US Army Corps
of Engineers®
Buffalo District

Eighteenmile Creek
Great Lakes Area of Concern (AOC)
Niagara County, New York

Concentrations, Bioaccumulation and Bioavailability of Contaminants in Surface Sediments

June 2008

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Eighteenmile Creek Great Lakes Area of Concern (AOC) has three identified use impairments, all of which are linked to sediment contamination: (1) restrictions on fish and wildlife consumption; (2) degradation of benthos; and (3) restrictions on dredging activities. The main contaminants of concern (COCs) associated with these impairments include the organic compounds chlorinated pesticides, polychlorinated biphenyls (PCBs) and dioxins/dibenzofurans (PCDD/Fs), and metals such as chromium, copper, lead, manganese, mercury, nickel, zinc and cyanide.

To assess the overall toxicological risk of surficial sediment contamination within the AOC that is currently exposed to the aquatic community, the U.S. Army Corps of Engineers (USACE), Buffalo District collected surface sediment samples from 15 locations within lower Eighteenmile Creek in August 2003. These discrete samples were composited to represent five separate reaches within the AOC: moving upstream from approximately upper Olcott Harbor to Burt Dam, these were Reaches EBU1, EBU2, EBU3, EBU4 and EBU5. The sediment samples were subjected to laboratory physical, chemical and bioaccumulation testing. Chemical testing included various heavy metals, and organic contaminants including chlorinated pesticides, PCBs and PCDD/Fs. The bioaccumulation experiments entailed a standard 28-day freshwater laboratory test using the surficial sediment deposit feeding aquatic oligochaete *Lumbriculus variegatus*, and focused on metals, chlorinated pesticides and PCBs. The specific objectives of this investigation were to:

- Ascertain the concentrations of all of the contaminants tested in surface sediments within the AOC. Evaluate these levels relative to selected freshwater toxicity threshold values, mainly relevant sediment quality criteria, and;
- Assess the bioaccumulation of metals, chlorinated pesticides and PCBs to determine their potential to bioaccumulate in aquatic organisms. Further, quantify and assess the bioavailability of pesticides and PCBs through the calculation and evaluation of biota-sediment accumulation factors (BSAFs).

Heavy metals data indicated that concentrations of various metals in surficial sediments, particularly copper, chromium, lead, nickel and zinc, may exert chronic toxicity throughout the AOC. Metal contamination in sediments within reaches EBU3 and EBU5 appear to have the most potential to pose chronic toxicity. Potential for sediment-associated lead and zinc toxicity was consistent throughout the AOC. The bioaccumulation data suggest little bioavailability or bioaccumulation risk associated with heavy metal contamination.

Organic contaminant data indicated that levels of the pesticide dichlorodiphenyldichloroethylene (DDE) in surficial sediments within Reaches EBU1 through EBU4 may be chronically toxic. Bioaccumulation data indicated that DDE was bioavailable throughout AOC surface sediments (mean BSAF range = 1.21 to 5.41). The high bioavailability of DDE in surficial sediment in Reaches EBU3 (BSAF = 4.60) and

EBU5 (BSAF = 5.41) indicate that it is bioaccumulating in benthic invertebrates, and is likely to bioaccumulate in predator fish and higher trophic levels. Sediment data suggest that PCBs in surficial sediments throughout most or all of the AOC pose a bioaccumulation risk to aquatic organisms. PCB concentrations are bioavailable in surface sediments throughout the AOC (mean BSAF range = 1.55 to 4.36). The high bioavailability of PCBs in the surficial sediments in Reaches EBU3 (BSAF = 2.95) and EBU5 (BSAF = 4.36) indicate that they are bioaccumulating in benthic invertebrates, and are likely to bioaccumulate in predator fish and higher trophic levels. The site-specific BSAFs determined in this investigation can be applied to conservatively predict the bioaccumulation of DDE and PCBs by indigenous benthic organisms from AOC sediments. PCDD/F contamination in surficial sediments throughout the AOC indicate a bioaccumulation risk to wildlife.

The results of this investigation indicate that surficial sediments throughout the AOC contain levels of contaminants that should be of toxicological concern. When considering both metal and organic compound contamination, surficial sediments within AOC Reaches EBU3 and EBU5 are the most contaminated and appear to present the highest toxicological risk.

This investigation was performed under the authority of Section 401 of the Water Resources Development Act (WRDA) of 1990, as Amended, with the Niagara County Department of Planning, Development and Tourism as a non-Federal cost-share partner. This report was prepared by Scott W. Pickard of the U.S. Army Corps of Engineers (USACE), Buffalo District[1] and reviewed by the U.S. Army Engineer Research and Development Center (USAERDC).

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INTRODUCTION

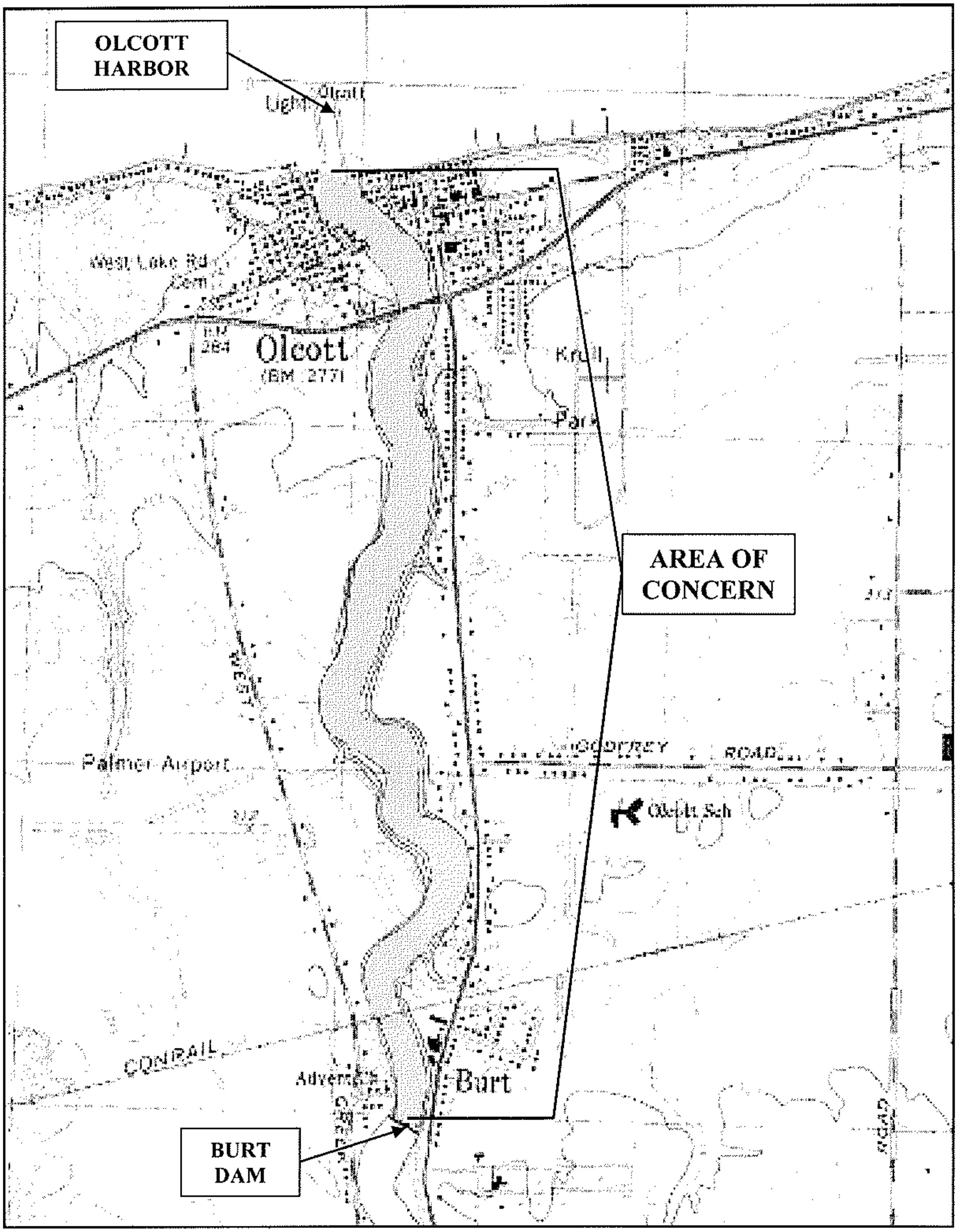
The Eighteenmile Creek AOC is located in the lower reach of Eighteenmile Creek near its mouth on Lake Ontario, in the hamlet of Olcott, Niagara County, New York (Figure 1). The creek flows from the south into the lake through Olcott Harbor, about 18 miles east of the Niagara River mouth at Lake Ontario. The AOC includes that portion of the creek between Olcott Harbor, upstream to the farthest point at which backwater conditions exist during Lake Ontario's highest monthly average lake level (generally, just downstream of Burt Dam) (U.S. Environmental Protection Agency [USEPA] 2001). Three use impairments have been identified in a combined Stage 1/2 Remedial Action Plan (RAP) report (New York State Department of Environmental Conservation [NYSDEC] 1997). All of these use impairments are linked to bottom sediment contamination. The primary COCs within the AOC include the organic compounds including chlorinated pesticides, PCBs and PCDD/Fs, and metals such as chromium, copper, lead, manganese, mercury, nickel, zinc and cyanide. Sources of contamination include upstream industrial discharges, inactive hazardous waste sites, contaminated sediments, air deposition and Lake Ontario. These COCs are present at the sediment-water interface and, consequently, may be available to impart toxicological effects on the existing aquatic community. Specific use impairments include:

- *Restrictions on fish and wildlife consumption due to PCB and PCDD/F contamination*
- *Degradation of benthos due to sediment contamination*
- *Restrictions on dredging activities due to sediment contamination*

It should be noted that NYSDEC has conducted remediation efforts for metals and polycyclic aromatic hydrocarbons (PAHs) at the former Flintkote Site along Eighteenmile Creek, upstream of Burt Dam in Lockport.

Sediment-associated contaminants in the aquatic environment behave differently, which depend largely, either directly or indirectly, on their chemical structure. All have a tendency to adsorb to fine particles (such as silts and clays) and total organic carbon (TOC) in bottom sediments. Metals typically bioaccumulate (accumulate in the tissues of organisms) at lower concentrations relative to hydrophobic organic compounds. However, they can be toxic at certain concentrations. In contrast, organic contaminants such as PCBs, pesticides and PCDD/Fs, are bioaccumulative and can also biomagnify (increase in concentration in the organism's predator). They are hydrophobic (do not mix with water and partition to TOC) and accumulate in organism lipid (fat) because they are lipophylic. They are neutral and do not tend to interact with other organic chemicals at environmentally-relevant concentrations. At certain concentrations, organic contaminants can also be either acutely or chronically toxic. The potential of a sediment-associated contaminant concentration to induce toxicity is considerably influenced by its concentration in the tissues (bioaccumulation), which in turn is influenced by the compound's bioavailability (portion of chemical available for biological uptake). A variety of physiochemical and biological factors can affect bioavailability, both independently and interactively. Therefore, information on bioavailability is integral to the assessment of a sediment contaminant's risk to the exposed aquatic community.

FIGURE 1. Eighteenmile Creek Great Lakes AOC.



The overall objectives of this investigation on the Eighteenmile Creek AOC were to (1) ascertain the levels of contaminants in surface sediments within the AOC; and (2) determine and evaluate the levels of the contaminants in these surface sediments relative to selected toxicity threshold values or potential to bioaccumulate in aquatic organisms. These objectives are consistent with a RAP remedial strategy focusing on "contaminated bottom sediment assessment and action determination" (NYSDEC 1997).

To accomplish the goals of this investigation, surficial sediment samples were collected from the AOC and analyzed for a variety of inorganic and organic contaminants. In addition, sediment samples were subjected to bioaccumulation testing for metals, chlorinated pesticides and PCBs. The data generated from these testing procedures were used to assess the potential toxicity, bioaccumulation and bioavailability of contaminants in AOC surface sediments to the aquatic community.

MATERIALS AND METHODS

In August 2003, discrete surficial sediment samples were collected from the bottom of Eighteenmile Creek at a total of 15 locations within the AOC (Figure 2). The sediment samples were obtained using a Peterson Grab sampler (typically obtains 4-6 inches of surface sediment) and a total volume of at least six liters were collected per site. The samples were gathered in a stainless steel pan and homogenized. For the discrete samples, equal amounts of sediment were placed in 0.95-liter glass jars and labeled EMC-1 through EMC-15. They were chemically analyzed in the laboratory for the following parameters:

- Heavy metals – Aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, selenium, silver, sodium, thallium, vanadium and zinc
- TOC
- Organic contaminants – Chlorinated pesticides, PCBs and PCDD/Fs

Another sample for each site was contained in labeled 0.95-liter glass jars for particle size analysis.

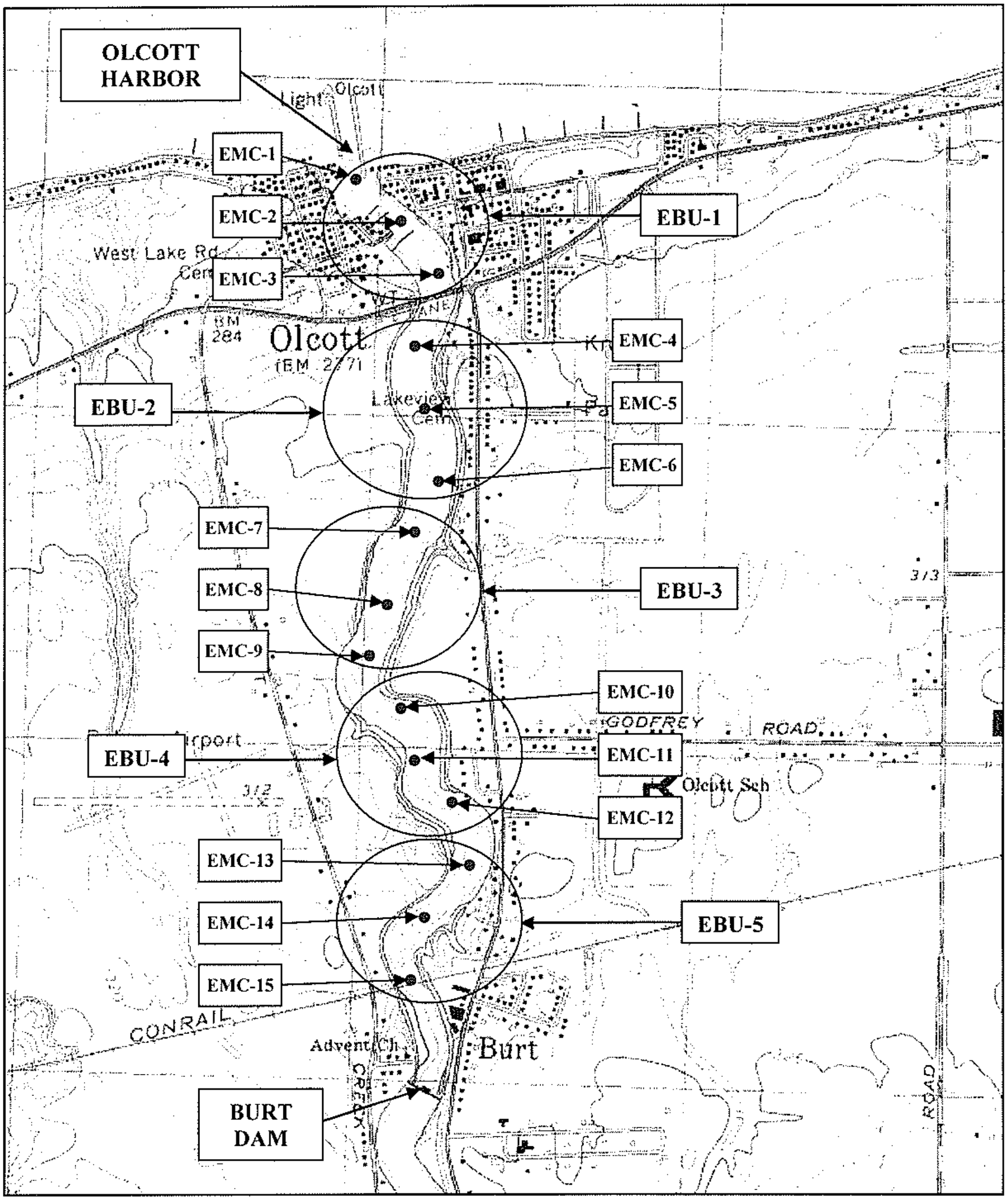
For the bioaccumulation testing, equal volumes of sediment from every three, successive discrete sample locations were combined and thoroughly mixed into a single 7.6-liter sample, resulting in a total of five composite samples. These samples were used to represent five separate reaches within the AOC, from downstream to upstream, as follows (Figure 2):

Reach Composite Sample	Composited Discrete Samples	Description
EBU1	EMC-1, EMC-2 and EMC-3	Just upstream of Olcott Harbor
EBU2	EMC-4, EMC-5 and EMC-6	Just South of State Route 104
EBU3	EMC-7, EMC-8 and EMC-9	Just upstream of unnamed tributary on east side of creek under Route 78
EBU4	EMC-10, EMC-11 and EMC-12	Foot of Godfrey Road
EBU5	EMC-13, EMC-14 and EMC-15	Just downstream of Burt Dam

These reach sediment samples were tested for:

- Concentrations of all the above listed heavy metals, pesticides, PCBs and TOC
- The bioaccumulation of heavy metals, chlorinated pesticides and PCBs

FIGURE 2. Eighteenmile Creek AOC sediment sampling sites and reaches.



USAERDC conducted the bioaccumulation tests using standard procedures. The freshwater aquatic, surficial deposit feeding oligochaete (worm) *Lumbriculus variegatus* was exposed to the sediment samples over a 28-day period in the laboratory according to guidelines provided in the USEPA/USACE Great Lakes Dredged Material Testing and Evaluation Manual (USEPA/USACE 1998). This procedure and test species was used because the bioaccumulation of PCBs by *L. variegatus* in the laboratory provides a reasonable quantitative estimate of the bioaccumulation of PCBs by oligochates in field sediment (i.e., Ankley *et al.* 1992). The worms were exposed to test and control (Browns Lake, Vicksburg, MS) sediments in 6-L box aquaria (31.5 x 18 x 10.5 cm) using five replicates per treatment. Adequate exposure conditions were maintained using an intermittent flow system for overlying water renewal. At exposure termination, worms were recovered from the test/control sediments, placed in water for gut purging (12-hour), blotted dry and frozen at –20°C. The worm tissues were subsequently analyzed for metals, chlorinated pesticides and PCBs, as well as for lipid content.

All chemical analyses on the sediment and worm tissues were performed by USAERDC and followed standard USEPA SW846 methodologies:

Matrix	Parameter	Method	Laboratory Reporting Limit (LRL) (unless otherwise noted)
Sediment	Metals (TAL)	6010B	0.050
	Mercury	7471	0.025
	TOC	9060 Modified	500
	PCB (congeners)	8082	0.010
	Pesticides	8081A	0.010
	PCDD/Fs	8290	0.000002
Tissue	Metals (TAL)	6020/6010B	0.025
	Mercury	7470A	0.0040
	PCBs (congener summations)	8082	0.025
	Pesticides	8081A	0.025
	Lipid	Van Handel (1995)	1 µg

Particle size analyses followed ASTM Procedure D422.

Using the metals bioaccumulation data, bioaccumulation factors (BAFs) were calculated for heavy metals to screen for overall bioavailability (Harrahy and Clements 1997):

$$BAF = \frac{C_t}{C_s}$$

Where:

C_t = Concentration of heavy metal in tissue (mg/kg wet weight)
C_s = Concentration of heavy metal in sediment (mg/kg dry weight)

Mean heavy metal BAFs were calculated for each reach of the AOC using the five replicate BAFs. For any non-detectable concentrations, the specified laboratory reporting limit (LRL) was used as a substitute to produce a maximum and most conservative BAF. Mean BAFs were also determined for the entire AOC.

For selected chlorinated pesticides and PCBs, biota-sediment accumulation factors (BSAFs) were calculated from the bioaccumulation data to express the bioavailability of the sediment-associated compounds (Ferraro *et al.* 1990):

$$BSAF = \frac{C_t / L}{C_s / TOC}$$

Where:

C_t = Concentration of neutral organic contaminant in tissue (μg/kg wet weight)
L = Concentration of lipid in *L. variegatus* tissue (percent of wet weight)
C_s = Concentration of neutral organic contaminant in sediment (μg/kg dry weight)
TOC = Total organic carbon concentration in sediment (percent of dry weight)

Mean BSAFs for chlorinated pesticides and PCBs were calculated for each AOC reach based on the five replicate BSAFs. For non-detectable concentrations, the specified LRL was used as a substitute to produce a maximum and most conservative BSAF. Mean BSAFs were also determined for the entire AOC.

RESULTS AND DISCUSSION

Raw data generated in this investigation are contained in USAERDC (2004). Therefore, the reader is referred to this report for further, more detailed information.

Particle Size Distribution and TOC Content of Sediments

A summary of the grain size distribution and TOC level data on the composited samples is presented in Table 1 (discrete data are available in USAERDC 2004). Grain size analyses showed that the AOC sediments were composed of between 19.5% (Reach EBU5) to 68.8% (Reach EBU2) silts and clays, and 31.3% (Reach EBU2) to 80.5% (Reach EBU5) sands and gravels. The sediments at Reaches EBU1 through EBU4 were composed of at least around one-half fine-grain particles, and sediments from Reach EBU5 were very coarse-grain. TOC levels in the sediments across the AOC reach samples were fairly consistent, ranging from 2.9 to 3.9% at Reaches EBU5 and EBU2, respectively.

TABLE 1. Particle size distribution and TOC level data on surficial composite sediment samples collected within the AOC (from USAERDC 2004).

AOC Reach	Particle Size Distribution (%)		TOC (%)
	Fines (silts/clays)	Coarse (sands/gravels)	
EBU1	48.7	50.9/0.4	3.3
EBU2	68.8	31.3/0	3.9
EBU3	67.5	31.3/1.2	3.6
EBU4	48.6	50.0/1.5	3.1
EBU5	19.5	40.9/39.6	2.9

Assessment of Sediment-Associated Contaminants

Metals

<u>Concentrations and Toxicity</u>

The concentrations of metals in the composited reach samples, and the corresponding mean bioaccumulated tissue residues, are summarized in Table 2 (for metals data on discrete samples, see USAERDC 2004). All of the heavy metals were detected in the majority of the sediment and tissue samples. The heavy metals data on the sediment samples were compared to four separate sets of non-site specific criteria:

- Sediment Quality Guideline (SQG) freshwater probable effect levels (PELs) (Environment Canada 2003)
- Severe effect levels (SELs) (NYSDEC 1999)
- Consensus-based freshwater sediment probable effect concentrations (PECs) (MacDonald *et al.* 2000)

- Lake Ontario reference area (background levels) (Engineering and Environment 1997)

TABLE 2. Concentrations of heavy metals in AOC reach surficial composite sediment samples, and in corresponding oligochaete tissues. All units are in mg/kg (from USAERDC 2004).

Heavy Metal	AOC Reach									
	EBU1		EBU2		EBU3		EBU4		EBU5	
	Sediment	Mean Tissue	Sediment	Mean Tissue	Sediment	Mean Tissue	Sediment	Mean Tissue	Sediment	Mean Tissue
Aluminum	10,800	292	12,800	422	11,600	409	12,800	585	10,700	632
Antimony	0.35	0.03	0.45	0.07	0.56	0.07	2.97	0.05	0.33	0.06
Arsenic	3.4	0.89	4.13	1.24	3.75	1.25	3.38	1.07	2.78	0.88
Barium	113	45.3	137	57.9	122	68.7	122	69.7	65.8	63.0
Beryllium	0.52	0.04	0.68	0.04	0.60	0.05	0.63	0.05	0.60	0.04
Cadmium	0.75	0.15	1.25	0.35	1.52	0.32	0.90	0.16	0.36	0.14
Calcium	20,000	1,781	14,300	1,079	10,400	1,164	19,200	1,791	12,900	1,358
Chromium	41	5.2	74.1	7.8	109	15.7	52.5	11.6	102	11.1
Cobalt	8.77	0.95	12.1	1.20	13.9	1.76	12.3	1.29	11.8	0.62
Copper	64.7	9.8	123	15.6	157	25.4	73.5	15.7	31.7	7.3
Iron	21,200	1,023	25,900	1,728	25,400	1,914	27,600	2,160	23,400	1,362
Lead	102	7.1	146	16.4	203	29.9	153	21.4	69.9	11.6
Magnesium	6,270	337	6,820	356	6,380	403	6,410	387	6,770	342
Manganese	535	41.5	409	24.4	475	40.0	517	42.6	440	34.7
Mercury	0.17	2.37	0.33	0.11	0.37	0.17	0.17	0.07	0.04	0.03
Nickel	31.2	4.7	56.9	8.5	20.5	20.3	47.9	5.3	39.9	2.9
Selenium	0.50	0.46	0.45	0.48	3.53	0.34	0.32	0.42	0.10	0.30
Silver	0.47	0.01	0.62	0.02	0.62	0.04	0.34	0.03	0.18	0.09
Sodium	187	628	180	661	158	589	186	670	463	547
Thallium	0.20	0.06	0.29	0.03	0.29	0.04	0.24	0.02	0.13	0.02
Vanadium	20.8	1.39	25.3	1.72	24.5	2.32	23.5	2.13	20.5	1.53
Zinc	328	70.0	536	102	800	173	444	93.1	238	93.1

Table 3 summarizes the numeric criteria to which the sediment concentration data were compared.

With respect to the metals data on the reach sediments, chromium exceeded the PEL at Reaches EBU3 and EBU5. The SEL and/or PEC for copper were exceeded at Reaches EBU2 and EBU3. Lead exceeded the PEL at Reaches EBU1 through EBU4, and the SEL and/or PEC at Reaches EBU2 through EBU4. The SEL for nickel was exceeded at Reach EBU2. In addition, the PEL, and SEL and/or PEC for zinc were exceeded at Reaches EBU1 through EBU4.

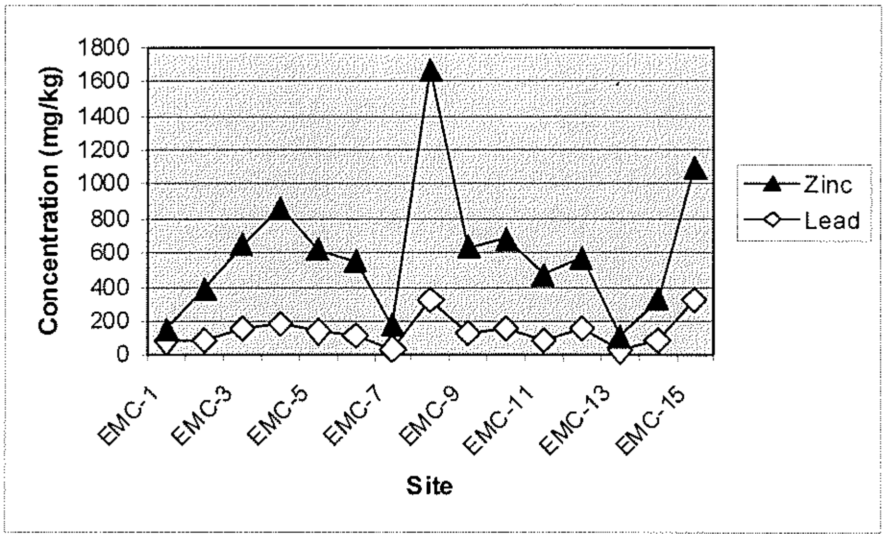
In general, the discrete sediment data were consistent with the data on the AOC Reach samples. However, some of the discrete samples showed significantly higher heavy metal concentrations or levels that did exceed a PEL, SEL and/or PEC. For example, at Site EMC-15, the chromium concentration of 867 mg/kg was about eight to nine times SEL and PEC, and PEL, respectively. Chromium concentrations also exceeded the PEL at Site EMC-4, and PEL, SEL and PEC at Site EMC-8. The copper level of 245 mg/kg at Site EMC-8 exceeded the PEL, SEL and PEC. Lead and zinc concentrations exceeded the PELs, SELs and PECs at many of the sites. In the case of zinc, the levels were several-fold the PEL and SEL at Sites EMC-4, EMC-8 and EMC-15. The lead concentration of 322 mg/kg at Site EMC-15 exceeded the PEL, SEL and PEC. The nickel concentration of 172 mg/kg at Site EMC-8 exceeded the SEL and PEC.

Figure 3 plots the lead and zinc levels in surficial sediments at discrete sites within the AOC. Both metals show peak concentrations at Sites EMC-4, 8 and 15, with the maximum levels at Site EMC-8.

TABLE 3. Summary of metal freshwater sediment quality criteria applied in this report. An asterisk denotes that the criterion was not determined.

Heavy Metal	Sediment Threshold Value (mg/kg, dry weight)			Lake Reference Level Range (mg/kg, dry weight)
	PEL	SEL	PEC	
Aluminum	-*	-	-	9,350-15,800
Antimony	-	25	-	0.81-1.37
Arsenic	17	33	33	5.24-8.8
Barium	-	-	-	62.8-101
Beryllium	-	-	-	0.49-0.90
Cadmium	3.5	9.0	4.98	0.87-1.20
Calcium	-	-	-	23,800-40,700
Chromium	90	110	111	26.2-33.6
Cobalt	-	-	-	7.29-11.4
Copper	197	110	149	25.6-41.3
Iron	-	40,000	-	18,200-28,800
Lead	91.3	110	128	24.5-32.2
Magnesium	-	-	-	9,440-16,200
Manganese	-	1100	-	499-767
Mercury	0.49	1.3	1.06	0.10-0.19
Nickel	-	50	48.6	23.1-35.0
Selenium	-	-	-	1.34-2.27
Silver	-	2.2	-	0.42-0.62
Sodium	-	-	-	229-265
Thallium	-	-	-	<0.51-<0.71
Vanadium	-	-	-	21.8-32.3
Zinc	315	270	459	109-152

FIGURE 3. Levels of lead and zinc in discrete surficial sediment samples collected from the AOC (based on data from USAERDC 2004).



The concentration of some metals in surface sediments from Reaches EMU1 through EMU3 were somewhat lower than those measured in the same reach of the creek by NYSDEC in 1994 (NYSDEC 1998). For example, levels of cadmium (up to 3.3 mg/kg), mercury (up to 2.25 mg/kg) and nickel (up to 151 mg/kg) in surface sediments measured in 1994 at some sites were higher and outside the range of those measured in this investigation.

Bioaccumulation and Bioavailability

With respect to the mean bioaccumulated heavy metal data contained in Table 2, sediments from AOC Reach EBU3 generally showed higher tissue residues (particularly for cadmium, cobalt, copper, lead, nickel and zinc). Table 4 summarizes the heavy metal BAFs. In general, the BAFs for most metals (except for cobalt, mercury, nickel and sodium) at Reach EBU5 were either comparable or higher when compared to the other reaches. This higher bioavailability was likely associated, to some extent, with the relatively higher coarse-grain content of the surficial sediment in this AOC reach (Table 1). An inordinately high level of mercury in the tissue of Replicate EBU1-2 (11.5 mg/kg) would have resulted in a very high BAF, and would have substantially increased the BAF for mercury across the AOC. Since this outlier appeared to be a legitimate observation, it was assumed to be indicative of a lognormal distribution. Therefore, geometric mean BAFs were determined to be appropriate for mercury.

TABLE 4. BAFs for heavy metals in surficial composite sediment samples collected from the AOC (based on data from USAERDC 2004).

Heavy Metal	AOC Reach					Mean BAF
	EBU1	EBU2	EBU3	EBU4	EBU5	
Aluminum	0.03	0.03	0.04	0.05	0.06	0.04
Antimony	0.10	0.16	0.12	0.02	0.18	0.11
Arsenic	0.26	0.30	0.33	0.32	0.32	0.31
Barium	0.40	0.42	0.56	0.57	0.96	0.58
Beryllium	0.07	0.07	0.09	0.08	0.07	0.08
Cadmium	0.19	0.28	0.21	0.17	0.38	0.25
Calcium	0.40	0.42	0.56	0.57	0.96	0.58
Chromium	0.13	0.11	0.14	0.22	0.11	0.14
Cobalt	0.11	0.08	0.13	0.11	0.05	0.09
Copper	0.15	0.13	0.16	0.21	0.23	0.18
Iron	0.05	0.07	0.08	0.08	0.06	0.07
Lead	0.07	0.11	0.15	0.14	0.17	0.13
Magnesium	0.06	0.05	0.06	0.06	0.05	0.06
Manganese	0.08	0.06	0.08	0.08	0.08	0.08
Mercury*	1.36	0.31	0.45	0.36	0.62	0.53
Nickel	0.15	0.15	0.99	0.11	0.07	0.30
Selenium	0.91	1.08	0.10	1.32	2.96	1.27
Sodium	3.36	3.67	3.72	3.6	1.18	3.11
Silver	0.05	0.05	0.07	0.11	0.53	0.16
Thallium	0.32	0.12	0.14	0.14	0.26	0.20
Vanadium	0.07	0.07	0.09	0.09	0.08	0.08
Zinc	0.21	0.19	0.22	0.21	0.39	0.24

*Geometric means.

Luomo and Rainbow (2005) outline the difficulties involved in using metal bioaccumulation data to evaluate ecological risks. While the bioaccumulation of metals and metalloids is of particular value in polluted ecosystems as an exposure indicator to organisms (mainly because metals are not metabolized), the process can be quite complex. It is influenced by multiple routes of exposure (diet and solution) and geochemical effects on bioavailability. Variable patterns of accumulation occur among species, including the regulation of body concentrations of some metals by some species, and vastly different concentrations among species and environments. The links between bioaccumulation and toxicity are intricate. Toxicity is determined by the uptake of metal internally, and the species-specific partitioning of accumulated metal between metabolically active and detoxified forms. For these reasons, the potential adverse effects metals in sediments are best evaluated using comparison to SQG and direct measurement of toxicity using laboratory sediment testing.

Summary of Heavy Metals Assessment

Table 5 identifies AOC reaches where the sediment-associated heavy metals in either composite or discrete sample-related data exceeded the selected toxicity criteria and/or were determined to preliminarily be a bioaccumulation/bioavailability risk based on the empirical uptake and/or BAF data. The intent of this table is to summarize the heavy metals data on AOC surficial sediments within a general toxicological risk framework. Based on this table, deductions with respect to the AOC reaches are as follows:

- **Reach EBU1**—All listed metal concentrations in these sediments, except for mercury, significantly exceeded lake reference levels. Copper, lead, nickel and zinc concentrations often appear to be chronically toxic. Mercury may more bioavailable and bioaccumulative when compared to the other reaches. Note that this heightened bioavailability is attributable to a single replicate sample.
- **Reach EBU2**—All listed metal concentrations in these sediments, except for selenium, notably exceeded lake reference levels. Copper, lead, nickel and zinc concentrations often appear to be chronically toxic. Some of the zinc concentrations were over twice the SEL and/or PEC.
- **Reach EBU3**—All listed metal concentrations in these sediments, except for cobalt and mercury, notably exceeded lake reference levels. Chromium, copper, lead, nickel and zinc concentrations often appear to be chronically toxic. Mercury may be chronically toxic in some instances. Some of the copper, lead and zinc concentrations were over twice the SEL and/or PEC.
- **Reach EBU4**—All listed metal concentrations in these sediments, except for silver, significantly exceeded lake reference levels. Lead and zinc concentrations often appear to be chronically toxic. Silver may be chronically toxic in some instances.

TABLE 5. AOC reaches where heavy metal concentrations appear to be a concern with respect to selected sediment criteria. If the metal concentration exceeded only the lake reference level, it was not included in the reach listing. KEY TO SHADED AREAS IN TABLE:

● = Reach sample level exceeded the specified criterion for this metal; discrete sample level also exceeded the specified criterion
○ = Discrete sample level for this metal exceeded the specified criterion, and possibly other criteria
◙ or ◘ = At least a discrete sample level within this reach was twice the SEL and/or PEC

AOC Reach	Heavy Metal	Criteria					
		PEL	SEL	PEC	Lake Reference	Bioaccumulation	High BAF
EBU1	Chromium				●		
	Copper		○		●		
	Lead	●	○		●		
	Mercury					●	●
	Nickel		○	○	○		
	Zinc	●	●		●		
EBU2	Cadmium				●		
	Chromium				●		
	Copper		●	○	●		
	Barium				●		
	Lead	●	●	●	●		
	Nickel		●	●	●		
	Selenium						
	Zinc	●	◙	◙	●		
EBU3	Cadmium				●	●	
	Chromium	●	○	○	●		
	Cobalt					●	
	Copper	○	◙	●	●	●	
	Lead	●	◙	◙	●	●	
	Mercury	○					
	Nickel		○	◘	○	●	●
	Zinc	●	◙	◙	●	●	
EBU4	Barium				●		
	Chromium				●		
	Copper				●		
	Lead	●	●	●	●		
	Silver		○				
	Zinc	●	●	●	●		
EBU5	Barium				○		
	Cadmium				○		
	Chromium	●	○	◘	●		
	Copper		○	○	○		
	Iron		◘		○		
	Lead	○	◘	◘	●		
	Selenium						●
	Zinc	○	◘	○	●		