A Long-Term Monitoring Plan for the Kingston Ash Spill

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Keywords: monitoring, Kingston, Ash, Spill

Abstract
TVA used a combination of hydraulic and mechanical dredging to remove most of the December, 2008, TVA Kingston fly ash spill from the Emory River. Legacy contaminants, primarily Cs-137 and mercury, made it impractical to dredge downstream of Emory River mile (ERM) 1.8. Consequently, approximately 500,000 cu yd of residual ash remains in the Emory, Clinch, and Tennessee Rivers, with most of that occurring between ERM 0—2.0. Following TVA’s evaluation of the cost, effectiveness, and feasibility of alternatives in a formal Engineering Evaluation/Cost Analysis (EE/CA) (TVA 2012a), EPA and TDEC selected Monitored Natural Recovery (MNR) as the removal action for the residual ash (TVA 2012b). The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), requires implementation of a long-term monitoring (LTM) plan, with reviews at least every five years to determine whether additional action is needed. This paper describes the LTM plan for monitoring the effectiveness of MNR in mitigating ecological risks for residual ash in the Emory-Clinch-Tennessee Rivers system near the TVA Kingston Fossil Plant.

Background
Immediately following the December 22, 2008 ash spill at Kingston Fossil Plant, TVA began comprehensive environmental monitoring and initiated investigations to evaluate immediate, intermediate, and long-term impacts of the ash spill on natural resources and public health. That effort involved numerous Federal laboratories, universities, environmental consulting firms, and commercial analytical laboratories, as well as TVA scientists and engineers. The studies covered a broad spectrum of disciplines and environmental media, and were conducted with rigorous quality assurance/quality control. Approximately 20,000 samples of water, air, ash, sediments, and biota (fish, birds, amphibians, reptiles, mammals, insects, snails, periphyton, and vascular plants) were collected over a four-year period, with about a half-million chemical analyses performed, long with thousands of field observations recorded.

These investigations provided much of the data for a Baseline Human Health Risk Assessment (BHHRA, Jacobs 2012) and a Baseline Ecological Risk Assessment (BERA, Arcadis 2012) evaluating potential long-term effects of the residual ash on humans and biota. The BHHRA found no significant human health risks from the residual ash; however the BERA found that there was potential for low to moderate risks to populations of benthic invertebrates and low risks to riparian- and aerial-feeding birds that consume benthic invertebrates. The potential risks for those three categories of organisms were sufficient that the BERA recommended management action.

Correlation of toxicity bioassay results for two test organisms with concentrations of arsenic and selenium in sediments yielded sediment Remediation Objectives (ROs) of 29–41 mg/kg for arsenic and 3.0—3.2 mg/kg for selenium (TVA 2012a). Sediment transport modeling results (Scott 2012) indicate natural processes of sedimentation, scouring, and re-deposition will achieve the ROs for this project in a relatively short time (<15 years). Consequently, natural recovery will reduce the potential for exposure of benthic invertebrates to the ash to near-background levels, thus reducing potential bio-uptake by riparian- or aerial-feeding birds for which aquatic insects may comprise a significant part of their diets.
The lack of significant human health risks and relatively low ecological risks due to the residual ash, the potential for increasing both ecological and human health risks by dredging in areas with legacy contaminants, the technical difficulty of conducting dredging without disturbing legacy sediments, the cost and questionable effectiveness of capping residual ash, and the effectiveness of natural sedimentation processes in diluting and capping residual ash were principal factors considered in the EE/CA (TVA 2012a). Following completion of the EE/CA, EPA and TDEC selected MNR as the preferred alternative (EE/CA Alternative 1) as the appropriate remedy in this situation (TVA 2012b).

**Data Quality Objectives (DQOs)**

To guide development of the LTM plan, TVA followed EPA’s seven-step iterative DQO approach (EPA 1997) to define the purposes of data collection efforts, clarify what data are needed to satisfy those purposes, and specify the quality of data required. The DQOs identified for the LTM plan are:

1. To evaluate the effectiveness of sediment scouring, mixing, transport, and re-deposition (i.e., ash transport and fate) to achieve CERCLA Remediation Objectives.
2. To measure MNR effectiveness in protecting ecological resources at risk (benthic invertebrates, riparian- and aerial-feeding birds).
3. To document restoration of the ecological function and recreational use of the river system to pre-release conditions.
4. To provide information for other purposes, including Natural Resources Damages Assessment (NRDA) and recovery.

Types of data required to address these objectives include:

1. Information on sediment scouring, mixing, transport, and deposition over time
2. Concentrations of ash and ash-related contaminants in sediment
3. Concentrations of ash-related contaminants in biota, especially in the area with most residual ash
4. Biota population, community, health, and reproductive competence measures

**Kingston LTM Plan Overview**

Given the relatively low levels of ecological risk associated with the residual ash, overall objectives for monitoring the natural recovery of the river system are to confirm that those risks remain low and concentrations of ash-related contaminants in sediments and biota decline over time. The plan focuses on the Emory River, where the greatest amount of residual ash is located, with limited collections on the Clinch and Tennessee Rivers.

The monitoring plan developed to address these objectives includes the following six components:

1. Ash fate and transport monitoring and modeling
2. Biennial sediment contaminants monitoring
3. Sediment toxicity testing
4. Biennial benthic invertebrate monitoring
5. Annual monitoring of biota in the lower Emory River (where the bulk of the residual ash occurs)
6. Non-CERCLA supplemental monitoring for NRDA and other purposes
Sediments, benthic invertebrates, and insect-eating birds are the primary monitoring foci of the LTM plan, tracking their responses to the MNR remedy. However, the plan also includes components to address Natural Resources Damages Assessment (NRDA) and other needs.

The LTM plan includes provisions for adaptive monitoring and management to ensure optimal use of available resources. Data will be evaluated annually or biennially to identify spatial and temporal trends that might justify changes in monitoring strategy or other actions. Adaptive management may include off-year follow-up monitoring to investigate unusual results, adjusting sampling locations or frequencies, discontinuing parts of the monitoring, and adopting more effective monitoring tools that may become available. Sediment modeling and monitoring results and evaluation of bioaccumulation trends for invertebrates, birds, and fish will determine whether contingent response actions or additional data gathering is warranted.

The following sections provide additional information on each of the LTM plan components.

1. Ash Fate and Transport Monitoring & Modeling

The U.S. Army Corps of Engineers, Engineer Research and Development Center (USACE-ERDC) performed baseline fate and transport modeling of the Emory and Clinch Rivers sediments to evaluate long-term effectiveness of MNR (Scott 2012). Those results indicate that dynamic natural processes will yield decreasing proportions of ash and decreasing concentrations of arsenic and selenium in sediments in the Emory and Clinch Rivers. Natural sedimentation and scour is predicted to produce a layer of mixed ash and sediment approximately 6 inches thick in depositional side channel areas that meets the project’s Removal Action Objectives (RAOs) within 10 to 15 years.

The modeling also shows that periodic severe storm flow events (greater than a 10-year recurrence interval) would scour portions of this natural cover, particularly in the main channel and in some of the side channel deposits. Such severe storm events may temporarily expose deeper sediments with higher concentrations of ash and ash-related constituents. However, the model predicts that the natural cover of mixed ash/sediment would redevelop in those areas, and that ash and natural sediment mixtures would continue to deposit in side channel areas of the Emory and Clinch Rivers. Over a period of several cycles of high flows, most of the residual ash in the lower part of the Emory River and Clinch Rivers that can be mobilized eventually would be transported downstream and re-deposited as thin layers of mixed sediment and ash in the lower end of Watts Bar Reservoir near Watts Bar Dam.

The sediment fate and transport model will be updated in 2013 with new, higher-resolution bathymetry from the Emory and Clinch Rivers. New data also will be developed in 2013 on the composition of recently-deposited sediments in several locations to re-calibrate the sediment transport model and improve confidence in the accuracy of its predictions of mixing and recovery rates. Modeling will also be performed after each >10-year recurrence interval (>110,000 cfs) storm event to evaluate sediment mixing and transport. Following each modeling run, “ground-truth” sediment samples will be collected from several depositional areas to confirm the modeled results and further refine the model, if needed. If a 10-year storm has not occurred during the initial five-year review period, the model will be re-run in 2017.

2. Biennial Sediment Contaminants Monitoring

Sediment contaminants monitoring will be conducted biennially in the fall at eleven locations in the Clinch and Emory Rivers, concurrent with fall benthic invertebrate community surveys. Ecological exposures occur primarily in the upper 6 inches of submerged sediments; therefore, samples will be collected of the upper 6 inches of sediments. Where appropriate, each transect will be divided into left, mid-channel (thalweg), and right areas, focusing on submerged terraces left and right of the thalweg that comprise the most suitable benthic invertebrate habitat. Several Ponar dredge samples will be collected in each area and composited by area, resulting in a maximum of three composite samples per transect. Percent ash and grain size distribution will be determined for each composite sample, as well as concentrations of arsenic and selenium.
In addition, discrete sediment samples will be collected for % ash analysis at each of the ten points along the biennial fall benthic invertebrate community survey transects performed at the same 11 river locations (see section 4, below).

3. Sediment Toxicity Tests
In Fall, 2013, 10-day definitive survival and growth tests for a laboratory test organism, Hyalella azteca, will be conducted for one transect in the lower portion of the Emory River (ERM 1.0 or ERM 0.7) and one transect in the Clinch River (CRM 3.0 or CRM 3.5) using 0%, 20%, 40%, 60%, 80%, and 100% serial dilutions of composited sediment samples. To the extent possible, sediment toxicity transects will be co-located with benthic invertebrate community transects, however locations may have to be adjusted slightly to ensure they include areas of active deposition on submerged terraces.

Similar to the Biennial Sediment Contaminants Monitoring described above, samples will be collected from the upper 6 inches of sediments. Sediments from up to three areas per transect (mid-channel, and left and right submerged terraces) will be composited by area. This will ensure representative sampling of areas most suitable as benthic invertebrate habitat. Several Ponar dredge samples will be collected in each area, compositing by area (maximum of three composite samples per transect).

Each composited sediment sample will be analyzed for a full suite of metals/metalloids, polychlorinated biphenyls (PCBs), pesticides, semi-volatile organics, total organic carbon (TOC), grain size, and % ash (by polarized light microscopy).

Sediment toxicity monitoring will be repeated in Fall, 2017, in order to have two rounds of sediment toxicity results available for the CERCLA 5-year review of the LTM plan to be conducted in 2017-2018.

4. Biennial Benthic Invertebrate Monitoring
Sampling for bioaccumulation in snails, larval mayflies, and adult mayflies will be conducted biennially in 2013, 2015, and 2017. Data will be reviewed as it becomes available to determine whether off-year follow-up sampling is needed.

Some locations will be sampled in 2013 in order to complete five continuous years of post-release annual data. Results for 2009—2012 suggest that the number of mayfly bioaccumulation sampling locations can be reduced after 2013, and that collections of snails can be discontinued. Decisions on those reductions will be made in 204, following analysis of the full 5-year-post-release (2009-2013) data record.

Spring Benthic Invertebrate Bioaccumulation — The BERA considered benthic invertebrates subject to moderate ecological risk in the lower part of the Emory River and low risk in the Clinch River due to exposure to arsenic and selenium in sediment. In addition, because they are at the base of the food chain, aquatic insect larvae and the emergent adult insects are prey for other ecological receptors.

Previous results suggest arsenic and selenium in mayfly nymphs peaked in 2010 or 2011. Annual maximum concentrations occurred at ERM 1.0 for both elements. Adult mayfly arsenic concentrations are about an order of magnitude lower than in nymphs, and appear to be only slightly higher at ash-impacted sites than at reference sites. Selenium in adult mayflies follows a similar temporal pattern as the nymphs, with concentrations apparently peaking in 2011. In contrast to arsenic, selenium concentrations in mayfly adults are more similar to those in nymphs.

Arsenic and selenium concentrations in snails generally decreased from 2010 to 2011, with concentrations similar to or only slightly greater than reference locations.

Given these trends, we anticipate analysis of the five-year data record will support reducing the number of mayfly sampling locations slightly in 2015 and discontinuing snail sampling.

Fall Benthic Invertebrate Community Surveys – Assessments of the composition and structure of benthic invertebrate communities provide direct evidence of the effects of sediment constituents and general habitat variations on naturally-occurring benthic communities. Biennial surveys of benthic invertebrate...
communities will be performed in the fall on the Emory (7 sites, 10 points per transect) and Clinch Rivers (4 sites, 10 points per transect).

Each sample substrate will be visually characterized in the field and a sub-sample will be submitted for laboratory determination of % ash. Taxonomic identification and enumeration of benthic invertebrates will be performed in the laboratory for all benthic community samples (i.e., for samples from each point on each transect). Results for overall invertebrate abundance, taxa richness, and taxa diversity will be used as indicators of community health. Benthic community results also will be compared with % ash for co-located points on transects and with physical and chemical data for co-located composite sediment samples (see item 2 above) to identify any significant relationships.

5. Annual Monitoring in the Lower Emory River
Because a large proportion of the residual ash is located in the lower reach of the Emory River, the highest potential for aquatic life exposure to residual ash occurs there. Bioaccumulation results also generally indicate the highest bioaccumulations of ash-related contaminants occur in that area. Annual monitoring will be performed in that reach (ERM 0.0—1.8) to measure the effectiveness of the selected CERCLA Removal Action in protecting ecological resources at risk.

This annual monitoring will include benthic invertebrate community surveys; bioaccumulation in benthic invertebrates, fish, and tree swallow egg tissues; and field observations of tree swallow clutch size, hatching success, and 15-day hatchling survival. This annual monitoring will provide empirical data to evaluate whether the ecological risks identified in the BERA actually are occurring in the river reach where the highest potential for exposure exists.

Bluegill, Redear, and Bass Bioaccumulation – Because bluegill and red ear sunfish have been demonstrated to exhibit high site fidelity and to bioaccumulate selenium to a greater extent than most other species of fish, the LTM plan focuses fish bioaccumulation monitoring on those two species of fish in ERM 0—1.8. Although bass appear to bioaccumulate contaminants to a much lesser extent, the LTM plan includes annual monitoring of largemouth bass in the lower Emory River because bass they are an important sport fish in the region. A target of six fish of each species will be collected. Fillet, ovary, and liver tissues will be analyzed for a suite of ash-related metals and metalloids contaminants.

Tree swallow monitoring – The ecological risk to aerial-feeding insectivores identified in the BERA is based on dietary exposure modeling, assuming adult mayflies are representative of the tree swallow diet. Studies conducted by Virginia Tech in 2011 indicate that mayflies may comprise only a small component of tree swallow diet and are virtually absent as a food source during the breeding season.

Tree swallow eggs will be collected annually from a location on the lower part of the Emory River (ERM 0-1.8) and a reference site on the Tennessee River, with a target of one egg from 20-25 different tree swallow boxes per location. Egg contents (excluding shells) will be analyzed for arsenic and selenium to evaluate exposure of insectivorous birds to ash-related constituents. Clutch size, hatching success, and nestling survival to day 15 will be recorded as indicators of reproductive success.

Tree swallow boxes also will be placed at the Lakeshore peninsula to maintain a tree swallow colony there for possible future evaluation.

6. Supplemental Long-Term Monitoring
Spring Fish Bioaccumulation – Fish bioaccumulation data provide an integrative measure of exposure and a direct measure of both human and ecological risks. Selenium concentrations in fish tissue were highest in 2011, the first year post-dredging. While results from 2012 suggest that concentrations may be decreasing after dredging activities ceased, additional data is required to infer a true temporal trend. Consequently, fillet, ovary, and liver tissues will be collected biennially in the spring from bluegill, redbreast sunfish, and largemouth bass (target of six fish of each species) on the Emory (3 sites) and Clinch Rivers (2 sites).
**Fall Fish Community Survey** – Biosurveys of the fish community will be conducted biennially in the fall on the Emory and Clinch Rivers for comparisons with historical and Valley-wide surveys. The community surveys will collect fish from a variety of habitat types based on their proportions in the study area to provide a representation of community structure and function. Standard aquatic and riparian habitat characteristics will be collected for each site and reference survey location. Fish collected will be identified as to species, enumerated, and examined for anomalies, with results reported for species abundance, richness, diversity, and physical condition (anomalies).

**Spring Sportfish Survey** – Spring sport fish surveys are used to develop key population metrics for black bass populations, including measures of catch rates, general fish condition (e.g., parasites and anomalies), and length frequency and relative weights. These surveys will be conducted biennially in the spring at one site each on the Emory and Clinch Rivers as part of the Valley-Wide Vital Signs Monitoring Program. Sampling occurs over a reach that may extend approximately 1-2 miles upstream and downstream of the nominal locations reported (ERM 2.5 and CRM 2.5).

**Spring Fish Health & Reproduction** – Fish health provides an important measure of fish condition that is important in interpreting both bioaccumulation and reproductive competence measures. While results to date suggest no ecologically significant adverse impacts on fish health or reproductive condition, the most recent histopathology data (fall 2011 samples) indicates that fish collected at locations near the spill have higher scores (i.e., more lesions) than those from reference locations and that fall 2011 samples have higher scores than samples from 2010.

Health metrics and reproductive condition will be evaluated concurrent with spring 2013 bioaccumulation sampling. Overall fish health and reproductive condition metrics will be collected for female bluegill, red ear sunfish, and largemouth bass from the Emory (3 sites) and Clinch Rivers (2 sites). A target of eight fish of each species will be collected. This includes the six individuals/species collected for bioaccumulation, plus two additional fish needed to increase the statistical power of the health and reproductive metrics analyses. Histopathology will also be conducted on key tissues.

References:


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April 24, 2013

Neil E. Carriker, PhD
A Long-term Monitoring Plan for the TVA Kingston Ash Spill

April 24, 2013

Neil E. Carriker, PhD

...and a capable supporting cast including Tyler Baker, Suzanne Young, Dan Jones, Mark Stack, Mike Houck, Rick Sherrard, Michelle Cagley, and several others
LTM Timeline

• January, 2012
  ➢ Meeting to discuss “in-between” monitoring

• February—December, 2012
  ➢ Continuing internal discussions, interpretation of results as BERA, HHRA, and EE/CA were prepared, culminating in a “straw man” LTM proposal

• January, 2013
  ➢ Data Quality Objectives Workshop—”Straw man” proposal presented, modified

• February, 2013
  ➢ Overview summary of proposed LTM, DQO tables circulated

• April, 2013
  ➢ Detailed LTM submitted to EPA & TDEC for approval
Ecological Data Available

- CERCLA Time-critical (2009-2010)
- River Sampling & Analysis Plan (2010-2011)
- External Research & Investigations (2009—present)
  - ORNL
  - USACE-ERDC
  - University researchers
- Continuing investigations
Reports & Evaluations Available

- Interim reports from TVA, ORNL, ERDC
  - Ecological investigations (fish, bugs, birds, amphibians...)
  - Groundwater modeling
  - Sediment transport modeling
  - Ash leaching
  - Toxicity testing

- Baseline Human Health Risk Assessment (HHRA)

- Baseline Ecological Risk Assessment (BERA)

- Engineering Evaluation/Cost Analysis (EE/CA)

- Annual progress reports from university researchers
Ecological Research Investigations

- **TVA Self-Performed Investigations**

- **Research grants administered by Oak Ridge Associated Universities (ORAU): Six universities and USGS**

- **Direct Funding from TVA:**
  - Oak Ridge National Laboratory (ORNL)
  - University of Tennessee
  - Virginia Tech
  - Appalachian State University
  - Middle Tennessee State University
  - Tennessee Wildlife Resources Agency (TWRA)
  - US Army Corps of Engineers—Engineer Research and Development Center (ERDC)
  - Brigham Young University

- **All investigations performed under Quality Assurance Project Plans (QAPP) prepared per CERCLA guidance**
TVA Self-Performed Investigations

- Air Monitoring
- Surface Water, Groundwater, Porewater Sampling
- Bathymetry
- Ash & Sediment Sampling
- Sediment Toxicity Investigations
- Fish Sampling & Community Assessments
- Field Assessments of Fish Health
- Benthic Invertebrate Sampling & Community Assessments
- Larval Fish Sampling
- Sampling for Bioaccumulation in:
  - Bird Eggs (Goose, Heron, & Osprey)
  - Amphibians (toads & frogs)
  - Tree swallows and turtles (2009 & 2010)
Old Dominion University
- Selenium Bio-Geochemistry in Flowing River Systems
- Flow-Through Leaching Procedure

North Carolina State University
- Geochemical & Mineralogical Characterization of Ash
- Geochemical Transformations—Effects on Selenium Uptake
- Trace Element Uptake by Periphyton

Duke University/University of Kentucky/University of Illinois
- Field Surveys—Water, Sediments, Porewaters
- Isotope Ratios as Ash Tracers
- Factors Affecting Potential for Mercury Methylation
- Trace Element Speciation & Transformations
- Geochemical Modeling

University of Colorado/USGS
- Effects of Dissolved Organic Matter & Mixing Energy on Ash Leaching
Direct-Funded Ecological Investigations

Oak Ridge National Laboratory
- Laboratory Fish Health Assessment, Fish Reproductive Competence, Ash-Related Contaminants Bioaccumulation
- Ash Effects on Fish Reproduction & Larval Fish (laboratory studies)
- Benthic Invertebrates Bioaccumulation (snails, mayflies)

Oak Ridge National Laboratory and Middle Tennessee State University
- Bluegill & Redear Sunfish Bioaccumulation Differences
- Aquatic Spiders’ Role in Transferring Contaminants to Terrestrial Ecosystem

Middle Tennessee State University and TWRA
- Freshwater Mussels (bioaccumulation, growth and reproduction)

University of Tennessee
- Raccoons (bioaccumulation, health effects)

Brigham Young University
- Flood risk modeling
Direct-Funded Ecological Investigations (continued)

USACE Engineering Research and Development Center
• Sediment Transport Modeling (funded through EPA)
• Geochemical Characterization of Ash and Ash Leaching
• Trace Element Speciation/Geochemical Modeling

Virginia Polytechnic Institute and State University (Virginia Tech)
• Tree Swallows (bioaccumulation, maternal transfer, reproductive effects)
• Turtles (bioaccumulation, maternal transfer, reproductive effects)

Appalachian State University
• Ash Deposit Stratigraphy & Geochemistry,
• Magnetic Susceptibility Potential for Ash Tracking
Environmental Data Collection Summary
2008-2012

Scope:
>19,000 samples collected and analyzed
  (air, water, groundwater, soil, sediments, ash, biota...)
>400,000 chemical analyses on these samples

Quality Assurance/Quality Control Program
  • Site-wide Quality Assurance Project Plan
  • 61 Standard Operating Procedures
  • Laboratory and field audits
  • “Hands-on” laboratory sample management

➤ 99.8% data acceptance
Focused on:

- Modeling ash transport
- Mapping residual ash
- Data for human health & ecological risk assessments
- Multiple approaches to evaluate effects
ERDC Sediment Transport Model

Model Parameters

- 2-Dimensional, USACE-ERDC Adaptive Hydraulics model (AdH)
- Model domain: Kingston site to Watts Bar dam
- 13 grain sizes (6 ash, 7 sediment; clay – sand size classes)
- 3 Simulations: May, 2009 event; 2-yr avg flow/high flow; 30-yr flow record

Results

- Ash resuspension now occurs only for flows >~70,000 cfs
- New sediments deposited in shallow areas in lower Emory & Clinch cap ash deposits, dilute ash in sediments
- 10-15 years to reduce arsenic levels to near-background
- High flows will ultimately scour & mix ash with native sediments, transport it to lower Watts Bar reservoir, & deposit it there in a thin layer over a large area
River SAP—Ash Mapping

- 269 Vibecores on grid system (Clinch Reach B & Emory Reaches A & B)
- 235 Between CRM 3 & ERM 3
- Field observation of ash depth & stratigraphy
- Field lab estimation of % ash
- Contract lab measured all field-estimated >50% ash, plus ~ 20% of other samples
River SAP: 10 River Reaches

- **Emory River**
  - Reference – above ERM 6.0
  - Reach C – ERM 3.5 to ERM 6.0
  - Reach B – ERM 1.5 to ERM 3.5
  - Reach A – ERM 0.0 to ERM 1.5

- **Clinch River**
  - Reference – above CRM 4.5
  - Reach B – CRM 3.0 to CRM 4.5
  - Reach A – CRM 0.0 to CRM 3.0

- **Tennessee River**
  - Reference – above TRM 568
  - Reach B – TRM 566 to TRM 568
  - Reach A – TRM 550 to TRM 566
Residual Ash Results

- Approximately 500,000 cubic yards remaining
  - 3% in Emory Reach C (ERM 3.5-6.0)
  - 82% in Emory Reaches A & B (ERM 0.0-3.5)
  - 14% in Clinch Reach B (CRM 3.0-4.5)
  - 1% in Clinch Reach A (0.0-3.0)

* Maximum ash depth ~ 4 to 6 feet
Sediment Toxicity Tests

• **Phased approach**
  – Screening
    – Short-term, undiluted, 3 test species
    – Emory and Clinch Rivers, 9 locations each
  – Chronic (“Definitive”)
    – Long-term, dilution series, 2 test species
    – Emory and Clinch Rivers, 4 locations each

• **Sediment chemistry and characteristics**
  – Metals, PAHs, PCBs, pesticides
  – % ash, grain size, TOC

• **Multivariate statistical analysis**
Sediment Toxicity Results

- Correlation of sediment toxicity with % ash, arsenic concentrations in sediments
- Minimal or no toxicity observed in sediments with less than about 40% ash
Ecological Risk Assessment

Findings:

- Moderate risk to benthic invertebrates that live in sediment
- Low risk to organisms that eat benthic invertebrates
  - Tree Swallows (aerial-feeding insectivore)
  - Killdeer (shoreline-feeding invertivore)

• Risk drivers:
  >40% ash
  Arsenic, selenium

TVA Restricted Information - Deliberative and Pre-Decisional Privileged
Human Health Risk Assessment

- Multiple exposure scenarios and receptors:
  - Drinking water
  - Recreation
  - Fish consumption
  - Adult & child residents, swimmers, beachcombers
- Used site-specific data
- Followed EPA risk assessment guidance

Findings:
- No unacceptable risks associated with residual ash
- Confirmed risks from legacy PCBs and Hg in fish tissues
  - TDEC fish consumption advisory pre-dating the spill
- Agrees with 2010 TN DOH Public Health Assessment
- Agrees with ORAU/Vanderbilt Medical Screenings
TVA & ORNL Benthic Invertebrate Investigations

• Mayfly larvae and adults--bioaccumulation
• Benthic community abundance and diversity
Obvious immediate impact, from which populations appear to have recovered quickly.

Minimal, if any effects on diversity, # species.

Other factors (hydrology, climate) appear to have more significant effects.

Bioaccumulation in most species peaked in 2010 or 2011, did not appear to reach adverse effects levels.

No significant effects on reproduction.
• Fish community results evaluated using multi-metric scoring method* based on:
  ➢ Species Richness and Composition
  ➢ Trophic Composition
  ➢ Fish Health and Abundance

• Fish bioaccumulation
  ➢ Focus on bluegill, redear, largemouth bass
  ➢ Focus on selenium & arsenic in muscle, ovaries, whole-body
  ➢ Multiple sites throughout study area

• Fish health and reproduction
  ➢ Blood chemistry, condition indices, histopathology
  ➢ Oocyte condition
  ➢ Laboratory studies

*Reservoir Fish Assemblage Index (RFAI) developed in early 1990s as part of TVA’s Valley-wide Vital Signs Monitoring Program
TVA & ORNL Fish Results

- Obvious immediate impact, from which populations appear to have recovered quickly
- Minimal, if any effects on diversity, # species
- Other factors (hydrology, climate) appear to have more significant effects
- Bioaccumulation in most species peaked in 2010, 2011
- No significant effects on reproduction
ORNL Fish Health & Reproduction Results

- Histopathology showed some gill degradation in 2009, no significant differences from reference sites since 2009
- Fish health measures (blood chemistry, various indices) have shown no significant effects
- Minimal, if any, reproductive competence impacts
- No ash impacts on survival, growth, or development of larval fish in lab studies with both lab-reared fish and fish captured in the Emory River
Tree Swallow Investigations

- ~600 Tree swallow boxes
- Four colonies in ash-impacted areas
- Three reference sites, plus positive control site
- Field observation of lower leg length, clutch size, hatching success, 15-day hatchling survival
- >1500 birds sampled for ash-related contaminants in eggs, blood, feathers, hatchlings
Preliminary Tree Swallow Results

- Some increased egg bioaccumulation of As & Se near the spill, but not to adverse effects levels
- Field data: Minimal differences in reproductive success and deformities between reference and ash-impacted areas
- Analysis is on-going: 2012 data just becoming available
University Research Results-to date

- U of Illinois researchers find that Hg stable isotope ratios can distinguish between Hg from ash, DOE-Oak Ridge, and upstream Emory River.
- Duke University field data compare well with TVA and EPA data. Some high porewater arsenic concentrations reported.
- Another Duke University study finds an indication that ash may increase methylation of mercury. Additional studies are in progress.
- U of Colorado researchers find more highly aromatic dissolved organic matter (DOM) is more effective in leaching metals, but DOM doesn’t appear to affect leaching of As & Se, which are present mainly as oxy-anions.
- ODU has demonstrated that a high liquid/solid ratio, short exposure leaching procedure produces reliable data. Further data analysis is in progress.
- Another ODU researcher detects increases in Se in water (at nano-molar concentrations) as it flows by the ash site, with subsequent algal uptake.
- NC State researchers are characterizing ash mineralogy, chemical speciation and leaching characteristics of selected trace elements relative to their mobility, bio-uptake and toxicity in sediments, water, and soils.
LTM Design

Taking everything into consideration:

• Develop Data Quality Objectives
• Identify Information Required
• Identify Boundaries
• Identify General Approach
• Flesh Out Details
The LTM Challenge:

Design a Long-Term Monitoring Plan that:

1. Evaluates the effectiveness of sediment scouring, mixing, transport, and re-deposition to achieve CERCLA Removal Action Objectives.

2. Measures the effectiveness of the selected CERCLA Remedy in protecting ecological resources at risk.
   - Benthic invertebrate populations
   - Riparian-feeding birds
   - Aerial-feeding birds

3. Documents restoration of the ecological function and recreational use of the river system to pre-release conditions.

4. Provides additional information for other purposes such as assessing Natural Resources Damages recovery

5. Includes Practical Adaptive Management
Information Needed

1. Information on sediment scouring, mixing, transport, and deposition over time
2. Concentrations of ash and ash-related contaminants in sediment
3. Concentrations of ash-related contaminants in biota, especially in the area with most residual ash
4. Biota population, community, health, and reproductive competence measures
Proposed Long-term Monitoring Plan

1. Ash fate & transport monitoring & modeling
2. Biennial sediment contaminants monitoring—several locations
4. Biennial benthic invertebrates monitoring
5. Annual monitoring in Lower Emory: invertebrates, sediments, birds, fish
6. Supplemental monitoring of fish bioaccumulation, community surveys, health & reproduction
Ash fate & transport modeling & monitoring

- Updated bathymetry at 200’ resolution for model refinement
- Sediment transport modeling following 10-yr storms (or at end of each 5-yr review period)
- “Ground truth” sediment sampling: ash depth, % ash, arsenic, selenium
Biennial Monitoring: Sediments & Bugs

- Fall sampling of benthic invertebrate community & contaminant bioaccumulation at 10 transects
- Sediment contaminants at benthic sampling transects
- “Off-year” confirmatory sampling if unusual results observed
Sediment Toxicity Monitoring

- Fall: 2013, 2017
- Up to three composite sediment samples per transect in areas with greatest residual ash (plus reference sites):
  - ERM 1.4, CRM 3.0, ERM & CRM reference sites
  - Mid-channel (thalweg)
  - Submerged terraces (depositional areas), left & right
- 10-d definitive survival & growth tests, *Hyalella azteca*
- Full suite of physical & chemical analyses
  - Grain size
  - Metals/metalloids
  - Semi-volatile organics
  - Pesticides
Annual monitoring in lower part of Emory River where >80% of the residual ash is located:

- Benthic invertebrate community composition & bioaccumulation

- Tree swallows:
  - Simple measures of reproductive success (clutch size, hatching success, nestling survival to 15-d)
  - Arsenic & selenium bioaccumulation in eggs

- Redear sunfish, bluegill, and bass
  - Arsenic & selenium bioaccumulation
Supplemental Long-Term Monitoring

- Biennial fall fish community assessment (RFAI)
- Biennial spring sport fish survey
  - Black bass & crappie
- Biennial spring fish bioaccumulation
  - Bluegill, redear sunfish, largemouth bass
  - Fillet, ovary, liver
- Biennial spring fish health & reproductive competence
  - Overall fish health metrics
  - Histopathology of key tissues
  - Reproductive condition metrics
• Evaluate results as soon as they are available (i.e., no delays in data analysis)

• Prepare annual/biennial reports summarizing spatial & temporal trends/relationships

• Repeat sampling in off-years (2014, 2016) for any results suggesting significant, unexplained spatial or temporal changes
Adaptive Monitoring & Management

- Continuously evaluate results to identify possible program improvements
  - Are study results showing changes?
  - Do results indicate locations & frequencies are optimized?
  - Do results justify discontinuing any monitoring?
  - Are better, updated monitoring techniques available?

- Develop recommendations for adaptive management for consideration by EPA & TDEC