

**CHEMISTRY OF BOTTOM SEDIMENTS
IN CRUM RESERVOIR, MARTIN COUNTY, EASTERN KENTUCKY,
COMPARED TO
A REFERENCE RESERVOIR IN CENTRAL KENTUCKY**



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KENTUCKY**

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Photo credits: Photo 1: Sediments team taking core samples from Crum Reservoir. Photo 2: Core sediment sample;
Photo 3: Matt Caddell, research assistant and graduate student in Earth Science Program –Eastern Kentucky University,
at Environmental Research and Training Laboratory, University of Kentucky preparing sediment samples for analysis.

LIST OF FIGURES AND TABLES

Figure 1: Locations of Martin County (Crum Reservoir) and Madison County (Owsley Reservoir)

Figure 2: Crum Reservoir, showing locations of sample collection sites

Figure 3: Photograph showing sediment core collected from Crum Reservoir. The fine grain sediments shown here are typical of the sediments collected from the Reservoir

Table 1: Sediment Quality Guideline (all units are in mg/kg)

Table 2a: Arsenic (As) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2b: Barium (Ba) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2c: Cadmium (Cd) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2d: Calcium (Ca) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2e: Chromium (Cr) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2f: Cobalt (Co) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2g: Copper (Cu) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2h: Iron (Fe) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2i: Lead (Pb) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 2j: Manganese (Mn) concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County)

Table 3: Comparison of Crum Reservoir sediment splits

Table 4: Total organic carbon (TOC) concentration in Crum and Owsley Reservoirs (nd=non detected)

INTRODUCTION

Curtis Crum Reservoir, near Inez, Kentucky, provides up to 3,100,000 gallons of storage for the public-water supply for Martin County (Figure 1). The 22-acre reservoir, stocked with largemouth bass, bluegill, and channel catfish, is also used regionally for recreational fishing. Along with all other Kentucky waters, Crum Reservoir is under a fish consumption advisory for low levels of mercury in fish, which may occur naturally as well as in response to anthropogenic contamination.

Blackwater events, during which sediment-laden water from coal slurry ponds enters a receiving stream, have been documented in streams in Martin County, including the Tug Fork of the Big Sandy River. This has created a concern that raw water entering the reservoir from Tug Fork may at times contain undesirable levels of metals or other contaminants transported as suspended, dissolved, or bedload sediments in streams. Additionally, leaching or erosion of coal slurry sediments deposited in the watersheds of Martin County may transfer a portion of the metals stored in soils to the reservoir. Of particular concern are suspended sediments, especially in times of high flow during storm events or accidental discharges from upstream storage ponds, since the typically fine-grained suspended sediments are more strongly associated with metals content (Moura and Sigolo, 2002). When sediment-laden, higher-energy water enters the reservoir, flow decreases and sediments are deposited. Therefore, the bottom sediments of lakes such as Crum Reservoir can become sinks, or storage areas, where concentrations of metals can accumulate. Over time, the accumulated metals may be sequestered as older layers of sediment become buried under newly-deposited layers. If sequestration is incomplete or lacking, however, metals attached to the sediment of the reservoir may come into contact with humans via one of several possible routes including direct contact; dust inhalation from dry, exposed sediment; or by eating fish, plants, or wildlife with accumulated levels of metals (Van Metre and Mahler, 2004). While metals are often bound to sediment particles, under certain conditions (for example, if changes in pH occur or if oxygen levels change significantly), metals may remobilized and re-

enter the water column of the reservoir, leading to an undesirable level of metals in the raw water for the public drinking water supply of Martin County (see Balistrieri, 1995; Munk *et al.*, 2002; Mihm *et al.*, 1976). In this case, contamination of reservoir water could continue to occur, even after blackwater events have ceased, and metals would more likely be ingested by fish, wildlife, or humans. Fish or wildlife that ingest metals from the reservoir may bio-accumulate levels of metals that are higher than levels in the water, representing an additional potential exposure risk for humans.

Reservoir size may also be a factor in the behavior of sediment-borne metals. In large water bodies, settling time is long and sedimentation rates are low. Resuspension of sediments is common. In small, shallow reservoirs, however, particle residence times are short, settling times are brief, and high sedimentation rates lead to rapid burial of sediment (Van Metre and Mahler, 2004), which may result in the sequestration of metals. Other factors that govern the distribution of heavy metals in reservoir bottom sediments may be linked to organic content, pH, and sediment grain size (Moura and Sigolo, 2002; Munk, 2002).

In addition to metals related to coal-bearing formations, organic chemicals are a potential area of concern. Coal contains a multitude of organic components, some of which are known to be toxic, and others for which toxicity is unknown (Feder, 2002). The effects of coal combustion have been widely studied, but little is known about the effect of long-term exposure to low levels of organic compounds entering water supplies from coal-derived materials (Orem, 2004).

To investigate the fate and transport of particle-attached metals in Crum Reservoir, on September 19, 2005, 34 sediment cores were collected from the reservoir and 5 from the Tug River. To provide an initial assessment of organic content, three grab samples were collected from the Crum Reservoir on June 9, 2006.

METHODS

Sample collection and handling

The reservoir was visually divided into five sections, and each section was sampled separately (Figure 2). Samples were collected using a 2” diameter, stainless steel hand liner-type corer sampler. A boat equipped with depth sounder and GPS unit was used to locate the deeper portions of Crum Reservoir. When an area appropriate for sampling was identified, the sampler was dropped from the boat into the reservoir and allowed to penetrate the soft bottom sediments. The sampler retrieved via a line attached to the clevis. A flap valve on the sampler closed during removal, preventing loss of sample.

After bringing the sampler into the boat, the plastic liner containing the sample was removed from the stainless steel tube assembly and the core was measured. The cores were examined for sediment layers indicative of coal slurry, which could be sampled and analyzed separately. However, such layers were not present (Figure 3). Several samples consisted of a layer of fine sediment about 2” thick, underlain by a thin layer of partially decomposed leaves, which was in turn underlain by more fine sediment. The upper 2” of core, therefore, was assumed to represent about one year of sediment deposition, with the leaf layer providing a defining lower horizon. In each section of the reservoir, three to five shallow cores were collected and used to form one composite sample representing recent deposition. The upper 2” of these cores were aggregated in a stainless steel mixing bowl and were homogenized by stirring with a large stainless steel spoon for a period of five minutes. The homogenized sample was collected in two new, labeled, acid-rinsed 125-mL sample containers and placed on ice. At two locations (stations 3 and 4) the homogenized sample was split into two equal portions and shipped to separate laboratories (Severn Trent Laboratories, St. Louis, Missouri, and the University of Kentucky Environmental Training and Research Laboratory (ERTL)).

In addition, a single long core was collected from each of the five sections identified for

sampling. The long cores were physically examined for evidence of an identifiable layer of coal slurry material. Finding no evidence of such layering, the upper nine inches of the longer cores were homogenized by mixing for five minutes using stainless steel equipment, placed into two labeled, new, acid-rinsed sample containers, and stored on ice.

Finally, five samples were collected by boat from the Tug River and homogenized as before. The sediments of the Tug River were considerably coarser, contained abundant coal fragments, and were more difficult to collect. Repeated attempts to obtain a longer core, representative of several years deposition, were unsuccessful. However, the shorter cores were consolidated as before to form a composite sample, collected in two labeled, new, acid-rinsed 125-mL containers, and stored on ice.

The sediment samples were transported to the Department of Earth Sciences at Eastern Kentucky University and placed in a freezer designated for environmental samples.

Analysis of Sediment Samples

Each sediment sample collected from Crum Reservoir or the Tug River is stored as two subsamples, in identical, labeled containers. One of each of the sample subsets was removed from the freezer, allowed to thaw, and used for moisture content analysis and metals analyses.

Moisture content analysis Samples were allowed to warm to room temperature and standing water in the container was carefully removed using a disposable pipette. Approximately 20 gm of the sediment from each sample was then removed, and each sample aliquot was weighed on a tared aluminum sample boat, then placed in a 105C drying oven for 24 hours.

After removal from the oven, sediment samples were weighed again, and the weights recorded for use in determining moisture content of the original sediment samples. About 1 gm of saturated sediment was weighed in a tared digestion vial, and the weight was recorded. Concentrated nitric acid was then added to each digestion vial and the samples were stored in a refrigerator dedicated to environmental samples until they were transported on ice to the

University of Kentucky Environmental Training and Research Laboratory (ERTL). At UK, the sediment samples were analyzed according to U.S. Environmental Protection Agency (EPA)-approved methods and the data subjected to strict quality control procedures.

Preparation for metals analyses About 1 gm of saturated sediment was weighed in a tared digestion vial, and the weight was recorded. Two and one half ml (2.5 ml) of concentrated metals-grade nitric acid was then added to each digestion vial and the samples were stored in a refrigerator dedicated to environmental samples prior to transport to the University of Kentucky Environmental Training and Research Laboratory (ERTL).

Following EPA method 7471, 0.5 mL of concentrated metals grade nitric acid and 2 mL of concentrated hydrochloric acid were added to samples intended for mercury analysis. The samples were digested by first heating to 95° C for 10 minutes, then, with the addition of 3 mL of 5% potassium permanganate, heated for an additional 30 minutes. After the samples cooled to room temperature, 3.0 mL of 12% hydroxyl amine hydrochloride solution was added, and each sample was diluted to 30 mL and filtered. Mercury analysis of the filtered solution was performed by Cold-Vapor Atomic Absorption.

Digestion followed EPA method 3050B for the remaining metals analyses. First, 2.5 mL of distilled water (18µm) was added to each digestion vial, which was then covered with a reflux cap and heated in a digestion hot block at 95° C for 15 minutes without boiling. The samples were then allowed to cool to room temperature, after which 5.0 mL of concentrated nitric acid was added to each sample. Samples were then heated at 95° C in 30-minute increments until the absence of brown fumes indicated that the process was complete. After, samples were covered with a ribbed watchglass and heated at 95° C for 1.5 hours. Then the samples were cooled to room temperature. Following cooling, 0.5 mL of 30% hydrogen peroxide was added to each sample, which was placed back into the 95° C digestion hot block at for 30 minutes. Then 5 mL of concentrated metals-grade hydrochloric acid was added to each sample and the samples were heated at 95° C for 15 minutes. After cooling, samples were diluted to 50 mL with a mixture of

1% nitric acid and distilled, deionized water, and filtered. The filtered solutions were dedicated for lead, arsenic, selenium, and cadmium analysis using a graphite furnace atomic absorption instrument. The remaining metals (cobalt, chromium, copper, manganese, barium, iron, and calcium), were analyzed by the inductively-coupled plasma – atomic emission spectrum technique.

The particular methods appropriate for the instruments at ERTL were derived from EPA methods and were based on the characteristics of the particular samples. In some instances, analytical methods required pre-testing on the graphite furnace atomic absorption instrument. Pre-testing was accomplished by preparing a batch of analytical samples consisting of triplicate sediment sample aliquots, three method blanks, and four lab control samples for a total of 10 sediments per batch. In this way, time-consuming complications associated with analytical analysis of metals in sediments were reduced.

Selection of comparison reservoir

Owsley Reservoir, Madison County, Kentucky, was selected as a reservoir against which to compare sediment samples collected from Crum Reservoir. Owsley Reservoir is located near Berea, in the Outer Bluegrass physiographic region of Kentucky and provided information relative to the metals content of reservoir bottom sediment in an area not associated with coal production.

RESULTS

Concentrations of metals in bottom sediments

Sediment quality guidelines are included in Table 1. No federal or state standards exist at present for acceptable concentrations of metals in the sediments of drinking-water supply reservoirs. A variety of approaches have been used, however, to evaluate sediment quality in general, generally with the goal of protecting aquatic health. Tables 2a.et.al compare concentrations of metals from the reservoir bottom sediments to three sets of sediment quality

guidelines developed for the National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA): typical background metal concentrations in freshwater sediments of the U.S., threshold effects levels (TELs) below which no effects are expected among benthic aquatic organisms living in and on the sediment, and probable effects levels (PELs) above which harmful effects may be expected in aquatic benthic organisms. Tables 2*et.al* also include consensus-based probable effect concentrations (PECs) based on evaluations of five different published standards for sediment quality (McDonald *et al.*, 2000), again with the goal of protecting aquatic ecosystems. Finally, the US Environmental Protection Agency (EPA) has compiled a list of freshwater sediment screening benchmarks used for contaminated sites, which are also included in Tables 2. The benchmarks are concentrations that represent levels below which further clean-up is not generally required. Individual results are discussed below.

Table 2a. Arsenic

The NOAA typical background level for arsenic in freshwater sediments of the United States is 1.10 mg/kg. All other values (TEL, PEL, PEC, and EPA) are higher, ranging from 5.90 mg/kg (TEL) to 33.0 (PEC). Arsenic concentrations in 22 of the 23 sediment samples from Crum and Owsley Reservoirs were higher than typical for US freshwater sediments. However, only one sample, from Owsley Reservoir, exceeded the NOAA TEL, the concentration at which it might be possible to notice some effects on aquatic health. No samples from either reservoir exceeded the NOAA PEL, the consensus-based PEC, or the EPA benchmark concentration. The average value for samples from Crum Reservoir (2.1 mg/kg) was slightly lower than the average for Owsley Reservoir (3.3 mg/kg).

Table 2b. Barium

Barium, a contaminant common in coal-mining areas, is not common in other parts of the country. Not a threat to aquatic health, there are no TEL, PEL, PEC or EPA concentrations for barium. All 23 samples from the two reservoirs had higher barium concentrations (31.7 – 129.5 mg/kg) than the typical concentration of 0.7 mg/kg found in freshwater sediments in the United States. The average concentration of barium in sediments from Crum Reservoir (96.1 mg/kg) was higher than the average from Owsley Reservoir (77.9 mg/kg), although both were significantly higher than typical values for the nation.

Table 2c. Cadmium

Cadmium concentrations in freshwater sediments in the US typically range from 0.10 to 0.30 mg/kg. Cadmium values in Crum Reservoir averaged 0.1 mg/kg, while concentrations in sediment samples from Owsley Reservoir averaged 0.3 mg/kg. One sample from Owsley Reservoir contained 0.4 mg/kg cadmium, higher than typical for the nation but still below levels at which any effects might be observed.

Table 2d. Calcium

Calcium is common in rock-forming minerals, especially in Kentucky. There are no state or federal guidelines for calcium concentrations. In the two reservoirs studied, calcium ranged from 843.7 to more than 50,000 mg/kg. Calcium was significantly higher in sediment samples from Owsley Reservoir, reflecting differences in geology between the two sites.

Table 2e. Chromium

Chromium concentrations in the two reservoirs ranged from 4.8 mg/kg to 30.4 mg/kg, compared to typical US freshwater sediment concentrations of 0.70 to 13.0 mg/kg. Ten of the 13

sediment samples from Crum Reservoir, and 8 of the 10 sediment samples from Owsley Reservoir, contained chromium concentrations higher than 13.0 mg/kg. None, however, exceeded the TEL, PEL, PEC, or EPA benchmark concentrations.

Table 2f. Cobalt

Concentrations of cobalt in samples from the two reservoirs ranged from 5.8 mg/kg (Owsley Reservoir) to 15.4 mg/kg (Crum Reservoir). Eleven of the 13 samples from Crum Reservoir, and 3 of the 10 sediment samples from Owsley Reservoir, contained more cobalt than the typical US freshwater sediment value of 10 mg/kg. There are no TEL, PEL, or PEC values for cobalt, which is not considered a threat to aquatic ecology. However, the EPA lists a freshwater sediment screening benchmark of 50 mg/kg, significantly higher than the values found in the Kentucky reservoirs.

Table 2g. Copper

Freshwater sediments in the US typically contain 10.0 to 25.0 mg/kg copper. All but 2 of the 13 Crum Reservoir sediment samples contained more than 10 mg/kg copper, although only 2 contained more than 25.0 mg/kg (25.1 and 26.9 mg/kg). Owsley Reservoir sediment samples contained from 29.5 mg/kg copper to 166.8 mg/kg, and 9 of the 10 samples exceeded both the EPA freshwater sediment screening benchmark of 31.6 mg/kg and the NOAA TEL, the value at which negative effects might be observed on aquatic ecology. One sample (166.8 mg/kg) exceeded the consensus-based PEC (probable effects concentration) of McDonald et al. (2000), but not the NOAA PEL. The higher copper levels in Owsley Reservoir are consistent with the use of copper sulphate as an algaecide, a common practice among water treatment plants.

Table 2h. Iron

Iron is relatively abundant in many soils and sediments, and concentrations in freshwater sediments in the US ranges from 9,900 to 18,000 mg/kg. No TEL, PEL, or PEC guidelines exist for iron; however, EPA has established a benchmark of 20,000 mg/kg for freshwater sediment at contaminated sites. Eleven of the 13 sediment samples from Crum Reservoir, and 7 of the 10 sediments from Owsley Reservoir, contained more than 20,000 mg/kg iron.

Table 2i. Lead

Lead is a metal of concern in many urban soils and sediments. Background concentrations of lead in freshwater sediments in the US typically range from 4.0 to 17.0 mg/kg. One sample from Crum Reservoir contained 4.1 mg/kg, while the remaining 12 samples were less than 4.0 mg/kg, the lower limit of typical values in US freshwater sediments. Sediment samples from Owsley Reservoir were also low, ranging from 2.1 mg/kg to 4.3 mg/kg.

Table 2j. Manganese

Manganese, like iron, is often found in rock-forming minerals. Typical manganese values in freshwater sediments in the US are about 400 mg/kg, a value exceeded in 5 of the 13 sediment samples from Crum Reservoir, and 3 of the 10 samples from Owsley Reservoir. No TEL, PEL, or PEC values exist for manganese. The EPA benchmark of 460 mg/kg was exceeded in 2 samples from Crum Reservoir and 3 samples from Owsley Reservoir.

Mercury and Selenium

Mercury is a volatile element, and care should be taken to provide undisturbed samples for mercury analysis. The sediment samples collected for this project were homogenized for five minutes, and therefore, were significantly disturbed. Therefore, mercury was not analyzed in the

13 Crum Reservoir sediment samples and 10 Owsley Reservoir sediment samples summarized in Table 2. However, mercury concentrations were measured in two Crum Reservoir samples analyzed separately. It is important to note that the mercury analyses were done on only two samples, and reflect conditions in disturbed sediments. The analyses are discussed here, however, to provide a sense of minimum mercury concentrations that might be expected in the bottom sediments of Crum Reservoir (though this is not presented in table form due to low sample numbers). Mercury concentrations in the two samples were 0.051 and 0.049 mg/kg, at the upper limit of typical concentrations in freshwater sediments in the US, and below the NOAA TEL (0.174 mg/kg) and EPA freshwater sediment benchmark value (0.18 mg/kg).

Selenium is typically found in concentrations of about 0.29 mg/kg in freshwater sediments in the US, a concentration that is below the detection limit of 1.0 mg/kg for the method used to measure selenium. No TEL, PEL, PEC, or EPA benchmarks exist for selenium. Each of the sediment samples collected from the two reservoirs contained less than 1.0 mg/kg of selenium. Due to no existing benchmarks for selenium and sample results less than detectable levels, data on selenium is not reported in table form.

Reservoir sediments are a complex mixture of organic and inorganic materials, and sediment analysis can be difficult. In addition, laboratories have different instruments, different technicians, and may on occasion use different EPA-approved methods to measure the same parameter; therefore, it is expected that analyses from different laboratories might be somewhat different. However, differences should not be significant. Two samples from Crum Reservoir (Stations 3 and 4) were split into two portions, each of which was analyzed at a different laboratory. Table 3 summarizes the results of those analyses. Samples analyzed by ERTL showed higher levels of barium, calcium, cobalt, copper, chromium, iron, and manganese. Samples analyzed by STL were higher in lead, and, in one of the two samples, higher in arsenic, than samples analyzed by ERTL. Concentrations of cadmium and selenium were not

significantly different between the two laboratories. The different concentrations reported by the laboratories may be due to differences in the actual samples, since sediment is a mixture of materials, or they may reflect better metals recovery in one laboratory due to advantages in instrumentation or technique. Examination of the laboratory control samples, a quality control technique used by laboratories, shows that, for example, STL recovered only 74% of a known iron standard, and 111% of a known lead standard, suggesting that iron values reported by STL may be somewhat low, and lead values may be somewhat high. ERTL reported 109% of iron recovery in its quality control standard, and 99% lead recovery, suggesting that iron values reported by that lab might be slightly high, and lead values are accurate. Because concentrations reported by both laboratories were similar, although not identical, the difference in reported values from the two laboratories is not a concern.

Concentrations of organic contaminants in bottom sediments

Table 4 summarizes the total organic carbon (TOC) content of 6 grab samples, 3 from Crum Reservoir and 3 from Owsley Reservoir. Concentrations of less than 10,000 mg/kg (equivalent to 1%) are considered low organic content. Crum Reservoir sediments contain approximately 300 mg/kg, or 0.03%, organic carbon. Owsley Reservoir, conversely, contains approximately 23,000 mg/kg, or 2.3%, organic carbon. Non-polar organic chemicals (such as TCE, trichloroethene, for example) are less likely to attach to particles in sediments with low concentrations of organic carbon. Based on the TOC analyses reported here, the sediments of Crum Reservoir are less likely than those of Owsley Reservoir to act as a storage site for many types of organic chemicals.

The list of organic compounds present on earth is seemingly endless, and it is not practical to test for all compounds in existence. Environmental studies frequently analyze for volatile organic compounds (VOCs) as a first pass, as certain VOCs such as TCE are included among the most common contaminants encountered in environmental studies. STL laboratories

analyzed for 57 standard organic compounds from sediment samples from the two reservoirs. Of the organic compounds for which the sediment samples were analyzed, none were identified except methylene chloride, a common lab contaminant that was also identified in a distilled water sample (a “blank”) included in the analysis as a quality control measure.

CONCLUSIONS

The data included in this final report represent our findings on the concentrations of metals of concern in the bottom sediments of Crum Reservoir. Extensive quality assurance protocols were followed during the study, and are on file at the Eastern Kentucky Environmental Research Institute (EKU) and the Environmental Research and Training Laboratory (ERTL) at the University of Kentucky. Results of the analyses from two split samples sent to Severn-Trent Laboratories are slightly lower but in general agreement with results from ERTL, and indicate that metals concentrations of bottom sediments in Curtis Crum Reservoir are so low as to not adversely impact the health of the aquatic community. Although guidelines do exist for overall sediment quality, there are no federal or state guidelines that specifically address maximum metals content of sediments in reservoirs that are used as sources for public water-treatment facilities. However, based on the guidelines for freshwater sediments in general, there is no evidence to suggest that the sediments are contributing significant amounts of metals to the water column or to the raw water intake of the water treatment plant.

The chemistry of the bottom sediments from the two reservoirs is similar. Both are slightly above typical national values for barium, iron, and manganese, which are not tied to aquatic ecological health. Both reservoirs contained slightly higher than typical concentrations of arsenic and chromium, which are tied to ecological health; however, concentrations of both metals were well below levels of concern. Crum Reservoir bottom sediments contain slightly more cobalt than does Owsley Reservoir, and Owsley Reservoir sediments are higher in copper than Crum Reservoir. Levels of copper in Owsley Reservoir are above the TEL established by

NOAA, suggesting that Owsley Reservoir is at risk for adverse effects on aquatic ecology.

The total organic content of the sediment samples from the two reservoirs is low, suggesting little tendency for the sediments to collect organic compounds. Analyses of VOC concentrations showed no detectable levels of these common organic contaminants in the sediments.

Additional data could be collected by sampling and analyzing the pore water of the sediments, and by collecting water from the reservoir water column directly, before it enters the treatment plant. These analyses would provide additional lines of evidence that would support or refute the data collected from analyses of the sediments. Given the low levels of metals found in the sediment analyses, however, it is likely that further analyses would result in findings very similar to the findings of this report.

ACKNOWLEDGEMENTS

We appreciate the partnership of the University of Kentucky Environmental Research and Training Laboratory (ERTL) throughout this project. Metals analysis of Martin County sediments, including Crum Reservoir and Tug Fork, was done at ERTL, which also provided training, supervision, and QA/QC protocols. Additionally, we incorporated data pertaining to metals concentrations in bottom sediments of Owsley Reservoir that was collected as part of an ERTL/NSF-funded research project.

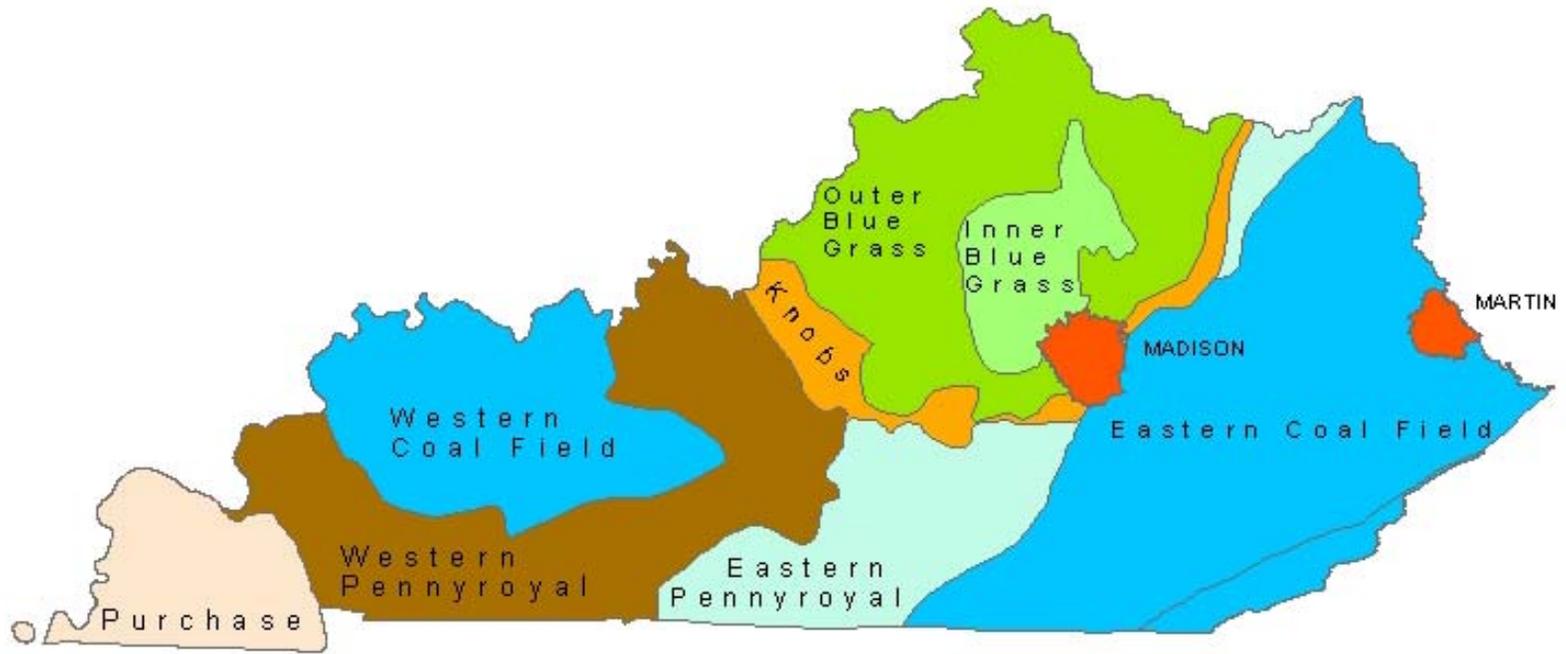


Figure 1. Locations of Martin County (Crum Reservoir) and Madison County (Owsley Reservoir).

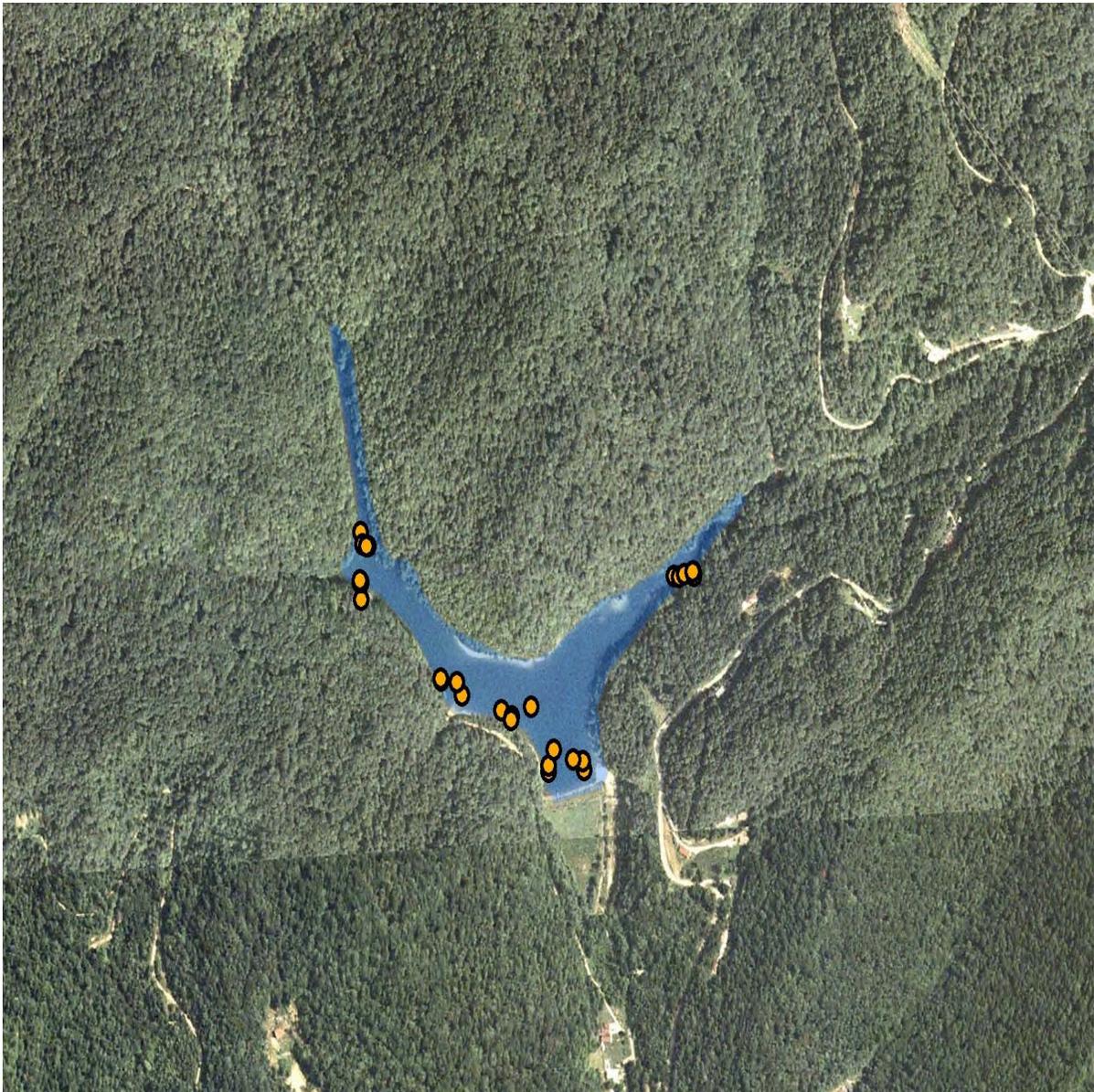


Figure 2. Crum Reservoir, showing locations of sample collection sites.



Figure 3. Photograph showing sediment core collected from Crum Reservoir. The fine-grained sediments shown here are typical of the sediments collected from the reservoir.

Table 1. Sediment quality guidelines. (all units are in mg/kg)

Metal	A	B	C	D	EPA FW sediment screening
Arsenic	1.10	5.90	17.00	33.00	9.80
Barium	0.7	-	-	-	
Cadmium	0.10 - 0.30	0.596	3.53	4.98	0.99
Calcium	-	-	-	-	
Chromium	0.70 - 13.0	37.3	90	111	43.4
Cobalt	10	-	-	-	50
Copper	10.0 - 25.0	35.7	197	149	31.6
Iron	9,900 - 18,000	-	-	-	20000
Lead	4.0 - 17.0	35.0	91.3	128	35.8
Manganese	400	-	-	-	460
Mercury	0.004 - 0.051	0.174	0.486	1.06	0.18
Selenium	0.29	-	-	-	-

A. NOAA (National Oceanic and Atmospheric Administration) typical background levels in U.S. freshwater sediments

B. NOAA threshold effects level (TELs)

C. NOAA probable effect levels (PELs)

D. Concensus-based probable effect concentrations (PECs) based on data from various agencies (McDonald et al., 2000)

Arsenic (As)

Table 2a. Arsenic (As) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data				Central Tendency	
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	1.5	1.8	2.4	1.8	0.33
Owsley Res.	10	0.9	3.4	6.0	3.3	1.4
NOAA	Typical background levels in U.S. freshwater sediments				1.1	
TEL	Threshold effect level				5.90	
PEL	Probable effect level.....				17.00	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				33.0	
EPA	Freshwater sediment benchmark.....				9.80	

NOAA – typical background levels in U.S. freshwater sediments
TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed
PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed
PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)
EPA – EPA freshwater sediment screening benchmark for use at remediation sites

Barium (Ba)

Table 2b. Barium (Ba) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data			Central Tendency		
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	74.9	110.6	123.6	106.5	13.8
Owsley Res.	10	54.8	68.8	129.5	77.9	23.7
NOAA	Typical background levels in U.S. freshwater sediments				0.7	
TEL	Threshold effect level				NA	
PEL	Probable effect level.....				NA	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				NA	
EPA	Freshwater sediment benchmark.....				NA	

NOAA – typical background levels in U.S. freshwater sediments

TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed

PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed

PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)

EPA – EPA freshwater sediment screening benchmark for use at remediation sites.

NA – Not applicable

Cadmium (Cd)

Table 2c. Cadmium (Cd) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data			Central Tendency		
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	0.1	0.09	0.2	0.1	0.03
Owsley Res.	10	0.1	0.3	0.2	0.3	0.07
NOAA	Typical background levels in U.S. freshwater sediments				0.10- 0.30	
TEL	Threshold effect level				0.596	
PEL	Probable effect level.....				3.53	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				4.98	
EPA	Freshwater sediment benchmark.....				0.99	

NOAA – typical background levels in U.S. freshwater sediments
TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed
PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed
PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)
EPA – EPA freshwater sediment screening benchmark for use at remediation sites

Calcium (Ca)

Table 2d. Calcium (Ca) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data				Central Tendency	
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	843.7	1097.2	2060.9	1294.1	435.4
Owsley Res.	9	1261.6	1908.3	11979.2	3256.6	3376.7
NOAA	Typical background levels in U.S. freshwater sediments				NA	
TEL	Threshold effect level				NA	
PEL	Probable effect level.....				NA	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				NA	
EPA	Freshwater sediment benchmark.....				NA	

NOAA – typical background levels in U.S. freshwater sediments
TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed
PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed
PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)
EPA – EPA freshwater sediment screening benchmark for use at remediation sites
NA – not applicable

Chromium (Cr)

Table 2e. Chromium (Cr) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data			Central Tendency		
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	12.9	15.4	18.6	15.7	1.6
Owsley Res.	10	11.4	17.5	30.4	19.0	6.2
NOAA	Typical background levels in U.S. freshwater sediments				0.70- 13.0	
TEL	Threshold effect level				37.3	
PEL	Probable effect level.....				90	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				111.0	
EPA	Freshwater sediment benchmark.....				43.4	

NOAA – typical background levels in U.S. freshwater sediments

TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed

PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed

PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)

EPA – EPA freshwater sediment screening benchmark for use at remediation sites

Cobalt (Co)

Table 2f. Cobalt (Co) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data				Central Tendency	
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	11.0	12.5	15.4	12.6	1.2
Owsley Res.	10	5.8	9.1	13.7	9.1	2.7
NOAA	Typical background levels in U.S. freshwater sediments				10	
TEL	Threshold effect level				NA	
PEL	Probable effect level.....				NA	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				NA	
EPA	Freshwater sediment benchmark.....				50	

NOAA – typical background levels in U.S. freshwater sediments

TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed

PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed

PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)

EPA – EPA freshwater sediment screening benchmark for use at remediation sites

NA – not applicable

Copper (Cu)

Table 2g. Copper (Cu) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data				Central Tendency	
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	19.2	23.1	26.9	22.6	2.6
Owsley Res.	10	29.5	59.6	166.8	73.8	45.5
NOAA	Typical background levels in U.S. freshwater sediments				10.0- 25.0	
TEL	Threshold effect level				35.7	
PEL	Probable effect level.....				197	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				149.0	
EPA	Freshwater sediment benchmark.....				31.6	

NOAA – typical background levels in U.S. freshwater sediments

TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed

PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed

PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)

EPA – EPA freshwater sediment screening benchmark for use at remediation sites

Iron (Fe)

Table 2h. Iron (Fe) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data			Central Tendency		
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	23103.1	28128.7	31010.2	27690.1	2386.7
Owsley Res.	10	16742.3	22456.0	33652.9	23428.3	6451.4
NOAA	Typical background levels in U.S. freshwater sediments				9900- 18000	
TEL	Threshold effect level				NA	
PEL	Probable effect level.....				NA	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				NA	
EPA	Freshwater sediment benchmark.....				20000	

NOAA – typical background levels in U.S. freshwater sediments

TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed

PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed

PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)

EPA – EPA freshwater sediment screening benchmark for use at remediation sites

NA – not applicable

Lead (Pb)

Table 2i. Lead (Pb) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data				Central Tendency	
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	10	2.3	3.3	4.1	3.2	0.5
Owsley Res.	10	2.1	3.0	4.3	3.1	0.7
NOAA	Typical background levels in U.S. freshwater sediments				4.0- 17.0	
TEL	Threshold effect level				35.0	
PEL	Probable effect level.....				91.3	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				128	
EPA	Freshwater sediment benchmark.....				35.8	

NOAA – typical background levels in U.S. freshwater sediments

TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed

PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed

PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)

EPA – EPA freshwater sediment screening benchmark for use at remediation sites

Manganese (Mn)

Table 2j. Manganese (Mn) Concentrations (mg/kg) in Bottom Sediments of Crum Reservoir (Martin County) and Owsley Reservoir (Madison County).

	Description of Laboratory Data				Central Tendency	
	# of Samples	Minimum Value	Median Value	Maximum Value	Mean	Standard Deviation
Crum Res.	11	253.6	351.0	557.9	369.0	97.8
Owsley Res.	10	174.1	286.0	634.0	350.4	155.4
NOAA	Typical background levels in U.S. freshwater sediments				400	
TEL	Threshold effect level				NA	
PEL	Probable effect level.....				NA	
PEC	Consensus-based estimate of concentration at which adverse effects on aquatic benthic organisms frequently occur				NA	
EPA	Freshwater sediment benchmark.....				460	

NOAA – typical background levels in U.S. freshwater sediments
TEL – NOAA guideline for threshold effects level, concentration at which effects on aquatic organisms might be observed
PEL-- NOAA probable effects level, concentration at which effects on aquatic organisms will likely be observed
PEC-- consensus-based Probable Effect Concentrations from various agencies (McDonald et. al. 2000)
EPA – EPA freshwater sediment screening benchmark for use at remediation sites

Table 3. Comparison of Crum Reservoir sediment splits.

Sample Locations <i>Analyzing Laboratory</i>	Station 3		Station 4	
	<i>ERTL</i>	<i>STL</i>	<i>ERTL</i>	<i>STL</i>
<u>Analyte</u>				
Arsenic	1.6	2.7	2.1	2.2
Barium	114.7	77.4	117.3	75.9
Calcium	843.7	545	1097.2	691
Cadmium	0.1	0.08	0.1	0.094
Cobalt	12.7	9.8	13.1	9.4
Copper	23.2	16	24.7	14.7
Chromium	14.9	8.9	15.7	7.5
Iron	27825.5	17500	29223.6	16400
Lead	2.9	13.9	3.5	15.2
Manganese	351	262	386.7	202
Mercury	na	0.051	na	0.049
Selenium	<1.0	nd	<1.0	0.49

Table 4. Total organic carbon (TOC) concentrations in Crum and Owsley Reservoirs. (nd = not detected)

Sample Locations	TOC, mg/kg
<u>Crum Reservoir</u>	
Sample 1	nd
Sample 2	288
Sample 3	308
<u>Owsley Reservoir</u>	
Sample 1	18600
Sample 2	23000
Sample 3	28600

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