TEMPORAL AND SPATIAL TRENDS IN SEDIMENT CHEMISTRY IMPOUNDED WITHIN A FLOOD CONTROL RESERVOIR: GRENADA LAKE, MS

Sean J. Bennett, Associate Professor, Department of Geography, University at Buffalo, Buffalo, NY, seanb@buffalo.edu; Fred E. Rhoton, Research Soil Scientist, USDA-ARS National Sedimentation Laboratory, PO Box 1157, Oxford, MS, frhoton@msa-oxford.ars.usda.gov; ShuMin Hsu, Graduate Student, University at Buffalo, Buffalo, NY; Carlos V. Alonso, Supervisory Research Hydraulic Engineer, USDA-ARS National Sedimentation Laboratory, PO Box 1157, Oxford, MS, calonso@msa-oxford.ars.usda.gov

Abstract: Sedimentation issues were examined in a relatively large flood control reservoir in a highly unstable, cultivated watershed. Collected sediment cores were analyzed for ^{137}Cs and texture, which demarcated the as-built reservoir timeline, and the bulk chemistry of the sediments. The concentrations of select elements (As, Cu, Cr, Pb, Hg, and Zn) are positively correlated with clay composition and are not atypical for soils. Statistical analyses showed that since dam construction (1) select element concentrations normalized by clay and aluminum content do not vary vertically within each sediment core; and (2) depth-averaged concentrations of select element concentrations normalized by clay and aluminum content show no spatial variation within the sediment impoundment. These results suggest that sediment-associated chemical loadings to this reservoir have remained nearly invariant in time and evenly dispersed within the impoundment.

INTRODUCTION

There are more than 75,000 dams in the U.S., and these structures provide opportunities for navigation, hydroelectric power, irrigation, flood control, and water supply (Graf, 2001 and Bennett et al., 2002). These dams trap much of the incoming sediment loads from upstream sources, and these sediments may be of poor quality with respect to heavy metals and agrichemicals. This is especially true for the more than 11,000 small flood control structures built by the USDA-NRCS since 1948 in agricultural watersheds where trapping efficiencies typically exceed 80% (Dendy, 1974, 1982 and Bennett et al., 2002). These high sedimentation rates may be further exacerbated by unstable stream systems, erodible landscapes, poor land management, and inappropriate channel modifications (Simon and Thomas, 2002 and Simon et al., 2004).

The overall goal of the current research program was to assess recent sedimentation issues within a relatively large flood control reservoir in a highly unstable, cultivated watershed. The objectives of the present paper were to determine the concentrations of sediment-associated elements, notably Arsenic (As), Copper (Cu), Chromium (Cr), Mercury (Hg), Lead (Pb), and Zinc (Zn), trapped within the impoundment since dam construction and to ascertain if these chemical loadings show any temporal or spatial trends.

FIELD LOCATION AND METHODS

Field Location: Grenada Lake is a relatively large U.S. Army Corps of Engineers flood control reservoir located in north-central Mississippi (Figure 1). The reservoir has been in operation

since January 1954 and has a flood storage capacity of 1.605 km^3. Two major rivers drain into the lake. The Yalobusha River is a 4th-order stream system with an upstream drainage area of 1530 km^2, and this watershed has a long history of channel instability and sedimentation-related flooding. Agricultural development in the middle 1800s caused severe soil erosion and excessive sedimentation in the river channels of northern Mississippi, and measures taken by federal agencies further destabilized the river networks (Simon and Thomas, 2002). The watershed still maintains production of sweet potato, cotton, soybean, and corn (Cooper et al., 2002). The Skuna River is a 4th-order stream system with an upstream drainage area of 1127 km^2. Compared to the Yalobusha River, it is a more stable stream system and the primary land-use is silviculture (forestry).

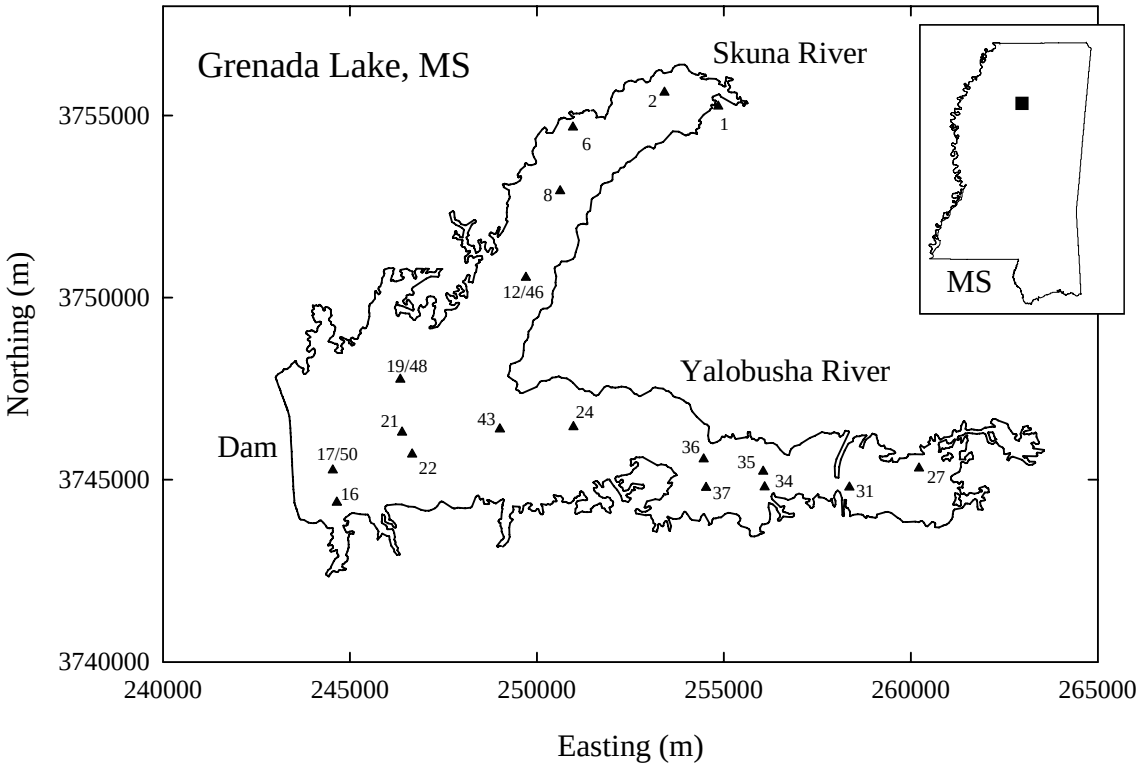

Figure 1 Map showing Grenada Lake in northern Mississippi (see inset), the location of select cores along the Skuna and Yalobusha River arms (numbers and symbols), and the position of the dam, which discharges to the west.

Sediment Coring and Chemical Analysis: Fifty sediment cores were collected and analyzed in this study, and only select cores will be discussed here (Figure 1). Cores were secured with a vibracoring system (Bennett et al., 2002), sealed, and returned to the laboratory where they were split, logged, and sampled incrementally. Bulk density was determined by weighing oven-dried samples of known core volumes. For particle size analysis, approximately 10 g of sediment was oven-dried at 70°C, crushed and sieved to less than 2 mm, treated with H_2O_2 to remove organic matter, and then shaken overnight in sodium hexametaphosphate for complete dispersion. Total clay (<2 μm) was determined by the pipette method (Method 3A1, Soil Survey Staff, 1992). Total sand (2000 to 53 μm) was determined by wet sieving the remaining sample though a 53-μm sieve and weighing the oven-dried fraction. Total silt (53 to 2 μm) was calculated by subtracting the sand and clay fractions from the original sample weight.

Selected cores were analyzed for radioactive cesium (^{137}Cs; 30-year half-life) for dating stratigraphic horizons. In the Northern Hemisphere, first deposition of ^{137}Cs occurred in 1954±2 due to above-ground nuclear testing and maximum deposition occurred in 1964±2 (Ritchie and McHenry, 1990). Approximately 50-g of dried, crushed, and sieved (2-mm) sediment samples were taken at 0.1-m increments from each core. All samples as well as the bulk sediment density data were sent to Flett Research Ltd., Winnipeg, Canada for analysis. Typical standard deviations for the measured ^{137}Cs emissions were about 0.08 pCi g^{-1}.

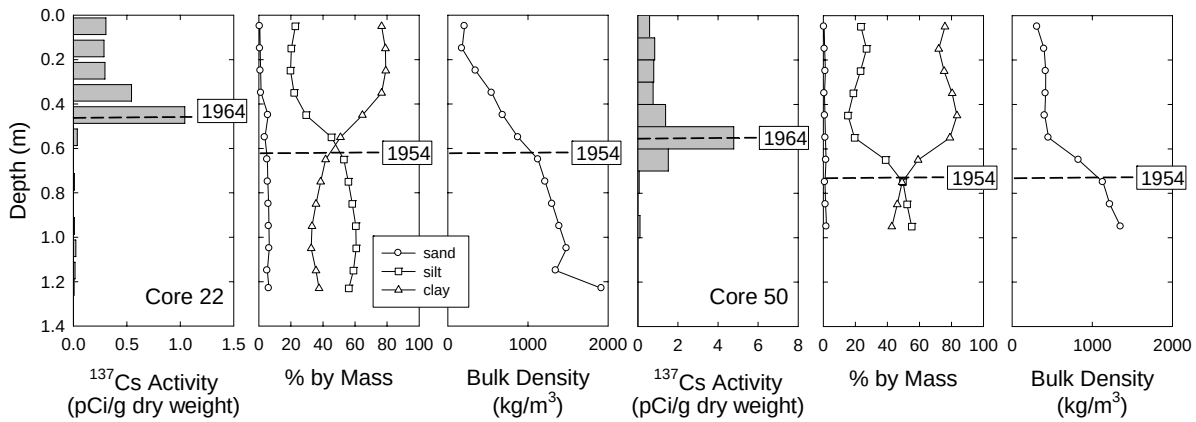

Figure 2 Vertical variations of ^{137}Cs emissions, sediment texture (sand, silt, and clay), and bulk density for Cores 22 (on left) and 50 (on right) in Grenada Lake (refer to Figure 1 for core locations). Also shown are the interpreted 1964±2 and dam construction (1954) timelines.

The bulk chemistry of sediment samples from select cores also was determined. Approximately 5 g of oven-dried, crushed sediment obtained from discrete layers were sent to Activation Laboratories, Ontario, Canada for analysis. A small subsample was digested using four acids (hydrofluouric HF, perchloric $HClO_4$, nitric HNO_3, and hydrochloric HCL; a near total digestion process) and analyzed for 48 elements using an inductively coupled plasma spectrometer and mercury using cold-vapor atomic absorption (cold vapor-flow injection mercury system). Only a small subset of these chemical results is presented here, which include Arsenic (As), Copper (Cu), Chromium (Cr), Mercury (Hg), Lead (Pb), Zinc (Zn), and Aluminum (Al).

RESULTS

Discriminating Post-impoundment Sedimentation: The most important interpretation of the sediment chemistry data within Grenada Lake is discriminating the post-impoundment sediment from the pre-existing or parent material. This interpretation is based on ^{137}Cs activity within the cores and variations in sediment texture with depth below the lake bottom.

The geochronologic results obtained for Cores 22 and 50 are plotted in Figure 2 alongside the variation of sediment texture and bulk density with depth. These cores show well-defined peaks in ^{137}Cs activity, which can be interpreted as the 1964±2 timeline. The reduced activities at depths greater than about 0.8 m correspond to dates earlier than this time (i.e., pre-dam construction). These timelines also correlate with variations in sediment texture and, to a lesser extent, bulk density with depth. For these cores, the post-impoundment sediments are markedly

enriched in clay and depleted in silt (and sand) as compared to the sediment located stratigraphically lower in these cores (Figure 2). Of the 19 cores analyzed for sediment texture, 11 of the cores or 58% showed this post-impoundment enrichment of clay and depletion of silt.

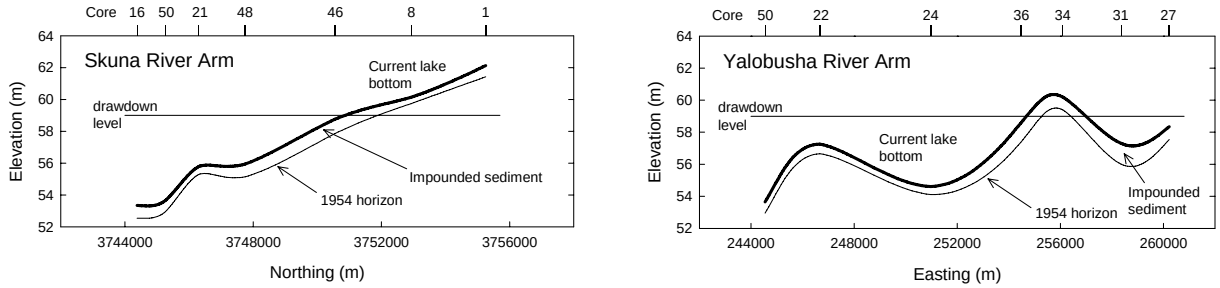

Figure 3 Profiles of current lake bathymetry and post-impoundment sediment thickness along the Skuna (left) and Yalobusha (right) River arms Grenada Lake based on ^{137}Cs emissions and vertical variations in sediment texture from select cores projected onto a line. Winter reservoir drawdown level also is shown, and refers to Figure 1 for core locations.

Bennett et al. (2005) used the geochronologic and textural results from these and other cores to define the 1954 stratigraphic horizon of dam construction. The thickness of the sediment impoundment in relation to current lake bathymetry is shown in Figure 3. These data show that the impounded sediment thickness changes monotonically along each arm of Granada Lake. The timeline is further extended here to include those cores having sediment chemical but no grain size data or ambiguous results.

Vertical Variations in Sediment Chemistry: For Cores 12, 16, and 34, the vertical variation of As, Cr, Hg, Pb, Zn, and Al concentrations, along with sand, silt, and clay content, are shown in Figure 4. For these sediments, concentrations for As range from 1 to 20 ppm, Cr ranges from 0 to 120 ppm, Pb ranges from 5 to 50 ppm, Hg ranges from 0 to 120 ppb, and Zn ranges from 10 to 140 ppm, and Al ranges from 1 to 15% by mass. These values are not atypical for element concentrations found in soils in the U.S. and worldwide (McBride, 1994).

The concentrations of these elements are strongly correlated with sediment texture, specifically clay content. Figure 5 shows that element concentrations can increase by orders of magnitude as sediment becomes increasingly rich in clay, and these increases clearly are related to mineralogy. Elements such as As, Pb, and Hg show more scatter than Cu and Zn, and this variability may be due to contributions from organic or atmospheric sources rather than mineralogic.

Because of these clear dependencies of element concentrations on soil texture, it is common to normalize chemical signatures by clay and/or Al content on the assumption that aluminosilicates dominate the clay-sized fractions (e.g., Schropp et al., 1990 and Abraham, 1998). Figure 6 replots these vertical variations in As, Cr, Hg, Pb, and Zn as normalized by the mass percent of Al and clay. Regression analyses performed on the vertical variations of these elements since dam construction, or post 1954 using the identified timeline, showed that none of the elements varied in any statistically significant way in any of the cores examined. Thus since dam construction, there has been no significant increase or decrease in the loadings of sediment-associated elements at-a-point within the reservoir.

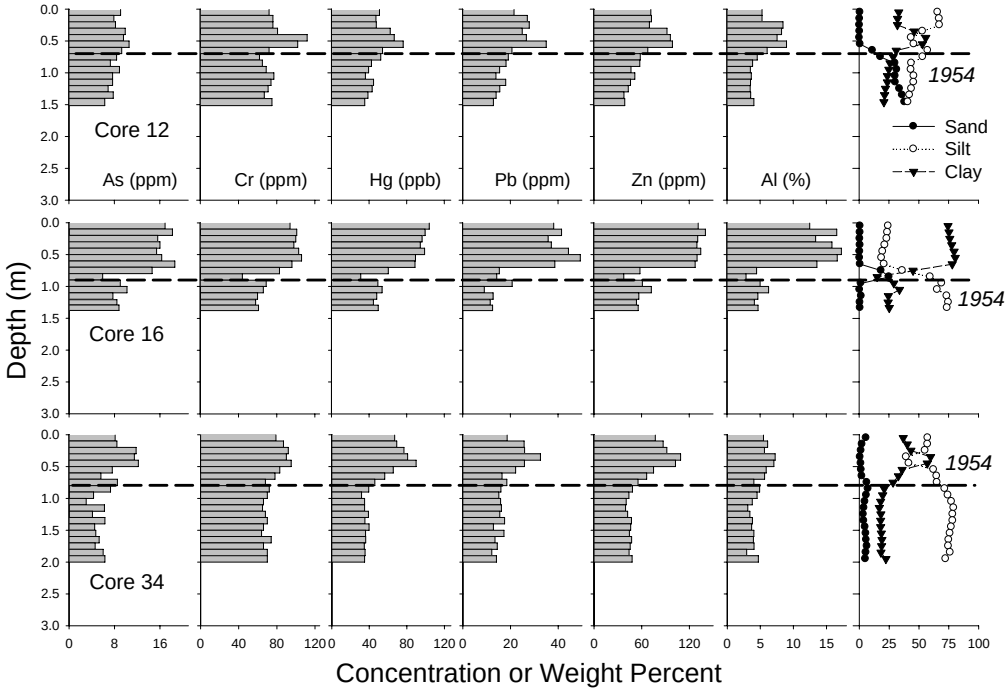

Figure 4 Vertical variations of Arsenic (As), Chromium (Cr), Mercury (Hg), Lead (Pb), Zinc (Zn), Aluminum (Al), and sediment texture (sand, silt, clay; from left to right) with depth for Cores 12 (upper), 16 (middle), and 34 (lower). Also shown are the interpreted dam construction (1954) timelines. Note variable units, and refer to Figure 1 for core locations.

Spatial Variations in Depth-averaged Sediment Chemistry: Since these sediment-associated chemical loadings showed no variation vertically within each core since the 1954 timeline, all sediment-associated chemical signals were depth-averaged and plotted simply as a function of downstream distance along the Skuna River arm (Figure 7) and the Yalobusha River arm (Figure 8), again normalized by Al and clay content. Interestingly, some trends show opposing tendencies depending upon the normalizing parameter (see Hg, Pb, and Zn, Figure 7; Cu, Cr, Hg, and Pb, Figure 8). Regression analyses performed on these spatial trends of depth-averaged concentrations showed that no element increased or decreased in concentration in any statistically significant way. Thus the depth-averaged sediment-associated concentrations of As, Cu, Cr, Hg, Pb, and Zn since dam construction show no spatial variation from the upstream arms of the Skuna and Yalobusha Rivers down to the pool region over distances of up to 16 km.

CONCLUSIONS

For Grenada Lake, a relatively large flood control reservoir in northern Mississippi, the discrimination of post-impoundment sedimentation was made possible through the combined use of ^{137}Cs emissions and vertical variations in sediment texture. This 1954 timeline then was used to segregate the post-impoundment sediment-associated chemical signatures from the pre-existing or parent material signatures.

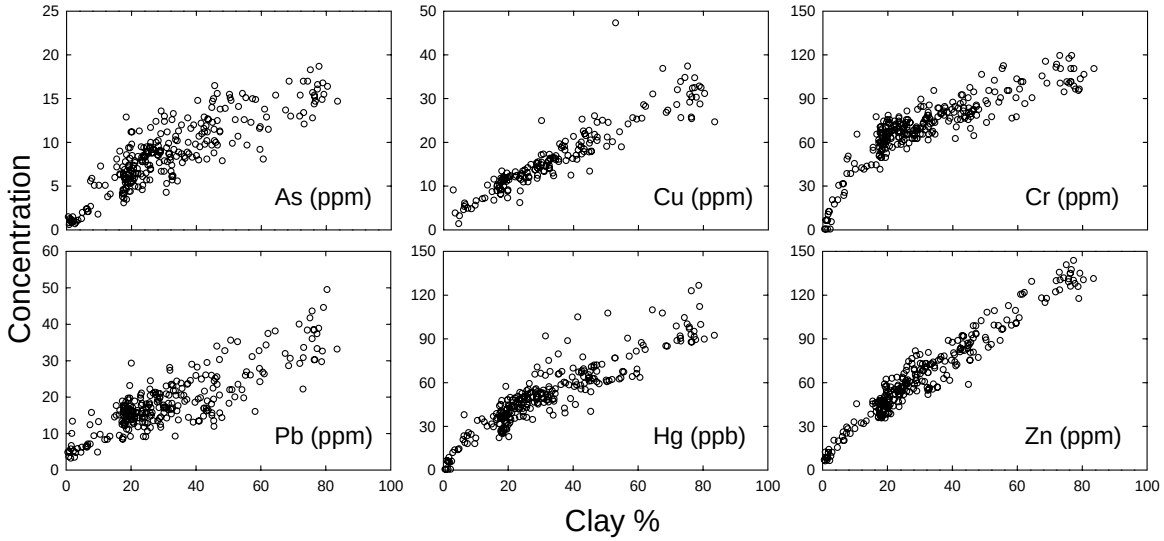

Figure 5 Concentration of Arsenic (As), Copper (Cu), Chromium (Cr), Lead (Pb), Mercury (Hg), and Zinc (Zn) for all sediment samples as a function of clay content. Note variable units.

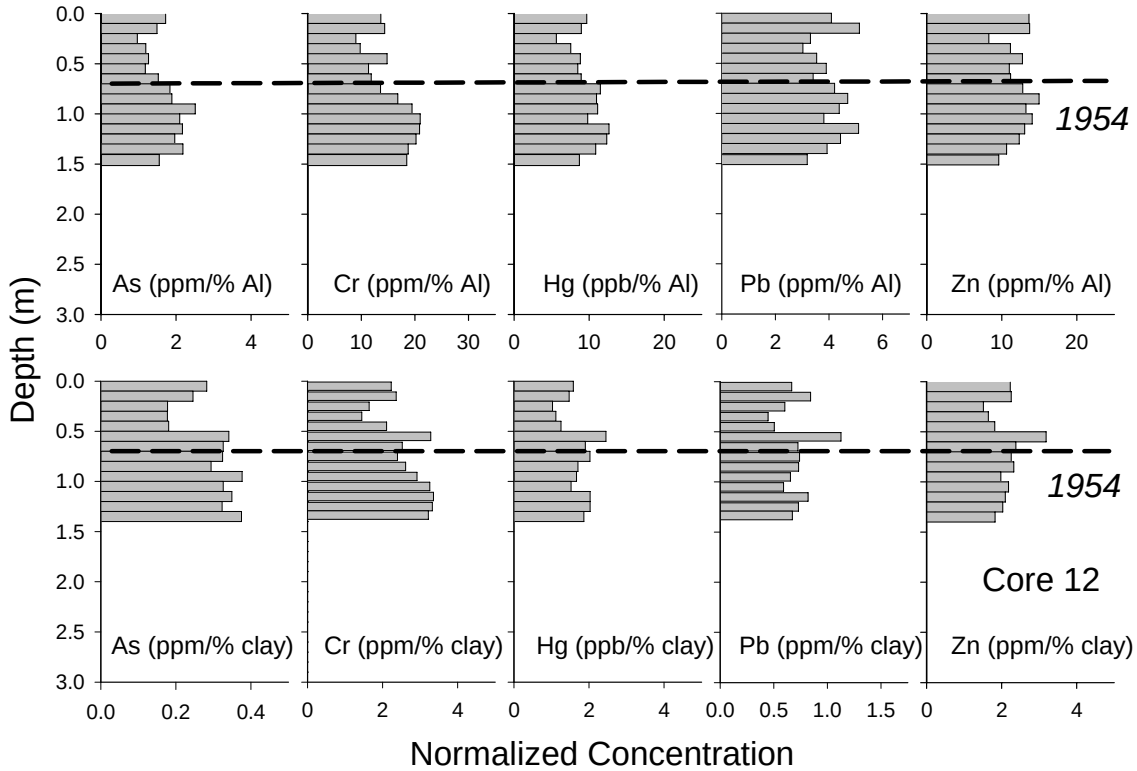

Figure 6 Vertical variations of Arsenic (As), Chromium (Cr), Mercury (Hg), Lead (Pb), and Zinc (Zn) (from left to right) with depth for Core 12 as normalized by mass percent of Aluminum (Al; upper) and clay (lower). Also shown is the interpreted dam construction (1954) timeline. Note variable units.

Concentrations of As, Cu, Cr, Hg, Pb, and Zn show a strong positive correlation with clay content, and all signatures were normalized by both mass percent of clay and Al. Regression analyses performed on each core, from the 1954 timeline to the present day or vertically within each sediment column, showed that none of these elements varied statistically in normalized

concentration. Moreover, regression analyses performed on the depth-averaged sediment-associated element concentrations since dam construction showed that none of these elements varied statistically in normalized concentration from the upstream areas within the reservoir to the pool region (upstream to downstream) over a 16 km distance. Thus since dam construction in 1954, sediment-associated loadings of As, Cu, Cr, Hg, Pb, and Zn were statistically invariant in time (at-a-point) and space (from upstream to downstream). These results suggest that the composition of the incoming sediments has not changed significantly over this time period and that the sediments are uniformly distributed in the reservoir.

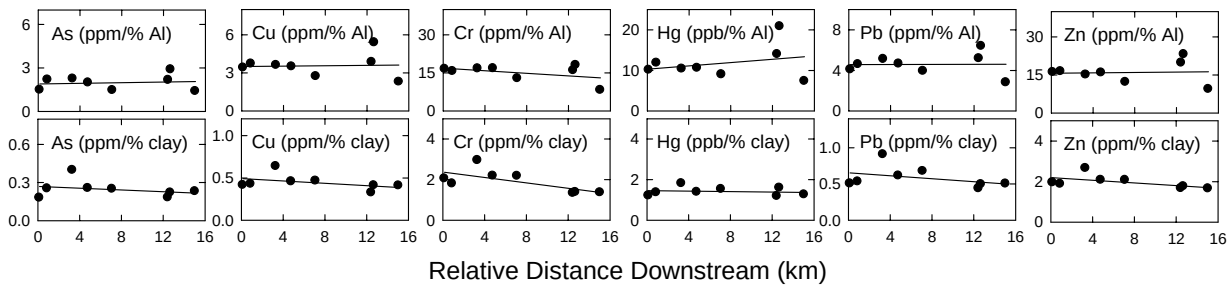

Figure 7 Spatial variations (from upstream to downstream) in depth-averaged concentrations of Arsenic (As), Copper (Cu), Chromium (Cr), Mercury (Hg), Lead (Pb), and Zinc (Zn) (from left to right) within the post-impoundment sediments along the Skuna River arm as projected onto a line, as normalized by mass percent of Aluminum (Al; upper) and clay (lower). Note variable units.

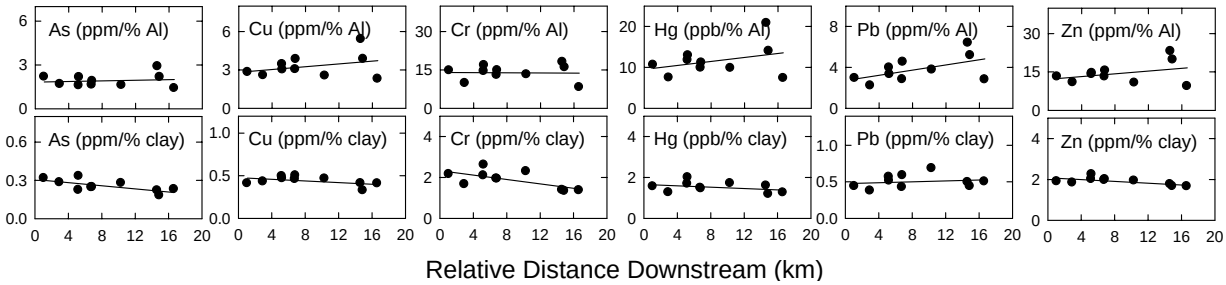

Figure 8 Spatial variations (from upstream to downstream) in depth-averaged concentrations of Arsenic (As), Copper (Cu), Chromium (Cr), Mercury (Hg), Lead (Pb), and Zinc (Zn) (from left to right) within the post-impoundment sediments along the Yalobusha River arm as projected onto a lime, as normalized by mass percent of Al (upper) and clay (lower). Note variable units.

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