liner, a geocomposite underdrain layer, and stone/sand protection and filter layers. Three contiguous 2-acre confined sediment basins (CSBs), a one-acre effluent collection pond, and 5-acre ash processing (drying) and operations support area would be constructed within the dewatering facility.

- No additional truck or rail loading infrastructure would likely be required; existing rail spurs and gravel pads in the Kingston rail yard would be used.

Dredging

Ash deposits would be dredged from the river system using primarily hydraulic dredging techniques. Approximately 440,000 cy of dredge-able ash deposits are present in the Emory River and upper Clinch River. A dredge-able ash deposit is considered an area where the ash content in a sediment sample constitutes more than 50% of the sediment and where the deposit is present in a layer at least 1 ft thick. This volume (440,000 cy) is therefore less than the total measurable volume in the river system (510,000 cy) as listed in Table 2-2. Figure 36 shows the distribution of dredge-able ash deposits.

Sediment containing less than 50% ash content, as determined by PLM analysis of sediment grab samples, has been shown to have minimal effect on benthic invertebrate test organisms based on results of sediment toxicity testing. A determination of >50 and <50% is a practical determination that can be made in the field based on field PLM analysis and confirmed by fixed-base laboratory PLM analysis.

Therefore, the 50% ash content has been selected as the appropriate target for dredging of identifiable ash deposits.

Experience and lessons learned from precision dredging operations conducted during the time-critical removal action at the Site have shown that dredging to within an accuracy of ±1 ft is a practical limitation using precision dredging techniques (Jacobs 2011b). The dredging strategy would be to maximize the removal of ash-contaminated sediment, while minimizing the disturbance and removal of native sediment. Therefore, the 1 ft thickness has been selected as the appropriate target for dredging of ash deposits.

Hydraulic dredging would be conducted using an Ellicott® Model 670 or a Dredging Supply 14 inch dredge, capable of reaching depths of up to 50 ft with system modifications. The deepest sediments potentially requiring removal are about 40 ft deep. Sediment dredged from the Intake Channel and areas within about a mile of the dewatering facility would be sluiced directly to the CSBs. Sediment from other more distant areas could be deposited into barges for transport to the docking station, where the sediment would be reslurried and pumped via double-wall slurry pipeline to the CSBs. To minimize impact of dredging operations on recreational and commercial uses of the river system, dredging would only be conducted Monday through Friday, with about 10 hours of operational time per day during the summer (8 hours during the winter). Hydraulic dredging operational capacity would average approximately 125 cy/hour. At an operating efficiency of 90%, dredging capacity would average approximately 1,125 cy/day during the 6-month summer season and 900 cy/day during the 6-month winter season, for an average rate of 1,000 cy/day.

As a contingent measure, mechanical dredging could be used for removal of debris or sediment in remote or deeper areas. Support equipment would include a minimum of three barges; one for loading, one for transporting, and one for unloading of dredged sediment/debris. Each barge would be approximately 20 ft by 50 ft in size with a holding capacity of approximately 110 cy. Up to 3 tug boats would also be used, depending on actual production rates, for movement of the three barges.

Targeted Dredging

Alternative 3b would target dredging within specific areas of the river system to maximize dredging effectiveness while minimizing short-term adverse impacts. Deep channel or thalweg areas greater than 15 ft water depth, or other areas where DO conditions or sediment conditions are unfavorable for benthic invertebrate communities, contribute little to ecological exposure. Alternative 3b would therefore not dredge ash deposits in those areas. Figure 35 shows the areas to be dredged under Alternative 3b. Approximately 160,000 cy of dredge-able ash deposits would be removed from the shallower water areas in the Emory River and upper Clinch River.

Thermal and DO stratification in the lower part of the Emory River are transient, and are greatly influenced by the cold water underflows from the Clinch River upstream to the plant Intake Channel. The DO profile typically shows a decrease in DO concentrations at about 10 to15 ft depth; however, the minimum concentrations vary both with location and date. This variation is due to a combination of meteorological and hydrological conditions, with plant operations having a significant daily influence. Aerobic biological organisms generally avoid living in conditions where DO drops below about 4 mg/L, and only a few such organisms are suited to living in places where either DO or temperature are likely to change substantially over short periods of time. Taken together, this means that the bottom-dwelling communities at depths greater than 10 to 15 ft in the Emory River are subject to significant disruptions, making that part of the river bottom less significant ecologically than shallower areas where the benthic communities are more stable and form a more consistent part of the base of the food chain.

Benthic invertebrate community structure (abundance of organisms and biodiversity) is constrained where the water depth is 15 ft or deeper. Qualitatively, based on results on community surveys conducted in 2010 and 2012, there is about a 25% reduction in invertebrate abundance and diversity below a depth of 15 ft. This reflects a lower level of ecological activity, including trophic interactions and exposure of vertebrate species. In addition, Alternative 3b would avoid dredging in shallow water areas that support annual or perennial wetland macrophyte species.

Therefore, based on the observed thermal and DO stratification, and benthic invertebrate community structure, the targeted dredging would be done only in areas where water depth is less than 15 ft deep at low pool reservoir levels.

Dewatering

Dewatering of the dredged spoils would be accomplished through use of gravity settling and windrowing; the dewatering process is depicted on Figure 38. The dredged material would be sluiced from the docking station to the intake manifold for the CSBs. Three contiguous 2-acre CSBs would be constructed, each with a capacity to contain at least one week of dredged slurry. At any given time, one CSB would be receiving incoming slurry, while ash/sediment is being removed from a second CSB, and a third held in reserve as contingency for overflow capacity. Each CSB would have an average solids accumulation depth of 3.5 ft, an operating water depth of 5.5 ft, and a 3-ft freeboard, for a total effective depth of 12 ft. Assuming less than 20% solids in the slurry, average pond inflow rate is estimated at about 5,000 gallons/min. Assuming 60% solids after settling, a storage capacity of 1,200 cy/day would be needed on average, or about 1,600 cy/day during peak dredging production. Total accumulation in a CSB after one week of operation would be approximately 6,000 cy on average and 8,000 cy during peak production.

Water would be decanted from the CSBs at a rate of about 2,700,000 gallons/day and would be discharged to the lined collection pond for flow equilibration and clarification. Storm water runoff and underdrainage from the entire dewater facility would also discharge to the collection pond. The collection pond would be approximately 800 ft long (extending the full width of the dewatering facility), 50 ft wide, and 15 ft deep, with a capacity of at least 2,700,000 gallons. Water would be subsequently pumped from the collection pond to the plant's existing Stilling Pond for discharge to the plant Intake Channel through the plant's NPDES outfall.

Ash/sediment would be recovered from the CSBs using mechanical excavators. The ash/sediment would be processed on the 5-acre ash processing area to allow it to dry sufficiently for disposal. Recovered ash/sediment would be placed into windrow piles, each about 12 ft high by 800 ft long, and containing a week's worth of recovered material. Three windrow piles would be maintained, to allow for up to 3 weeks of dewatering.

Disposal

Three disposal options have been retained for further evaluation in this EE/CA. Approximately 130,000 cy of recovered ash/sediment would be dredged from Emory River Reach B and C, which would not contain cesium-137, and may therefore be disposed at a permitted Subtitle D landfill, such as the Chestnut Ridge Landfill in Anderson County, Tennessee. Approximately 310,000 cy of recovered ash/sediment would be dredged from Emory River Reach C, the Intake Channel, and the Clinch River, which would contain low levels of cesium-137, and must therefore be disposed of properly as low level radioactive waste. This material could be disposed at the Chestnut Ridge landfill Under TDEC's Bulk Survey for Release (BSFR) program. Alternate disposal facilities for material containing cesium-137 may include the Energy Solutions landfill in Clive, Utah, or possibly the DOE EMWMF in Oak Ridge, Tennessee. For targeted dredging (Alternative 3b), approximately 30,000 cy would not contain cesium-137 and would be disposed at a permitted Subtitle D landfill and 130,000 cy would contain cesium-137 and would be disposed at a low level radioactive waste disposal facility.

For disposal at either a local Subtitle D landfill or the EMWMF, dewatered ash/sediment would be loaded into lined intermodal containers. Intermodal containers are large aluminum containers with continuously welded interior seams and a gasket sealing system so that they are water tight, roll-off capable, and stackable. Each intermodal container would hold approximately 18 cy, for a net payload capacity of about 47,000 pounds. To keep pace with the estimated 1,000 cy/day hydraulic dredging production rate, approximately 56 truck trips per day would be required.

For disposal at the Energy Solutions landfill, dewatered ash/sediment would be loaded into lined containers (lift liners) for shipment by rail to Utah. Lift liners are a soft-sided waste packaging system with several protective layers (woven outer polypropylene fabric shell with a water- resistant coating and a double layer polypropylene inner liner). Each container would hold approximately 9 cy, for a net payload capacity of about 23,500 pounds. Containers would be stored either at the dewatering facility, or staged at a secondary location near the dedicated rail spur. Each railcar would hold seven containers, for a total of 63 cy/railcar. To keep pace with the estimated 1,000 cy/day hydraulic dredging production rate, approximately 5 days would be required to fill an 80-car train.

Monitoring of Dredging Operations

Monitoring during construction would include routine air, surface water, and waste sampling. Routine air monitoring would be conducted around the land-based barge unloading, dewatering, and rail spur facilities to check for air-borne particulates, including silica, on a daily basis. Routine surface water monitoring would be conducted upstream and downstream of active dredging operations to check for turbidity and TSS on a daily basis. Routine waste material monitoring would include moisture content, cesium-137 activity, and TCLP testing, as required to verify compliance with waste acceptance criteria at the disposal facility.

Monitoring of Sediment

Three discrete samples of sediment would be collected from each of the seven monitoring transects. Samples would be taken using vibracore sampling techniques to determine depth of any ash deposit that may be present. Samples of sediment would be selected from the top 6 inches of the vibracore sample for analysis of percent ash content and of arsenic and selenium concentrations. Sampling would be conducted once per year for up to 30 years until results show that concentrations of arsenic and selenium in sediment have declined to below sediment RGs. For cost estimating purposes, 30 years of monitoring has been assumed.

Monitoring of Biota

Monitoring would involve collection of benthic invertebrate adult emergent and larval insect (mayfly) body burden data for use in dietary risk calculations. Three composite samples of mayflies would be collected from the area surrounding each monitoring transect. Samples of mayfly whole body would be analyzed for arsenic and selenium. Sampling would be conducted once per year for up to 30 years until results show that concentrations of arsenic and selenium in biota have declined to below TMEs. For cost estimating purposes, 30 years of monitoring has been assumed.

Monitoring of Effects

Monitoring would involve collection of benthic invertebrate community structure data for evaluation of abundance and diversity. Up to ten discrete samples would be collected from each of the seven monitoring transects. Sampling would be conducted once per year for up to 30 years. Similar to sediment and biota monitoring, for cost estimating purposes, 30 years of community surveys has been assumed.

Each year, a monitoring report would be prepared, documenting any changes in the sediment and biota analytical results or the invertebrate community structure. Risk evaluations would be conducted to compare invertebrate-feeding bird and mammal risk parameters (invertebrate community abundance and diversity, mayfly body burdens) relative to those derived for reference locations and to those documented in the baseline.

Modeling of Sediment Transport

Monitoring results would be compared against predicted rates of natural recovery, in particular, the predicted rate of reduction in ash content and the predicted rate of reduction in arsenic and selenium concentrations. The sediment fate and transport modeling would be updated every 5 years to forecast future recovery rates, using updated bathymetry and ash deposit locations.

Institutional Controls

To protect safety of workers and public during dredging, river use restrictions and no wake zones would be established in portions of the river where active dredging operations are occurring. Such restrictions would be removed once the dredging is completed. Longer-term institutional controls would include restrictions on dredging within the Emory River to ensure proper characterization and disposal of any future dredge spoils. Land-based facilities (barge unloading, dewatering facility, and rail spur area) would be incorporated into the CERCLA Site boundaries. Other controls for land-based facilities would include construction fencing placed around the facilities for access control, dust control by watering roadways and work areas or use of Flexterra® polymer treatment, and storm water pollution prevention and erosion and sediment control.

5.2.4 Components Common to All Alternatives

The following are activities that would be conducted under each of the alternatives described above.

Environmental Health and Safety

TVA and its contractors would systematically integrate safety into management and work practices so that the implementation of the removal action is accomplished while protecting the public, the worker, and the environment. This would be accomplished through effective integration of safety management into all facets of work planning and execution. Environmental safety and health management would be implemented under appropriate work plans and health and safety plans and would include the following elements:

- Personal protective equipment (PPE), including steel-toed boots, hard hats, and reflective vests
- Institutional hygiene monitoring of workers
- Vehicle washing upon leaving the Site

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6. ANALYSIS OF ALTERNATIVES

6.1 INDIVIDUAL ANALYSIS OF ALTERNATIVES

This section presents an individual analysis of the alternatives based on effectiveness, implementability, and cost.

Effectiveness. The effectiveness of each technology to meet the RAOs is evaluated in terms of overall protection of human health and the environment, compliance with ARARs, long-term effectiveness and permanence, and short-term effectiveness. Long-term effectiveness considers the magnitude of residual risk, degree of reduction expected in waste toxicity, mobility or volume; the adequacy and reliability of controls; the degree to which treatment is irreversible; and the type and quantity of residuals remaining after treatment. Short-term effectiveness considers protection of workers and the community during the action, environmental impacts, and time until RAOs are achieved.

Implementability. The implementability of each technology addresses the technical and administrative feasibility of implementing an alternative and the availability of materials, equipment, or services required during implementation. This criterion considers the ability to construct and operate the technology within the Site and time constraints for the non-time-critical removal action, the time to procure and install necessary equipment and specialists, ability to monitor effectiveness, ease of implementing additional technologies (if necessary), and ability to obtain approval from other agencies.

Cost. The relative cost of each technology is estimated, considering capital cost of material, equipment and installation, as well as the annual O&M costs such as long-term monitoring or cap repair. The capital costs are estimated in 2012 dollars with no adjustment for inflation due to the short time frame associated with the removal action. A present worth analysis is used to compare long-term O&M costs of alternatives that occur over different time periods by discounting future costs to a common base year, 2012. The present worth represents the amount of money that, if invested in the base year and disbursed as needed, would be sufficient to cover costs associated with long-term O&M. A discount rate of 5% before taxes and after inflation was assumed, as recommended by EPA. Costs are considered planning-level estimates, within an accuracy of -30 to +50%.

6.1.1 Alternative 1: Monitored Natural Recovery (MNR)

<u>Effectiveness</u>

Alternative 1 would meet RAOs. The ash deposits within the river system would gradually reduce in thickness through natural processes of scour and sediment deposition. Biouptake of arsenic and selenium in benthic invertebrates would correspondingly decrease, thereby restoring the ecological function and recreational use of the river system to pre-release conditions. Monitoring would be used to demonstrate that these processes are occurring. As a result, the terms of both the TDEC Commissioner's Order and the EPA Order would be met.

Overall Protectiveness. Alternative 1 would be protective of both human health and the environment. Results of the BHHRA concluded that there is no risk to human health from ash-related constituents, so that no removal action is needed for protection of human receptors. Results of the BERA concluded that there is relatively low risk to benthic invertebrates and birds that feed on them due to uptake of arsenic and selenium in their diet. Scour and sedimentation processes would result in mixing of ash and natural sediments within the upper 6 inches of sediment. Percentage of ash in the sediment, concentrations of arsenic and selenium in the sediment, and biouptake by benthic invertebrates would therefore decline. Consequently, risks would be eliminated gradually over time. MNR would result in little short-term impact to the environment, since there would be no activity conducted in the river to disturb the aquatic ecosystem. Alternative 1 would likely achieve mixed sediment accumulation greater than 6 inches in 10 to 15 years; however, nearly 30 years may be required to fully achieve RAOs, depending on effects of severe storm flow events.

Compliance with ARARs. Alternative 1 would comply with all ARARs, as listed in Appendix F. Natural recovery of the rivers would gradually restore waters of the state for fish and aquatic wildlife and recreation in compliance with Tennessee rule 1200-4-3 and associated ARARs. Because only monitoring activities would be conducted within the rivers, no location- or action-specific ARARs would be invoked under Alternative 1.

Effectiveness over the long term. Alternative 1 would be effective over the long-term. MNR would consist of permanent and irreversible processes of scour and sedimentation. Over the long-term, MNR would gradually eliminate direct contact of benthic invertebrates with arsenic and selenium in the ash and biouptake from ash-contaminated sediment to riparian- and aerial-feeding birds. Long-term effectiveness is further discussed below.

- Effectiveness of scour and sedimentation processes. The ERDCWES has performed baseline fate and transport modeling of the Emory and Clinch Rivers sediment to evaluate long-term effectiveness. Flume testing was performed using ash, native sediment, and ash-sediment mixes to provide model input data on critical shear stress and bed scour (erosion rates). The model was established to represent how the river system would respond to periodic floods and low flow periods. Modeling was conducted using a two-dimensional adaptive hydraulics numerical model developed at ERDCWES. The model performed a simulation of sediment transport over a 30-year timeframe, using actual river flows and flood events as recorded for the years 1978 to 2008. Within that time, a total of 13 flood events with river flows ranging from 60,000 to 170,000 cfs were recorded, and used in the simulation. Results of that modeling (ERDCWES 2012) indicate that over the long term natural sediment dynamic processes yield decreasing proportions of ash and decreasing concentrations of arsenic and selenium in sediment in the Emory and Clinch Rivers. Natural sedimentation and scour processes would likely produce a layer of mixed ash and sediment approximately 6 inches thick over a period of 10 to 15 years in depositional side channel areas. This mixed ash/sediment layer has been observed in vibracore sampling performed in 2009 and 2010, confirming the model predictions. Scour and sedimentation processes would therefore be effective in producing a natural cover over any residual ash deposits, with declining concentrations in arsenic and selenium.

  The modeling also showed that periodic severe storm flow events (greater than a 10-year recurrence interval) would be expected to result in scouring portions of this natural cover, particularly in the main channel as well as some of the side channel deposits. The bulk of the residual ash would be transported downstream and out of the lower Emory and Clinch Rivers. Following such severe storm flow events, deeper sediments with potentially higher levels of ash and ash-related constituents could become exposed. However, the model predicted that ash and natural sediment mixtures would deposit in side channel areas of the Emory and Clinch Rivers, and that the natural cover of mixed ash/sediment would redevelop. Deposition rates in the Emory and Clinch Rivers averaged about 0.5 inch per year over the 30-year simulation.

  The model results showed considerable variability between different reaches of the river. Main channel areas exposed to flows exceeding 50,000 cfs would be scoured; the remaining side channel areas would remain depositional even following severe storm flow events. As such, deposition in side channel areas is projected to be substantially higher. In Emory River Reach C (model point P2), the model predicted a sediment accumulation depth of 65 inches (over 5 ft) after 30 years; in Emory River Reach B (model point P3), the model predicted a sediment accumulation depth of 21 inches (nearly 2 ft) after 30 years; and in Emory River Reach A (model points P4 and P5), accumulation depths of 10.5 to 14 inches (approximately 1 ft) were projected. Similarly, in Clinch River Reach B (model points P6 and P7), sediment accumulation depths of 17 inches were projected after 30 years. Therefore, the model predicts substantial depths of deposition in side channel areas in the Emory and Clinch Rivers over a 30-year period.

The model predicted the percentage of ash in the ash/sediment side channel deposits would gradually decrease over time with mixing and redeposition throughout the river system. Based on the model predictions, ash/sediment mixtures would contain less than 50% ash in approximately 10 years, and would continue to decline thereafter. This mixture of ash and sediment of has been observed in vibracore sampling performed in 2009 and 2010, confirming the model predictions.

Similar to sediment accumulation, the model results showed considerable variability in predicted ash percentages between different reaches of the river. Assuming initial 50% ash in the deposits, the percent of ash residual in the deposits after 14 years ranged from 5 to 15% for the Emory and Clinch Rivers and about 10 to 20% for the lower Watts Bar Reservoir. After 30 years, the percent of residual ash dropped due to continuous deposition of natural sediments, to approximately 3 to 8% in the Emory and Clinch River deposits and 5 to 10% in the lower Watts Bar Reservoir. This represents a dilution ratio of approximately 9 parts sediment to 1 part ash (a reduction from 50 to 5% ash in deposits).

- Effectiveness of MNR at other sites. MNR has proven effective at other sites in remediation of contaminated sediments. DOE selected MNR as the remedy for management of contaminated sediments in the Clinch River (DOE 1997) and in Watts Bar Reservoir, downstream in the Tennessee River (DOE 1995). The selected remedies established that the sediment not be removed because there would be more risk from removing it than leaving it in place due to high rates of sediment resuspension and impacts to the benthic invertebrate population. Natural sedimentation was found to cover existing contamination and reduce its availability to the environment; as a result, mercury contamination in fish has shown a decreasing trend since the 1990s (DOE 2012). The U.S. Department of Defense, Environmental Security Technology Certification Program (ESTCP) evaluated more than a dozen case studies of sites throughout the U.S. for which MNR was selected as a remedy component (ESTCP 2009). The primary reasons for selecting MNR in these cases included ability of MNR to achieve RAOs within an acceptable time period and at a reasonable cost, preservation of valuable habitat that would otherwise be destroyed by capping or dredging, and infeasibility of capping or dredging, or their inability to achieve better results than MNR. Natural sedimentation and dispersion (scour/mixing with natural sediments) were found to result in reduction in contaminant concentrations and associated sediment toxicity. In almost every case where long-term monitoring was sufficient to evaluate remedy success, the results indicated appropriate progress toward achieving remedial goals.

- Effectiveness of risk reduction. Based on the results of the ERDCWES transport modeling, estimates were made of the rate of decline in arsenic and selenium concentrations in sediment and benthic organisms. These estimates assumed average concentrations for ash and native sediment as independent matrices, then predicted changes in concentrations based on the mixing of these matrices over time as a result of scour and deposition processes. Estimates of biouptake assumed that bioaccumulation is proportional to the change in constituent concentration in sediment, consistent with bioaccumulation factors used in the BERA.

  The BERA has concluded there is a moderate risk to benthic invertebrates due to exposure to arsenic and selenium in sediment. Results of toxicity testing have suggested statistically significant reductions in growth and biomass could occur when percent ash in the sediment yields concentrations greater than the selected RGs for arsenic and selenium. Risks to benthic invertebrates would gradually reduce over time as ash-related constituent concentrations in sediment decline to below the selected TMEs. Based on the results of the ERDCWES fate and transport modeling, sediment mixing and redeposition would likely result in average arsenic concentrations declining to less than the uppermost part of the RG range of 41 mg/kg in all areas of the river system in less than 12 years. Similarly, average selenium concentrations would decline to less than the uppermost part of the RG of 3.2 mg/kg in less than 26 years.

Following periodic severe storm flow events, exposures may increase briefly in some scour areas; however, as the natural cover redevelops, exposure concentrations and associated risks would decline. Given that baseline levels of unacceptable ecological risk are confined to few receptors and are already low, these short-term scour events would have little likelihood of increasing risks over the long term. MNR would therefore effectively meet RAOs for protection of benthic invertebrates.

The BERA has concluded there is a low risk to birds that feed on benthic organisms. These low risks would further reduce over time, as ash-related constituent concentrations in benthic invertebrate tissue decline to below the selected TMEs. MNR would therefore effectively meet RAOs for protection of invertebrate-feeding birds.

- Reliability of transport modeling and risk reduction estimates. There is considerable uncertainty in the model results and prediction of future mass transport and rate of concentration decline. The inflowing sediment boundary conditions were estimated based on relatively old bed sediment surveys in Watts Bar Reservoir. The maximum channel scour depth in the Emory and Clinch Rivers was assumed at 30 inches because there are no vertical profile data on sediment depth to bedrock or other non-erodible (armored) layers. Temporal trends in percent ash or arsenic/selenium concentrations cannot be ascertained from historical sampling events due to the short period since time-critical dredging has ceased. Further monitoring would be used to establish these trends and monitoring results would be compared against predicted rates of natural recovery, in particular, the predicted rate of reduction in ash content and the predicted rate of reduction in arsenic and selenium concentrations both in sediment and in benthic invertebrate tissue.

- Results of the transport modeling are considered reasonable predictions of the sedimentation dynamics of Watts Bar Reservoir and overall trends in the river system, based on well-known geomorphological processes. The model would predict greater scour in the river thalweg (main channel areas) than in calmer shallow water (side channel areas), and greater deposition on inside curves of river meanders, which is consistent with observations of natural river behavior. Deposition would be greatest downriver in the Tennessee River due to the fine grained nature of the sediment, which is consistent with observed deposition in Watts Bar Reservoir over the past 70 years. Reliability of the transport model would be further improved by updating the sediment fate and transport modeling every 5 years to forecast future recovery rates, using updated bathymetry and ash deposit locations. Effectiveness and reliability of sediment and biota monitoring. Reliability of the risk reduction estimates would be further improved by monitoring of sediment and benthic organisms annually. Results would be compared to baseline conditions measured in 2010 to demonstrate the rate of decline in constituent concentrations. Results would also be compared to the RG/TMEs to demonstrate the rate at which the alternative is achieving RAOs. Risk evaluations would be conducted to compare benthic community metrics (invertebrate community abundance and diversity) and invertebrate-feeding bird risk parameters (HQs) relative to those derived for reference locations and to those documented in the baseline.

  The monitoring of sediment and biota would be effective and reliable. Monitoring techniques have been proven effective in establishing baseline conditions and would have strong comparability to data used in the risk assessments. Data quality assessments would be implemented to verify that data meet data quality objectives for sensitivity, precision, accuracy, representativeness, and completeness. Monitoring of six transects in the lower Emory and Clinch Rivers and one upstream transect provides reasonable spatial distribution of data collection and evaluation of trends in the area where ash deposits are prevalent. Collection of up to ten samples from each transect would provide reasonable replication of results to demonstrate variability at each transect.

Effectiveness over the short term. Alternative 1 would be effective over the short term. Because natural processes would occur gradually over time, RAOs would only be achieved over the long term, once concentrations have declined to levels below the selected RG/TMEs, a process expected to occur over 10 to 15 years. Concentrations may briefly increase due to periodic severe storm flow events that could occur over several decades.

However, ecological populations would be adequately protected over the short term. The BERA has identified moderate risk to benthic invertebrates based on potential toxicity due to long-term exposure to ash-related constituents in the sediment. The benthic invertebrate community survey did not show substantial impacts attributable to the ash release; on the contrary, macroinvertebrate density and taxa richness in the immediate area of the ash release were similar to or even greater than other locations in the river system. The data did not indicate a trend of decreasing macroinvertebrate abundance or decreasing richness. Combined, these results showed no obvious patterns of persistent adverse impacts from the ash release and differences are likely the result of habitat variation and substrate type. The BERA concludes it is possible over the long term that reductions in growth and biomass could result in a measurable impact on reproduction or community structure. Therefore, the short-term risk to benthic invertebrates is relatively low and MNR would be effective in demonstrating these low short-term risks do not increase.

The BERA has identified low risks to invertebrate-feeding birds based on conservative dietary exposure models. Risks for the tree swallow are based on site-specific reproductive measures that show little, if any, reduction in female fledglings produced per nesting female; the probability of selenium dietary HQs exceeding 1 is low (10 to 30%). Therefore, the short-term risks to invertebrate-feeding birds are low and MNR would be effective in demonstrating these low short-term risks do not increase.

Short-term impacts are not likely under Alternative 1. There would be no action taken in the river system or on land that would impair the ecological habitat or increase short-term risks to human health or the environment. There is a DOE Record of Decision (DOE 1995) in place for Lower Watts Bar Reservoir, downstream in the Tennessee River, which establishes that the sediment not be removed because there is more risk from removing it than leaving it in place due to high rates of sediment resuspension and impacts to the benthic invertebrate population. Alternative 1 would therefore be consistent with this existing DOE Record of Decision.

<u>Implementability</u>

Alternative 1 would be implementable immediately following preparation of a non-time-critical removal action work plan for the monitoring. No construction activities would be required. Monitoring of sediment and biota are proven technologies that have been used extensively at the Site. Fate and transport modeling is also a proven technology and current models have already been calibrated for site-specific bathymetry and ash deposit locations. No specialty contractors would be required; TVA maintains a pool of qualified laboratories for analysis of samples.

Long-term O&M activities would include routine monitoring of sediment and biota, fate and transport modeling, and residual risk evaluation for a period of up to 30 years. Long-term institutional controls would not be required under Alternative 1.

Cost

There are no capital costs associated with implementing Alternative 1. Ongoing O&M costs are estimated at $543,000/year (2012 dollars) for up to 30 years. Costs of other monitoring are estimated at $339,000/year for up to 5 years. Total present worth of capital, O&M, and other costs is $10.0 million for a 30-year monitoring period.

6.1.2 Alternative 2: In-Situ Capping and MNR

Effectiveness

Alternative 2 would meet RAOs. The ash deposits within the river system would be covered, so as to protect ecological receptors and restore river use. Monitoring would be used to demonstrate that the cap is functioning as intended. As a result, the terms of both the TDEC Commissioner's Order and the EPA Order would be met.

Overall protectiveness. Alternative 2 would be protective of both human health and the environment. Results of the BHHRA concluded that there is no risk to human health from ash-related constituents, so that no removal action is needed for protection of human receptors. Results of the BERA concluded that there is low risk to benthic invertebrates and birds that feed on them due to uptake of arsenic and selenium in their diet. Capping of ash deposits greater than 6 inches in thickness would eliminate direct contact with much of the exposed ash deposits and would reduce potential scour during flood events that would otherwise expose deeper ash deposits. Consequently, risks would be substantially eliminated in capped areas. However, capping would result in substantial short-term impact to the environment, since the activity would greatly disturb the aquatic ecosystem. Existing benthic invertebrate communities beneath the cap would be smothered by the cap materials. The cap materials would consist of gravel-sized particles to resist scour; yet those materials would inhibit burrowing of benthic organisms, which could result in reduced abundance and biodiversity.

Compliance with ARARs. Alternative 2 would comply with all ARARs, as listed in Appendix F. Natural recovery of the rivers would gradually restore waters of the state for fish and aquatic wildlife and recreation in compliance with Tennessee rule 1200-4-3 and associated ARARs.

Capping would involve placing of materials within the floodplain, invoking location-specific ARARs. The action would need to comply with TVA Instruction (Section IX Environmental Review) and with substantive requirements of 40 CFR 230 and of the Nation Wide Permit (33 CFR 323). The placement of 129,000 to 161,000 cy of material would result in negligible reduction in reservoir storage capacity. However, because the material would be located within a published floodway in the Emory and Clinch Rivers, capping could impact both flood elevations and velocities. A hydraulic analysis would have to be performed. If capping were to result in flood elevations increasing less than 0.01 ft, then a No Rise Certification would be possible. Otherwise, changes to update the Roane County Flood Insurance Study would have to be made including sending letters to property owners who may have increased flood risk. There would be no practical measures to minimize these floodplain impacts, since the purpose of the capping would be to contain the ash-related constituents within the sediment.

Capping would need to comply with the substantive requirements of the Aquatic Resources Alteration Permit (ARAP), per Tennessee rule 1200-4-7. Because the action would modify the water body, the effects on fish and wildlife resources and their habitat must be considered, in compliance with the fish and Wildlife Coordination Act (16 USC 661 et seq.). The action would benefit fish and wildlife resources by reducing potential ecological risks to benthic invertebrates and the animals that feed on them. The action would also beneficially reduce potential scour within the river, further protecting water resources.

Conversely, the action would result in potential adverse impacts on the aquatic ecosystem by inhibiting the burrowing of benthic organisms, which could result in reduced abundance and biodiversity.

Capping would not impact known threatened, endangered, or rare species or wildlife resources in need of management, and would therefore comply with Tennessee Code Annotated (TCA) 70-8-103 and 50 CFR 17. As described in Section 1.1.8, several such species could be present in the river system, although none have been found to occur specifically in the areas of the Emory and Clinch Rivers to be capped. Conversely, capping may benefit these species by reducing contact with ash-contaminated sediment and reducing sediment scour.

Because capping actions would occur predominantly in and below the water surface, other action-specific ARARs regarding site preparation, construction, and excavation activities and/or waste characterization, storage and disposal activities would not be invoked.

Effectiveness over the long term. Alternative 2 would be partially effective over the long-term. Biota exposure in capped areas would be eliminated following cap placement, and levels of arsenic and selenium in benthic organisms would rapidly decline thereafter. Benthic communities would become re-established within a year or so, similar to the re-establishment of benthic communities following the time-critical removal action, although the cap materials may inhibit burrowing of benthic organisms. Outside of the capped areas where exposures are lower, natural processes of scour and deposition would occur gradually over time. RAOs would be achieved once average concentrations across a river transect have declined to levels below the selected RG/TMEs. Long-term effectiveness is further discussed below.

- Effectiveness in preventing direct contact. The purpose of the cap is to eliminate biouptake by benthic invertebrates of arsenic and selenium from ash-contaminated sediment by preventing the organisms from coming into contact with the ash. The area to be capped includes areas where the ash deposits are at least 6 inches thick based on practical measurement of deposit thickness. Because the organisms typically burrow up to 6 inches into the sediment, the 6 inches of cap would effectively prevent direct contact with ash-contaminated sediment. The coarse cap materials, varying from 1/4- to 1-inch size, would also discourage burrowing.

  Benthic organisms would continue to be in direct contact with thinner ash deposits outside of the cap limits, reducing the effectiveness of the alternative. However, biouptake would be limited in these areas because (1) burrowing organisms would also contact underlying sediment, effectively reducing their exposure, and (2) natural sedimentation processes would continue to deposit native sediment on top of the thin ash deposits, further reducing their exposure.

- Effectiveness of scour protection. The cap protection would be effective so long as the cap materials remain in place. The ERDCWES has performed baseline fate and transport modeling of bed shear to determine the grain size needed for the cap material in each area of the lower Emory and Clinch Rivers to protect the cap from scour. The conceptual cap material would be sized to effectively prevent erosion of the cap material up to a 25-year storm event, or 150,000 cfs river flow. However, effectiveness of the cap would be severely limited if a greater storm event were to occur. Because the ash-related constituents are metals that would not degrade over time, the long-term protectiveness of a cap could be reduced if severe storm events result in scouring of areas of the cap.

- Reliability of capping for long-term protection. There is uncertainty in the long-term effectiveness of capping. As noted above, severe storm events could result in scour of the thin cap, exposing the ash to contact by benthic organisms. Anthropogenic activities, such as channel dredging or anchoring of boat anchors could damage the integrity of the cap. Some organisms may burrow through the coarse cap to underlying substrate, where they could contact the ash. Ash particles, due to their very fine grained particle size, could migrate through the coarse cap materials. Contingent actions, including restrictions on dredging tolerances, placement of an intermediate sand blanket, or repair of the cap by placement of additional cap material could be implemented to mitigate these uncertainties.

- Effectiveness of risk reduction. The capped area, approximately 200 acres for Alternative 2a and 160 acres for Alternative 2b, represents only a portion of the riverbed area in the reaches to be covered, but virtually all of the area of ash-contaminated sediment contributing to risk. Where ash deposits are thin (less than 6 inches thick), risks to benthic invertebrates would be minimal, because the organisms typically burrow up to 6 inches into the sediment and would therefore be exposed to both ash and native sediment.

  Benthic invertebrate populations would become re-established and risks to benthic invertebrates would be reduced relatively quickly. In capped areas, benthic invertebrate exposure to ash-contaminated sediment in capped areas would be substantially reduced immediately following cap placement. Levels of arsenic and selenium in benthic organisms would rapidly decline thereafter, within a few years, as individual organisms complete their annual life cycle. Outside of the capped areas where exposures are lower, natural processes of scour and deposition would occur, gradually mixing materials at the surface of the riverbed over time. Average concentrations of arsenic and selenium across a river transect would decline to levels below the selected RGs within a few years, based on the limited areal extent of uncapped areas, as long-term scour/sedimentation processes take place. Capping would therefore effectively meet RAOs for protection of benthic invertebrates, as long as the cap remains in place.

  Risks to birds that feed on benthic organisms would also be reduced relatively quickly, as the ash-related constituent concentrations in benthic invertebrate tissue decline to below the selected RGs. While levels of arsenic and selenium may remain high in adult birds, average levels across the population would decline as individual organisms complete their life cycle. Predicted rates of decline suggest TMEs would be achieved within a few years. Capping would therefore effectively meet RAOs for protection of invertebrate-feeding birds.

- Reliability of transport modeling and risk reduction estimates. Transport modeling was used in establishing conceptual cap material sizes based on conceptual design storm events. This conceptual design would be further developed during final design activities. As a result, there is relatively low uncertainty in the transport model results.

  Risk reduction estimates are based on conceptual limits of capping, and reduction in bioaccumulation across the receptor population. Limits of capping would be further evaluated during final design of this alternative through additional vibracore sampling. Reduction in bioaccumulation in the benthic invertebrate community would be proportional to the area capped and to the declining concentrations of arsenic and selenium in uncapped areas, and would be confirmed over time by monitoring. As a result, there is low uncertainty in the risk reduction estimates.

- Effectiveness and reliability of sediment and biota monitoring. Similar to Alternative 1, the monitoring of sediment and biota would be effective and reliable. Monitoring would use proven techniques, resulting in reliable data quality.

Effectiveness over the short term. Alternative 2 would be effective over the short term, although short-term impacts would occur during construction and for a year or so afterwards as benthic invertebrate communities become re-established. RAOs would therefore be achieved within a few years after construction is complete.

Short-term impacts to the environment could occur as a result of placing nearly 129,000 to 161,000 cy of cap material under water over a 18 to 22 month period (Alternatives 2b and 2a, respectively). Existing benthic invertebrate communities beneath the cap would be smothered by the cap materials. Although the benthic invertebrate community was found to rebound quickly following the time-critical dredging activities, rebound in capped areas may be inhibited by the cap itself, which would discourage burrowing and provide a poor substrate for benthic invertebrates. The cap design would attempt to balance trade-offs between the ability of the cap to sustain itself from erosion and its ability to sustain the benthic invertebrate community. Other cap materials were considered that would provide better substrate, but would not provide adequate erosion protection.

Under Alternative 2b, targeted capping would not cap areas where bed shear is less than 1.6 Pa, which would be resistant to scour during storm events. These areas are typically located near shore where biological activity is most abundant. As a result, targeted capping would limit disturbance to ecological resources.

Placement of cap materials would disturb ash and sediment on the riverbed, which could result in short-term turbidity impacts on water quality. These impacts would be mitigated through use of placement techniques that minimize disturbance, such as broadcast capping, underwater discharge of materials from clamshells, or tremie techniques; and through use of proper engineering controls, such as silt controls and turbidity monitoring during cap placement. Water quality impacts would be much less than those experienced during the time-critical dredging activities, which rarely exceeded TWQC.

Impacts on the public during construction would be negligible. Recreational river traffic would be controlled to avoid interference with barge traffic and cap placement operations, but such controls would impact only a small portion of the river at any given time and not require closing of the river to recreational boaters. Short-term impacts to water quality during construction would be minor and would not pose unacceptable risk to the public during swimming, fishing, or other recreational use of the river.

Because ash and sediment would not be excavated, workers would not be exposed to the ash-related constituents. Short-term risks to workers would include conventional construction-related risks associated with operation of heavy machinery and equipment and bulk material handling, especially over water. Engineering measures would be implemented to protect remediation workers, including Occupational Safety and Health Administration (OSHA) health and safety measures, such as PPE, water safety procedures, and construction safety program.

Inherent short-term risks would be associated with hauling of the cap material over public roadways, loading onto barges, and transport to the placement location. Short-term risks of traffic accidents would be proportionate to the number of truck trip-miles, which would be small due to the availability of local quarries. Assuming a travel distance from the quarry of less than 10 miles one way, hauling 161,000 cy of material to the Site would involve 8,900 round trips over public roadways. Estimates of the potential number of accidents, injuries, and/or fatalities were made based on rate information for truck transport (U.S. Department of Transportation [DOT] 2011). Rates for accidents, injuries and fatalities were multiplied by the number of truck miles. Due to reporting differences, the number of accidents does not necessarily correlate to the number of injuries or fatalities, since not all accidents result in an injury or fatality, nor are all injuries or fatalities a result of vehicle collisions. These calculations resulted in an estimate of less than one truck accident, with no injuries or fatalities.

<u>Implementability</u>

Alternative 2 would be implementable within 18 to 22 months following design of the removal action. Capping would involve use of conventional equipment and earthmoving operations, so that specialty contractors would not be required. Control of river traffic during construction would require relatively minor administrative control.

Implementation would require particular care in placement of the cap materials. Difficulties would be expected in placing the materials on the riverbed while limiting the disturbance of sediment and limiting turbidity. Difficulties would also be expected in placing the cap to a uniform thin layer underwater, since visibility would be impaired. These difficulties would be mitigated through use of proper work planning and training in underwater placement, monitoring of water quality, and frequent surveys using bathymetric soundings to verify cap thickness.

Implementation of MNR activities following capping would be similar to Alternative 1. Monitoring of sediment and biota are proven technologies that have been used extensively at the Site. Fate and transport modeling is also a proven technology and current models have already been calibrated for site-specific bathymetry and ash deposit locations. No specialty contractors would be required; TVA maintains a pool of qualified laboratories for analysis of samples.

O&M activities would include routine monitoring of sediment and biota, fate and transport modeling, and residual risk evaluation. For cost estimating purposes, a monitoring period of 30 years has been assumed. Long-term O&M would include routine inspection and surveying of the cap to verify it remains in place, particularly following major storm events, and repair or replacement of the cap as required. For cost estimating purposes, a cap maintenance period of 30 years has been assumed for long-term O&M.

Long-term institutional controls would be required under Alternative 2 to prevent damage to the cap. Restrictions would be placed on dredging tolerances during maintenance of the navigational channel.

Cost

Capital costs associated with implementing Alternative 2 are estimated at $31.9 million for Alternative 2a and $25.9 million for Alternative 2b. Ongoing O&M costs are estimated at $747,000/year (2012 dollars) for up to 30 years. Costs of other monitoring are estimated at $290,000/year for up to 5 years. Total present worth of capital, O&M, and other monitoring costs is $44.8 million for Alternative 2a and $38.7 million for Alternative 2b, for a 3- to 5-year monitoring period and 30-year cap maintenance period.

6.1.3 Alternative 3: Dredging and MNR

Effectiveness

Alternative 3 would meet RAOs. The dredge-able ash deposits within the river system would be removed. Any residual ash deposits would gradually reduce through natural processes of scour and sediment deposition. Biouptake of arsenic and selenium in benthic invertebrates would correspondingly decrease, so as to restore the ecological function and recreational use of the river system to pre-release conditions. Monitoring would be used to demonstrate that these processes are occurring. As a result, the terms of both the TDEC Commissioner's Order and the EPA Order would be met.

Overall protectiveness. Alternative 3 would be protective of both human health and the environment. Results of the BHHRA concluded that there is no risk to human health from ash-related constituents, so that no removal action is needed for protection of human receptors. Results of the BERA concluded that there is low risk to benthic invertebrates and animals that feed on them due to uptake of arsenic and selenium in their diet. Removal of ash deposits greater than 1 ft in thickness would reduce the total volume of ash in the river system by 80% and reduce the area extent of residual ash deposits by half. Subsequent scour and sedimentation processes would result in mixing of ash and natural sediments within the upper 6 inches of sediment. Percentage of ash in the sediment, concentrations of arsenic and selenium in the sediment, and biouptake by benthic invertebrates would therefore decline over time. Consequently, risks due to ash-associated constituents would be reduced immediately and subsequently eliminated gradually over time. However, dredging would result in substantial short-term impact to the environment, since the activity would greatly disturb the aquatic ecosystem. Existing benthic invertebrate communities within the dredged areas would be virtually eliminated by dredging. Dredging would result in short-term turbidity and suspended solids impacts on water quality near the dredging operations and could expose cesium-137 contaminated sediments to the aquatic environment.

Compliance with ARARs. Alternative 3 would comply with all ARARs, as listed in Appendix F. Natural recovery of the rivers would gradually restore waters of the state for fish and aquatic wildlife and recreation in compliance with Tennessee rule 1200-4-3 and associated ARARs. Removal of ash-contaminated sediment from the river system would restore waters of the state and the associated floodplain and wetland areas impacted by the ash in compliance with TDEC 1200-4-3 and associated ARARs. Removal of the ash would remove the ash-related constituents that could produce toxic effects on wildlife resources. Water quality would be restored to meet TWQC in surface water. Waters would therefore not contain residual pollutants from the ash that may impair the usefulness of the river water as a source of domestic or industrial water supply, recreation, or irrigation, or that may impair the health of fish or aquatic life.

Dredging would involve activities within the floodplain, invoking location-specific ARARs. The action would need to comply with TVA Instruction (Section IX Environmental Review) and with substantive requirements of 40 CFR 230 and of the Nation Wide Permit (33 CFR 323). Dredging would need to comply with the substantive requirements of the ARAP, per Tennessee rule 1200-4-7. Because the action would modify the water body, the effects on fish and wildlife resources and their habitat must be considered, in compliance with the Fish and Wildlife Coordination Act (16 USC 661 et seq.). The removal of up to 440,000 cy of material would beneficially result in an increase in reservoir storage capacity (although negligible), and would not adversely impact flood elevations or velocities. The action would benefit fish and wildlife resources by reducing potential ecological risks to benthic invertebrates and the animals that feed on them. Conversely, the action would result in potential short-term adverse impacts on the aquatic ecosystem by eliminating benthic organisms in the dredged area, but these resources would be expected to quickly rebound, as seen during the time-critical removal action. The action could also result in potential long-term adverse impacts on the aquatic ecosystem by exposing sediments containing cesium-137, PCBs, or mercury, although these sediments are at depth and natural sedimentation processes would be expected to re-establish a native sediment cover gradually over time.

Dredging would not impact known threatened, endangered, or rare species or wildlife resources in need of management, and would therefore comply with TCA 70-8-103 and 50 CFR 17. As described in Section 1.1.8, several such species could be present in the river system, although none have been found to occur specifically in the areas of the Emory and Clinch Rivers to be dredged. Conversely, dredging may benefit these species by reducing contact with ash-contaminated sediment.

Management of dredged spoils would invoke other action-specific ARARs regarding site preparation, construction, and excavation activities and waste characterization, storage and disposal activities. Site preparation, construction, and excavation activities would be conducted in compliance with TDEC 1200-3-8, TDEC 1200-1-7, and TDEC 1200-4-10, including precautions to control fugitive dust emissions, erosion, and sedimentation. The requirements of General Permit No. TNR10-0000 Section 4.3.2 would apply to stormwater discharges from construction activities as "To Be Considered" guidance. Treatment of wastewater generated from the dewatering of dredged material would need to comply with the requirements of 40 CFR 122 and 125. Dredged material removed from the river system would not be placed into an aquatic ecosystem, in compliance with 40 CFR 230.10(a).

Excavated ash would be characterized, managed and disposed in compliance with 40 CFR 262.11 and TDEC 1200-1-11. Excavated ash would be stored temporarily in staging piles in a previously uncontaminated area, requiring specific containment and management controls in accordance with 40 CFR 264. ARARs pertaining to generation and storage of used oil would be applicable per 40 CFR 279 and TDEC 1200-1-11. Because ash would be disposed offsite, ARARs pertaining to offsite disposal or transportation of hazardous materials would be applicable per 40 CFR 268, 49 CFR 171, 40 CFR 261, and 40 CFR 262.

Effectiveness over the long term. Alternative 3 would be effective over the long term. Removing the ash from the river system would be a permanent action that would effectively restore the waters of the state and eliminate migration of that ash further downriver. Biota exposure in dredged areas would be greatly reduced, but not fully eliminated, following dredging. MNR would consist of permanent and irreversible processes of scour and sedimentation to address residual undredged ash and ash outside of the dredged areas. Over the long-term, MNR would gradually eliminate direct contact of benthic invertebrates with arsenic and selenium in the ash and biouptake from ash-contaminated sediment to riparian- and aerial-feeding birds. RAOs would be achieved once average concentrations across a river transect have declined to levels below the selected RG/TMEs, over a period of several years. Long-term effectiveness is further discussed in the following paragraphs.

- Effectiveness of dredging. Dredging would involve the permanent and irreversible removal of ash-contaminated sediment. Experience gained during the time-critical removal action demonstrated that precision dredging is effective and reliable in removing large quantities of retrievable ash (Jacobs 2011b). Precision dredging was aimed at thinner layers of ash (generally less than 10 ft thick) using equipment that could allow for final cuts to the pre-release river bottom elevations. The dredging strategy balanced ash removal against native sediment removal. It was determined that positioning the cutter head at the pre-release river bed elevation would entrain the highest percentage of ash, while minimizing the uptake of native sediment. Field adjustments were made by incrementally raising or lowering the cutter head in response to changing field conditions, such as encountering bedrock or native material. This strategy minimized the disturbance of native sediment and maximized the removal of ash. Over-dredging of native sediment would be particularly undesirable in the lower Emory and Clinch Rivers due to the presence of cesium-137, PCBs, PAHs, mercury, and other legacy contaminants in underlying sediments that are not related to the ash release.

  The dredges during the time-critical removal action used a cutter head with variable speed operation and with a boom long enough to reach the final depth required. The cutter head was positioned with a global positioning system operated onboard to maintain dredging within the specified limits. Precision was improved by use of an eTrak system on some of the dredges to control the cutter heads to the target river bottom elevations. Both swing and target depths were automated so that dredged elevations were within approximately 1 ft of the target elevations. Additional precision was not feasible due to inherent mechanical limitations of cables and hydraulics at the end of a 50-ft boom, with boat tilt and wave action. These techniques would be applied to the non-time-critical removal action in the lower Emory and Clinch Rivers to improve effectiveness of dredging; however, residual ash lenses about 1 ft in thickness would likely remain over half of the dredged area.

- Effectiveness of dredged spoils management. Dredged ash processing would consist of gravity settlement followed by windrow drying, processes that were used during the time-critical removal action and were demonstrated to be effective and reliable. Gravity settling ponds for the non-time-critical removal action would be much smaller than the Rim Ditch/Sluice Trench/Ash Pond series of ponds used during the time-critical removal action; however the dredging rates would be substantially lower. The ponds would be designed to be more efficient in layout and operation, since they would be new construction, rather than retrofit of existing facilities. Conceptual design, described in Section

5.2.3, estimates incoming dredged spoils at up to 1,250 cy/day and up to 20% solids would be effectively clarified to 60% solids following gravity settling.

Solids removed from the gravity settling ponds would be further processed by piling the material in windrows, which would be successively turned to facilitate drying. Experience gained during the time-critical removal action demonstrated that windrow drying is effective and reliable in achieving moisture contents in the processed ash suitable for offsite shipment and disposal. However, effectiveness of drying could be severely impacted during periods of extended inclement weather. Contingent actions, including use of superabsorbent polymers or lime treatment, could be used to enhance effectiveness of drying. Conceptual design, described in Section 5.2.3, estimates retrieved ash at up to 1250 cy/day would be effectively dried to less than 30% moisture following ash processing.

- Effectiveness of disposal. Offsite disposal would be at existing, permitted solid waste facilities. Each landfill would operate under the restrictions of its specific permit, including waste acceptance criteria, groundwater protection systems, leachate collection and treatment systems, interim and final cover, and other terms of the operating permit. Offsite disposal would therefore be effective in providing permanent containment of the retrieved ash. EPA and TDEC would need to approve the specific landfill prior to shipment of any ash.

- Effectiveness of scour and sedimentation processes. Following dredging, residual undredged ash and ash outside of the dredged areas would be addressed by MNR processes of scour and sedimentation to further reduce ash content in the sediment. Similar to Alternative 1, The ERDCWES has performed baseline fate and transport modeling of the Emory and Clinch River sediment to evaluate the long-term effectiveness. Results of that modeling (ERDCWES 2012) indicate that over the long term natural sediment dynamic processes would be effective in producing a natural cover over any residual ash deposits, with declining concentrations in arsenic and selenium. Periodic severe storm flow events would be expected to result in scouring portions of this natural cover, exposing deeper sediments; however, the natural cover would redevelop. Because residual ash deposits would be less than 1 ft thick, impact of any severe storm flow event is expected to be minor.

- Effectiveness of risk reduction. Based on the results of the ERDCWES transport modeling, estimates were made of the rate of decline in arsenic and selenium concentrations in sediment and benthic organisms. These estimates assumed average concentrations for ash and native sediment as independent matrices, then predicted changes in concentrations based on the mixing of these matrices over time as a result of scour and deposition processes. Estimates of biouptake assumed that bioaccumulation is proportional to the change in constituent concentration in sediment, consistent with bioaccumulation factors used in the BERA.

  The BERA concluded there is a moderate risk to benthic invertebrates due to exposure to arsenic and selenium in sediment. Risks to benthic invertebrates would gradually reduce over time as ash-related constituent concentrations in sediment decline to below the selected RGs. Short-term scour events would have little likelihood of increasing risks over the long term. MNR would therefore effectively meet RAOs for protection of benthic invertebrates.

  The BERA has concluded there is a low risk to birds that feed on benthic organisms. These low risks would further reduce over time, as ash-related constituent concentrations in benthic invertebrate tissue decline to below the selected TMEs. MNR would therefore effectively meet RAOs for protection of invertebrate-feeding birds

- Reliability of transport modeling and risk reduction estimates. Similar to Alternative 1, results of the transport modeling are considered reasonable predictions of overall trends in the river system, based on well-known geomorphological processes. Reliability of the transport model would be further improved by updating the sediment fate and transport modeling every 5 years to forecast future recovery rates, using updated bathymetry and ash deposit locations.

  There is considerable uncertainty in the prediction of future mass transport and rate of concentration decline. Temporal trends in percent ash or arsenic/selenium concentrations cannot be ascertained from historical sampling events due to the short period since time-critical dredging has ceased. Further monitoring would be used to establish these trends and monitoring results would be compared against predicted rates of natural recovery, in particular, the predicted rate of reduction in ash content and the predicted rate of reduction in arsenic and selenium concentrations both in sediment and in benthic invertebrate tissue.

- Effectiveness and reliability of sediment and biota monitoring. Similar to Alternative 1, the monitoring of sediment and biota would be effective and reliable. Monitoring would use proven techniques, resulting in reliable data quality.

Effectiveness over the short term. Alternative 3 would be effective over the short term, although short-term impacts would occur during the estimated 22 months of dredging operations for Alternative 3a and 8 months for Alternative 3b. Following dredging, natural processes would occur gradually over time, so that RAOs would only be achieved over the long term, once concentrations have declined to levels below the selected RG/TMEs, a process expected to occur in less than 10 years.

Short-term impacts to the environment could occur as a result of dredging. Existing benthic invertebrate communities within the 130-acre dredged area would be virtually eliminated by the dredging. However, the benthic invertebrate community was found to rebound quickly following the time-critical dredging activities (within one year); similar rapid rebound would be expected for this non-time-critical action, minimizing the magnitude of any short-term impacts. Impacts would not be substantially less for Alternative 3b, even though the disturbed area would be less (50 acres), because dredging would coincide with the area of ecological significance where the benthic community is most abundant.

Dredging of ash and sediment would greatly disturb the riverbed, which would likely result in short-term turbidity impacts on water quality. During the time-critical removal action, turbidity monitoring within the downstream plume showed that over 40% of the samples collected from the dredge plumes exceeded the TWQC for arsenic in samples; other metals had infrequent exceedances (Jacobs 2011b). Similar dredge plume impacts would be expected under non-time-critical dredging, although the size of the dredge plume would be much smaller, since only one dredge would operate at any given time in the river. These impacts would be mitigated through use of proper engineering controls, such as silt controls and turbidity monitoring during dredging.

Dredging would greatly increase the potential exposure of underlying sediments containing cesium-137, mercury, PCBs, or other legacy constituents not related to the ash. There is a DOE Record of Decision in place for the Clinch River (DOE 1997) and for the Lower Watts Bar Reservoir, downstream in the Tennessee River (DOE 1995), which establishes that the sediment not be removed because there is more risk from removing it than leaving it in place due to high rates of sediment resuspension and impacts to the benthic invertebrate population.

Impacts on the public during construction would be negligible. Recreational river traffic would be controlled to avoid interference with barge and dredge operations, but such controls would impact only a small portion of the river at any given time and not require closing of the river to recreational boaters.

Public access to the dredge plume area would be restricted, so any short-term impacts to water quality during construction would not pose unacceptable risk to the public during swimming, fishing, or other recreational use of the river further downstream.

Workers would be exposed to ash-related constituents during material handling operations on shore. Short-term risks to workers would include direct contact with hazardous substances, potential air inhalation, and conventional construction-related risks associated with operation of heavy machinery and equipment and bulk material handling, especially over water. Engineering measures would be implemented to protect remediation workers and the community, including (1) OSHA health and safety measures, such as use of PPE, air monitoring, water safety procedures, and construction safety program; (2) transportation control measures, such as placarding, lining, and shipping in accordance with DOT regulations, to protect the community and minimize spills; and (3) dust control and erosion and sediment control measures, such as sediment basins, check dams, temporary seeding, diversion berms, interceptor trenches, silt fences, and erosion protection blankets, to minimize erosion and transport of the ash during construction.

Inherent short-term risks would be associated with shipment of the material over public railways or roadways. Short-term risks of traffic incidents or truck-vehicle intersection accidents would be proportionate to the number of trip-miles. Disposal of materials has been assumed to occur at Chestnut Ridge landfill in Anderson County, Tennessee, approximately 50 miles from the Site, and is accessible by truck hauling over public roadways. Assuming a 18-cy truck capacity, hauling 440,000 cy of material to the Chestnut Ridge landfill would involve nearly over 2.4 million round trip-miles over public roadways.

Estimates of the potential number of transportation-related accidents, injuries, and/or fatalities were made based on rate information for truck transport (DOT 2011). Rates for accidents, injuries and fatalities were multiplied by the number of truck round trip-miles. Due to reporting differences, the number of accidents does not necessarily correlate to the number of injuries or fatalities, since not all accidents result in an injury or fatality, nor are all injuries or fatalities a result of vehicle collisions. For disposal at the Chestnut Ridge landfill, these calculations resulted in an estimate of potentially two truck accidents, with no injuries or fatalities. For Alternative 3b, less hauling would result in an estimate of less than one truck accident.

Other disposal options would greatly affect these short-term risk estimates. The Energy Solutions Landfill, which is located in Clive, Utah, approximately 2,000 miles from the Site, and is accessible by rail. Estimates of the potential number of transportation-related accidents, injuries, and/or fatalities were made based on rate information for rail transport obtained from Argonne National Laboratory (2009). Assuming average 80-car trains having 5,040 cy capacity, hauling ash to the Energy Solutions Landfill would involve over 170,000 trip-miles by rail. Transportation risk calculations would result in an estimate of one rail accident, with one potential injury and no fatalities.

Implementability

Alternative 3a would be implementable within 25 months following design of the removal action (including 3 months for infrastructure construction and 22 months for dredging operations); Alternative 3b within 11 months (3 months for infrastructure and 8 months for dredging). MNR would continue for several years thereafter. Conventional materials, equipment, or services would be available for excavation/dredging, ash processing, and hauling for disposal. Similar construction equipment was used in implementing portions of the time-critical removal action, demonstrating that the removal action would be implementable and providing valuable lessons learned for design of the non-time-critical removal action. However, significant challenges would be anticipated in implementing the alternative.

Excavation of ash would be complicated by the need to coordinate dredging in shallow water areas with fluctuations in reservoir levels. Dredges and barges with shallow draft depth would be used since the shallow depth of water would preclude use of larger dredges. Dredging in shallow water areas would be implemented during summer months when reservoir levels are highest.

Properties of the fine-grained ash would complicate ash dewatering. Experience gained during the time-critical removal action has shown that wetter material at depth or material that becomes wetter as a result of sustained rainfall is difficult to dewater. For optimum material handling and shipping, the moisture content must be reduced from over 100% moisture in the dredge spoils to less than 30% moisture in the transport vehicle. Wet ash processing areas would be needed to temporarily disk, blade, or turn the ash in piles or windrows to facilitate drying by evaporation. Use of polymer absorbents or lime treatment may be needed as contingent actions to absorb water that may rise to the top of the truck or rail car bed as a result of vibrations during shipment, and would be disposed with the ash.

Transportation of the ash would be complicated by the large volume of material and limited disposal options. For Alternative 3a, transport by truck would require 24,000 truckloads hauling an average of 10 hours/day for 22 months. Transport by rail would require approximately 87 trainloads averaging 5,040 cy per train and hauling once a week for 22 months. For Alternative 3b, these impacts would be a third of those for Alternative 3a due to the lower volume of material.

The greatest difficulty in implementing Alternative 3 would be the availability of suitable disposal facilities due to potential cesium-137 contamination in the ash. The ash is non-hazardous waste material, as evidenced by the results of routine TCLP testing during the time-critical removal action (Jacobs 2011b). But areas downstream of ERM 2.0 may contain cesium-137 at radioactivities up to 18 pCi/g. These materials would have to be disposed at specific landfills able to accept them as low level radioactive waste.

TDEC's Division of Radiological Health has developed a BSFR program as a licensed process to analyze bulk materials (such as soil and sediment) with low levels of radioactive contamination for disposal in specified Class I landfills. Four licensees in Tennessee are currently authorized to conduct the BSFR program: IMPACt, Studsvik-RACE, Toxco, and Duratek/Energy Solutions. There are four Class I landfills in Tennessee authorized to receive wastes under the BSFR program: Chestnut Ridge landfill facility in Anderson County, Carter Valley landfill in Hawkins County, and the North Shelby County and South Shelby County landfills in Shelby County. Conceptual design has assumed disposal at the Chestnut Ridge landfill in Anderson County. Before being transported to the BSFR facility, the recovered ash material would be evaluated at the Kingston site to ensure the material does not exceed predetermined limits set by the BSFR program. Upon receipt at the BSFR facility, the material would pass through detection monitors and would be sampled and analyzed for compliance with BSFR waste acceptance criteria. The BSFR waste acceptance criteria are conservative: BSFR waste cannot contribute more than 5% of the total landfill waste, and it cannot contribute a dose of more than one millirem per year to any member of the public. Waste shipments meeting the BSFR waste acceptance criteria would then be transported from the BSFR facility to the landfill.

Any material that does not meet the strict requirements of Tennessee's BSFR program would need to be disposed of in a licensed radioactive waste facility. Therefore, implementation of this alternative has also considered disposal at the Energy Solutions Landfill in Clive, Utah, which is able to accept cesium-137 contaminated waste materials. Alternate facilities may also become available. The DOE operates an EMWMF in Oak Ridge, Tennessee; because the cesium-137 contamination is the result of former DOE operations, that facility may be able to accept waste from TVA's ash recovery operations.

Regulatory and/or public opposition to use of a particular disposal facility would complicate implementability of these disposal options. There is therefore uncertainty as to whether sufficient offsite disposal capacity is available.

Implementation of dredging in the lower Emory River and in the Clinch River would be a substantive change from the approved Record of Decision for the Clinch River (DOE 1997). Any such change would require negotiation for concurrence with DOE and EPA before any change could be implemented.

Implementation of MNR activities following dredging would be similar to Alternative 1. Monitoring of sediment and biota are proven technologies that have been used extensively at the Site. Fate and transport modeling is also a proven technology and current models have already been calibrated for site-specific bathymetry and ash deposit locations. No specialty contractors would be required; TVA maintains a pool of qualified laboratories for analysis of samples.

O&M activities would include routine monitoring of sediment and biota, fate and transport modeling, and residual risk evaluation, until RG/TMEs for arsenic and selenium in sediment and benthic invertebrate tissue have been met. For cost estimating purposes, a monitoring period of 30 years has been assumed. No long-term institutional controls would be required under Alternative 3.

Cost

Capital costs associated with implementing Alternative 3 are estimated at $169.4 million for Alternative 3a and $73.7 million for Alternative 3b. Ongoing O&M costs are estimated at $543,000/year (2012 dollars) for up to 30 years. Costs of other monitoring are estimated at $290,000/year for up to 5 years. Total present worth of capital and O&M costs is $179.1 million for Alternative 3a and $83.4 million for Alternative 3b, for a 30-year monitoring period.

Cost of disposal of any cesium-137 contaminated waste material is highly uncertain. Capital costs for Alternative 3 have been estimated based on disposal at the Chestnut Ridge Landfill in Anderson County, Tennessee, at a cost of $333/cy for transport and disposal. However, costs could range from as low as $14/cy for transport and disposal at the DOE EMWMF in Oak Ridge, Tennessee, to as much as $700/cy for transport and disposal at the Energy Solutions Landfill in Clive, Utah.

6.2 COMPARATIVE ANALYSIS OF ALTERNATIVES

This section evaluates the relative performance of each alternative in relation to each of the criteria presented in Section 4.1. The purpose of this comparative analysis is to highlight the advantages and disadvantages of each alternative relative to one another so that key tradeoffs that would affect the remedy selection can be identified. Table 6-1 summarizes the comparative analysis of alternatives for each of the evaluation factors.

6.2.1 Effectiveness

Each of the three alternatives would meet RAOs. Under Alternative 1, the ash deposits within the river system would gradually reduce in thickness through natural processes of scour and sediment deposition. In Alternative 3, most of the ash deposits would initially be removed, while residual ash deposits would gradually reduce in thickness similar to Alternative 1. Biouptake of arsenic and selenium in benthic macroinvertebrates would correspondingly decrease, so as to restore the ecological function and recreational use of the river system to pre-release conditions. Monitoring would be used to demonstrate that these processes are occurring. Under Alternative 2, the ash deposits within the river system would be covered, so as to protect ecological receptors and restore river use. Monitoring would be used to demonstrate that the cap is functioning as intended. As a result, the terms of both the TDEC Commissioner's Order and the EPA Order would be met under each alternative.

Overall Protectiveness. Each of the alternatives would be protective of both human health and the environment. Results of the BHHRA concluded that there is no risk to human health due to ash-related constituents, so that no removal action is needed for protection of human receptors. Results of the BERA concluded that there is relatively low risk to benthic invertebrates and birds that feed on them due to uptake of arsenic and selenium in their diet. Under Alternative 1, scour and sedimentation processes would result in mixing of ash and natural sediments within the upper 6 inches of sediment. Percentage of ash in the sediment, concentrations of arsenic and selenium in the sediment, and biouptake by benthic invertebrates would therefore decline. Consequently, risks would be eliminated gradually over time. MNR would result in little short-term impact to the environment, since there would be no activity conducted in the river to disturb the aquatic ecosystem. Alternative 1 would likely achieve mixed sediment accumulation greater than 6 inches in 10 to 15 years; however, nearly 30 years may be required to fully achieve RAOs, depending on effects of severe storm flow events.

Under Alternative 2, Capping of ash deposits greater than 6 inches in thickness would eliminate direct contact with much of the exposed ash deposits and would reduce potential scour during flood events that would otherwise expose deeper ash deposits. Consequently, risks would be substantially eliminated in capped areas. However, capping would result in substantial short-term impact to the environment, since the activity would greatly disturb the aquatic ecosystem. Existing benthic invertebrate communities beneath the cap would be smothered by the cap materials. The cap materials would consist of gravel-sized particles to resist scour; however, those materials would inhibit burrowing of benthic organisms, which could result in reduced abundance and biodiversity.

Under Alternative 3, removal of ash deposits greater than 1 ft in thickness would reduce the total volume of ash in the river system by 80% and reduce the area extent of residual ash deposits by half. Subsequent scour and sedimentation processes would result in mixing of any residual ash and natural sediments within the upper 6 inches of sediment. Percentage of residual ash in the sediment, concentrations of arsenic and selenium in the sediment, and biouptake by benthic invertebrates would therefore decline over time. Consequently, risks would be reduced immediately and subsequently eliminated gradually over time. However, dredging would result in substantial short-term impact to the environment, since the activity would greatly disturb the aquatic ecosystem. Existing benthic invertebrate communities within the dredged areas would be virtually eliminated by dredging. Dredging would result in short-term turbidity and suspended solids impacts on water quality near the dredging operations.

Compliance with ARARs. Each of the alternatives would comply with ARARs, as listed in Appendix F. Under all three alternatives, natural recovery of the rivers would gradually restore waters of the state for fish and aquatic wildlife and recreation in compliance with Tennessee rule 1200-4-3 and associated ARARs. Under Alternative 1, no location- or action-specific ARARs would be invoked because only monitoring activities would be conducted within the rivers.

Under Alternatives 2 and 3, capping and dredging would involve activities within the floodplain, invoking location-specific ARARs. The actions would need to comply with TVA Instruction (Section IX Environmental Review) and the substantive requirements of the ARAP, per Tennessee rule 1200-4-7.

Table 6-1 Summary of Comparative Analysis of Alternatives

	Alternative 1 **Monitored Natural Recovery**	**Alternative 2** **In-Situ Capping with MNR**	**Alternative 3** **Dredging with MNR**
Effectiveness			
Overall Protectiveness	Protective; scour and sedimentation processes reduce exposure gradually over time.	Protective; ash covered to eliminate exposure as long as cap remains in place.	Protective; ash removed over much of area; scour and sedimentation processes further reduce exposure over time.
Compliance with ARARs	Complies with ARARs for restoration of waters of state. No location- or action-specific ARARs invoked.	Complies with ARARs for restoration of waters of state; placement of materials in waters of state invoke location-specific ARARs for floodplains and wetlands/	Complies with ARARs for restoration of waters of state; invokes ARARs for dust emissions & erosion control and waste handling, transportation and disposal.
Long-Term Effectiveness	Effective in naturally establishing a mixed ash and sediment cover. Severe storm flow events induce uncertainty in exposing ash, although natural cover would become reestablished.	Effective in establishing protective cover resistant to scour. High uncertainty in cap remaining in place following severe storm flow events.	Effective in removing source of exposure and naturally establishing a mixed ash and sediment cover not greatly affected by severe storm flow events.
Short-term Effectiveness	Effective in avoiding short-term impacts to environment. RAOs may not be fully achieved for nearly 30 years due to severe storm flow events.	Results in environmental impacts (turbidity, invertebrate loss), but expected to rebound quickly. Results in transportation impacts due to hauling of cap materials to the Site. Cap uncertain as suitable substrate for benthic invertebrate habitat. RAOs likely achieved in few years.	Results in environmental impacts (turbidity, invertebrate loss), but expected to rebound quickly. Controls on construction impacts (dust control, health & safety). Results in transportation impacts due to hauling of waste materials offsite. RAOs likely achieved in several years.
Implementability			
Time to Implement	Implementable immediately (no construction).	Implementable within 20 months (Alt 2a); 16 months (Alt 2b).	Implementable within18 months (Alt 3a); 6 months (Alt 3b).
Implementability of Actions	Conventional, proven technologies for monitoring and evaluation. Demonstrated previously at Site.	Conventional, proven technologies for capping. Cap covers 200 acres (Alt 2a) or 160 acres (Alt 2b). Difficulties in controlling disturbance of sediment, turbidity, placing cap to a uniform thin layer underwater. Requires long-term O&M for cap maintenance.	Conventional, proven technologies for dredging; demonstrated previously at Site. Dredging generates waste of 440,000 cy (Alt 3a) or 160,000 cy (Alt 3b). Difficulties in controlling disturbance of sediment, turbidity during dredging. High uncertainty in capacity of offsite disposal.

Table 6-1. Summary of Comparative Analysis of Alternatives (continued)

	Alternative 1 **Monitored Natural Recovery**	**Alternative 2** **In-Situ Capping with MNR**	**Alternative 3** **Dredging with MNR**
Cost			
Capital Cost	$0	$31.9M (2a) $25.9M (2b)	$169.4M (3a) $73.7M (3b)
O&M Cost	$543,000/year	$747,000/year	$543,000/year
O&M period	30 years	30 years	30 years
Other Monitoring	$339,000/year (5 years)	$290,000/year (5 years)	$290,000/year (5 years)
Total Present Worth Cost (2012 dollars)	$10.0M	$44.8M (Alt 2a) $38.7M (Alt 2b)	$179.1M (Alt 3a) $83.4M (Alt 3b)

Because these actions would modify the water body, the effects on fish and wildlife resources and their habitat must be considered, in compliance with the Fish and Wildlife Coordination Act (16 USC 661 et seq.). Both actions would benefit fish and wildlife resources by reducing potential ecological risks to benthic invertebrates and the animals that feed on them. These actions would not impact known threatened, endangered, or rare species or wildlife resources in need of management, and would therefore comply with TCA 70-8-103 and 50 CFR 17. As described in Section 1.1.8, several such species could be present in the river system, although none have been found to occur specifically in the areas of the Emory and Clinch Rivers to be capped or dredged.

Capping under Alternative 2 would need to comply with substantive requirements of 40 CFR 230 and of the Nation Wide Permit (33 CFR 323). The placement of 129,000 to 161,000 cy of material would result in negligible reduction in reservoir storage capacity. However, because the material would be located within a published floodway in the Emory and Clinch Rivers, capping could impact both flood elevations and velocities. A hydraulic analysis would have to be performed. If capping were to result in flood elevations increasing less than 0.01 ft, then a No Rise Certification would be possible; otherwise, changes to update the Roane County Flood Insurance Study would have be made including sending letters to property owners who may have increased flood risk. There would be no practical measures to minimize these floodplain impacts, since the purpose of the capping would be to contain the ash-related constituents within the sediment. The action would also beneficially reduce potential scour within the river, further protecting water resources. Conversely, the action would result in potential adverse impacts on the aquatic ecosystem by inhibiting the burrowing of benthic organisms, which could result in reduced abundance and biodiversity. Because capping actions would occur predominantly in and below the water surface, other action-specific ARARs regarding site preparation, construction, and excavation activities and/or waste characterization, storage and disposal activities would not be invoked.

Under Alternative 3, the removal of 160,000 to 440,000 cy of material would not adversely impact flood elevations or velocities. Dredging would result in potential short-term adverse impacts on the aquatic ecosystem by eliminating benthic organisms in the dredged area, but these resources would be expected to quickly rebound, as seen during the time-critical removal action. The action could also result in potential long-term adverse impacts on the aquatic ecosystem by exposing sediments containing cesium-137, although these sediments are at depth and natural sedimentation processes would be expected to re-establish a native sediment cover gradually over time.

Management of dredged spoils under Alternative 3 would invoke other action-specific ARARs regarding site preparation, construction, excavation, and waste characterization, storage and disposal activities. Site preparation, construction, and excavation activities would be conducted in compliance with TDEC 1200-3-8 and TDEC 1200-4-10, including precautions to control fugitive dust emissions, erosion, and sedimentation. Dredged material removed from the river system would not be placed into an aquatic ecosystem, in compliance with 40 CFR 230.10(a). Instead, excavated ash would be characterized, managed and disposed in compliance with 40 CFR 262.11 and TDEC 1200-1-11. Excavated ash would be stored temporarily in staging piles in a previously uncontaminated area, requiring specific containment and management controls in accordance with 40 CFR 264. Because ash would be disposed offsite under Alternative 3, ARARs pertaining to offsite disposal or transportation of hazardous materials would be applicable per 40 CFR 268, 49 CFR 171, and 40 CFR 262.

Effectiveness over the long term. Each of the alternatives would be effective over the long term, although in differing ways and to differing degrees. MNR under Alternative 1 would rely on permanent and irreversible processes of scour and sedimentation. Over the long-term, MNR would gradually eliminate direct contact of benthic invertebrates with arsenic and selenium in the ash and biouptake from ash-contaminated sediment to riparian- and aerial-feeding birds. Under Alternative 2, biota exposure in capped areas would be eliminated following cap placement, and levels of arsenic and selenium in benthic organisms would rapidly decline thereafter. Under Alternative 3, removing the ash from the river system would be a permanent action that would effectively restore the waters of the state and eliminate migration of that ash further downriver. Biota exposure in dredged areas would be greatly reduced, but not fully eliminated, following dredging. Under both Alternatives 2 and 3, following the active remediation, natural processes of scour and deposition would occur gradually over time to address any residual undredged ash or ash in areas outside of the capped or dredged areas. RAOs would be achieved once average concentrations across a river transect have declined to levels below the selected RG/TMEs, over a period of several years.

Long-term effectiveness is further discussed in the following paragraphs.

- Effectiveness of MNR processes. Alternative 1 would rely entirely on the natural reduction in arsenic and selenium concentrations in sediment through natural processes of scour and sedimentation. However, Alternatives 2 and 3 would also rely on these same processes to address residual ash. The ERDCWES performed a simulation of sediment transport over a 30-year timeframe. Results of that modeling (ERDCWES 2012) indicate that over the long term natural sediment dynamic processes yield decreasing proportions of ash and decreasing concentrations of arsenic and selenium in sediment in the Emory and Clinch Rivers. Natural sedimentation and scour processes would likely produce a layer of mixed ash and sediment approximately 6 inches thick over a period of 10 to 15 years in depositional side channel areas. This mixed ash/sediment layer has been observed in vibracore sampling performed in 2009 and 2010, confirming the model predictions. Scour and sedimentation processes would therefore be effective in producing a natural cover over any residual ash deposits, with declining concentrations in arsenic and selenium.

  The modeling also showed that periodic severe storm flow events (greater than a 10-year recurrence interval) would be expected to result in scouring portions of this natural cover, particularly in the main channel as well as some of the side channel deposits. The bulk of the residual ash would be transported downstream and out of the lower Emory and Clinch Rivers. Following such severe storm flow events, deeper sediments with potentially higher levels of ash and ash-related constituents could become exposed. However, the model predicted that ash and natural sediment mixtures would deposit in side channel areas of the Emory and Clinch Rivers, and that the natural cover of mixed ash/sediment would redevelop. Deposition rates in the Emory and Clinch Rivers averaged about 0.5 inch per year over the 30-year simulation.

  The model predicted the percentage of ash in the ash/sediment side channel deposits would gradually decrease over time with mixing and redeposition throughout the river system. Based on the model predictions, ash/sediment mixtures would contain less than 50% ash in approximately 10 years, and would continue to decline thereafter.

  These results suggest that MNR processes would be effective at naturally establishing a mixed ash and native sediment cover at least 6 inches thick that would provide suitable substrate for benthic invertebrates that would be protective against biouptake from ash-contaminated sediment. Under Alternative 1, severe storm flow events, as might occur every 10 years or so, could result in erosion of this cover; subsequent scour/sedimentation processes would reestablish the protective cover. Permanent protective cover not subject to subsequent erosion could effectively develop after several severe storm flow events have passed. Under Alternative 3, similar severe storm flow event erosion could result; however, permanent protective cover may involve but a single event, after which there would be no measurable ash deposits subject to erosion. Alternative 2 would rely on the cap as scour protection to prevent erosion of the ash deposits.

- Effectiveness in reducing risks to benthic invertebrates. The BERA concluded there is a moderate risk to benthic invertebrates due to exposure to arsenic and selenium in sediment. Results of toxicity testing have suggested statistically significant reductions in growth and biomass could occur when percent ash in the sediment results in concentrations of arsenic and selenium greater than the selected RGs.

  Under Alternative 1, risks to benthic invertebrates would gradually reduce over time as ash-related constituent concentrations in sediment decline to below the selected RGs. Based on the results of modeling, average arsenic concentrations would decline to less than the uppermost part of the RG range of 41 mg/kg in less than 12 years, and average selenium concentrations would decline to less than the uppermost part of the RG range of 3.2 mg/kg in less than 26 years. Following periodic severe storm flow events, exposures may increase briefly in some scour areas, but as the natural cover redevelops, exposure concentrations, and therefore risks, would decline. Given that baseline levels of unacceptable ecological risk are confined to few receptors and are already low, these short-term scour events would have little likelihood of increasing risks over the long term.

  Under Alternative 2, capping would reduce exposure in the area of ash-contaminated sediment contributing to risk. As a result, risks to benthic invertebrates would be reduced relatively quickly, as long as the cap remains in place. Benthic invertebrate exposure to ash-contaminated sediment in capped areas would be eliminated following cap placement. Levels of arsenic and selenium in benthic organisms would rapidly decline thereafter, within less than a year, as individual organisms complete their annual life cycle. Outside of the capped areas where exposures are lower, natural processes of scour and deposition would occur, gradually mixing materials at the surface of the riverbed over time. Average concentrations of arsenic and selenium across a river transect would decline to levels below the selected TMEs within a few years.

  Under Alternative 3, the area of ash-contaminated sediment would likely be reduced; however, to avoid over-dredging into cesium-contaminated sediment, some residual ash will likely remain even in the dredged areas. The area over which benthic invertebrates would be exposed to ash-contaminated sediment would therefore be similar to Alternative 1 immediately following dredging. Risks to benthic invertebrates would gradually reduce over time as ash-related constituent concentrations in sediment decline to below the selected RGs. Because residual ash deposits would be much thinner than current deposits, this time duration would be less than predicted for Alternative 1, over a period of several years.

- Effectiveness in reducing risks to birds. The BERA has concluded there is a low risk to birds that feed on the benthic organisms. Under Alternative 1, these low risks would further reduce over time, as ash-related constituent concentrations in sediment and correspondingly in benthic invertebrate tissue decline to below the selected TMEs. Under Alternative 2, capping would eliminate exposure of benthic organisms relatively quickly, so that risks to birds that feed on those benthic organisms would also be reduced relatively quickly. Under Alternative 3, risks would be similar to Alternative 1 immediately following dredging. However, since the thickness of residual ash deposits would be less than 1 ft, these risks would reduce over a shorter period of time, and would therefore be more effective.

- Cap effectiveness and reliability (Alternative 2). The purpose of the cap is to eliminate biouptake by benthic invertebrates of arsenic and selenium from ash-contaminated sediment by preventing the organisms from coming into contact with the ash. The area to be capped includes areas where the ash deposits are at least 6 inches thick based on practical measurement of deposit thickness. Because the organisms typically burrow up to 6 inches into the sediment, the 6 inches of cap would effectively prevent direct contact with ash-contaminated sediment. The coarse cap materials, varying from 1/4- to 1-inch size, would also discourage burrowing.

Benthic organisms would continue to be in direct contact with thinner ash deposits outside of the cap limits, reducing the effectiveness of the alternative. However, biouptake would be limited in these areas because (1) burrowing organisms would also contact underlying sediment, effectively reducing their exposure, and (2) natural sedimentation processes would continue to deposit native sediment on top of the thin ash deposits, further reducing their exposure.

The cap protection would be effective so long as the cap materials remain in place. The ERDCWES has performed baseline fate and transport modeling of bed shear to determine the grain size needed for the cap material in each area of the lower Emory and Clinch Rivers to protect the cap from scour. The conceptual cap material would be sized to effectively prevent erosion of the cap material up to a 25-year storm event, or 150,000 cfs river flow. However, effectiveness of the cap would be severely limited if a greater storm event were to occur. Because the ash-related constituents are metals that would not degrade over time, the long-term protectiveness of a cap would be doubtful because severe storm events would likely result in scouring of areas of the cap.

There is uncertainty in the long-term effectiveness of capping. As noted above, severe storm events could result in scour of the thin cap, exposing the ash to contact by benthic organisms. Anthropogenic activities, such as channel dredging or anchoring of boat anchors could damage the integrity of the cap. Some organisms may burrow through the coarse cap to underlying substrate, where they could contact the ash. Ash particles, due to their very fine grained particle size, could migrate through the coarse cap materials. Contingent actions, including restrictions on dredging tolerances, placement of an intermediate sand blanket, or frequent repair of the cap by placement of additional cap material could be implemented to mitigate these uncertainties.

- Dredging effectiveness and reliability (Alternative 3). Dredging would involve the permanent and irreversible removal of ash-contaminated sediment. Experience gained during the time-critical removal action demonstrated that precision dredging is effective and reliable in removing large quantities of retrievable ash while minimizing the disturbance of native sediment. Over-dredging of native sediment would be particularly undesirable in the lower Emory and Clinch Rivers due to the presence of cesium-137, PCBs, PAHs, mercury, and other legacy contaminants in underlying sediments that are not related to the ash release. Similar dredging techniques would be applied to the non-time-critical removal action to improve effectiveness of dredging; however, residual ash lenses about 1 ft in thickness would likely remain over half of the dredged area.

  Dredged ash processing would consist of gravity settlement followed by windrow drying, processes that were used during the time-critical removal action and were demonstrated to be effective and reliable in achieving moisture contents in the processed ash suitable for offsite shipment and disposal. However, effectiveness of drying could be severely impacted during periods of extended inclement weather. Contingent actions, including use of superabsorbent polymers or lime treatment, could be used to enhance effectiveness of drying. Conceptual design estimates retrieved ash at 1,250 cy/day would be effectively dried to less than 30% moisture following ash processing.

  Offsite disposal of retrieved ash would be at existing, permitted solid waste facilities. The landfill would operate under the restrictions of its specific permit, including waste acceptance criteria, groundwater protection systems, leachate collection and treatment systems, interim and final cover, and other terms of the operating permit. Offsite disposal would therefore be effective in providing permanent containment of the retrieved ash. EPA and TDEC would need to approve the specific landfill prior to shipment of any ash.

- Reliability of transport modeling and risk reduction estimates. There is considerable uncertainty in the model results and prediction of future mass transport and rate of concentration decline. Temporal trends cannot be ascertained from historical sampling events, due to the short period since time-critical dredging has ceased. Further monitoring would be used to establish these trends and monitoring results would be compared against predicted rates of natural recovery, in particular the predicted rate of reduction in ash content and the predicted rate of reduction in arsenic and selenium concentrations both in sediment and benthic invertebrate tissue. Alternative 1 would have greater uncertainty in model predictions than the other alternatives, because it would rely exclusively on MNR processes. Alternatives 2 and 3 would be similar in reliability for residual ash deposits.

  For Alternative 2, transport modeling was used in establishing conceptual cap material sizes based on conceptual design storm events. This conceptual design would be further developed during final design activities. As a result, there is relatively low uncertainty in the transport model results.

- Effectiveness and reliability of sediment and biota monitoring. Each alternative would be similar. The monitoring of sediment and biota would be effective and reliable. Monitoring would use proven techniques, resulting in reliable data quality.

Effectiveness over the short term. Alternative 1 would be effective over the short term. Because natural processes would occur gradually over time, RAOs would only be achieved over the long term, once concentrations have declined to levels below the selected RG/TMEs, a process expected to occur over 5 to 6 years. Concentrations may briefly increase due to periodic severe storm flow events that could occur over several decades. Alternatives 2 and 3 would likely achieve RAOs in a much shorter time frame. For Alternative 2, RAOs would be achieved within a few years after capping is complete. For Alternative 3, RAOs would likely be achieved within 10 years after dredging is complete.

Short-term impacts are not likely under Alternative 1. There would be no action taken in the river system or on land that would impair the ecological habitat or increase short-term risks to human health or the environment. Although RAOs would only be achieved over the long term, ecological populations would be adequately protected over the short term under Alternative 1. The BERA has identified relatively low risks to benthic invertebrates and invertebrate-feeding birds, and MNR would be effective in demonstrating these low short-term risks do not increase.

Short-term impacts would be much greater under both Alternatives 2 and 3 than Alternative 1. Under Alternative 2, short-term impacts to the environment could occur as a result of placing 129,000 to 161,000 cy of cap material under water over a 18- to 22-month period; existing benthic invertebrate communities beneath the cap would be smothered by the cap materials. Under Alternative 2b, targeted capping would not cap areas where bed shear is less than 1.6 Pa, which are typically located near shore where biological activity is most abundant. As a result, targeted capping would limit disturbance to ecological resources. Under Alternative 3, short-term impacts could occur as a result of dredging nearly 160,000 to 440,000 cy of ash material over a 8- to 22-month period; existing benthic invertebrate communities within the dredge area would be virtually eliminated by the dredging. The benthic invertebrate community was found to rebound quickly following the time-critical dredging activities, (within one year), so similar rapid rebound would be expected. Rebound in capped areas (Alternative 2) may be inhibited by the cap itself, which would discourage burrowing and provide a poor substrate for benthic invertebrates.

Either the placement of cap materials (Alternative 2) or the dredging of ash and sediment (Alternative 3) would disturb ash and sediment on the riverbed, which could result in short-term turbidity impacts on water quality. These impacts would likely be greater under Alternative 3, due to the higher degree of disturbance. However, because dredge rates would be less, water quality impacts would also likely be less than those experienced during the time-critical dredging activities, which rarely exceeded TWQC. Any impacts would be mitigated through use of proper engineering controls, such as silt controls and turbidity monitoring during cap placement or dredging.

There is a DOE Record of Decision (DOE 1997) in place for the Clinch River, which establishes that the sediment not be removed because there is more risk from removing it than leaving it in place due to high rates of sediment resuspension and impacts to the benthic invertebrate population. Alternative 1 would be consistent with this existing DOE Record of Decision; dredging under Alternative 3 would not be consistent and would require negotiation for concurrence with DOE and EPA for a substantive change to that Record of Decision.

Impacts on the public during construction of either Alternative 2 or 3 would be greater than Alternative 1, but would be negligible. Recreational river traffic would be controlled to avoid interference with barge traffic, cap placement, or dredging operations, but such controls would impact only a small portion of the river at any given time and not require closing of the river to recreational boaters. Short-term impacts to water quality during construction would be minor and would not pose unacceptable risk to the public during swimming, fishing, or other recreational use of the river.

Short-term risks to workers would be greatest under Alternative 3 due to the greater amount of material handling. Workers would be exposed to ash-related constituents during material handling operations on shore. Short-term risks to workers would include direct contact with hazardous substances, potential air inhalation, and conventional construction-related risks associated with operation of heavy machinery and equipment and bulk material handling, especially over water. Engineering measures would be implemented to protect remediation workers and the community, including (1) OSHA health and safety measures, such as use of PPE, air monitoring, water safety procedures, and construction safety program; (2) transportation control measures, such as placarding, lining, and shipping in accordance with DOT regulations, to protect the community and minimize spills; and (3) dust control and erosion and sediment control measures, such as sediment basins, check dams, temporary seeding, diversion berms, interceptor trenches, silt fences, and erosion protection blankets, to minimize erosion and transport of the ash during construction.

Inherent short-term risks would be associated with shipment of materials over public roadways. Estimates of the potential number of transportation-related accidents, injuries, and/or fatalities were made based on rate information for truck transport. Rates for accidents, injuries and fatalities were multiplied by the number of truck-miles. Due to reporting differences, the number of accidents does not necessarily correlate to the number of injuries or fatalities, since not all accidents result in an injury or fatality, nor are all injuries or fatalities a result of vehicle collisions. Alternative 2 would involve hauling up to 161,000 cy of cap materials, resulting in estimated transportation risks of less than one truck accident, with no injuries or fatalities. Alternative 3 would involve hauling up to 440,000 cy of waste materials, resulting in nearly 2.4 million trip miles and estimated transportation risks of two potential truck accidents, with no injuries or fatalities. Disposal of materials has been assumed to occur at the Chestnut Ridge landfill in Anderson County, Tennessee, approximately 50 miles from the Site. Other disposal options would affect these short-term risk estimates.

6.2.2 Implementability

Each of the alternatives would be implementable using conventional technologies. Alternative 1 would be implementable immediately, since no construction would be required. Monitoring of sediment and biota are proven technologies that have been used extensively at the Site. Fate and transport modeling is also a proven technology. Long-term O&M activities would include routine monitoring of sediment and biota, fate and transport modeling, and residual risk evaluation for a period of 30 years. Implementation of MNR activities following capping (Alternative 2) or dredging (Alternative 3) would be similar to Alternative 1.

Alternative 2 would be implementable within 18 to 22 months years following design of the removal action. Implementation would require particular care in placement of the cap materials. Difficulties would be expected in placing the materials on the riverbed while limiting the disturbance of sediment and limiting turbidity. Difficulties would also be expected in placing the cap to a uniform thin layer underwater, since visibility would be impaired. These difficulties would be mitigated through use of proper work planning and training in underwater placement, monitoring of water quality, and frequent surveys using bathymetric soundings to verify cap thickness. Control of river traffic during construction would require relatively minor administrative control.

Alternative 3a would be implementable within 25 months following design of the removal action (including 3 months for infrastructure construction and 22 months for dredging operations); Alternative 3b within 11 months. However, significant challenges would be anticipated in implementing the alternative. Excavation of ash would be complicated by the need to coordinate dredging in shallow water areas with fluctuations in reservoir levels; dredges and barges with shallow draft depth would be used since the shallow depth of water would preclude use of larger dredges. Properties of the fine-grained ash would complicate ash dewatering particularly during periods of prolonged inclement weather. Wet ash processing areas would be needed to temporarily disk, blade, or turn the ash in piles or windrows to facilitate drying by evaporation and use of polymer absorbents or lime treatment may be needed as contingent actions. Transportation of the ash would be complicated by the large volume of material and limited disposal options. Transport by truck would require 24,000 truckloads hauling an average of 10 hours/day for 22 months for Alternative 3a and about 9,000 truckloads for 8 months for Alternative 3b.

The greatest difficulty in implementing Alternative 3 would be the availability of suitable disposal facilities due to potential cesium-137 contamination in the ash. The ash is non-hazardous waste material, but areas downstream of ERM 2.0 may contain cesium-137 at activities up to 18 pCi/g. These materials would have to be disposed at specific landfills able to accept them.

TDEC has developed a BSFR program as a licensed process to analyze bulk materials (such as soil and sediment) with low levels of radioactive contamination for disposal in specified Class I landfills. Four licensees in Tennessee are currently authorized to conduct the BSFR program and four Class I landfills in Tennessee authorized to receive wastes under the BSFR program, including the Chestnut Ridge landfill in Anderson County. Before being transported to the BSFR, the recovered ash material would be evaluated at the Kingston site to ensure the material does not exceed predetermined limits set by the BSFR program. Upon receipt at the BSFR facility, the material would pass through detection monitors and would be sampled and analyzed for compliance with BSFR waste acceptance criteria. The BSFR waste acceptance criteria are conservative: BSFR waste cannot contribute more than 5% of the total landfill waste, and it cannot contribute a dose of more than one millirem per year to any member of the public. Any material that does not meet the strict requirements of Tennessee's BSFR program would need to be disposed of in a licensed radioactive waste facility. Therefore, implementation of Alternative 3 has also considered disposal at the Energy Solutions Landfill in Clive, Utah, or at the DOE EMWMF in Oak Ridge, Tennessee.

Regulatory and/or public opposition to use of a particular disposal facility would complicate implementability of these disposal options. There is therefore uncertainty as to whether sufficient offsite disposal capacity is available.

Long-term O&M would be greatest under Alternative 2. In addition to monitoring, O&M would include routine inspection and surveying of the cap to verify it remains in place, particularly following major storm events, and repair or replacement of the cap as required. Long-term institutional controls would be required under Alternative 2 to prevent damage to the cap. Restrictions would be placed on dredging tolerances during maintenance of the navigational channel.

6.2.3 Cost

There are no estimated capital costs for Alternative 1 because there would be no active construction. Capital costs for Alternative 2 are moderate ($25.9 million for Alternative 2b to $31.9 million for Alternative 2a). Capital costs are highest for Alternative 3 ($73.7 million for Alternative 3b to $169.4 million for Alternative 3a) due to the high cost of transport and disposal of large volumes of material. Capital costs for Alternative 3 are highly dependent on the ultimate disposal location, which results in considerable uncertainty.

Annual O&M costs are the comparable for all alternatives, since the O&M activities for sediment and biota monitoring are much the same. Alternative 2 O&M costs are greater than Alternatives 1 and 3 because routine O&M activities would have to be implemented to inspect and repair and damage to the cap. Estimated annual O&M costs range between $543,000/year (2012 dollars) for Alternatives 1 and 3 to 747,000/year for Alternative 2.

Other monitoring for supplemental investigation of fish bioaccumulation, fish community surveys, or sediment toxicity testing may be conducted for up to 5 years to confirm trends. Costs of other monitoring are estimated at $339,000/year for Alternative 1 and $290,000/year for Alternatives 2 and 3.

Present worth costs, which reflect combined capital, annual O&M, and other monitoring costs, are highly dependent on the duration of MNR following construction. This time frame is uncertain due to the considerable uncertainty in the prediction of future mass transport and rate of concentration decline. A total O&M period of 30 years has been used in evaluating present worth costs for all three alternatives. Total present worth costs are estimated to be $10.0 million for Alternative 1, $44.8 million for Alternative 2a, $38.7 million for Alternative 2b, $179.1 million for Alternative 3a, and $83.4 million for Alternative 3b.

7. RECOMMENDED REMOVAL ACTION ALTERNATIVE

This section identifies the removal action alternative that best satisfies the evaluation criteria based on the comparative analysis described in Section 6.

THIS CHAPTER WILL BE WRITTEN FOLLOWING RECEIPT OF COMMENTS AND INPUTS FROM THE PUBLIC.

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8. REFERENCES

Argonne National Library 2009. *State-Level Accident Rates of Surface Freight Transportation: a Reexamination Argonne National Laboratory* (ANL/ESD/TM-150). April 1999.

Aquaveo 2011. FEMA Flood Insurance Study: Flood Frequency and Hydraulic Analysis of Emory River near Kingston, Tennessee. Prepared by Aquaveo, LLC. March 29, 2011.

Arcadis 2012. *Kingston Ash Recovery Project Non-Time Critical Removal Action River System Baseline Ecological Risk Assessment*. Document No. EPA-EO-050. August 3, 2012.

DOE 1995a. *Remedial Investigation/Feasibility Study Report for Lower Watts Bar Reservoir Operable Unit*. Document No. DOE/OR/01-1282&D4. March 1995.

DOE 1995b. *Record of Decision for the Lower Watts Bar Reservoir*, Document No. DOE/OR/02-1373&D3, September 1995.

DOE 1996. *Remedial Investigation/Feasibility Study of the Clinch River/Poplar Creek Operable Unit.* DOE/OR/01-1393/V1&D3. June 1996.

DOE 1997, *Record of Decision for the Clinch River/Poplar Creek Operable Unit.* Document No. DOE/OR/02-1547&D3. August 1997.

DOE 2012. *2012 Remediation Effectiveness Report for the DOE Oak Ridge Reservation.* Document No. DOE/OR/01-2544&D1. March 2012.

DOT 2011. *Large Truck and Bus Crash Facts 2009* US Department of Transportation Analysis Division Federal Motor Carrier Safety Administration. October 2011.

EPA 1989. Risk Assessment Guidance for Superfund, Vol. 1: Human Health Evaluation Manual (Part A), EPA/540/1-89/002, Office of Emergency and Remedial Response, Washington, D.C.

EPA 1993. *Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA*. Prepared by the U.S. Environmental Protection Agency. December 1993.

EPA 2000. Supplemental Guidance to RAGS: Region IV Bulletins, Human Health Risk Assessment, Atlanta, GA. Available at http://www.epa.gov/region4/waste/ots/healtbul.htm.

EPA 2003. Human Health Toxicity Values in Superfund Risk Assessments, OSWER Directive 9285.7-53.

EPA 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites, EPA-540-R-05-012, OSWER 9355.0-85. December 2005 (r2).

EPA 2009. Administrative Order and Agreement on Consent. In the Matter of: TVA Kingston Fossil Fuel Plant Release Site, Roane, County, Tennessee. Tennessee Valley Authority, Respondent. Prepared by the U.S. Environmental Protection Agency. May 11, 2009.

ERDC, Environmental Laboratory 2009. *Evaluation of Metals Release from Oxidation of Fly Ash during Dredging of the Emory River, TN.* Prepared by Dr. Jeffery A. Steevens U.S. Army ERDC, Vicksburg, MS. October 9, 2009.

ERDCWES 2012. *Long Term Simulation of Residual Fly Ash Transport and Fate in the Watts Bar Reservoir System*. Stephen H. Scott. Coastal and Hydraulics Laboratory; U.S. Army engineer Research and Development Center. Vicksburg, MS. June 2012.

ESTCP 2009. *Monitored Natural Recovery at Contaminated Sediment Sites*, ESTCP Project ER-0622, May 2009.

Geosyntec 2011. *Final White Paper, Kingston Ash Recovery Project, Natural Attenuation of Chromium, Mercury, Selenium and Thorium-228*. Prepared by Geosyntec Consultants, Inc. June 7, 2011.

Jacobs 2010a. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, Embayment/Dredge Cell Engineering Evaluation/Cost Analysis (EE/CA) Work Plan*. Document No. RAWP-085. January 2010.

Jacobs 2010b. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, Embayment/Dredge Cell Engineering Evaluation/Cost Analysis (EE/CA)*. Document No. EPA-AO-008. January 15, 2010.

Jacobs 2010c. *Kingston Ash Recovery Project Non-Time-Critical Removal Action Embayment/Dredge Cell Action Memorandum*. Document No. EPA-AO-024. May 15, 2010 (EPA approval).

Jacobs 2010d. *Non-Time-Critical Removal Action for the River System, Sampling and Analysis Plan (SAP)*. Revision 3. Document No. EPA-AO-021. June 1, 2010 (EPA approval).

Jacobs 2010e. *Kingston Ash Recovery Project, Non-Time-Critical Removal Action for the River System, Ash Leaching Test Results*, Document No. RPT-072. June 4, 2010.

Jacobs 2011a. *Kingston Ash Recovery Project Non-Time-Critical Removal Action for the River System Supplemental Ash Leaching Test Plan*. Document No. RAWP-072A. March 23, 2011.

Jacobs 2011b. *TVA Kingston Fossil Fuel Plant Release Site, On-Scene Coordinator Report for the Time-Critical Removal Action, May 11, 2009 through December 2010*. Document No. EPA-AO-030. March 31, 2011 (EPA approval).

Jacobs 2011c. *Kingston Ash Recovery Project Non-Time-Critical Removal Action for the River System Supplemental Ash Leaching Test Results*. Document No. RPT-072A. April 11, 2011.

Jacobs 2011d. *Kingston Ash Recovery Project, Groundwater Flow and Transport Model Report*. Document No. EPA-RPT-1002. July 25, 2011 (issued for Regulatory review).

Jacobs 2011e. *Kingston Ash Recovery Project Non-Time-Critical Removal Action for the River System Supplemental Ash Leaching Test Results for Stabilized Ash*. Document No. RAWP-072B. July 26, 2011.

Jacobs 2011f. *Kingston Ash Recovery Project Non-Time-Critical Removal Action for the River System Supplemental Ash Leaching Test Results*. Document No. RAWP-072C. December 5, 2011.

Jacobs 2012a. *Kingston Ash Recovery Project Non-Time-Critical Removal Action River System Baseline Human Health Risk Assessment*. Document No. EPA-EO-052. July 11, 2012.

Jacobs 2012b. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Surface Water*. Document No. EPA-AO-035. May 4, 2012.

Jacobs 2012c. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Amphibian Sampling*. Document No. EPA-RPT-021A. May 4, 2012.

Jacobs 2012d. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Piscivorous and Herbivorous Bird Egg Sampling*. Document No. EPA-RPT-021B. May 4, 2012.

Jacobs 2012e. *Kingston Ash Recovery Project, Non-Time-Critical Removal Action, River System Sampling and Analysis Plan, Task Completion Technical Memorandum; Groundwater Sampling*. Document No. EPA-RPT-021C. May 5, 2012.

Jacobs 2012f. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Tree Swallow Sampling*. Document No. EPA-RPT-021D. May 4, 2012.

Jacobs 2012g. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Turtle Sampling*. Document No. EPA-RPT-021E. May 4, 2012.

Jacobs 2012h. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Fish Sampling*. Document No. EPA-RPT-021F. May 4, 2012.

Jacobs 2012i. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Raccoon Sampling*. Document No. EPA-RPT-021G. May 4, 2012.

Jacobs 2012j. *Kingston Ash Recovery Project, Non-Time-Critical Removal Action, River System Sampling and Analysis Plan, Task Completion Technical Memorandum; Ash Deposits, Submerged Sediment, and Seasonally-Exposed Sediment*. Document No. EPA-RPT-021H. May 4, 2012.

Jacobs 2012k. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Aquatic Vegetation and Periphyton Sampling*. Document No. EPA-RPT-021I. May 4, 2012.

Jacobs 2012l. *Kingston Ash Recovery Project, Non-Time-Critical Removal Action, River System Sampling and Analysis Plan, Task Completion Technical Memorandum; Sediment Bioassay and Porewater Sampling*. Document No. EPA-RPT-021J. May 4, 2012.

Jacobs 2012m. *Kingston Ash Recovery Project Non-Time-Critical Removal Action, River System Sampling and Analysis Plan Task Completion Technical Memorandum; Benthic Invertebrate Sampling*. Document No. EPA-RPT-021E. May 4, 2012.

NAVFAC 2005. *NAVFAC User's Guide: Implementation Guide for Assessing and Managing Contaminated Sediment at Navy Facilities UG-2053-ENV Rev 2*. January 2005.

National Weather Service (NWS) 2006. *Oak Ridge Climate Normals and Records (1971-2000)*, National Weather Service Forecast Office, Morristown, Tennessee. March 7, 2006.

TDEC 2006, *Registration Authorizing Solid Waste Disposal Activities in Tennessee, Registration No. IDL 73-0094*, Issued to Tennessee Valley Authority Kingston Fossil Plant. September 12, 2006.

TDEC 2004. *Reservoir Operations Study-Final Programmatic Environmental Impact Study, Record of Decision*. Prepared by TVA in cooperation with the U.S. Army Corps of Engineers and U.S. Fish and Wildlife Service. May 2004.

TDEC 2009. Commissioner's Order, Case No. OGC09-0001 In the Matter of: Tennessee Valley Authority. Prepared by the Tennessee Department of Environment and Conservation. January 12, 2009.

TVA 2009a. *Environmental Assessment, Initial Emergency Response Actions for the Kingston Fossil Plant Ash Dike Failure, Roane County, Tennessee.* Prepared by TVA. February 2009.

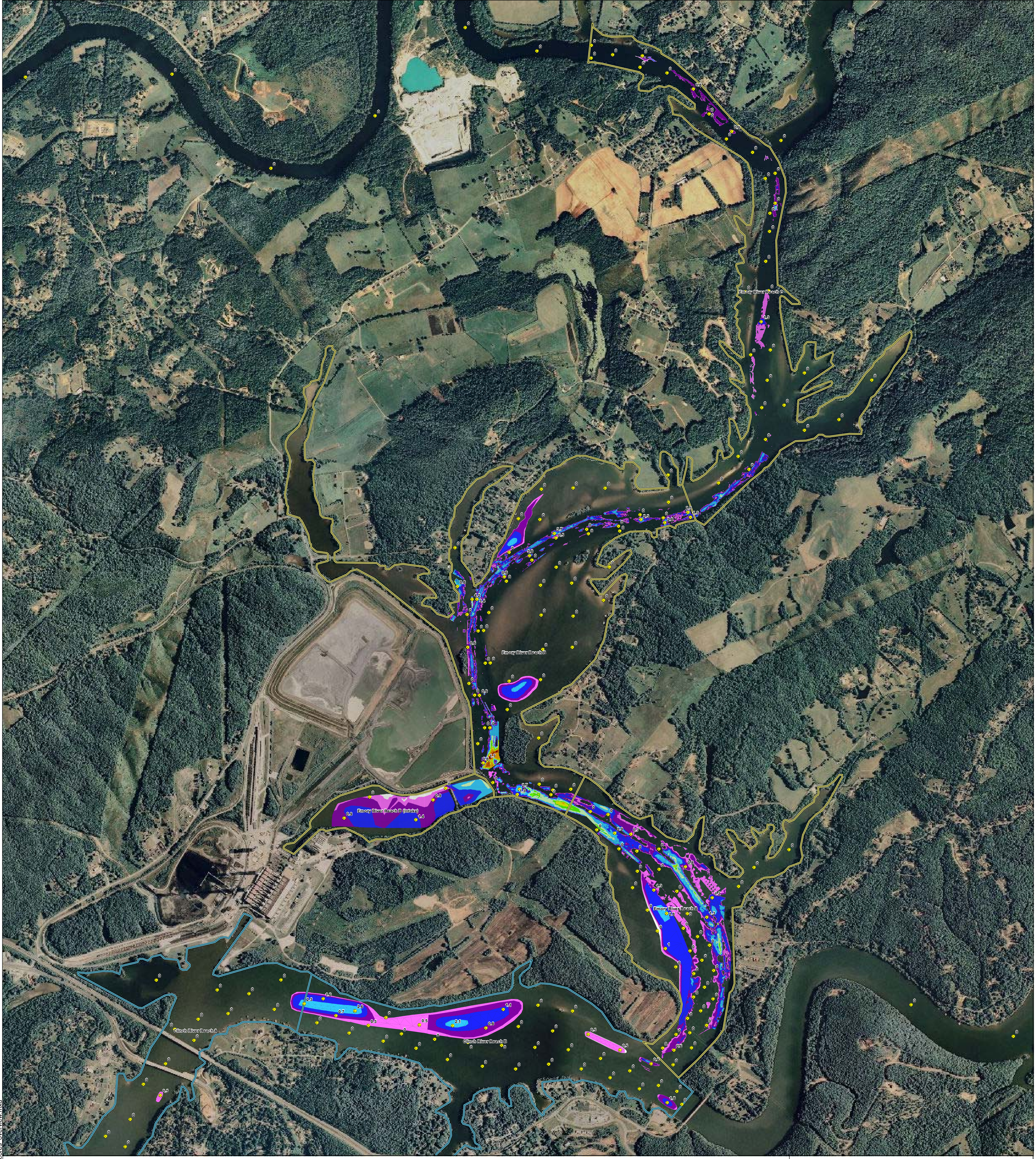
TVA 2009b. *Corrective Action Plan for the TVA Kingston Fossil Plant Ash Release*. Document No. EPA-AO-023. Prepared by the Tennessee Valley Authority. March 2, 2009.

TVA 2009c. *Action Memorandum: Request for Removal Action at the TVA Kingston Fossil Fuel Plant Release Site, Roane County, Tennessee*. Document No. EPA-AO-005. Prepared by the Tennessee Valley Authority. August 4, 2009 (EPA approval).

TVA 2010. *Time-Critical Removal Action Completion Report for River System Phase II Nature and Extent of Ash Investigation*. Prepared by the Tennessee Valley Authority. April 21, 2010 (EPA approval).

Yorkley 2005. *Freshwater Mussel Survey of Impounded Area of the Clinch River Adjacent to the Power Plant, TVA, Kingston, Tennessee*. Prepared by the Yokley Environmental Consulting Service. October 14, 2005.

Plates



Legend

- Vibracore Location Labeled with Ash Thickness (ft) (if < 50% Ash, Ash Thickness = 0)
- Emory River Reaches A, B, & C
- Clinch River Reaches A & B

Thickness of Ash in Vibracores > 50% Ash

No Ash	6 ft - 8 ft
Less Than 0.5 Feet	8 ft - 10 ft
0.5 ft - 1.0 ft	10 ft - 15 ft
1 ft - 2 ft	15 ft- 20 ft
2 ft - 4 ft	20 ft - 25 ft
4 ft - 6 ft	

0 1,300 2,600 Feet 1:7,800

N

JACOBS

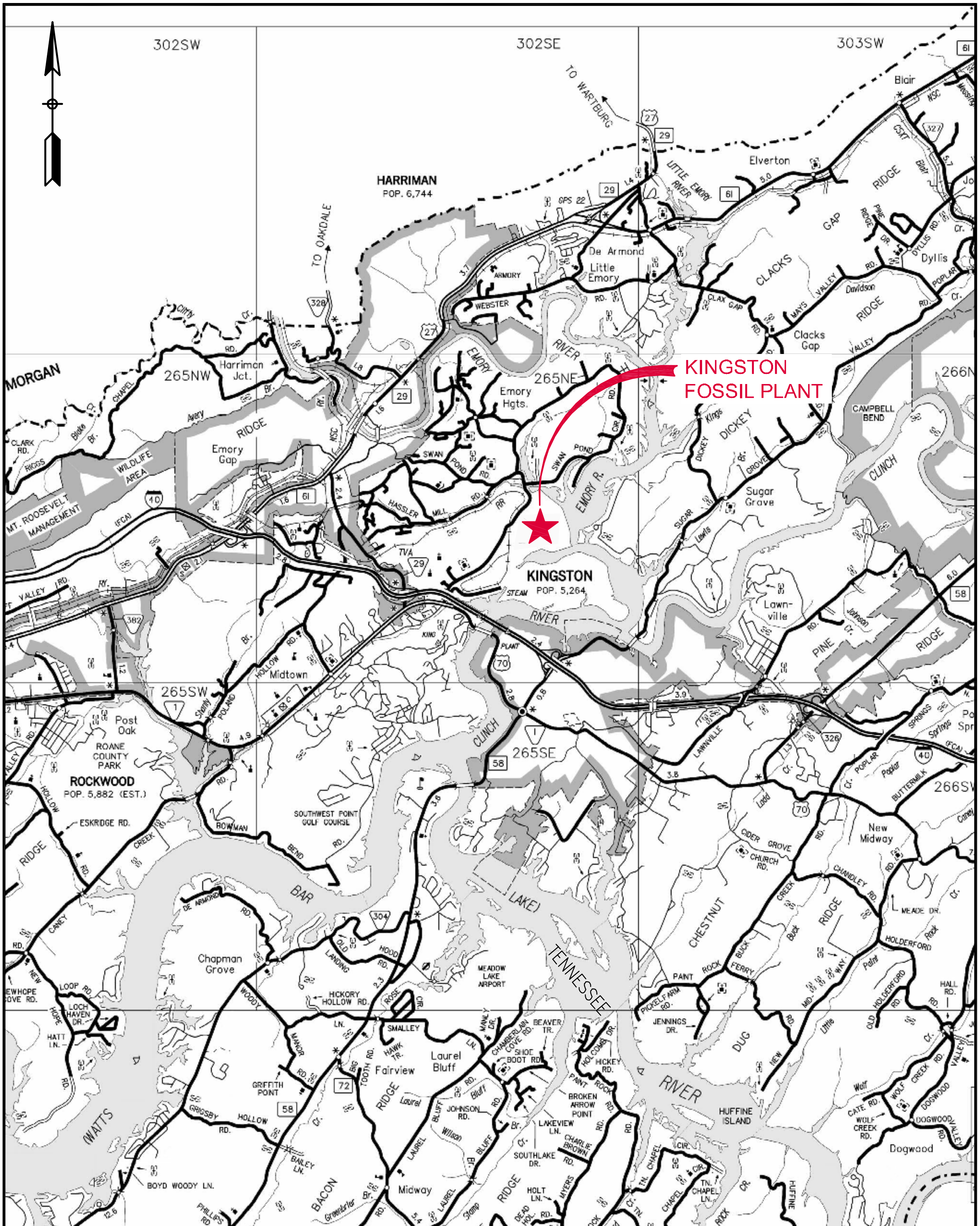
Ash Recovered in Vibracores with Ash Content > 50% Ash October 2011

NAME: croberts DATE: 01/09/2012

Plate 1

Y:\TVA\Projects\05DJ5400\20120109\ArcGIS\ash_remaining_cores_overview.mxd

Figures



SOURCE:
GENERAL HIGHWAY MAP, ROANE COUNTY, TENNESSEE
TENNESSEE DEPARTMENT OF TRANSPORTATION, 2006

0 1 2 4
SCALE IN MILES

FIGURE 1
LOCATION OF THE KINGSTON FOSSIL PLANT

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 1 Location Map.dwg Aug 01,2012 -bperatro

DATE OF PHOTOGRAPHY: APRIL 5, 2005

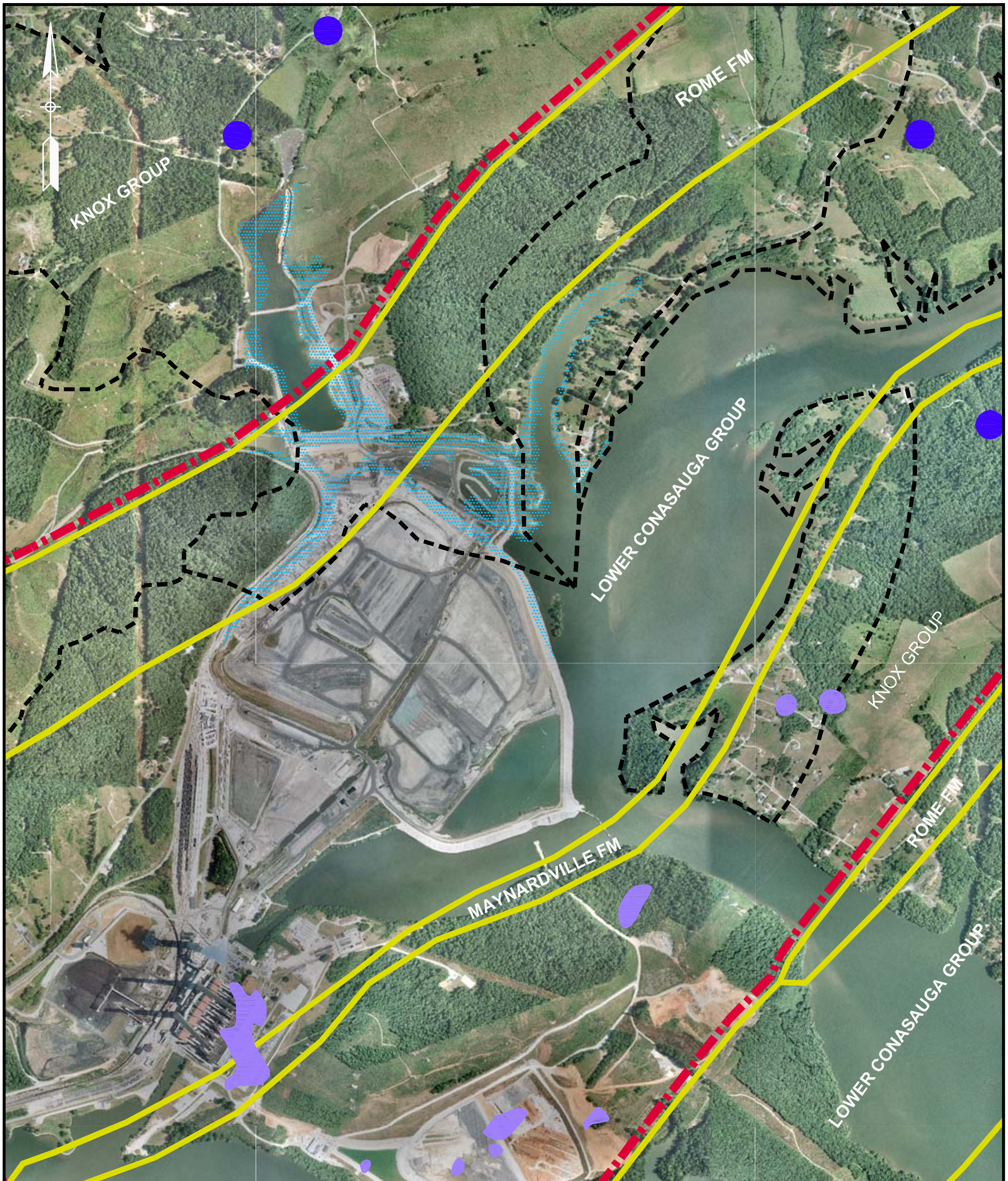
0 750 1500 3000
SCALE IN FEET

FIGURE 2
KINGSTON FOSSIL PLANT
PRE-SPILL CONDITIONS
KINGSTON ASH RECOVERY PROJECT

DATE: 2 Aug 2012

PHASE: NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 2 KIF Pre-Spill Conditions.dwg Aug 01,2012 -bperatro



LEGEND:

- SPRING
- ASH-IMPACTED LAND ABOVE WINTER POOL SHORELINE
- GEOLOGIC CONTACT
- GEOLOGIC FAULT
- SINKHOLE
- WATERSHED BOUNDARY

DATE OF IMAGE: JUNE 28, 2012

0 1000 2000 4000
SCALE IN FEET

FIGURE 3
HYDROGEOLOGIC FEATURES OF THE KIF SITE
KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 3 Hydrogeologic Features.dwg Aug 01,2012 -bperatro

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 4 CSM Groundwater Transport.dwg Aug 01,2012 -bperatro

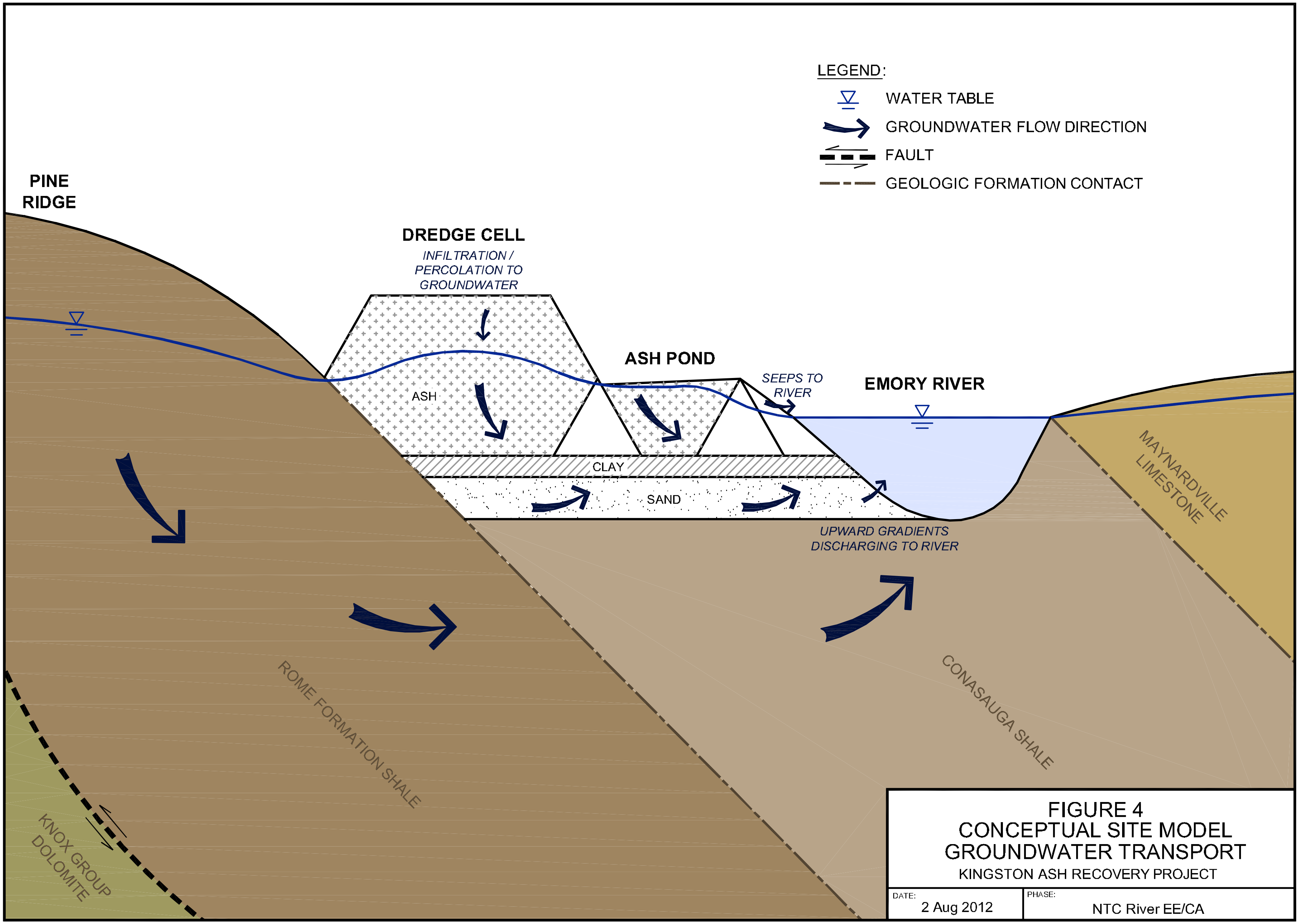


FIGURE 4
CONCEPTUAL SITE MODEL
GROUNDWATER TRANSPORT
KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

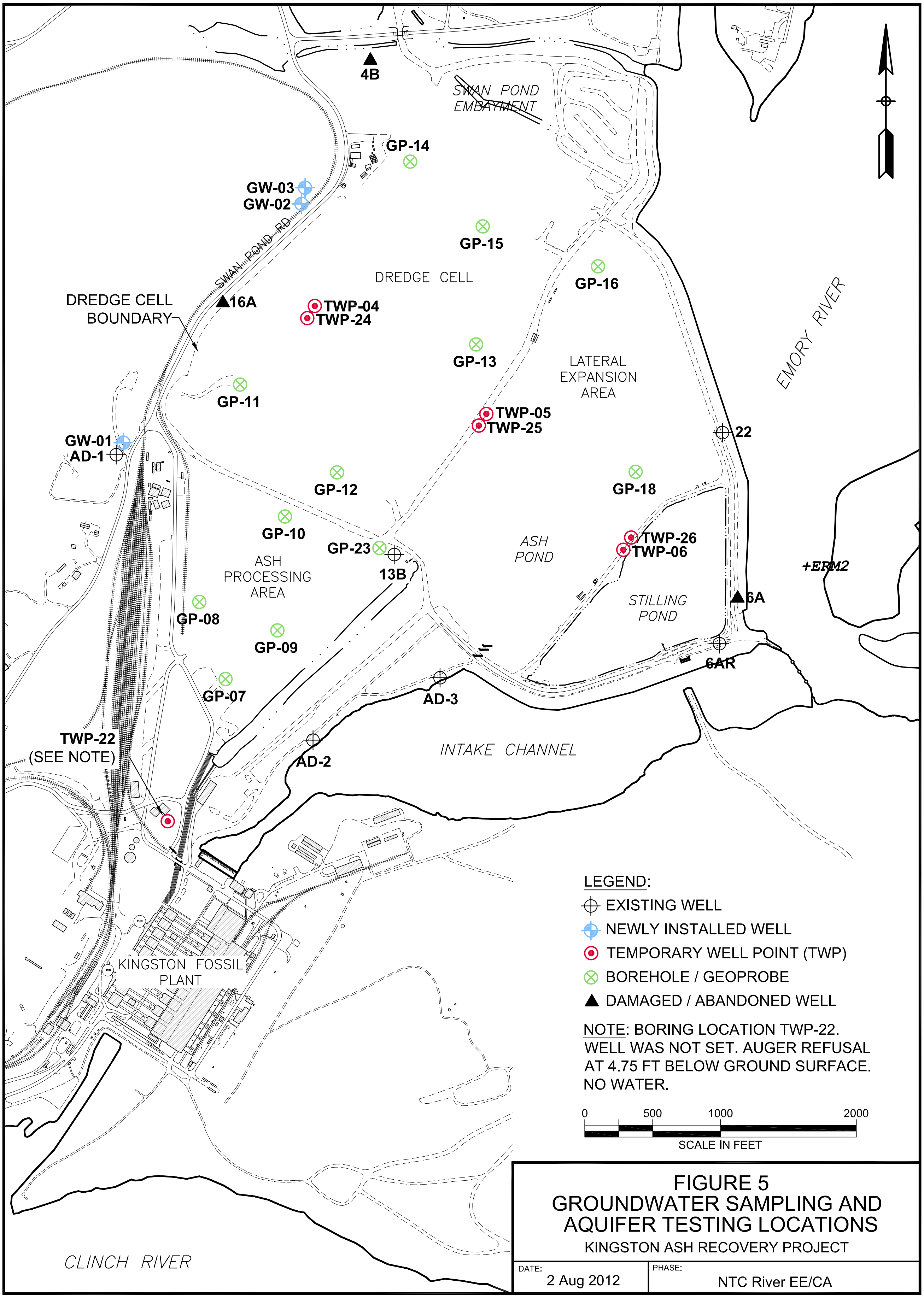


FIGURE 5
GROUNDWATER SAMPLING AND AQUIFER TESTING LOCATIONS
KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 5 Groundwater Sampling and Aquifer Testing.dwg Aug 01,2012 -bperatro

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 6 Groundwater Elevations.dwg Aug 01,2012 -bperatro

LEGEND:

MONITORING WELL

DATE OF IMAGE: 6-23-2011

NOTES:

1. TOPO INFORMATION FROM THE GROUNDWATER FLOW AND TRANSPORT MODEL REPORT.
2. CONTOURS ARE IN FEET-MSL.

0 500 1000 2000

SCALE IN FEET

FIGURE 6
GROUNDWATER ELEVATIONS IN ASH AND SHALLOW SOILS (JULY 2010)

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

FIGURE 7
KEY SITE FEATURES

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 7 Key Site Features.dwg Aug 01,2012 -bperatro

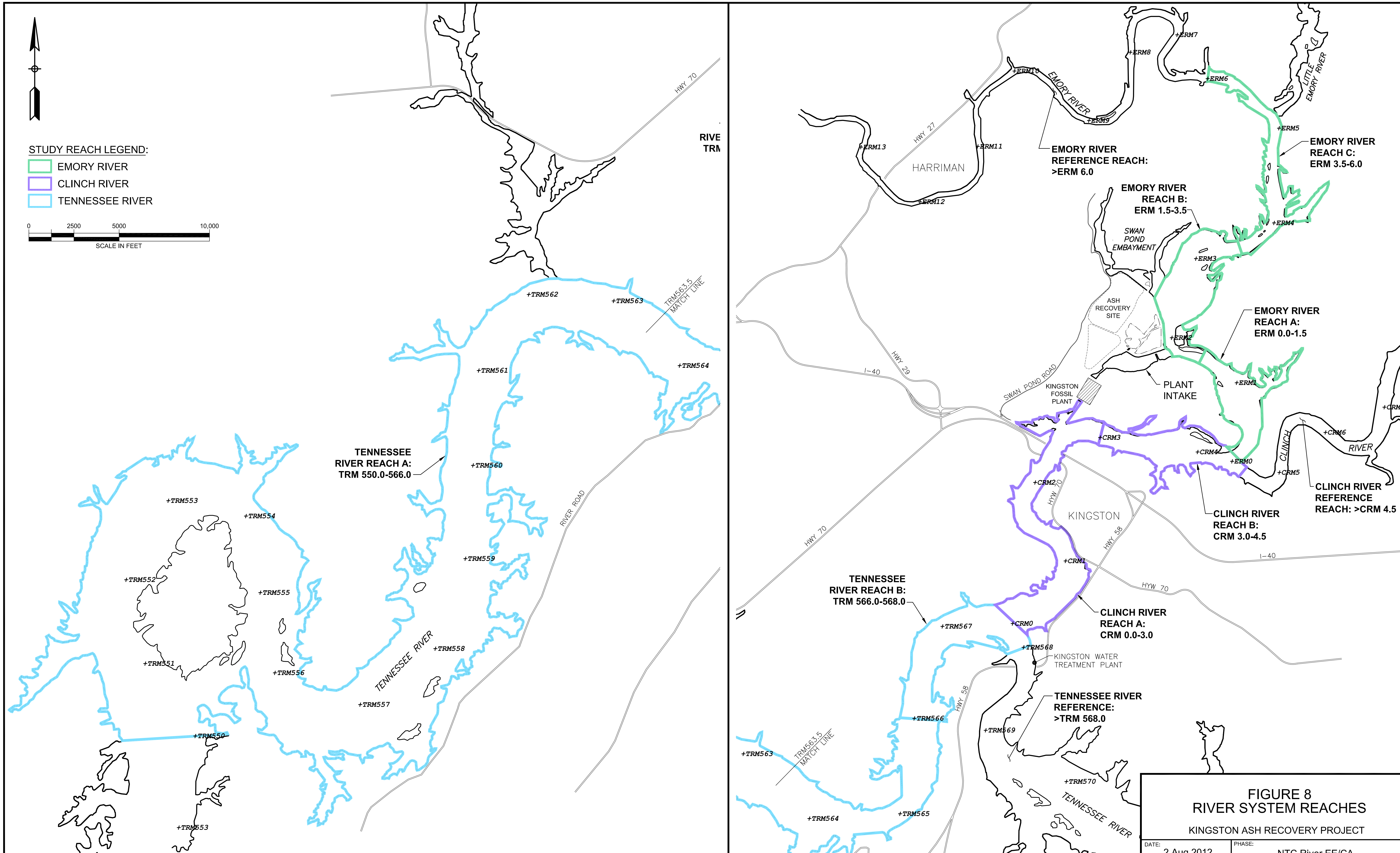


FIGURE 8
RIVER SYSTEM REACHES

KINGSTON ASH RECOVERY PROJECT

DATE: 2 Aug 2012	PHASE: NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 8 River Reaches.dwg Aug 01,2012 -bperatro

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 9-10 Seasonally-Exposed Sediment Results.dwg Aug 01,2012 -bperatro

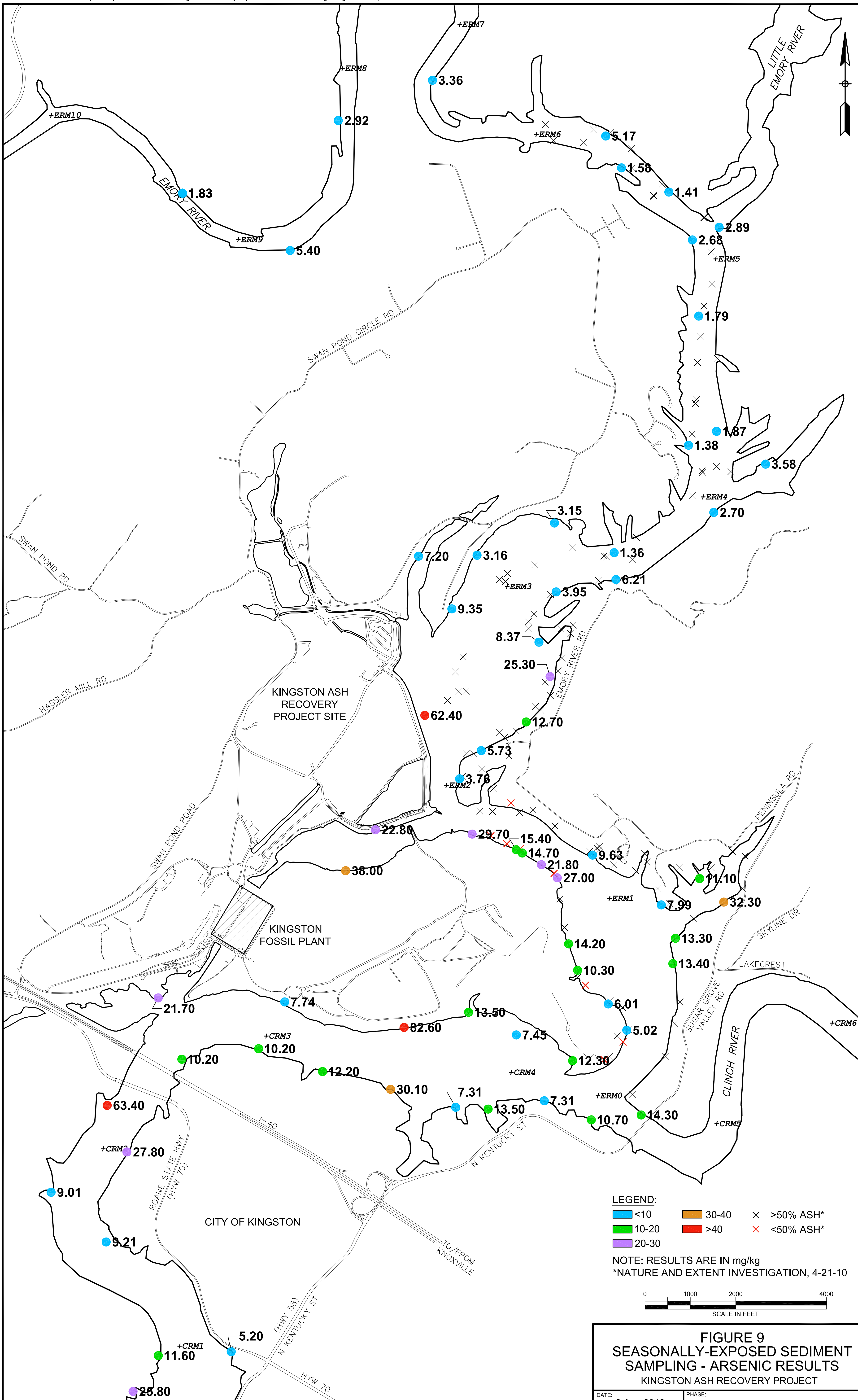
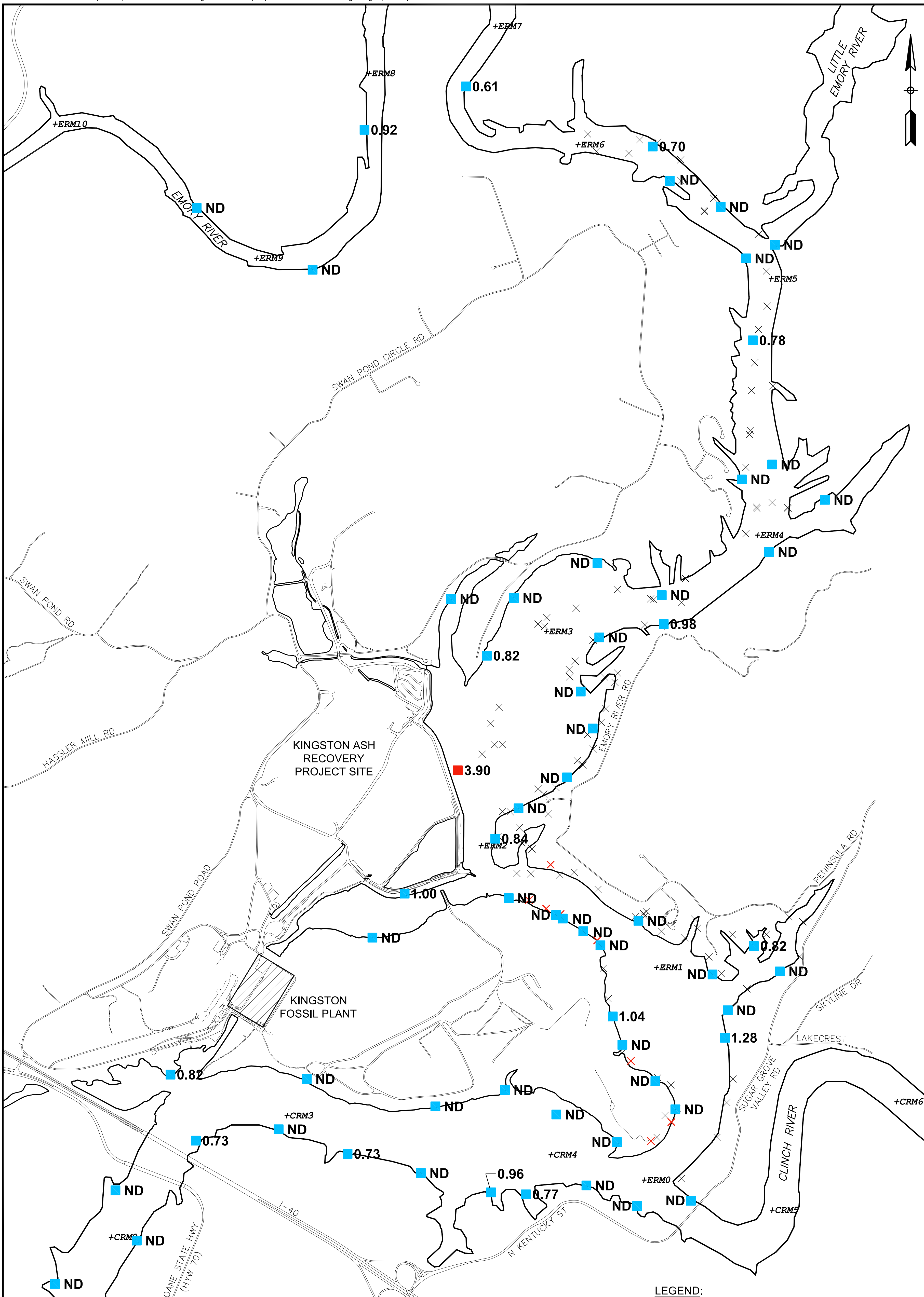


FIGURE 9
SEASONALLY-EXPOSED SEDIMENT SAMPLING - ARSENIC RESULTS
KINGSTON ASH RECOVERY PROJECT

DATE: 2 Aug 2012
PHASE: NTC River EE/CA



LEGEND:

- <2.5
- 2.5-5.0
- 5.0-7.5
- × >50% ASH*
- × <50% ASH*
- ND = NONDETECT

NOTE: RESULTS ARE IN mg/kg
*NATURE AND EXTENT INVESTIGATION, 4-21-10

0 1000 2000 4000
SCALE IN FEET

FIGURE 10
SEASONALLY-EXPOSED SEDIMENT SAMPLING - SELENIUM RESULTS

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

Figure 11. Average Speciation Results
Multiple Media - All River Reaches

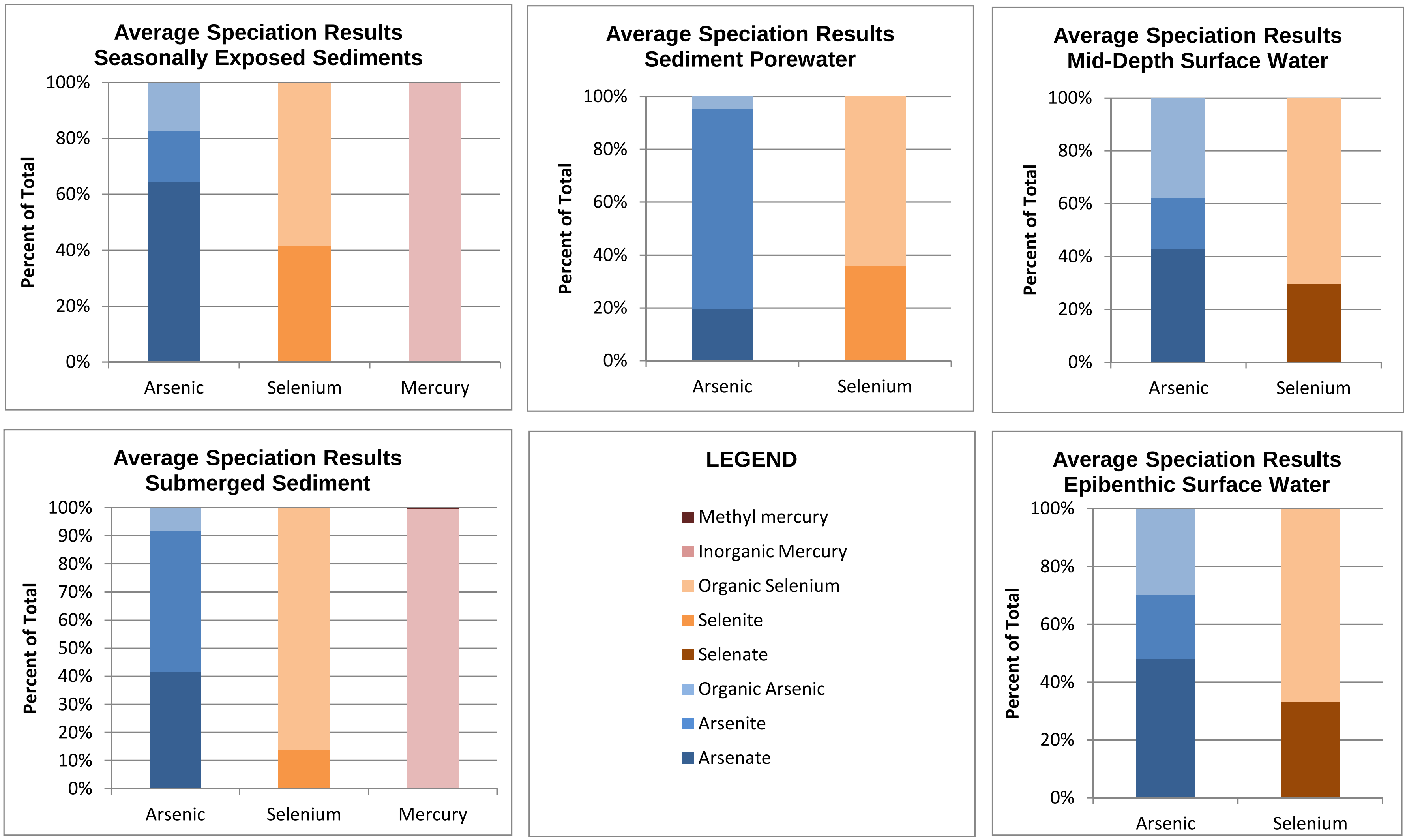
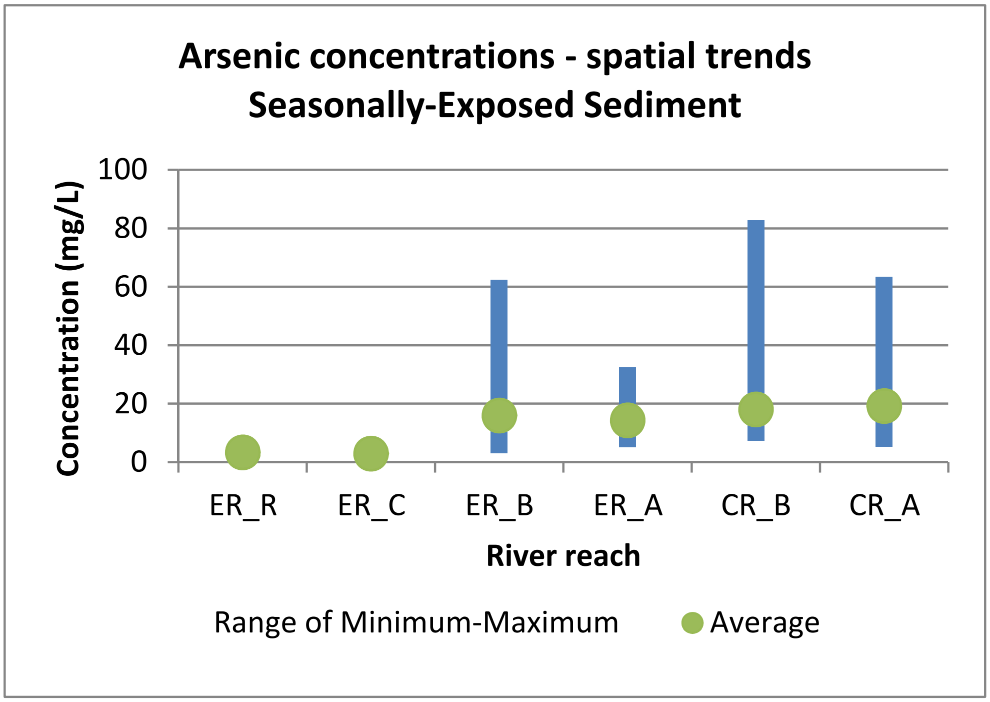
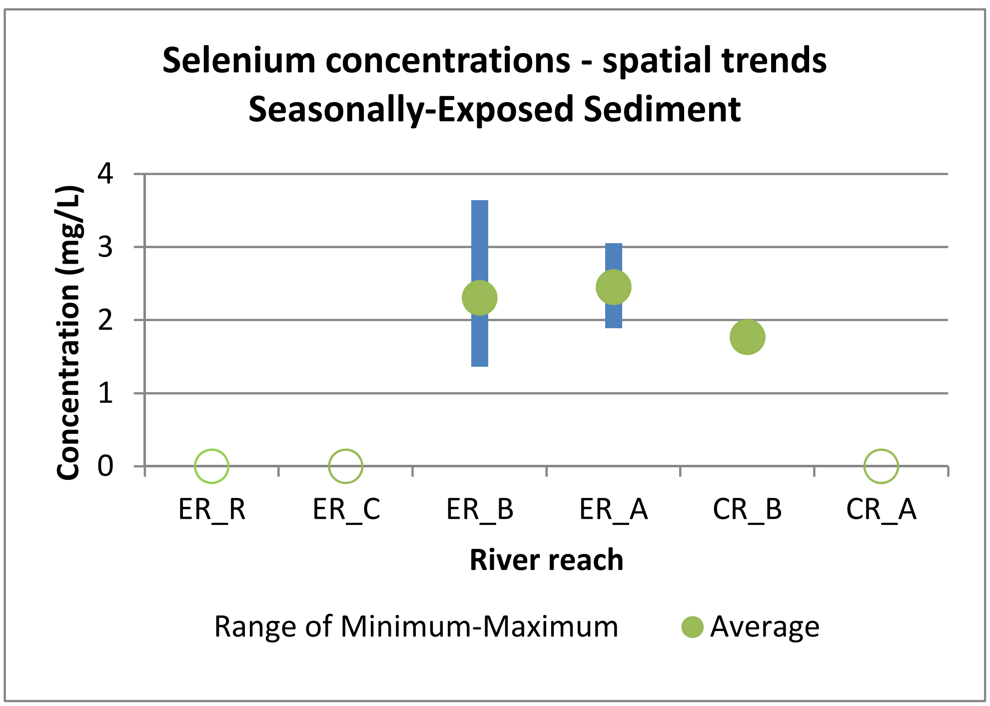


Figure 12. Spatial Trends in Seasonally-Exposed Sediment





I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 13-14 Submerged Sediment Results.dwg Aug 01,2012 -bperatro

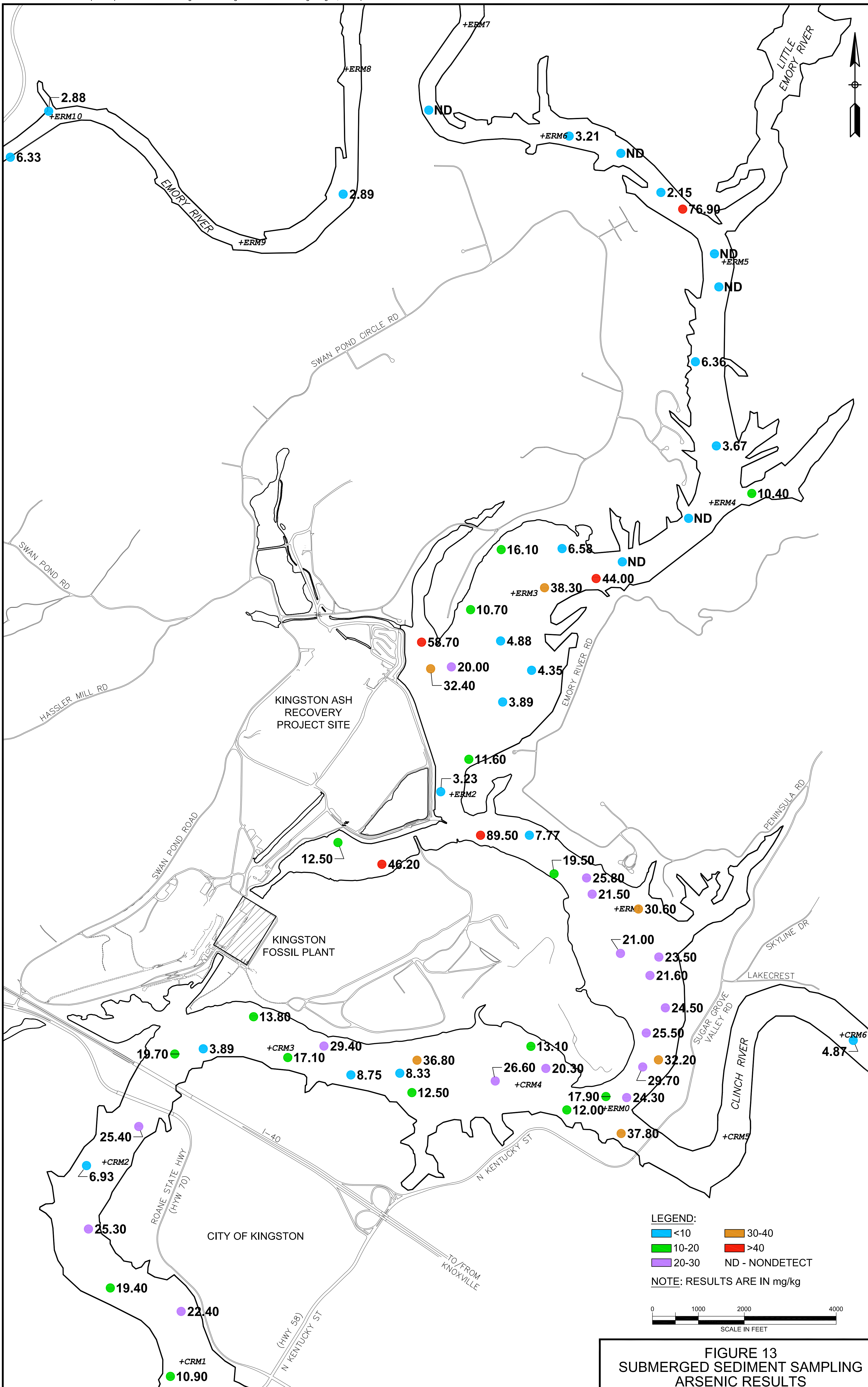


FIGURE 13
SUBMERGED SEDIMENT SAMPLING
ARSENIC RESULTS
KINGSTON ASH RECOVERY PROJECT

DATE: 2 Aug 2012
PHASE: NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 13-14 Submerged Sediment Results.dwg Aug 01,2012 -bperatro

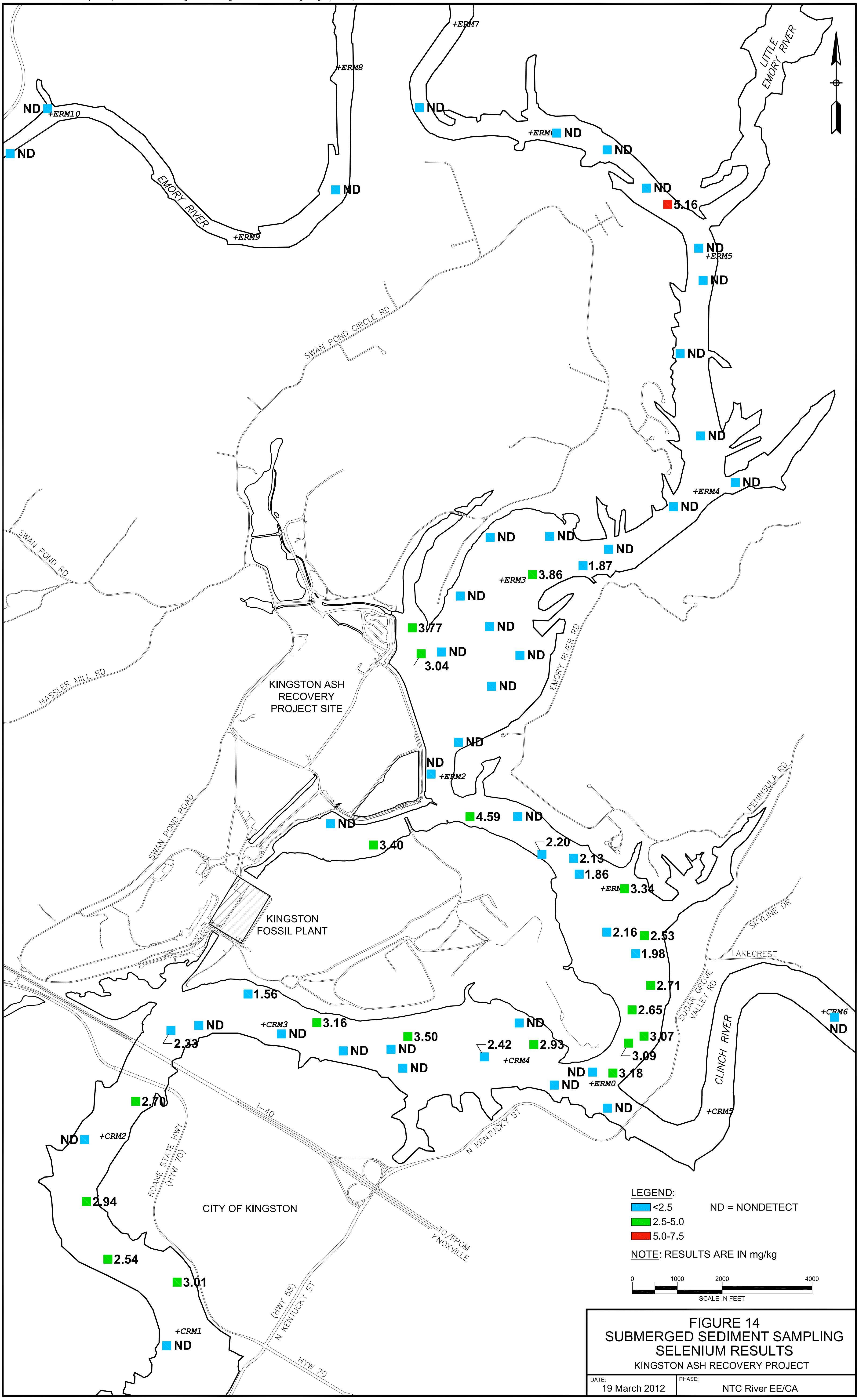


FIGURE 14
SUBMERGED SEDIMENT SAMPLING
SELENIUM RESULTS
KINGSTON ASH RECOVERY PROJECT

DATE: 19 March 2012

PHASE: NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 15 Celenium 137 Results.dwg Aug 01,2012 -bperatro

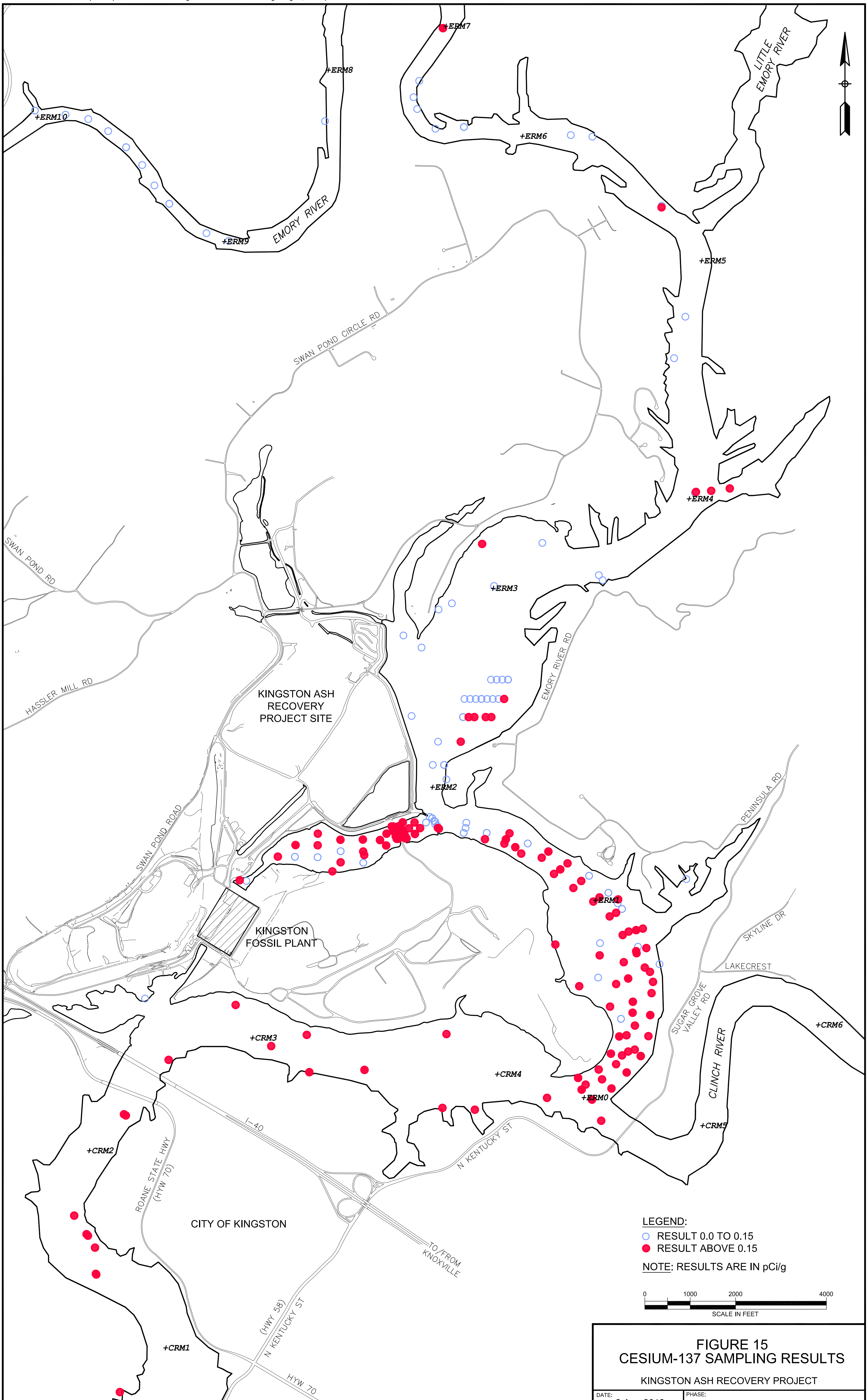
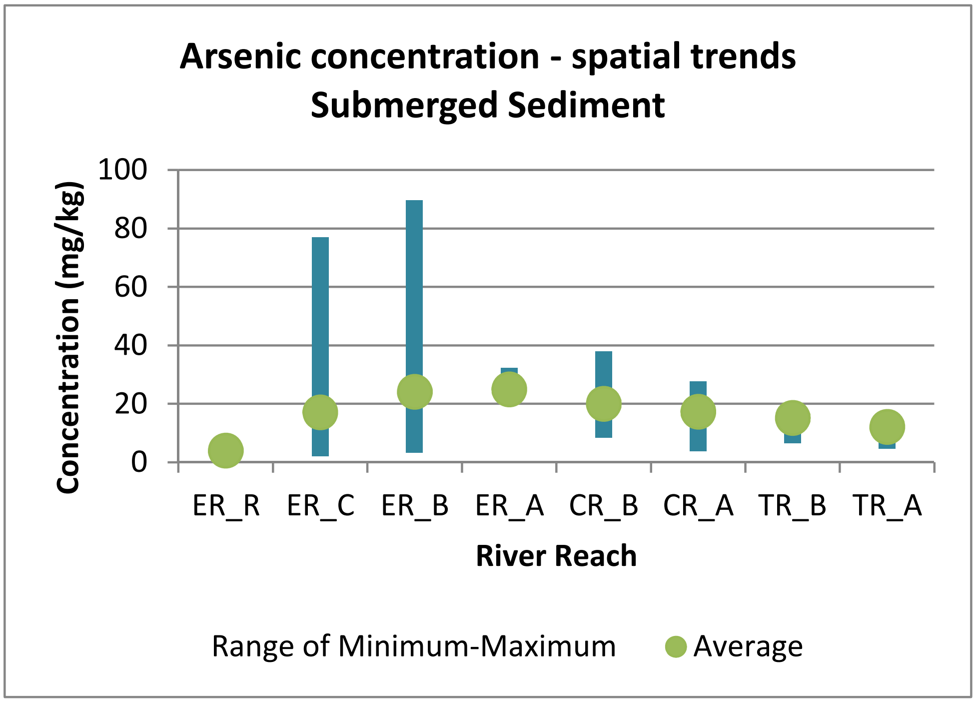


FIGURE 15
CESIUM-137 SAMPLING RESULTS

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

Figure 16. Spatial Trends in Submerged Sediment



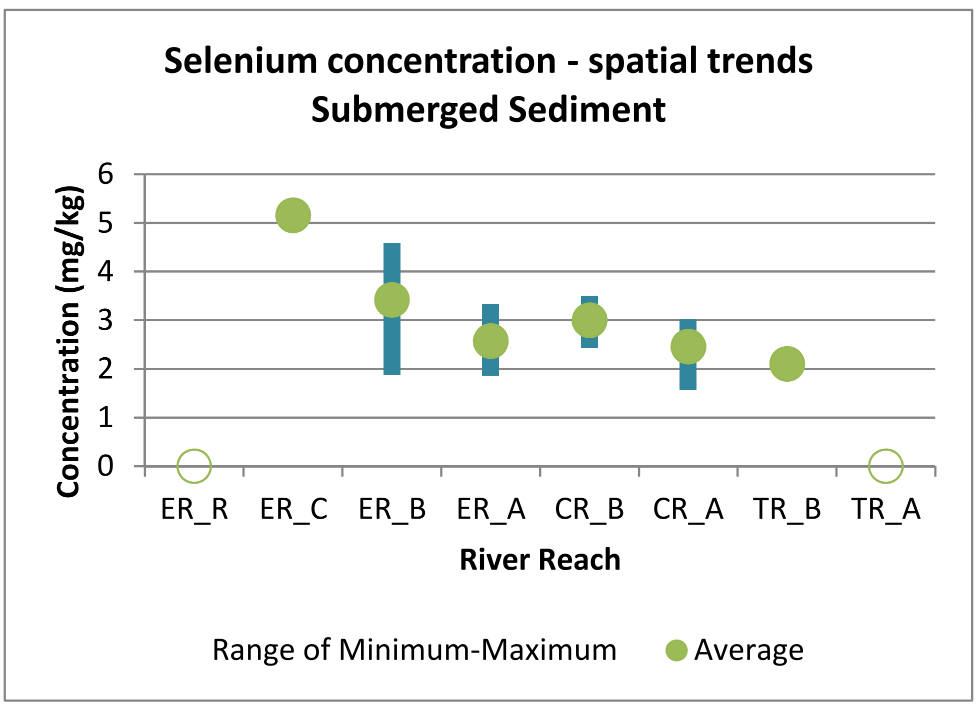
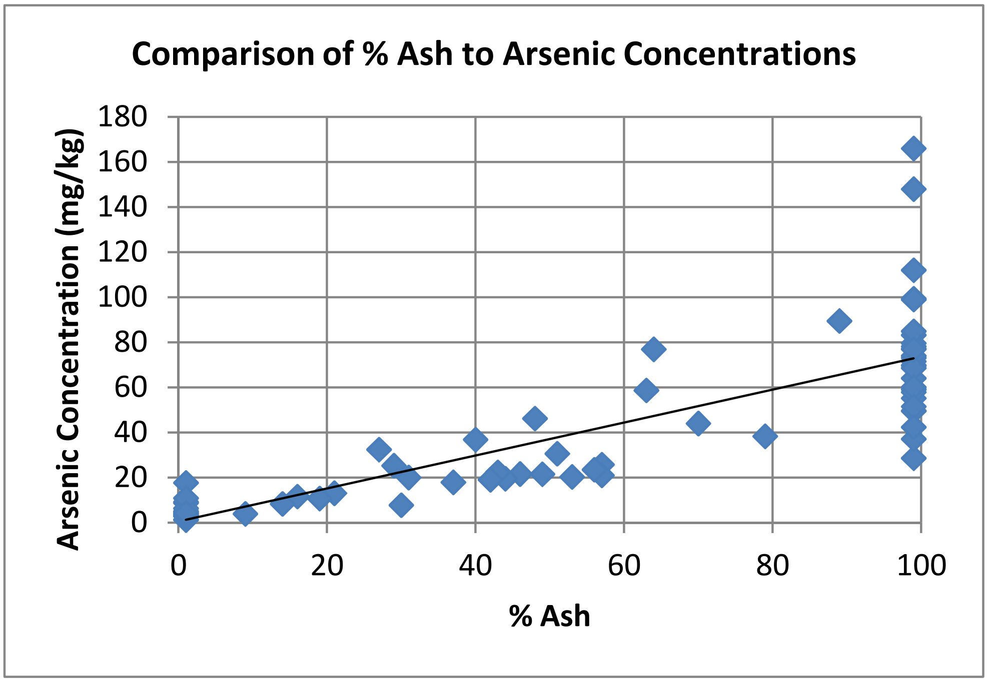
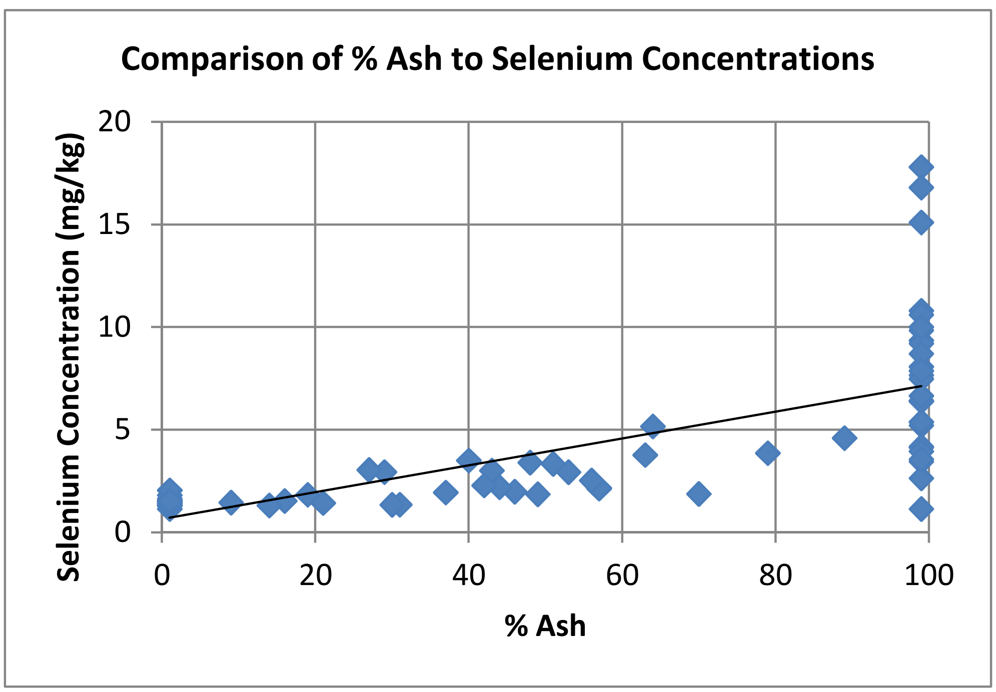


Figure 17. Comparison Between Percent Ash Content and Constituent Concentration in Submerged Sediment





I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 18-19 Sediment Porewater Results.dwg Aug 01,2012 -bperatro

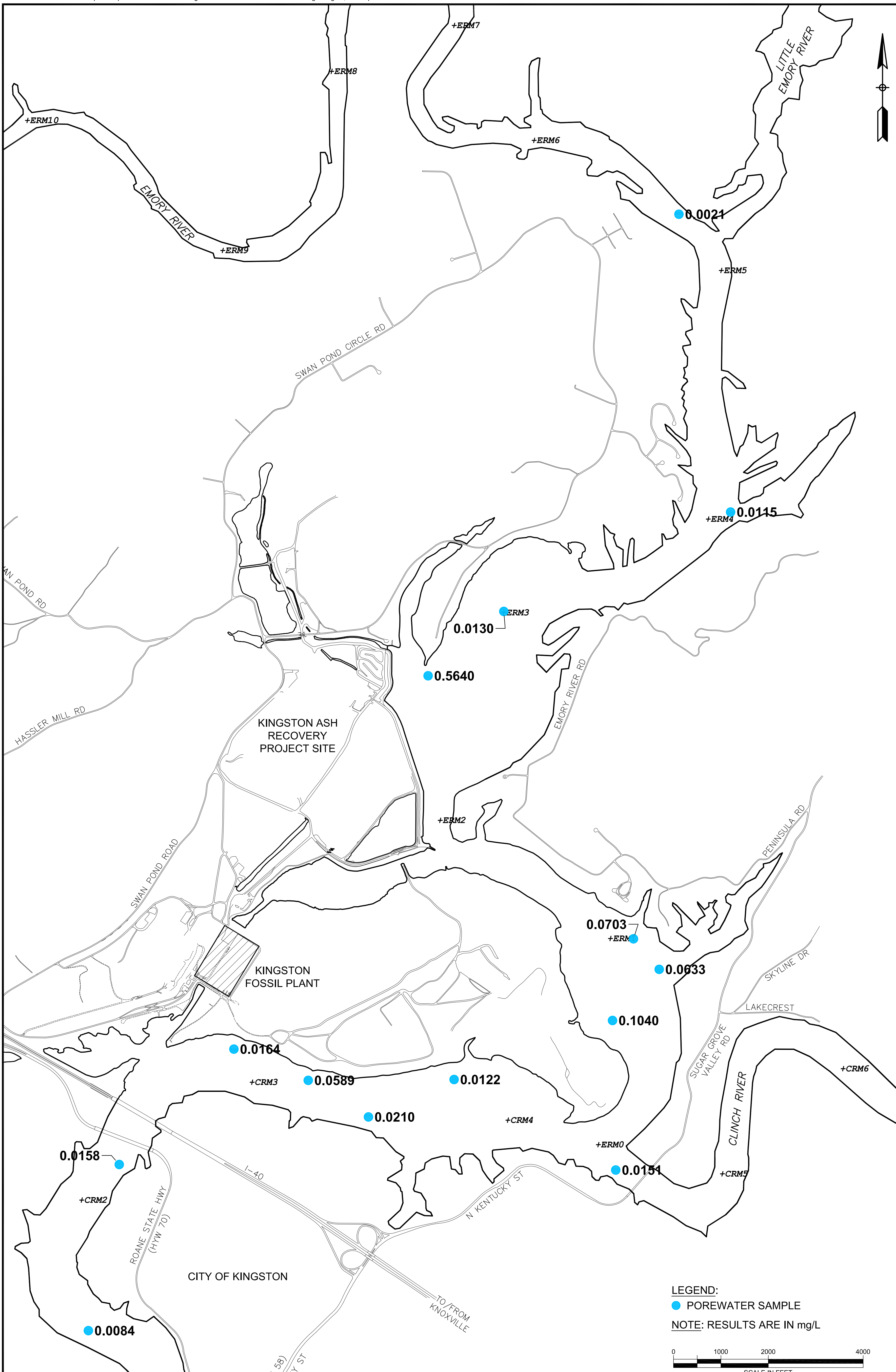


FIGURE 18
SEDIMENT POREWATER SAMPLING
ARSENIC RESULTS
KINGSTON ASH RECOVERY PROJECT

DATE: 2 Aug 2012

PHASE: NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 18-19 Sediment Porewater Results.dwg Aug 01,2012 -bperatro

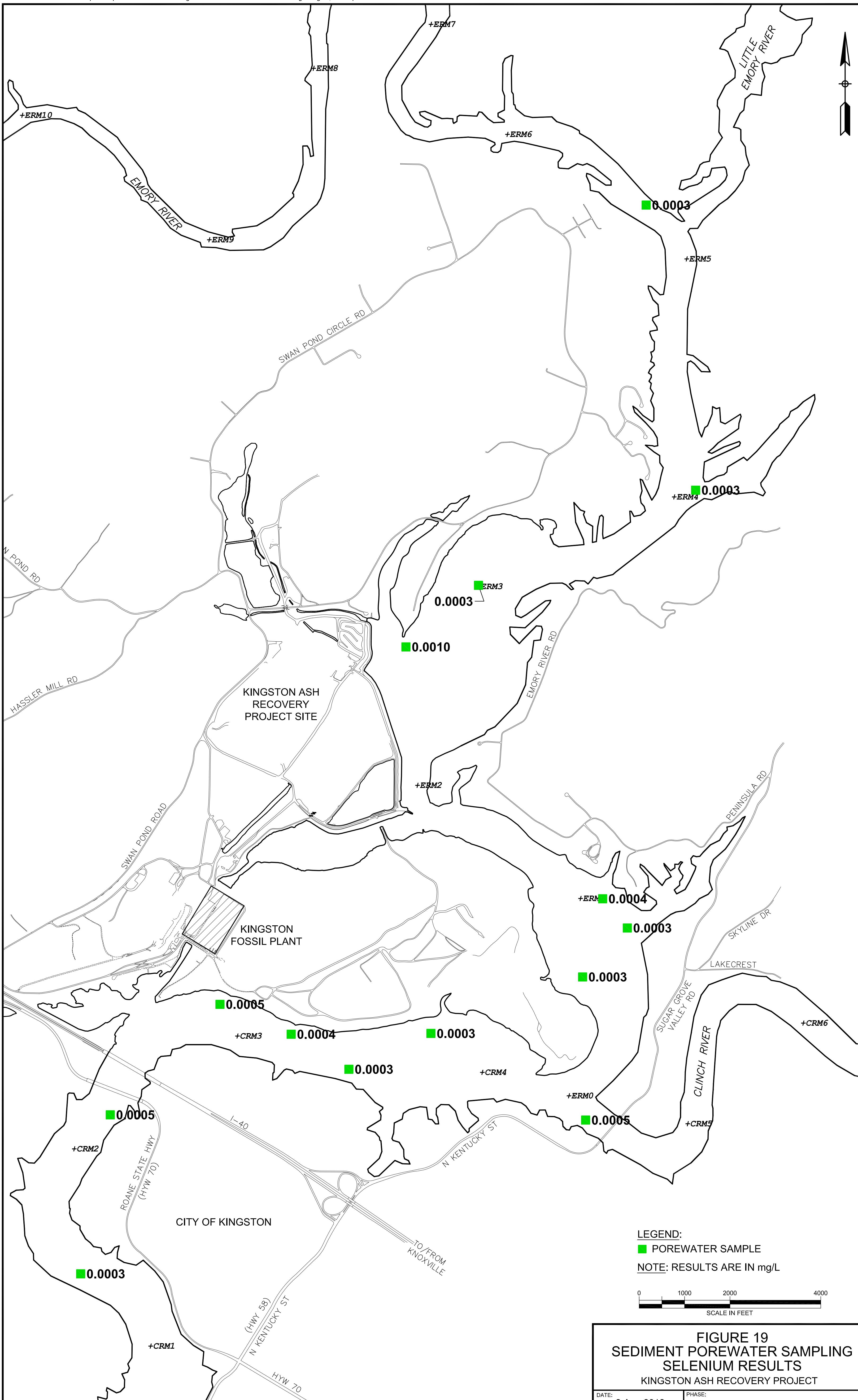
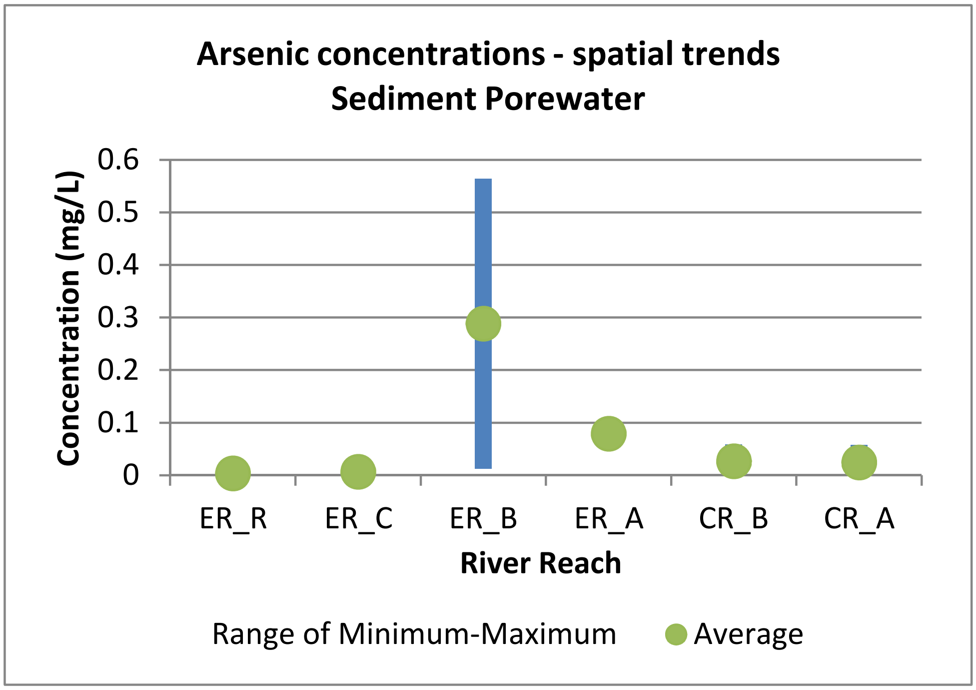


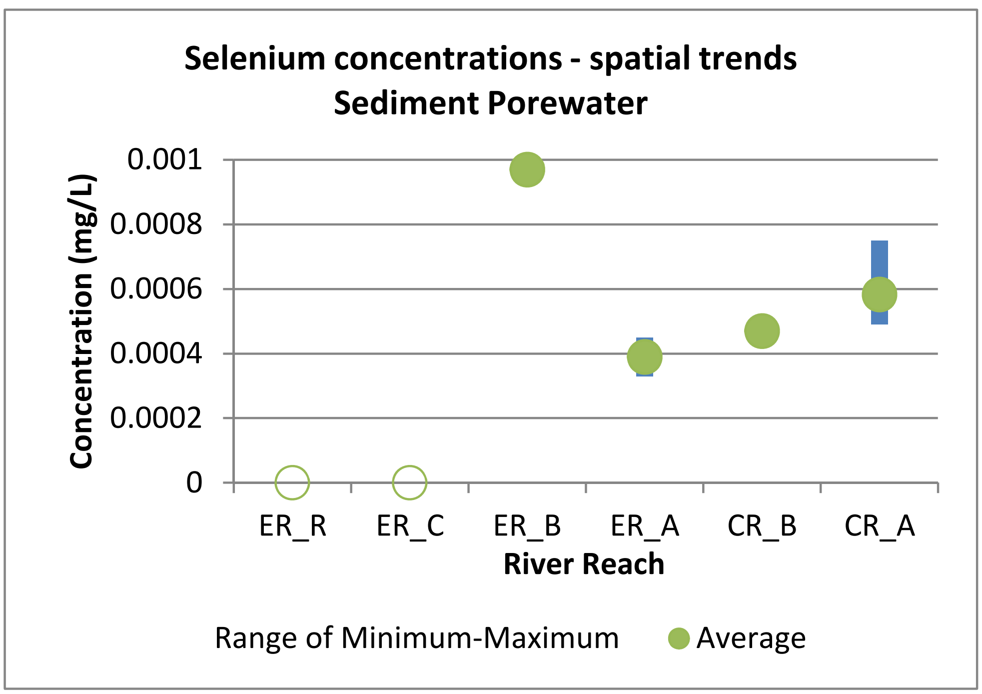
FIGURE 19
SEDIMENT POREWATER SAMPLING
SELENIUM RESULTS
KINGSTON ASH RECOVERY PROJECT

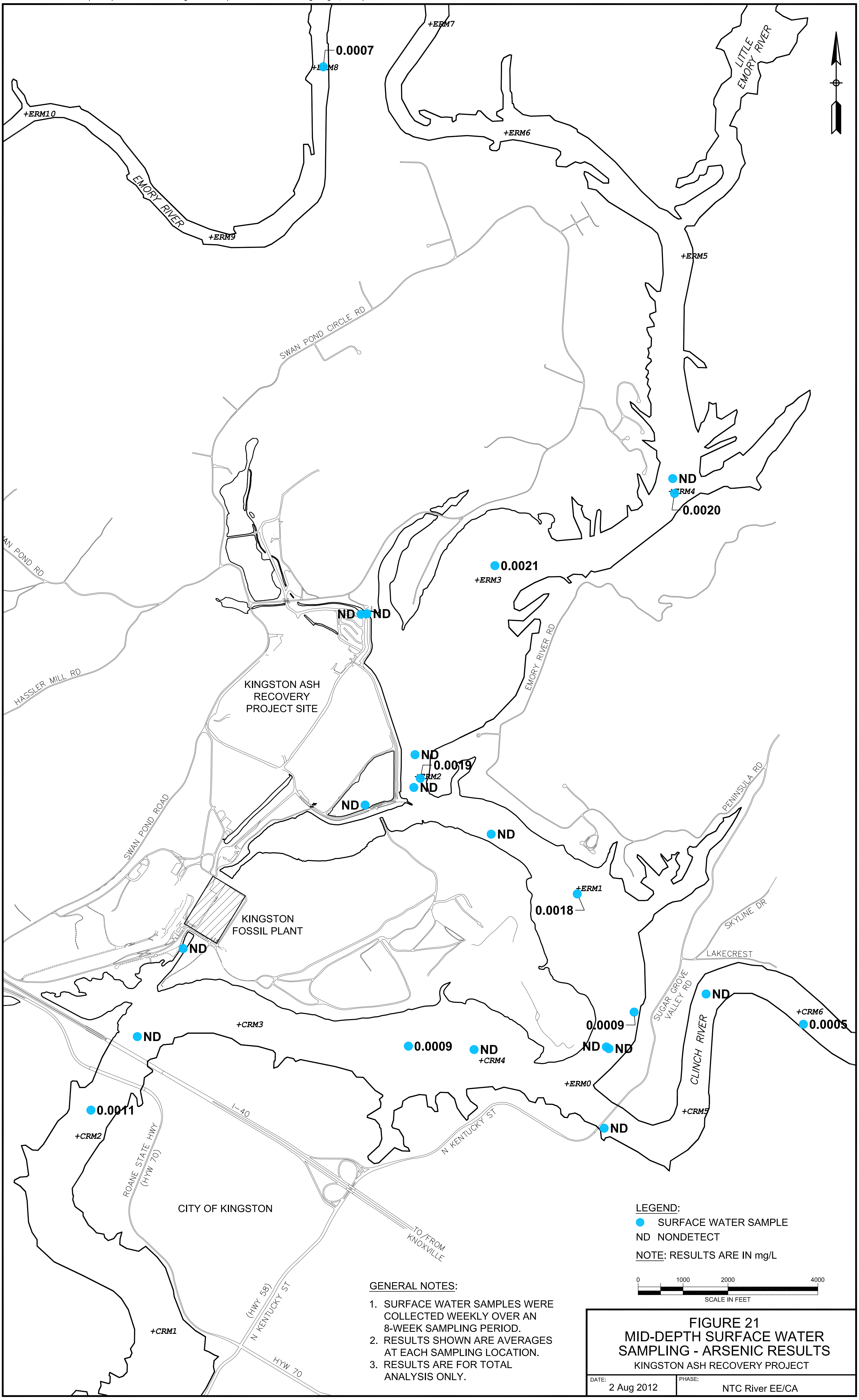
DATE: 2 Aug 2012

PHASE: NTC River EE/CA

Figure 20. Spatial Trends in Sediment Porewater







LEGEND:

- SURFACE WATER SAMPLE
- ND NONDETECT

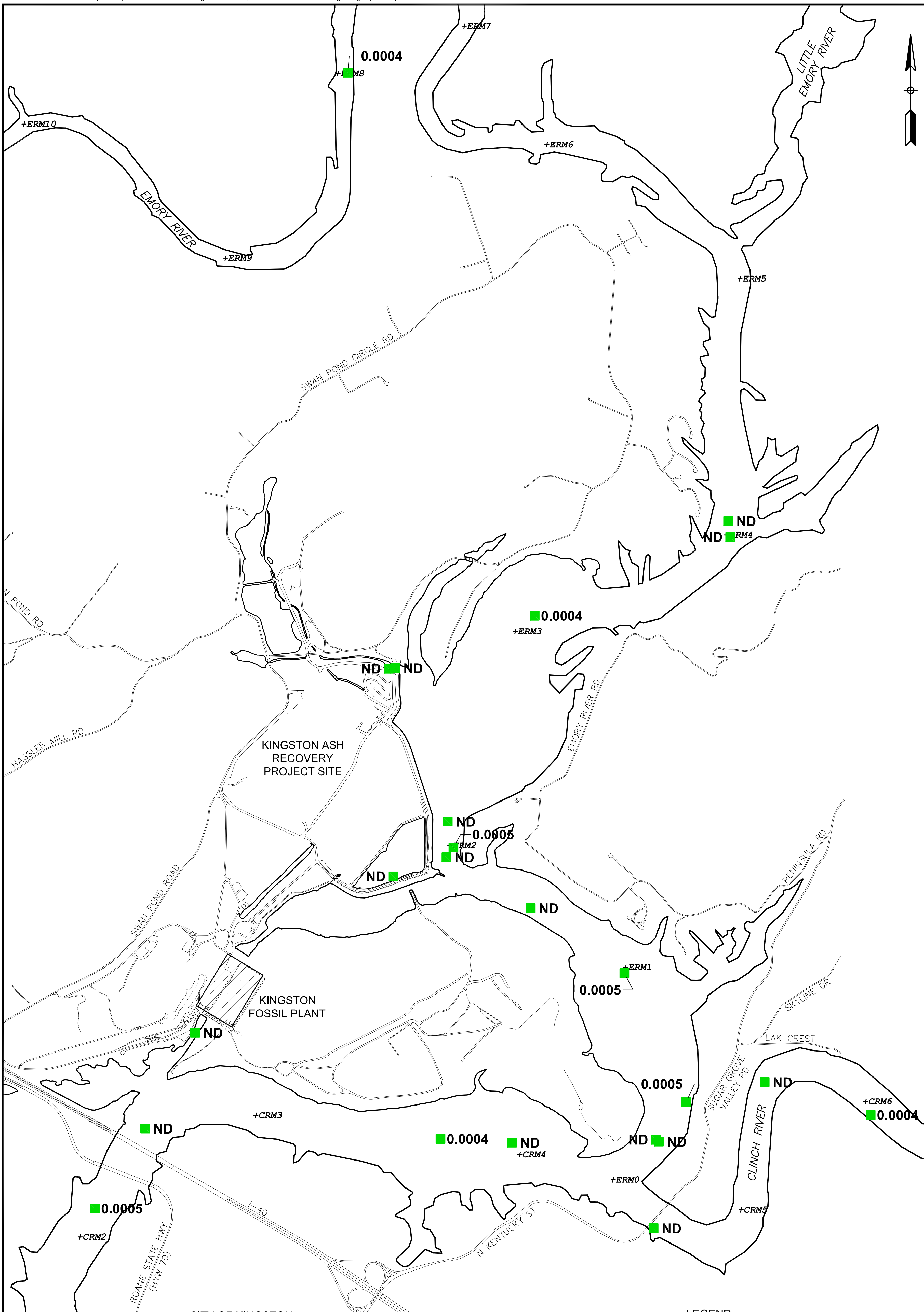
NOTE: RESULTS ARE IN mg/L

GENERAL NOTES:

1. SURFACE WATER SAMPLES WERE COLLECTED WEEKLY OVER AN 8-WEEK SAMPLING PERIOD.
2. RESULTS SHOWN ARE AVERAGES AT EACH SAMPLING LOCATION.
3. RESULTS ARE FOR TOTAL ANALYSIS ONLY.

FIGURE 21
MID-DEPTH SURFACE WATER SAMPLING - ARSENIC RESULTS
KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA



LEGEND:
- SURFACE WATER SAMPLE
- ND NONDETECT

NOTE: RESULTS ARE IN mg/L

0 1000 2000 4000
SCALE IN FEET

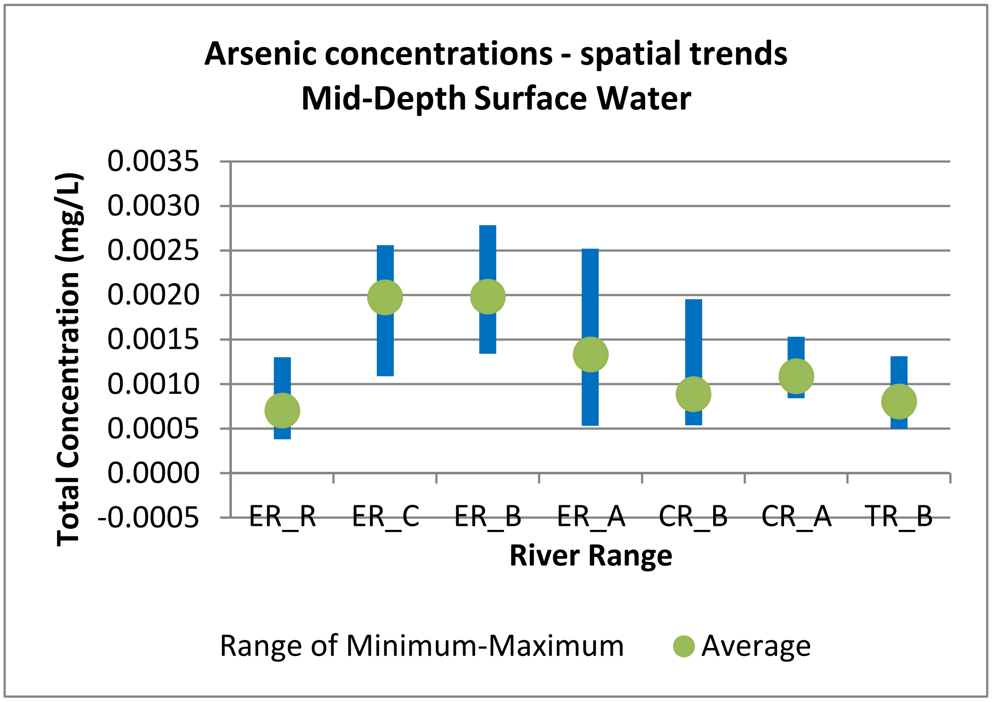
GENERAL NOTES:

1. SURFACE WATER SAMPLES WERE COLLECTED WEEKLY OVER AN 8-WEEK SAMPLING PERIOD.
2. RESULTS SHOWN ARE AVERAGES AT EACH SAMPLING LOCATION.
3. RESULTS ARE FOR TOTAL ANALYSIS ONLY.

FIGURE 22
MID-DEPTH SURFACE WATER SAMPLING - SELENIUM RESULTS
KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

Figure 23. Spatial Trends in Mid-Depth Surface Water



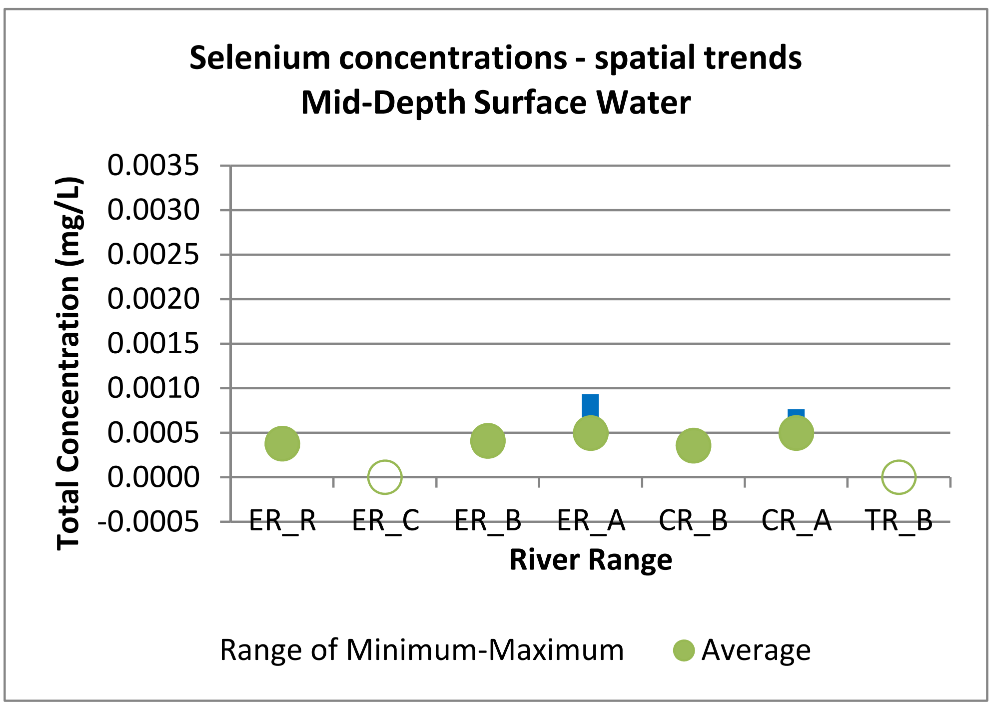
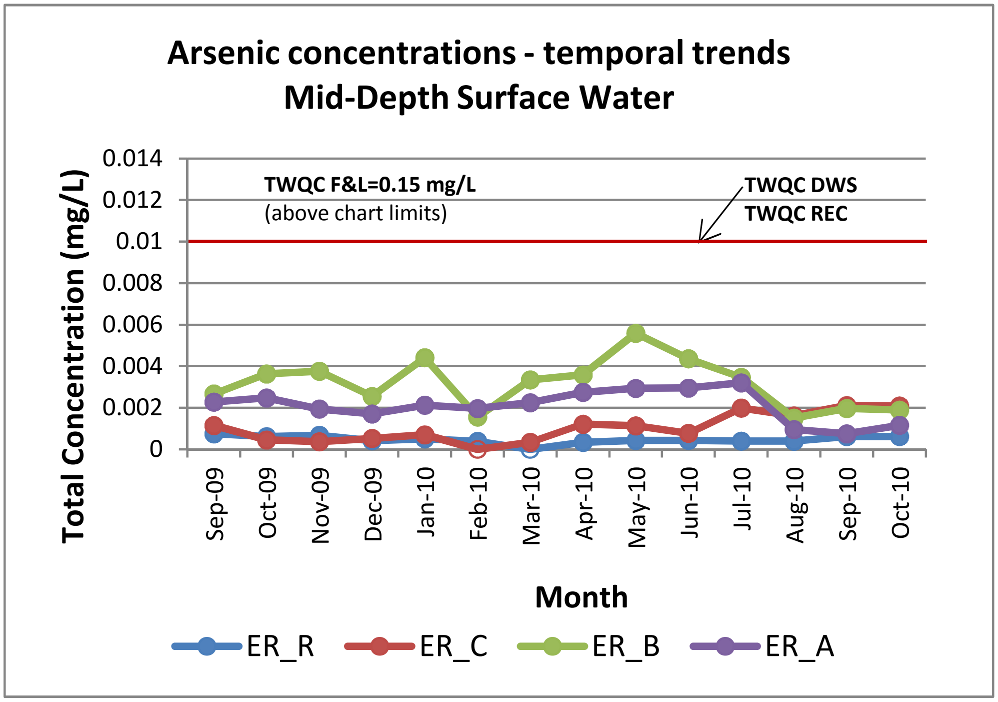
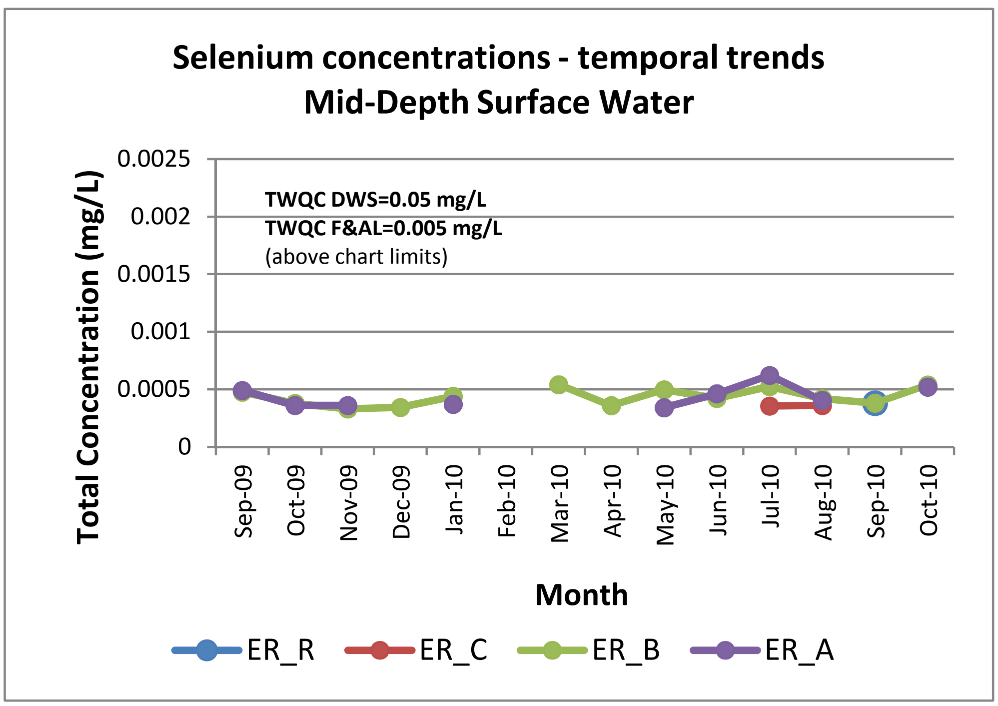


Figure 24. Temporal Trends in Mid-Depth Surface Water





Footnotes:

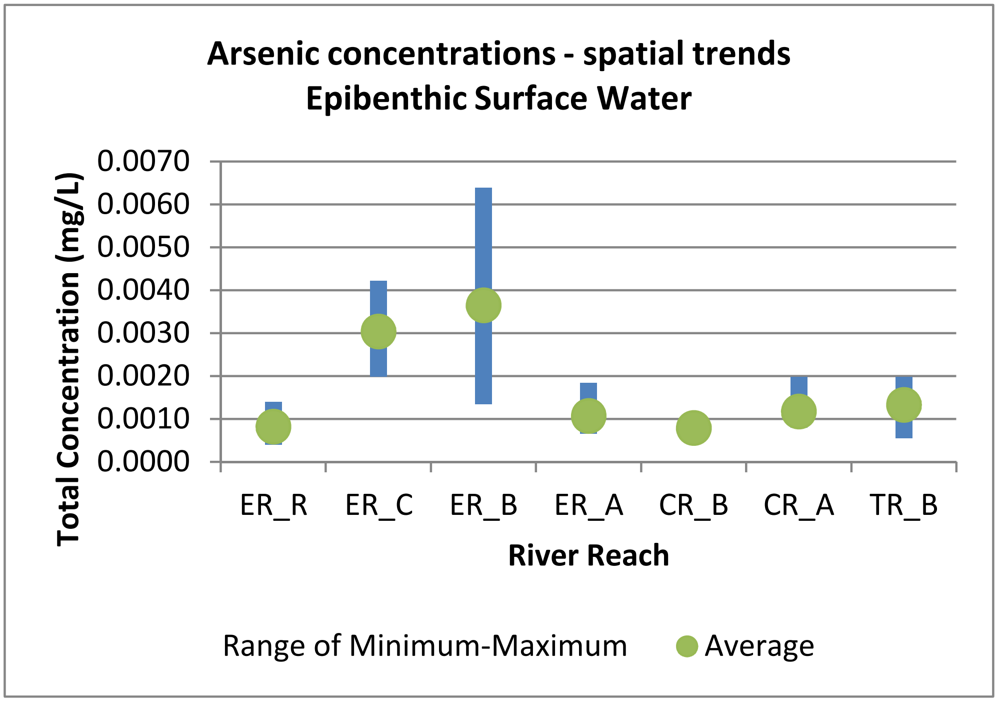
TWQC = Tennessee Water Quality Criteria

DWS = Domestic Water Supply

REC = Recreational - Consumption of water and organisms

F&AL = Fish and Aquatic Life

Figure 25. Spatial Trends in Epibenthic Surface Water



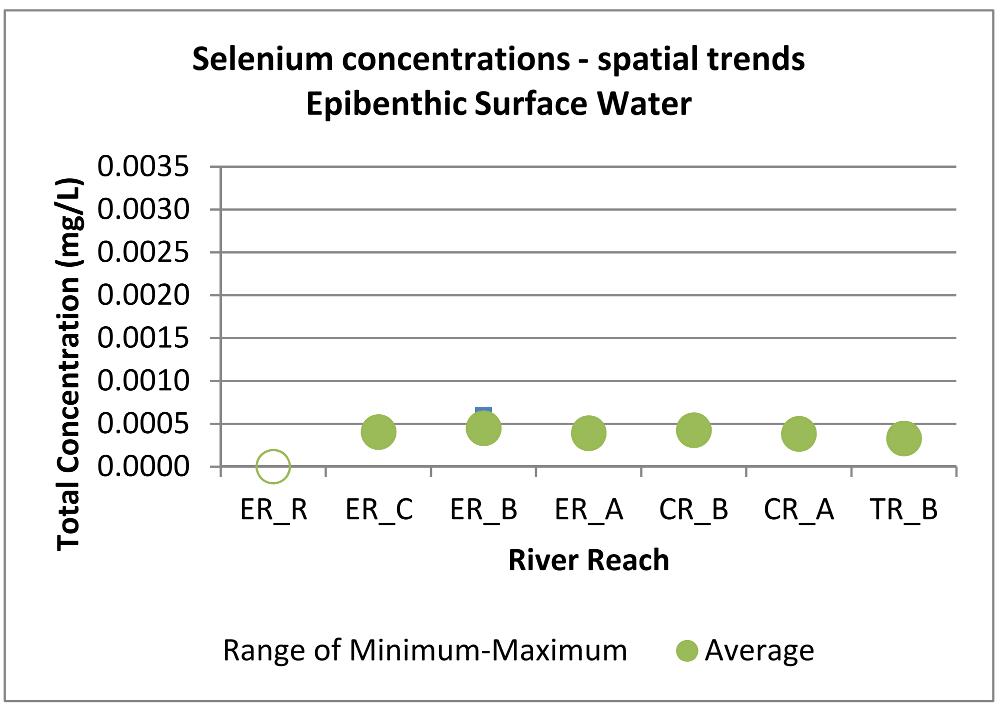
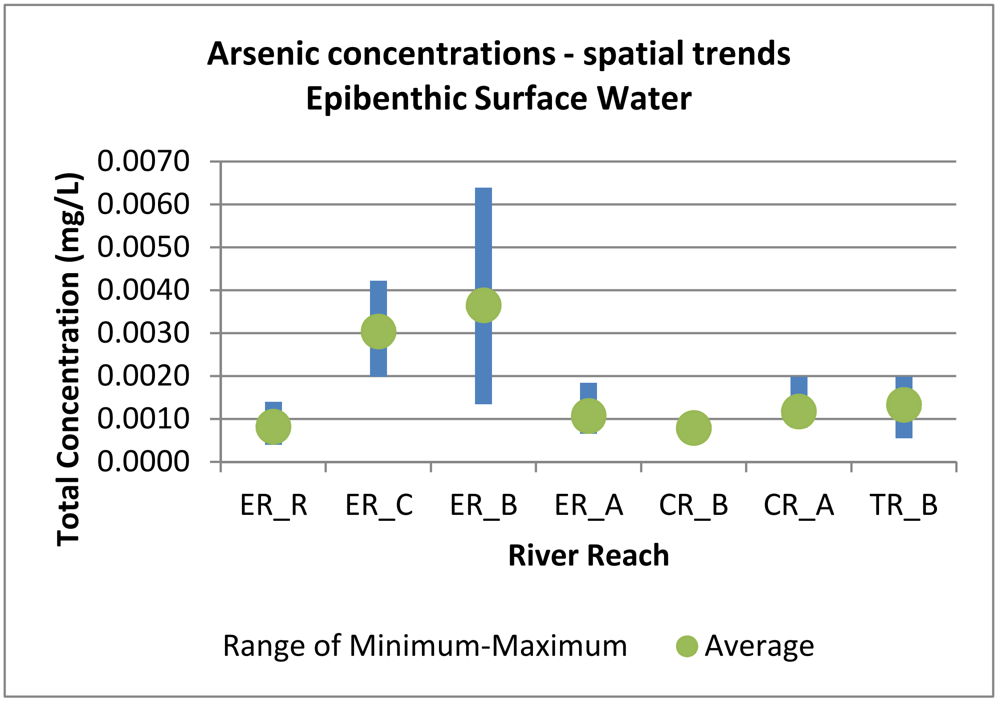


Figure 26. Spatial Trends in Epibenthic Surface Water



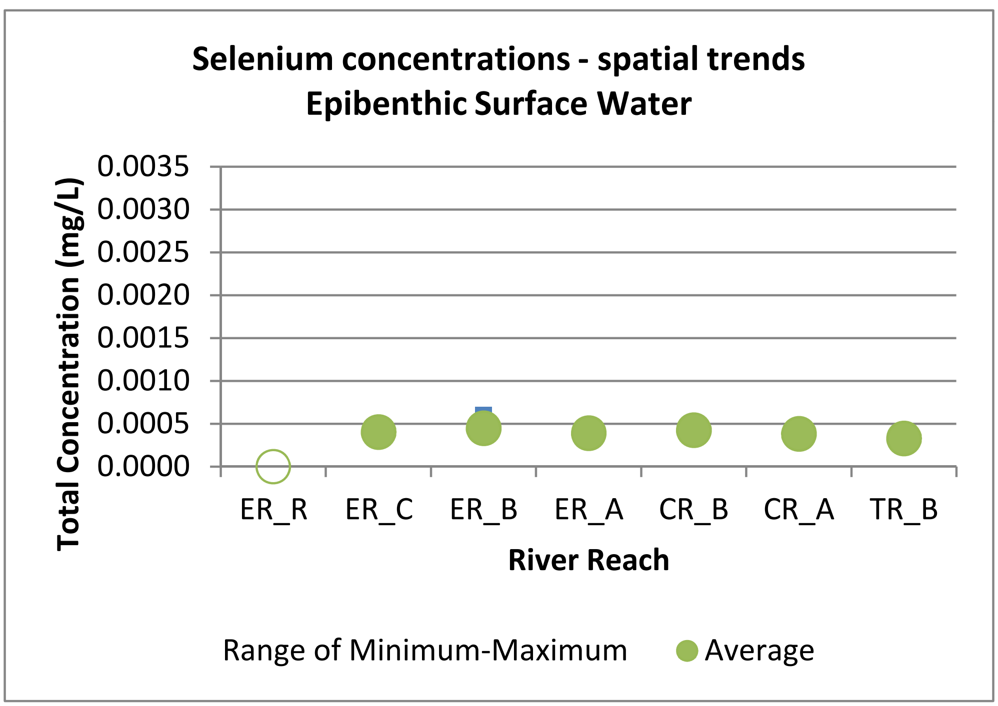
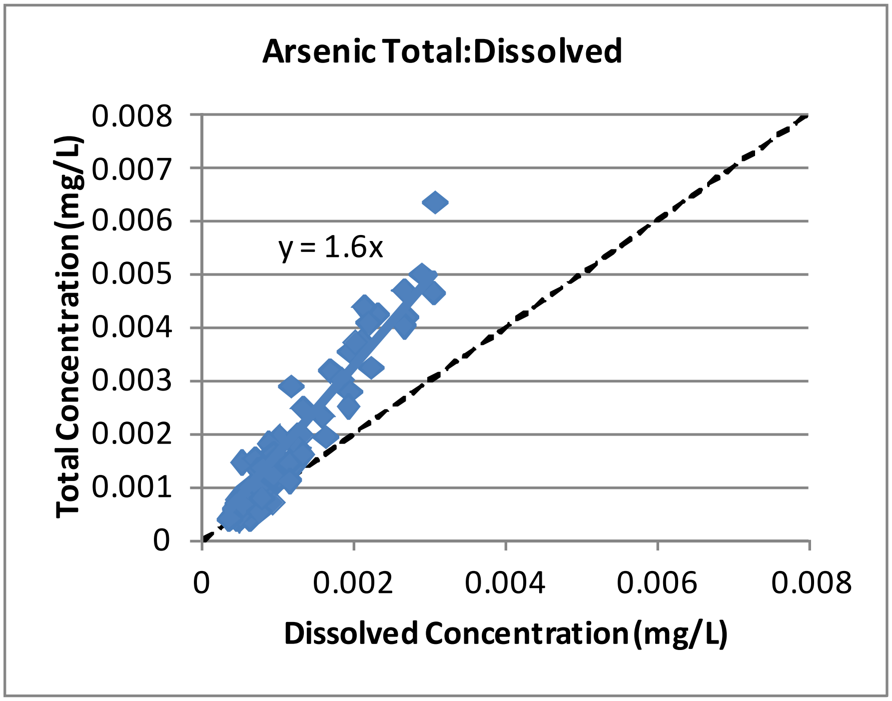


Figure 27. Comparison of Total and Dissolved Concentrations
Epibenthic Surface Water



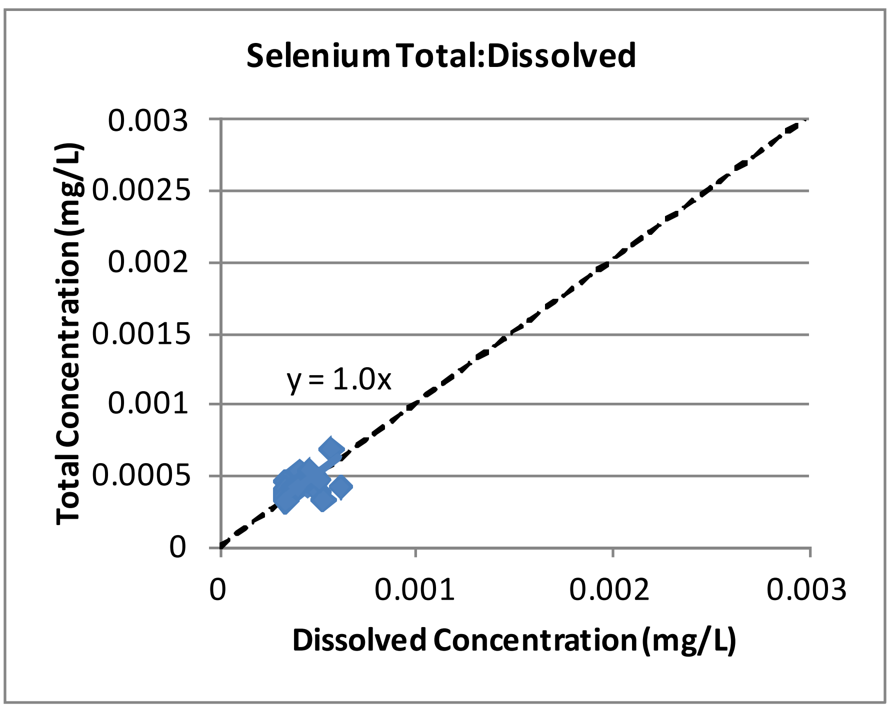
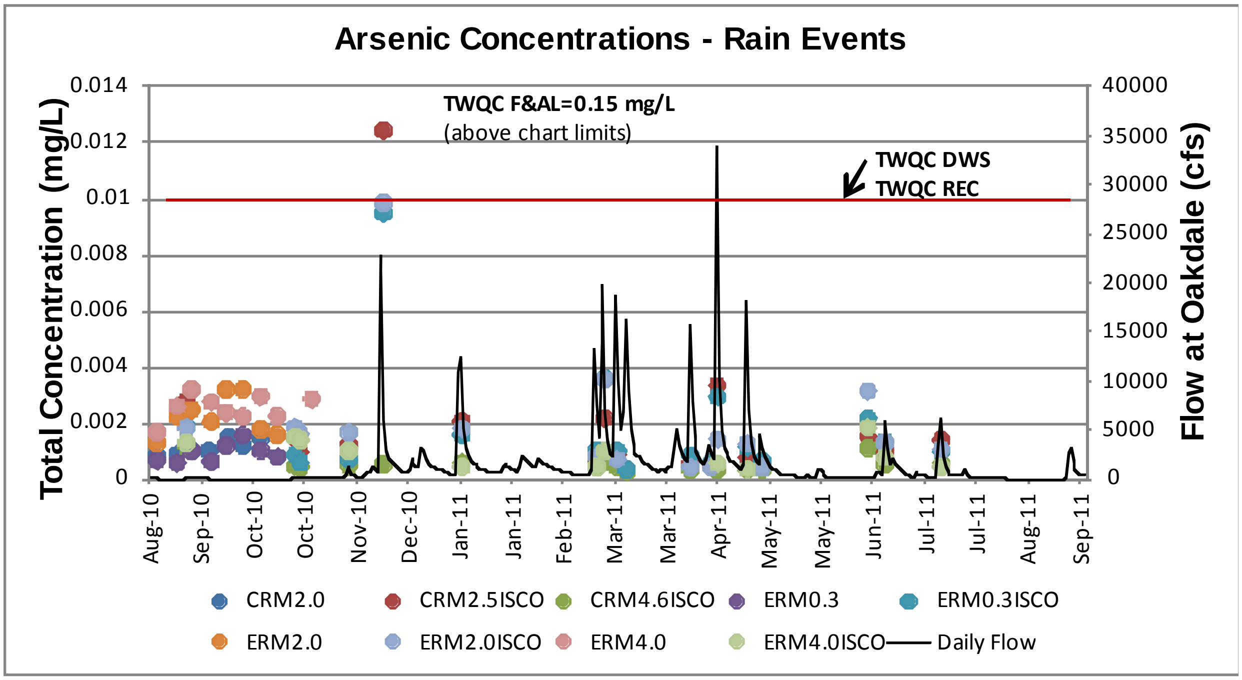
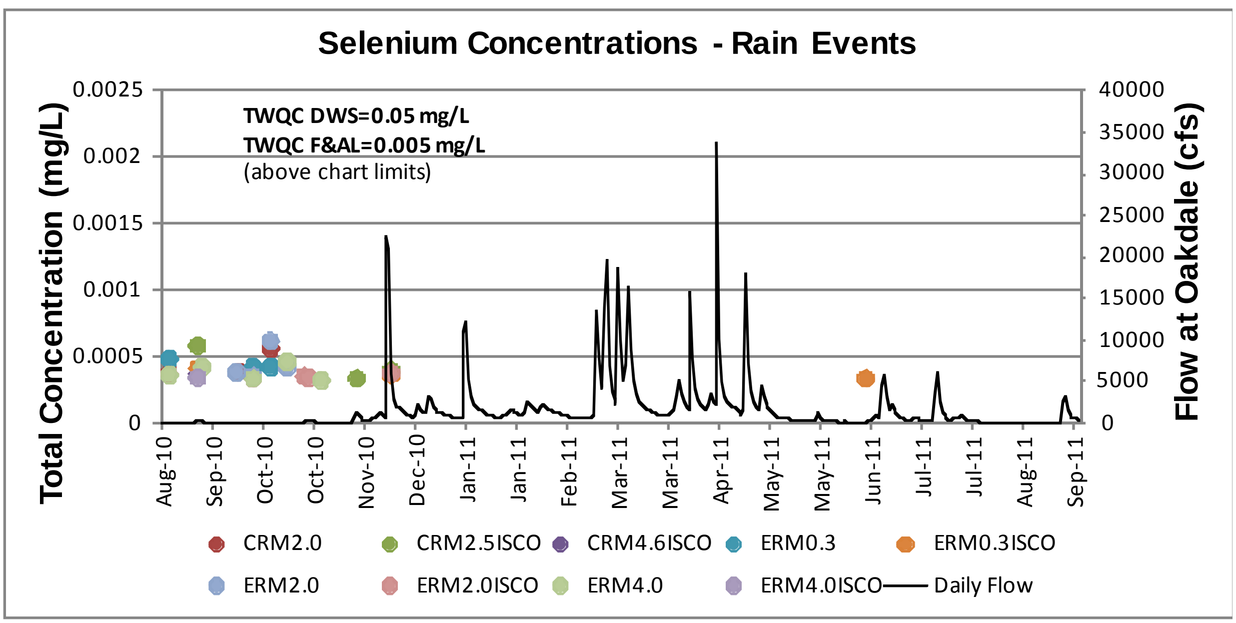


Figure 28. Rain Event Sampling
Mid-Depth Surface Water





Footnotes:
TWQC = Tennessee Water Quality Criteria
DWS = Domestic Water Supply
REC = Recreational - Consumption of water and organisms
F&AL = Fish and Aquatic Life

LEGEND:

- MONITORING WELL
- TEMPORARY WELL POINT
- BOREHOLE / GEOPROBE

DATE OF IMAGE: 6-28-12

NOTES:

1. CONCENTRATION CONTOURS FROM GEOSYNTEC (2010).
2. AQUEOUS CONCENTRATIONS ARE IN ug/L IN ALLUVIUM.

FIGURE 29
GROUNDWATER SAMPLING
DISSOLVED ARSENIC RESULTS
KINGSTON ASH RECOVERY PROJECT

DATE: 2 Aug 2012
PHASE: NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 29 Groundwater Sampling.dwg Aug 01,2012 -bperatro

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 30 Total Arsenic Trends in GW.dwg Aug 01,2012 -bperatro

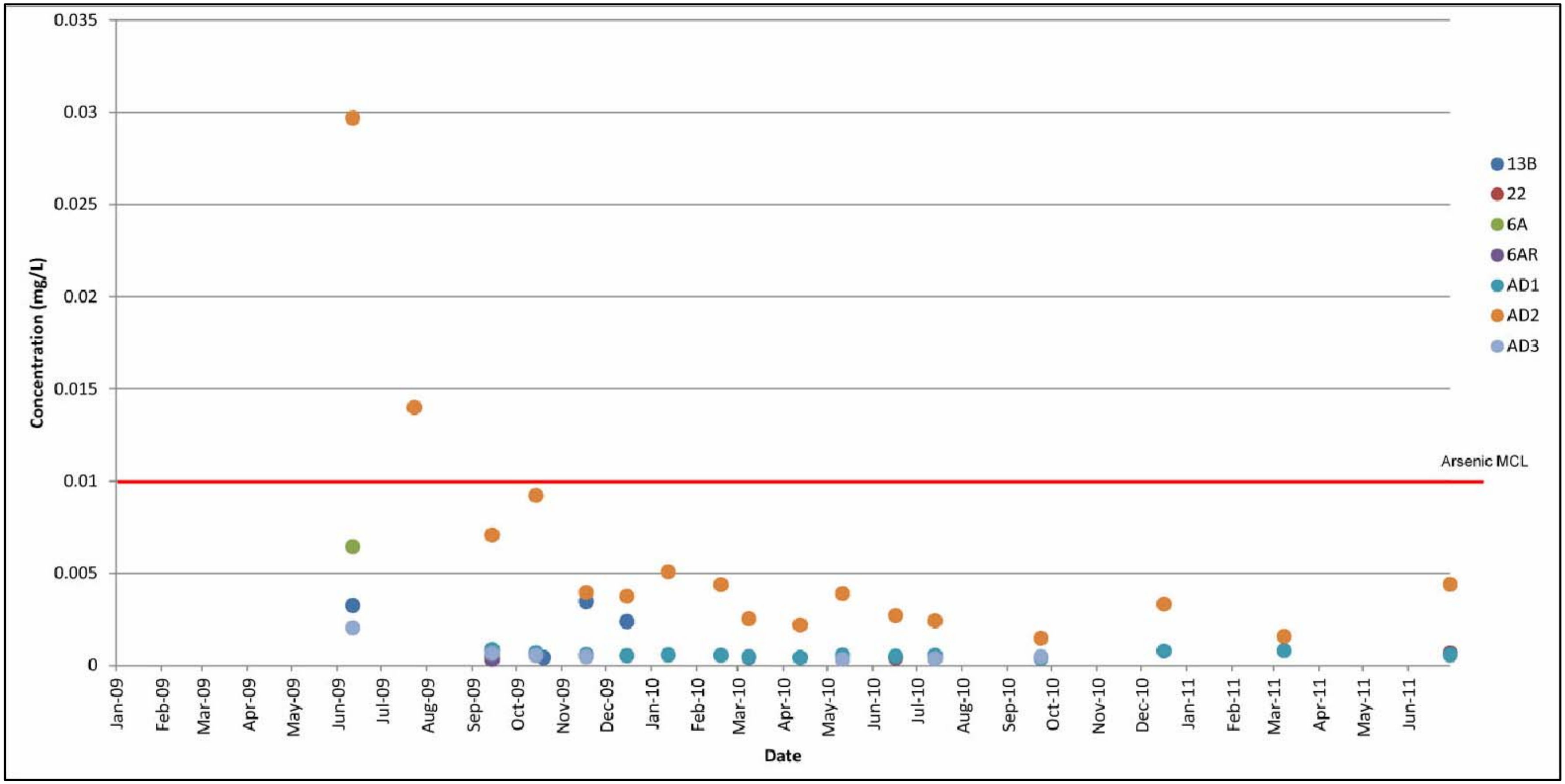


FIGURE 30
TOTAL ARSENIC TRENDS IN GROUNDWATER
KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

NOTE:
CONTOURS FROM GEOSYNTEC (2010)

DATE OF IMAGE: JUNE 28, 2012

0 500 1000 2000
SCALE IN FEET

FIGURE 31
PREDICTED POTENTIOMETRIC HEADS IN ASH FOR CALIBRATED MODEL

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 31 Predicted Potentiometric Heads in Ash.dwg Aug 01,2012 -bperatro

NOTES:
1. CONCENTRATION CONTOURS FROM GEOSYNTEC (2010).
2. CONCENTRATIONS ARE IN ug/L.

DATE OF IMAGE: JUNE 28, 2012

0 500 1000 2000
SCALE IN FEET

FIGURE 32
PREDICTED ARSENIC DISTRIBUTION AT 100 YEARS

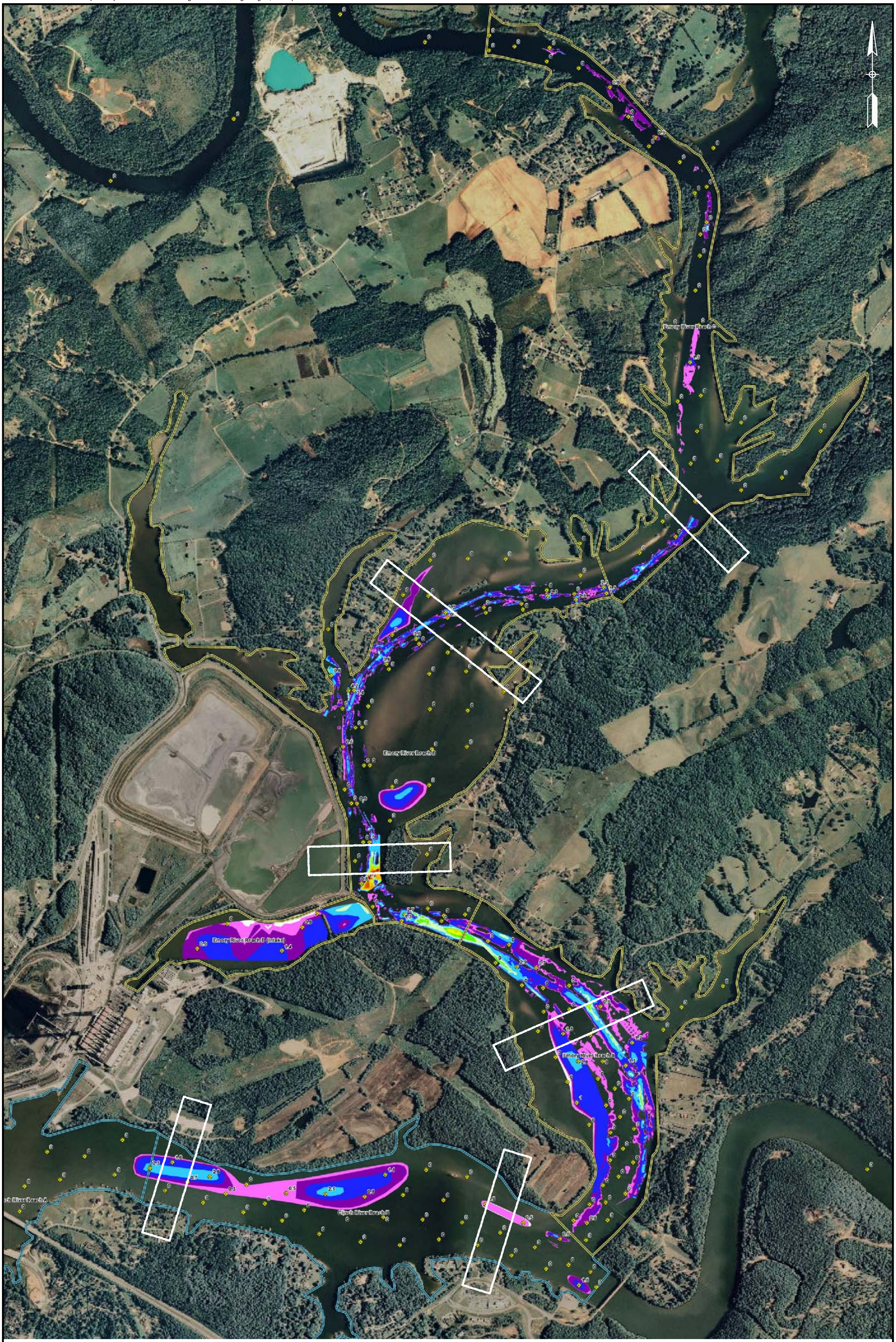
KINGSTON ASH RECOVERY PROJECT

DATE: 2 Aug 2012

PHASE: NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 32 Arsenic at 100 Years.dwg Aug 07,2012 -bperatro

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 33 Alt 1 MNR.dwg Aug 01,2012 -bperatro



Legend

Vibracore Location
Labeled with Ash Thickness (ft)
(if < 50% Ash, Ash Thickness = 0)

Emory River Reachs A, B, & C

Clinch River Reachs A & B

Locations of Monitoring Transects

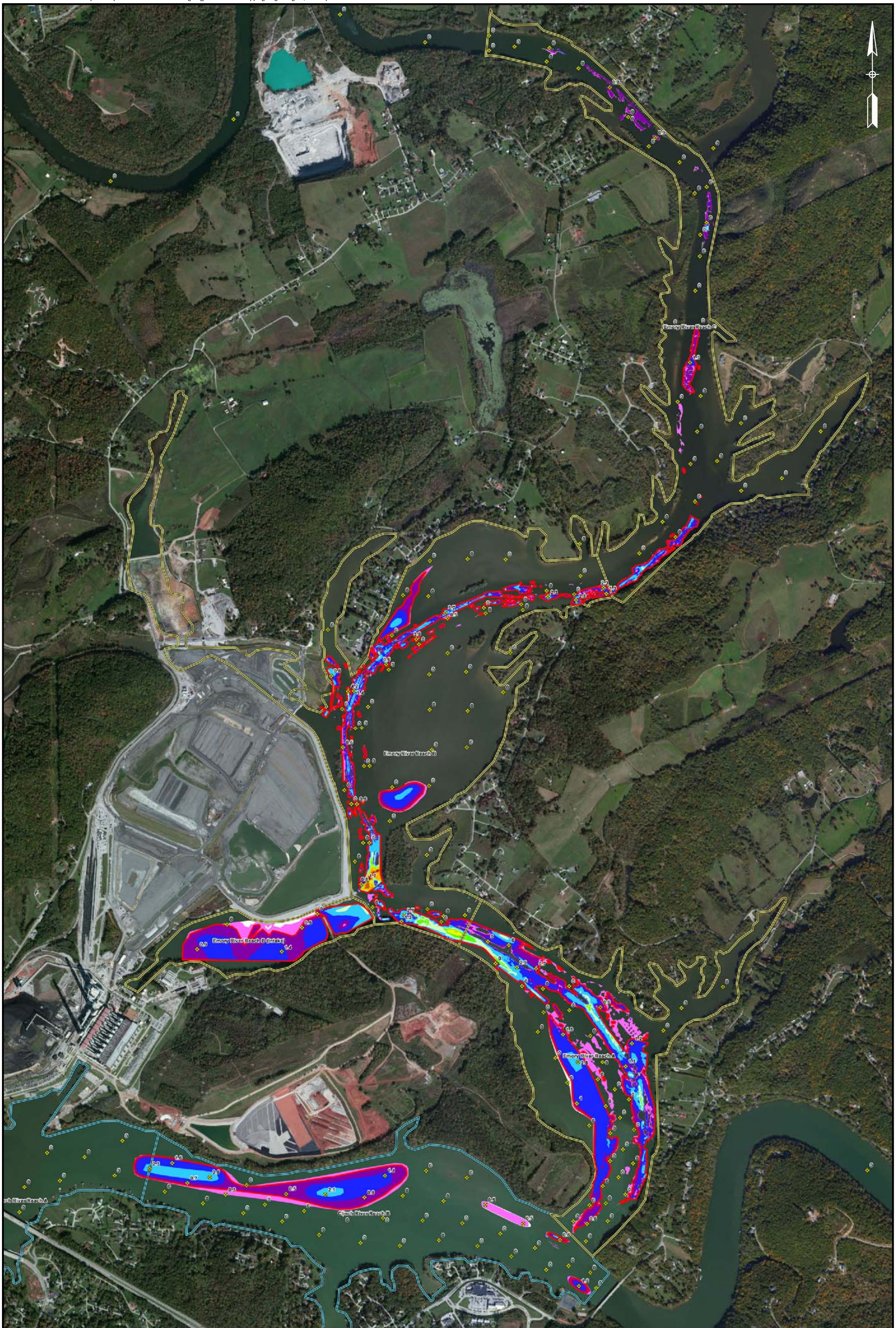
Thickness of Ash in Vibracores >50% Ash

No Ash
Less Than 0.5 ft
0.5 ft - 1.0 ft
1 ft - 2 ft
2 ft - 4 ft
4 ft - 6 ft
6 ft - 8 ft
8 ft - 10 ft
10 ft - 15 ft
15 ft- 20 ft
20 ft - 25 ft

FIGURE 33
ALTERNATIVE 1: MONITORED NATURAL RECOVERY
KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 34_Alt 2a In-Situ Capping.dwg   Aug 01,2012 -bperatro



Legend

- Vibracore Location Labeled with Ash Thickness (ft) (if < 50% Ash, Ash Thickness = 0)
- Emory River Reachs A, B, & C
- Clinch River Reachs A & B
- Area to be Capped

Thickness of Ash in Vibracores > 50% Ash

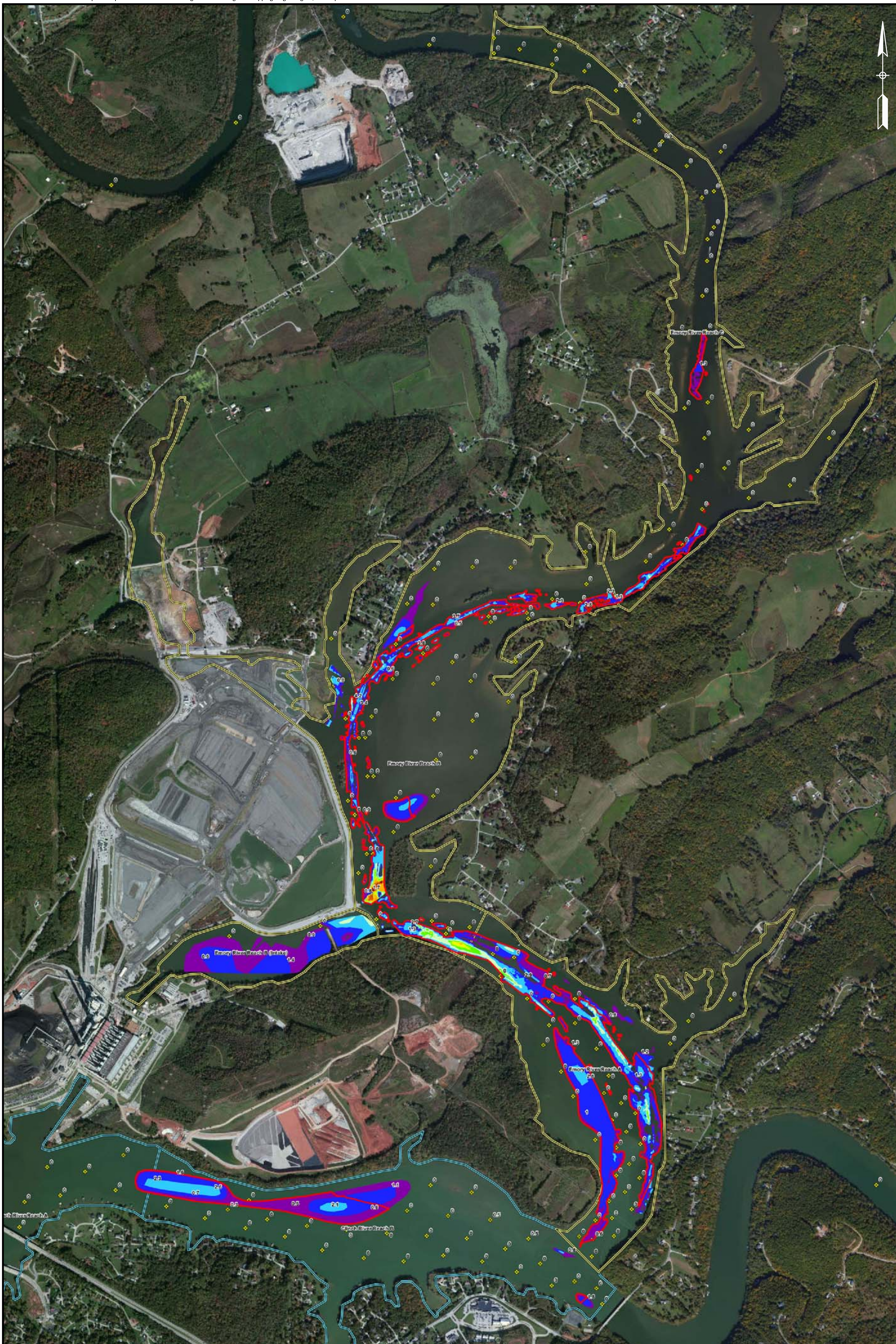
- No Ash
- Less Than 0.5 Feet
- 0.5 ft - 1.0 ft
- 1 ft - 2 ft
- 2 ft - 4 ft
- 4 ft - 6 ft
- 6 ft - 8 ft
- 8 ft - 10 ft
- 10 ft - 15 ft
- 15 ft- 20 ft
- 20 ft - 25 ft

FIGURE 34
ALTERNATIVE 2A: IN-SITU CAPPING

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 35 Alt 2b Targeted Capping.dwg Aug 01,2012 -bperatro



Legend

- Vibracore Location Labeled with Ash Thickness (ft) (if < 50% Ash, Ash Thickness = 0)
- Emory River Reachs A, B, & C
- Clinch River Reachs A & B
- Area to be Capped

Thickness of Ash in Vibracores > 50% Ash

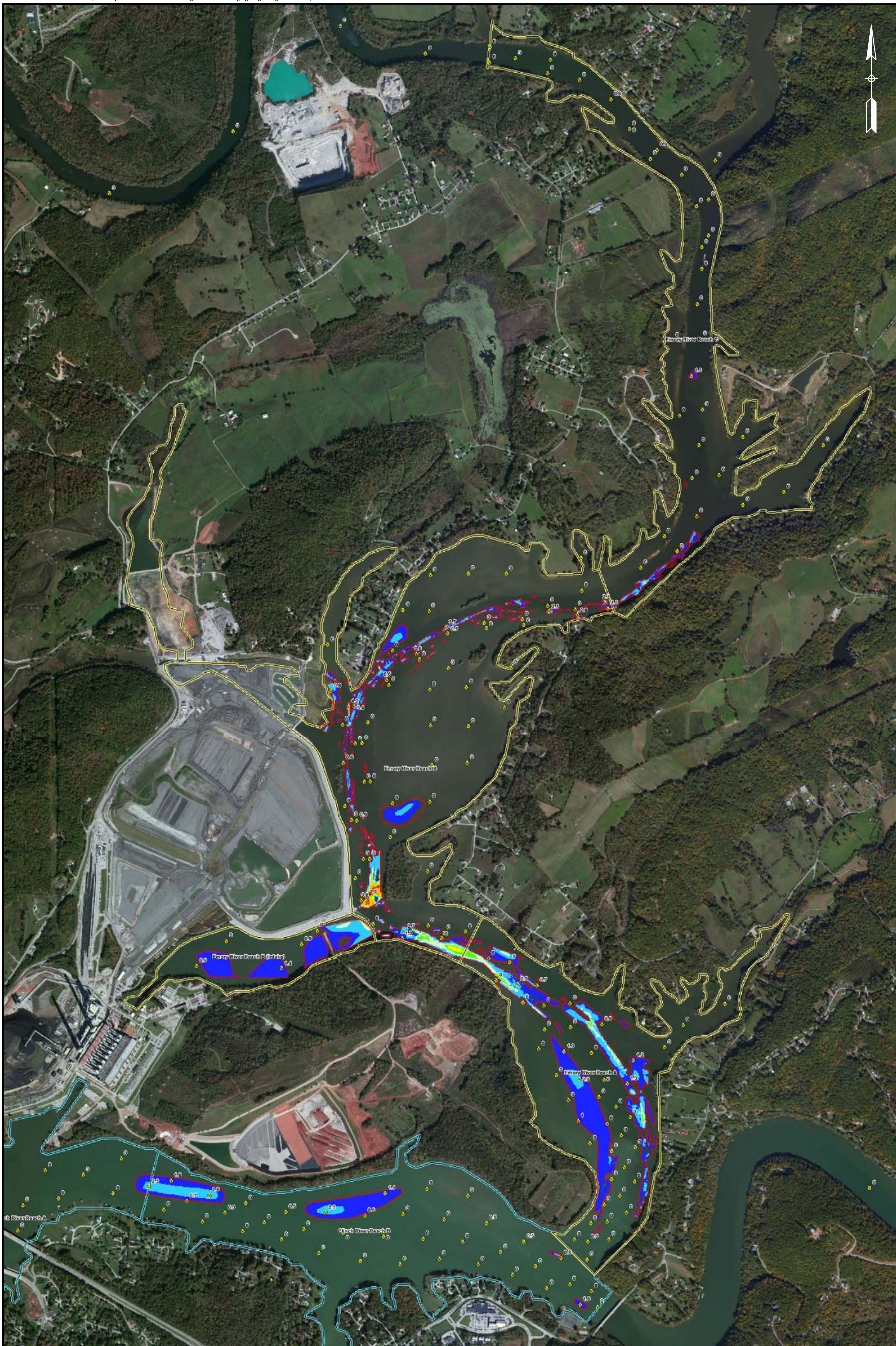
- 0.5 ft - 1.0 ft
- 1 ft - 2 ft
- 2 ft - 4 ft
- 4 ft - 6 ft
- 6 ft - 8 ft
- 8 ft - 10 ft
- 10 ft - 15 ft
- 15 ft- 20 ft
- 20 ft - 25 ft

FIGURE 35
ALTERNATIVE 2B: TARGETED CAPPING

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 36 Alt 3a Dredging.dwg Aug 01,2012 -bperatro



Legend

- Vibracore Location Labeled with Ash Thickness (ft) (if < 50% Ash, Ash Thickness = 0)
- Emory River Reachs A, B, & C
- Clinch River Reachs A & B
- Area to be Dredged

Thickness of Ash in Vibracores > 50% Ash
Volume of ash > 1 foot = 433,498cy

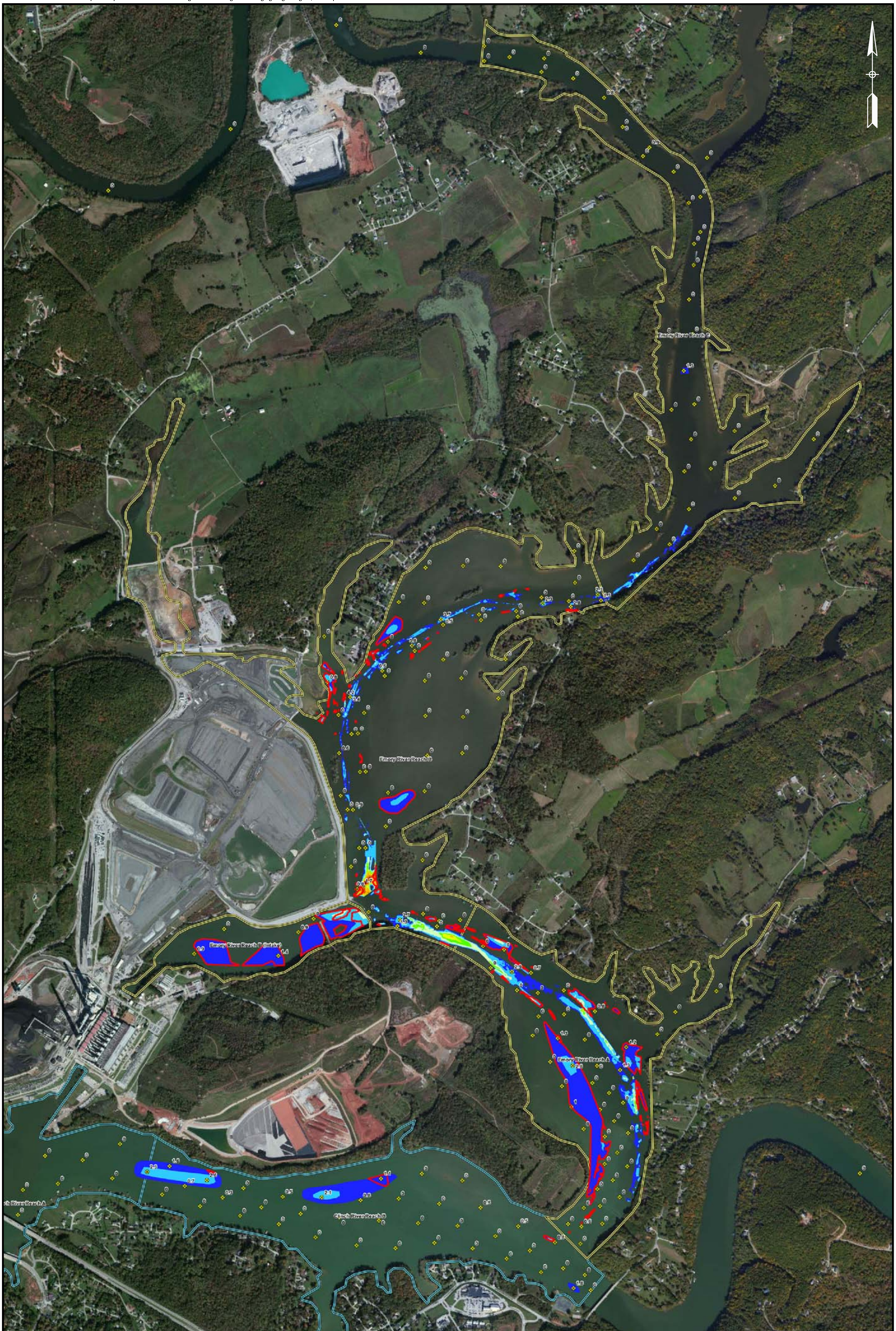
- 1 ft - 2 ft
- 2 ft - 4 ft
- 4 ft - 6 ft
- 6 ft - 8 ft
- 8 ft - 10 ft
- 10 ft - 15 ft
- 15 ft- 20 ft
- 20 ft - 25 ft

FIGURE 36
ALTERNATIVE 3A: DREDGING

KINGSTON ASH RECOVERY PROJECT

DATE: 2 Aug 2012

PHASE: NTC River EE/CA



Legend

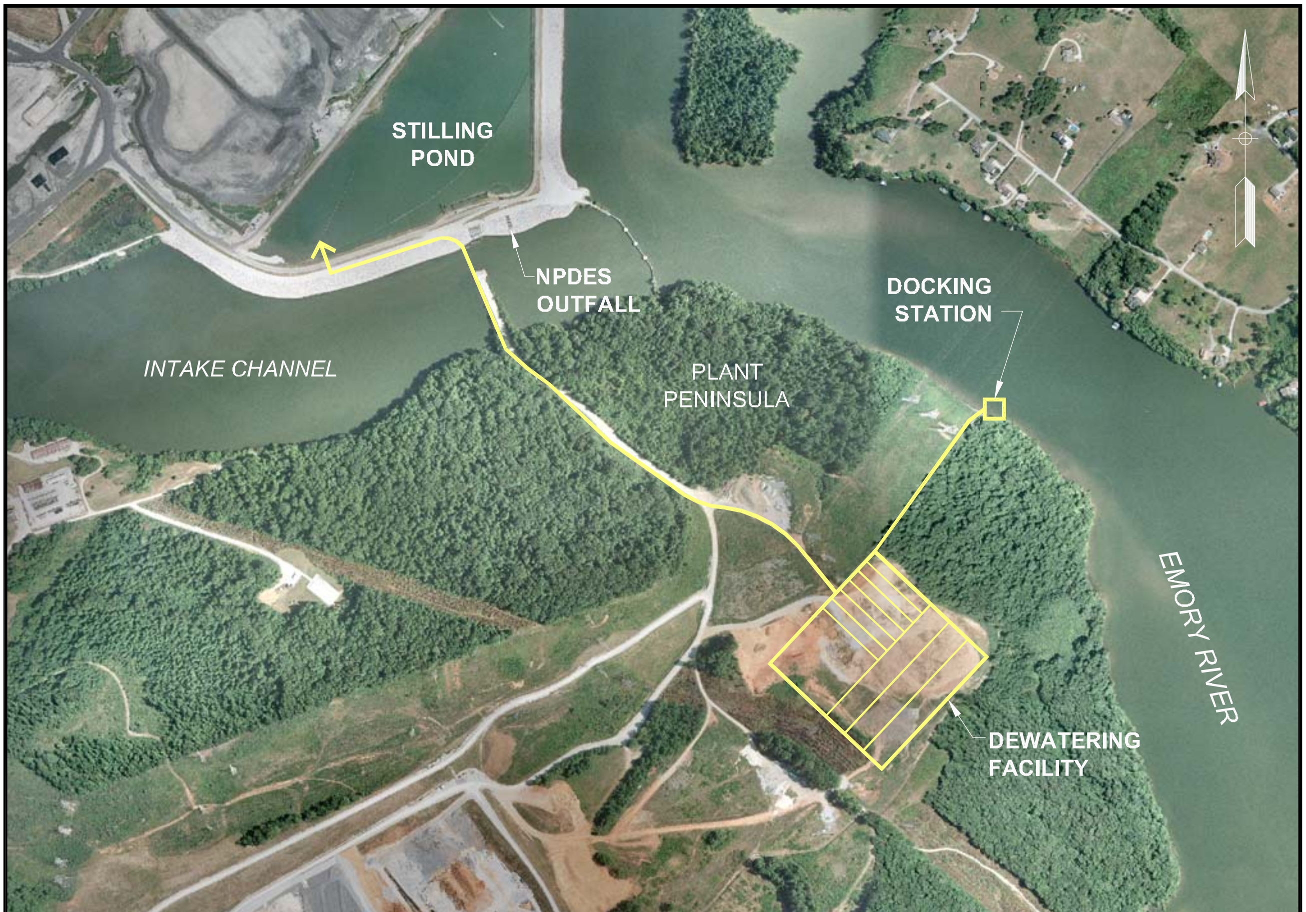
- Vibracore Location Labeled with Ash Thickness (ft) (if < 50% Ash, Ash Thickness = 0)
- Emory River Reachs A, B, & C
- Clinch River Reachs A & B
- Area to be Dredged

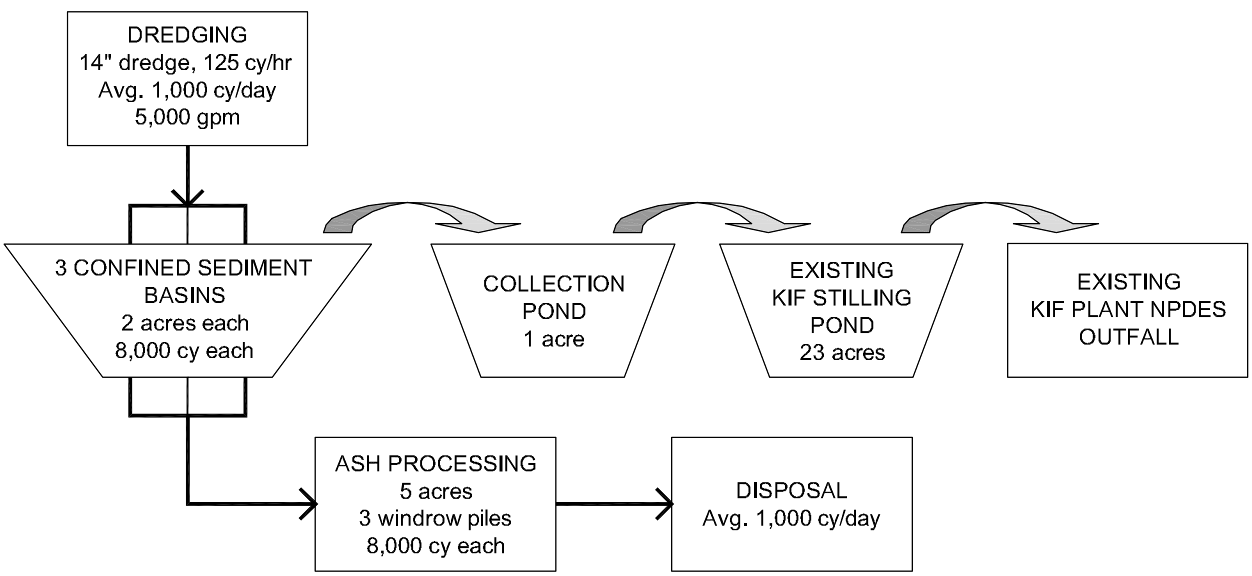
Thickness of Ash in Vibracores > 50% Ash

- 1 ft - 2 ft
- 2 ft - 4 ft
- 4 ft - 6 ft
- 6 ft - 8 ft
- 8 ft - 10 ft
- 10 ft - 15 ft
- 15 ft- 20 ft
- 20 ft - 25 ft

FIGURE 37
ALTERNATIVE 3B: TARGETED DREDGING
KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA





DEWATERING PROCESS SCHEMATIC
NTS

DATE OF IMAGE: JUNE 28, 2012

0 500 1000 2000
SCALE IN FEET

FIGURE 38
DEWATERING FACILITY

KINGSTON ASH RECOVERY PROJECT

DATE:	PHASE:
2 Aug 2012	NTC River EE/CA

I:\0002 ENGINEERING\Civil\Report Graphics\NTC River EE-CA\Fig 38 Dewatering Facility.dwg Aug 01,2012 -bperairo