US Army Corps of Engineers
Buffalo District

# EVALUATION OF LORAIN HARBOR (RIVER CHANNEL) FEDERAL NAVIGATION CHANNEL SEDIMENTS WITH RESPECT TO THEIR SUITABILITY FOR OPEN-LAKE PLACEMENT

## I. Introduction.

This assessment serves as a Tiered Evaluation on Lorain Harbor, Ohio River Channel sediments in the lower Black River. The purpose of this Tiered Evaluation is to determine what material dredged from the Black River Channel meets Federal guidelines for open-lake placement. It was performed in accordance with guidelines contained in the U.S. Environmental Protection Agency (USEPA)/U.S. Army Corps of Engineers (USACE) Great Lakes Dredged Material Testing and Evaluation Manual (1998). This evaluation emphasizes Lorain Harbor sediment quality data from 2006, 2005, and 2001 and 2000, and considers other relevant information.

## II. Sediment Quality Assessment.

*Background and Potential Sources of Sediment Contamination*

The Lorain Harbor River Channel is located within the Black River Great Lakes Area of Concern (AOC). The Black River drainage basin is dominated by almost 90% agricultural and rural land uses, with the remainder residential, industrial and recreational uses (OEPA 2006). Republic Technologies International, Inc. (RTI) is the primary industry located adjacent to the upper end of the River Channel. Its predecessor (USS/KOBE Steel Company) operated a coking facility until 1982 that was considered to be the major source of polycyclic aromatic hydrocarbons (PAHs) to the lower Black River. Although levels of PAHs in this area of the river declined since 1982, they continued to be of concern. Therefore, a 1985 Consent Decree required that 38,000 cubic yards of PAH-contaminated sediments in the Black River, just upstream of the River Channel near the coke plant outfall, be removed down to hard shale bedrock. This action was completed in 1990 and PAH concentrations in the area declined by 80% to 95% by 1992. In addition to this source of contamination, the AOC has 26 industrial and 19 municipal permitted National Pollution Discharge Elimination System (NPDES) wastewater discharges. The only “major” industrial discharge is RTI.

*Sediment Evaluation Based on Existing Sediment Data*

This assessment is based on 2005 and 2006 sediment quality data on sediments collected from the Lorain Harbor River Channel (Engineering and Environment, Inc. [EEI] 2005 and ASCi Corporation 2006a/2006b, respectively) and also considers toxicological data on the Outer Harbor sediments. In addition, 2000 and 2001 sediment quality data on the River Channel and Outer Harbor channels are used to evaluate trends in sediment contamination (EEI 2000; EEI 2001). In 2005 and 2000/2001, bulk surface grab sediment samples were collected from the River Channel (Sites LR-1 through LR-9) (Figure 1), open-lake reference (LL-1 through LL-4) and designated open-lake placement areas (LD-1 and LD-2) in Lake Erie (Figure 2). One Quality Control (QC) sample was run on the sediments collected from Site LR-5. All samples were analyzed for particle size, bulk inorganics, PAHs, polychlorinated biphenyls (PCBs), and pesticides. Elutriate testing for inorganics, PAHs, PCBs and pesticides was performed on all of the River Channel sediment samples. In 2005, two prescribed solid-phase bioassays were applied to composited River Channel Management Unit sediments LRB-1 through LRB-3 (USEPA/USCAE 1998) (Figure 3). In 2006, one prescribed solid-phase bioassay (USEPA/USACE 1998) was again applied to these same management unit sediments (Figure 3; NOTE: the MU location labels contained in the ASCi 2006a/b reports were reversed—R-1=LRB-3 and R-3=LRB-1; for consistency, the labeling used in the 2005 sampling will retained in this evaluation). In 2000/2001, particle size, bulk inorganics, PAHs, PCBs and pesticide analyses, as well as elutriate testing for inorganics, PAHs, PCBs and pesticides, were performed on Management Unit sediments LRB-1, LRB-2 and LRB-3 (Figure 3). In addition, two prescribed solid phase bioassays (USEPA/USACE 1998) were applied to these MU sediments.

The plan for the 2005 sediment sampling and analyses was coordinated with the Ohio Environmental Protection Agency (OEPA) in a letter from the Buffalo District dated March 3, 2005. OEPA endorsed this plan in an e-mail message dated April 18, 2005.

The following discussion summarizes the evaluation of sediments from the Lorain Harbor River Channel.

a. <u>Bulk sediment analyses</u>.

1. *Physical testing*—Table 1 presents the results of the 2005 grain size analyses on the River Channel sediment samples. With the exception of Sites LR-1 and LR-9, bottom sediments collected from the channel ranged from 83.8% to 97.9% silts/clays at Sites LR-8 and LR-5, respectively. Sediments collected from Sites LR-1 and LR-9 contained notably more coarse-grain material, having only 66.1% and 47.3% silts/clays, respectively. Sediments collected from

the open-lake reference area were comprised of between 84% and 99.3%, with the remainder sand. At the open-lake placement area, sediments were comprised of mostly coarse-grain particles (82.6 to 87.2% sands/gravels), with the remainder silts/clays.

2. *Chemical testing*

(a) Inorganic analyses—Table 2 presents the results of the 2005 inorganic analyses on the River Channel, and open-lake reference and placement area sediments.

(1) River Channel and Open-lake Reference Area Sediments—Total organic carbon (TOC) levels were fairly consistent across the River Channel sites, ranging from 2.66% to 3.61%. Generally, metal concentrations measured in the River Channel sediments were lower than those found at the open-lake reference area. Arsenic concentrations at many of the sites exceeded the open-lake reference area levels, ranging from 7.5 to 12.1 mg/kg. In addition, manganese levels at various sites in the River Channel (590 to 930 mg/kg) exceeded those relative to the open-lake reference area. Such levels of arsenic and manganese are not of significant toxicological concern. At Sites LR-8 and/or LR-9 within the LRB-1 Management Unit near the mouth of Black River, concentrations of beryllium, cadmium, copper, lead, silver, zinc and cyanide significantly exceeded open-lake reference area levels. However, only the levels of beryllium (2.72 to 4.03 mg/kg), cadmium (8.68 to 14.8 mg/kg), zinc (529 to 844 mg/kg) and possibly cyanide (1.67 to 4.29 mg/kg) would be of potential concern at both of these sites. Therefore, these metals are considered to be contaminants of concern (COCs) at these sites within this reach of River Channel.

Based on the 2000/2001 results on the River Channel sediments (EEI 2000; 2001), cadmium was identified as a COC in Management Units LRB-1, LRB-2 and LRB-3 (range 2.14 to 6.24 mg/kg) (note that the 2000 open-lake reference area data were used for comparison purposes because the 2001 sediment data on the open-lake reference and placement areas showed unacceptably low test species survivals and/or growth).

(2) Open-lake Placement Area Sediments—Some of the metal concentrations (Table 2) in the two samples from the open-lake placement area significantly exceeded those of the open-lake reference area, including cadmium, chromium, zinc and cyanide. TOC levels ranged from 2.42 to 4.28 percent, which is relatively high when considering the predominant coarse-grain nature of the sediments.

(b) Organic analyses

(1) PAHs

●Bulk concentrations—Table 3 presents the results of the 2005 PAH analyses on the sediment sampling. Total PAH levels in all of the River Channel sediment samples ranged from 1.12 (LR-5) to 5.6 mg/kg (LR-8) and exceeded those measured at the open-lake reference area. The 2000/2001 results on the River Channel sediments composited for each management unit showed that total PAH levels ranged from 3.1 (LRB-2) to 10.2 mg/kg (LRB-3) and were higher than those measured the open-lake reference area sediments (EEI 2001). At the time, PAHs were identified as a COC in these sediments. However, newer PAH toxicity modeling (i.e., USEPA 2003) predict that these PAH mixtures are likely not associated with significant acute toxicity.

The potential risk of PAH mixtures in the LR-8 (2005) and LRB-3 (2001) sediment samples to the freshwater amphipod *Hyalella azteca* was estimated using hydrocarbon narcosis and equilibrium partitioning (EqP) models (USEPA 2003). These two samples were selected because they offered the highest PAH concentrations across the two sampling events. Note that sediments typically contain a mixture of PAHs from both petrogenic and pyrogenic sources. In comparison to petrogenic PAHs, pyrogenic PAH compounds are often more persistent and less mobile and bioavailable in the environment, often resulting in lower toxicities (Gustaffsson *et al.* 1997). PAH mixtures that arise from pyrogenic sources indicate the presence of black carbon forms that have exhibited an unusually strong partitioning behavior. Such mixtures strongly adsorb to this black carbon, thus limiting their concentration in interstitial water, and reducing mobility, bioavailability and toxicity (on a bulk sediment concentration basis) (e.g., Pastorok *et al.* 1994).

To decipher the predominant origin of PAH mixtures, PAH compound diagnostic ratios were determined for the sediment samples. Neff *et al.* (2005) recommends that fluoranthene/pyrene (Fl/Py) and phenanthrene/anthracene (Ph/An) ratios both be used to aid in differentiating between sediment-associated pyrogenic and petrogenic PAHs. The Fl/Py ratios for samples LR-8 and LRB-3 were 1.46 and 1.45, respectively, both of which were greater than 1.0, indicating that they were of pyrogenic origin. The Ph/An ratios for samples LR-8 and LRB-3 were 1.86 and 4.88. The LR-8 Ph/An ratio suggests pyrogenic origin because it is less than 4.11 (Iqbal *et al.* 2008). The Ph/An ratio for LRB-3 suggests petrogenic origin because it is greater than 4.11, within the range of 3 to 26 (Colombo *et al.* 1989), and approaching 5.0 (Neff *et al.* 2005). A closer examination of the discrete Ph/An sample ratios suggest both petrogenic and pyrogenic PAH sources in the LRB-3 composite sample.

The hydrocarbon narcosis and EqP models (USEPA 2003) assume that the risk of PAH mixtures to benthic organisms is attributable to the number of PAH toxic units that are freely dissolved in sediment pore water, and is used to calculate EqP Sediment Benchmark Toxic Units, Final Acute Value ($\sum ESBTU_{FAV}$) (USEPA 2003). The presence of TOC is an important partitioning parameter as it acts to sequester PAHs in the sediment phase, thus lowering the amount of PAHs available in the water phase. $ESBTU_{FAV}$s are calculated as follows:

$$ESBTU_{FAV} = \frac{C/f_{OC}}{C_{OC\ PAHi,\ FAVi}}$$

Where:
$C_{OC,\ PAHi,\ FAVi}$ = Final acute (FAV) concentration in sediment ($\mu g/g_{OC}$) (see USEPA 2003)
C = Concentration of PAH compound in sediment (µg/g dry weight)
$f_{OC}$ = Decimal fraction of TOC in sediment (TOC) ($\mu g/g_{OC}$ dry weight)

Freshwater sediments containing $\sum ESBTU_{FAV} < 1.0$ for a mixture of 34 or more PAH compounds are predicted to be acceptable for the protection of benthic organisms. Conversely, $\sum ESBTU_{FAV} \geq 1.0$ suggest that sensitive benthic organisms may be affected by the PAH mixture. USACE guidelines (USEPA/USACE 1998) emphasize acute toxicity tests for dredged material evaluations. This model employed $C_{OC,\ PAHi,\ FAVi}$ specific to the freshwater amphipod *Hyalella azteca* (Kreitinger, personal communication; USEPA 2003), which is one of two recommended test species used for standard acute toxicity tests in dredged material toxicity evaluations (USEPA/USACE 1998), and is anticipated to be more sensitive to PAHs than most other freshwater organisms (including the midge *Chironomus dilutus*). The $C_{OC\ PAHi,FAVi}$ values for *H. azteca* are based on an acute toxicity critical body burden of 13.9 µmol/g lipid, which is the geometric mean of the acute value for fluoranthene within the genus (GMAV) based on data originally published by Spehar *et al.* (1999) (see Appendix C of USEPA 2003). Use of this single critical body burden in the model is assumed to be valid because hydrophobicity-normalized toxicity is considered to be equivalent among Type I narcotic chemicals. The 13.9 µmol/g octanol GMAV for *H. azteca* has been confirmed in the literature. Hawthorn *et al.* (2007) predicted a critical body burden of 15 µmol/g lipid (lower 95% confidence interval) for 85% or greater survival when 97 field collected sediments were evaluated in 28-day laboratory tests and the dissolved PAH concentration in sediment porewater was determined by ASTM D7363 (Hawthorne *et al*. 2007). In addition, the lethal residue ($LR_{50}$) value of 33.0 µmol/g lipid determined by Hawthorne *et al.* (2007) using these 97 field samples was in very good agreement with the $LR_{50}$ value of

32 µmol/g lipid determined in water-only laboratory exposures using radio-labeled fluoranthene (Schuler *et al.* 2006).

The calculation of $C_{OC\ PAHi,FAVi}$ for individual PAH compounds was based on the following equation:

$$C_{OC\ PAHi,FAVi} = K_{oc}*MW*[10^{-0.945*\log(Kow)+\log(GMAV)}]$$

Where:
$K_{OC}$ = Organic carbon-water partition coefficient for PAH compound
$K_{OW}$ = Octanol-water partition coefficient for PAH compound
MW = Molecular weight of PAH compound, g/mol
GMAV = Geometric mean of acute toxicity (critical body burden) values for fluoranthene within the genus, 13.9 µmol/g lipid

For PAH mixtures in the LR-8 sample, an uncertainty factor of 3.6 with a confidence level of 95% (Hawthorne *et al.* 2006) was applied to the $\sum ESBTU_{FAV}$ because the analyses covered only the 16 USEPA priority pollutant PAH compounds, and because the PAHs were assumed to be predominantly of pyrogenic origin based on the diagnostic ratios. An uncertainty factor of 11.5 with a confidence interval of 95% (which is an imprecise estimate) (USEPA 2003) was conservatively used for the LRB-3 sample because the Ph/An diagnostic ratio was assumed to evidence that the PAH assemblage may be petrogenic in nature.

Tables 4 and 5 present the calculated sediment PAH mixture $\sum ESBTU_{FAVs}$ in these two samples; the $\sum ESBTU_{FAVs}$ for LR-8 and LRB-3 were 0.14 and 0.75, respectively. Both values showed $\sum ESBTU_{FAV} < 1.0$, indicating low PAH-associated acute toxicity to *H. azteca* in these sediments. This toxicity model prediction suggests that PAHs in the River Channel sediments should not be regarded as a COC.

Note that a comparison of the 2001 and 2005 data show that total PAH concentrations in the sediments declined on the order of 50% over the five-year timeframe.

(2) PCBs—Table 6 presents the results of the PCB analyses on the River Channel and open-lake sediment samples. All PCBs were quantified as Aroclors. No Aroclors were detected in any of the sediment samples. Laboratory reporting limits (LRLs) for the River Channel sediments ranged from 1.80 to 2.54 µg/kg. In the open-lake reference and placement area sediments, Aroclors were not detected at LRLs ranging from 4.67 to 4.92 and 1.63 to 1.88 µg/kg, respectively. The 2001 data showed no detected Aroclors in any of the harbor or lake sediment samples with LRLs ranging from 11 to 17 µg/kg (EEI 2001).

(3) Pesticides—Table 7 presents the results of these analyses on the River Channel and open-lake sediment samples.

●River Channel and Open-lake Reference Area Sediments—Pesticides concentrations were generally non-detectable in virtually all River Channel sediments with LRLs ranging from 1.08 to 1.52 µg/kg. Gamma-chlordane was detected at 3.85 µg/kg at Site LR-7 and methoxychlor was detected at 2.08 µg/kg at Site LR-8. In addition, 4,4'-dichlorodiphenyldichloroethane (DDT) was measured at 2.41 µg/kg at Site LR-9. Only the gamma-chlordane concentration was significantly elevated relative to the open-lake reference area levels. Such levels of gamma-chlordane, 4,4'-DDT (or ∑DDT) are not considered to be of significant toxicological concern. Pesticides were not detected in the open-lake reference area sediments at LRLs ranging from 1.87 to 1.97 µg/kg. The 2001 data showed no detected pesticides in any of the harbor or lake sediment samples with LRLs ranging from 1 to 34 µg/kg (EEI 2001).

●Open-lake Placement Area Sediments—Many pesticides were detected at Site LD-2. Most notable were delta-BHC and methoxychlor.

3. *Biological testing*

(a) 2001/2005 bioassays—In 2001, two prescribed solid-phase bioassays were applied to the River Channel sediments (USEPA/USACE 1998). These tests were generally applied to assess the toxicological effects associated with PAHs (see earlier related discussions) and various metals in the River Channel sediments (EEI 2001). The following is a summary of the results of the two bioassays performed on 2001 composited River Channel and 2005 open-lake reference area sediment samples:

●*H. azteca* (10-day)—Mean survival is the measurement endpoint for this test. Table 8 summarizes the results of this bioassay. Mean survival relative to the River Channel sediments ranged from 70±10.5 to 94±2.4%, compared to the open-lake reference area mean survival of 90±6.3%. For Management Units LRB-1 and LRB-2 sediments, the mean survival of the test organisms exposed to the River Channel sediments was not more than 10% less, and was not statistically different (Fisher's Least Significant Difference [LSD] Test; $P<0.05$) than that associated with the reference area sediments (U.S. Army Engineer Research and Development Center [USAERDC] 2011). Therefore, the material in these management units met this guideline. For Management Unit LRB-3, the mean survival of *H. azteca* exposed to the sediments of 70±10.5% was more than 10% less, and statistically different (LSD

test; P<0.05) than that associated with the open-lake reference area sediments (90±6.3%) (USAERDC 2011). Therefore, the material in this management unit did not meet this guideline.

- *C. dilutus* (10-day)—Survival and growth are the measurement endpoints for this test. The results of this bioassay are also presented in Table 8. Mean survival relative to the River Channel sediments ranged from 68±5.8 to 72±10.2%, compared to the open-lake reference area mean survival of 95±2.9%. For Management Units LRB-1 and LRB-2, the mean survival of the test organisms exposed to the sediments was 72±10.2% and 72±6.6%, respectively. These were more than 20% less, and statistically different (LSD test; P<0.05) than that associated with the open-lake reference area sediments (95±2.9%) (USAERDC 2011). However, a 72% survival for this test species in cleaner sediments is not unusual and the control survival in this test suite (96%) was very high. The control-corrected mean survival value of 75% is comparable to the arbitrary 75% survival used as an acceptable measurement endpoint for acute toxicity in this species (USEPA 2004). For Management Unit LRB-3, the mean survival of the test organisms of 68±5.8% exposed to the sediments was more than 20% less, and also statistically different than that associated with the reference area sediments (LSD test; P<0.05). Further, the control-corrected mean survival value of 71% is lower than the arbitrary 75% acceptable survival measurement endpoint (USEPA 2004). Therefore, the material in Management Unit LRB-3 did not meet this guideline.

With respect to the growth measurement endpoint, the mean dry weight (MDW) of test organisms exposed to Management Unit LRB-2 and LRB-3 sediments was not more than 10% less, and not statistically different (LSD test; P<0.05) than that associated with the open-lake reference area sediments (1.72±0.23 mg) (USAERDC 2011). For Management Unit LRB-1, the MDW of test organisms exposed to the sediments of 1.37±0.13 mg was more than 10% less, but not statistically different (LSD test; P<0.05) than that associated with the open-lake reference area sediments (USAERDC 2011). Therefore, the material in all three management units met this guideline.

In summary, the 2001/2005 bioassay data suggest:

- Sediments within Management Units LRB-1 and LRB-2 showed insignificant toxicity. For LRB-1, even through the growth of *C. dilutus* was more than 10% less when compared to the open-lake reference area sediments, it was comparable to (greater than) both 2001 and 2005 control values. Such results indicate that the toxicity associated with the COCs was not significant.
- Sediments within Management Unit LRB-3 showed marginal acute toxicity with respect to the *C. dilutus* survival bioassay. However, given the

bioassay results on the remainder of the River Channel sediments with similar or higher levels of PAHs, as well as the lower *H. azteca* $\sum ESBTU_{FAV}$ calculated for the maximum composite 2001 bulk total PAH concentration of 10.2 mg (Table 5), the cause of the evidenced acute toxicity would not appear to not be related to PAHs.

(b) 2006 bioassays—In order to verify the results and conclusions relative to the 2001/2005 bioassay tests, the *C. dilutus* solid phase bioassay (USEPA/USACE 1998) was re-applied to new sediment samples collected from River Channel Management Units LRB-1 through LRB-3 (Figure 3). The results, as generated by ASCi (2006a), are summarized in Table 9. Mean survival ranged from 18±15.6% to 80±8.4%, compared to the open-lake reference area mean survival of 80±5.5%. For Management Units LRB-1 and LRB-2, mean survivals of the test organisms exposed to the sediments were not more than 20% less, and not statistically different (t-test on rankits; $P<0.05$) than that associated with the reference area sediments (USAERDC 2011). Therefore, the material in these management units met this guideline. For Management Unit LRB-3, the mean survival of the test organisms exposed to the sediments of 18±15.6% was more than 20% less, and statistically different (t-test on rankits; $P<0.05$) than that associated with the reference area sediments (USAERDC 2011). Therefore, the material in this management unit did not meet this guideline.

With respect to the growth measurement endpoint, the MDW of test organisms exposed to Management Unit LRB-1 and LRB-2 sediments was not more than 10% less, and not statistically different (t-test; $P<0.05$) than that associated with the open-lake reference area sediments (2.09±0.09 mg) (USAERDC 2011). Therefore, the material in these managements units met this guideline. For Management Unit LRB-3, the MDW of test organisms exposed to the sediments of 1.25±0.28 mg was more than 10% less, and statistically different (t-test; $P<0.05$) than that associated with the open-lake reference area sediments (USAERDC 2011). Therefore, the material in this management unit did not meet this guideline.

The 2006 test results were not inconsistent with the 2005 bioassay data as they evidenced acute toxicity associated with Management Unit LRB-3 sediments that could not be attributed to any specific COC. Follow-up *C. dilutus* bioassay testing that treated Management Unit LRB-3 sediment with zeolite to reduce the toxic effects of ammonia indicated that ammonia was not associated with the significantly reduced survival and growth (ASCi 2006b).

b. Comparison of River Channel to Outer Harbor Channel Sediment Quality.

1. *PAH mixture patterns*—Calculations of the percentage of mean PAH compounds to mean total PAH concentrations indicate that the sources of PAHs in surface sediments to the River Channel and Outer Harbor channels are similar (Figure 4). The compounds with the highest percentages included fluoranthene (FlA) (TEF=0.001), benzo(a)anthracene (BaA) (TEF=0.1), chrysene (Chy) (TEF=0.01), benzo(a)pyrene (BaP) (TEF=1), phenanthrene (PhA) (TEF=0.001) and pyrene (Py) (TEF=0.001) (Nisbet and Lagoy 1992).

The patterns of PAH mixtures can provide useful information on their source(s). To first confirm whether PAHs in Lorain Harbor sediments originated from similar sources, the mean percentage of each compound relative to the mean total PAH concentration was used to assess the general variation among the sampling sites. Limited variation in the relative percentages among the River Channel and Outer Harbor sediments confirmed similar sources of PAHs.

One screening method used to determine PAH sources is a basic comparison to known PAH source profiles (i.e., Christensen *et al.* 1997). Several other semi-quantitative approaches to source-apportion PAH compounds can be used. These are summarized and applied as follows:

(a) PAH:naphthalene (NaP) ratios (or sum percentage of NaP) (Curran *et al.* 2000)—Using this method, average PAH:NaP concentration ratios for the River Channel and Outer Harbor channel sediments were calculated. Figure 5 illustrates the Lorain Harbor PAH:NaP ratios in comparison to various other source signatures from Curran *et al.* (2000). This graph suggests that the PAH sources to Lorain Harbor most approach that of highway runoff (HWY), based on the following rationale: (1) the majority of the PAH:NaP ratios for Lorain Harbor sediments and the HWY source are generally within the range of 0.1 to 1.0; and (2) the trend lines are most consistent with the HWY source. However, there are some resemblances to the Coke-B source, mainly (1) many of the PAH:NaP ratios on Lorain Harbor sediments and the Coke-B source are generally within the range of 0.1 to 1.0 (BaA, BaP and Py are major exceptions); and (2) the trend lines are consistent with this source for many of the compounds (K.N. Irvine, personal communication, 2006). In addition, on average, NaP in the sediments comprised 2.9% and 1.7% of the total concentration in the River Channel (Table 3) and Outer Harbor (Table 10) sediments, respectively, which is consistent with the low percentage (i.e., <4%) in urban dust and runoff reported by Ngabe *et al.* (2000) and calculated by Van Dolah *et al.* (2005). This information also suggests pyrogenic sources (versus petrogenic sources) of PAHs. However, it should be noted that these two studies summed similar, but some additional PAH compounds.

(b) FlA:Py ratios (Van Dolah *et al.* 2005)—On average, FlA:Py ratios for sediments in the River Channel (Table 3) and Outer Harbor (Table 10) sediments were 1.5 and 1.6, respectively, which is comparable to the 1.1 to 1.4 ratios for urban dust and runoff reported by Van Dolah *et al.* (2005). These ratios also suggest pyrogenic combustion sources.

Another line of evidence that the PAHs arise from both HWY and the former coking plant is that the top seven compounds in the harbor sediments are generally FlA, Py, BbFlA, BaA, PhA, BaP and Chy. All but BaA and BaP and are among the top five compounds found in urban dust and highway runoff when considering the combined results of Van Dolah *et al.* (2005) and Christensen *et al.* (1997), and BaA and BaP are among the top five compounds associated with coke production (Christensen *et al.* 1997).

Because the Lorain Harbor PAH:NaP ratios are more similar to a HWY source, most of the PAH compound indicators between the two sources overlap, and the former coking plant source on the lower Black River was remediated in 1990, the weight-of-the-evidence suggests that the majority of PAH contamination in Lorain Harbor Federal navigation channels now arises from HWY, with residual input from the former coking plant. Coal pile, coal tire and coal and wood gasification were eliminated as significant sources because the Lorain Harbor PAH fingerprint did not resemble the source signature from Curran *et al.* (2000). Gasoline exhaust coal tar (GEET) was eliminated as a significant source to Lorain Harbor sediments because pyrene was not the most abundant constituent and was not a dominant PAH compound (Christensen *et al.* 1997).

2. *PAH concentrations*—Total PAH concentrations in the River Channel sediments (1.12 to 5.6 mg/kg) (Table 3) was comparable to the Outer Harbor range of 0.54 to 4.48 mg/kg (Table 10). The mean total PAH level in River Channel sediments (3.26 mg/kg) was almost double that of the Outer Harbor sediments (1.88 mg/kg). When eliminating Sites LR-8 and LR-9, the mean total PAHs in River Channel sediments was reduced to 2.73 mg/kg and was comparable to that of the Outer Harbor. While PAHs were initially considered COCs in the Outer Harbor sediments, they were shown to not be acutely toxic based on two prescribed Tier 3 bioassays (USEPA/USACE 1998). Therefore, they were eliminated as COCs in the Outer Harbor sediments.

3. *Metal COC concentrations*—Beryllium, cadmium, zinc, and possibly cyanide and silver were considered to be COCs at River Channel Sites LR-8 and/or LR-9 because they significantly exceeded open-lake reference area levels (Table 2). Based on 2000/2001 data (EEI 2000; 2001), cadmium was considered a COC in all River Channel sediments. No metal COCs were identified in the Outer Harbor channel sediments (USACE 2006).

4. *Pesticide concentrations*—No pesticide COCs were identified in the River Channel sediments (Table 7). In the Outer Harbor channel sediments, delta-BHC was identified as a COC at one site (USACE 2006). Based on the two prescribed bioassays, the delta-BHC concentration was not acutely toxic (see Table 8).

5. *Biological testing*—The two prescribed solid-phase bioassays were applied to the Outer Harbor channel sediments in 2005 (EEI 2005). At the time, these tests were presumably applied to assess the toxicological effects associated with PAHs. The following is a summary of the results of the two bioassays performed on composited Outer Harbor and open-lake reference area sediment samples:

(a) *H. azteca* (10-day)—Table 8 includes the results of this bioassay. Mean survival relative to the Outer Harbor sediments ranged from 88±17.9% to 100%, compared to the open-lake reference area mean survival of 90±6.3%. The mean survival of the test organisms exposed to Outer Harbor sediments was not more than 10% less, and was not statistically different than that associated with the reference area sediments. Therefore, the Outer Harbor channel material met this guideline.

(b) *C. dilutus*—The results of this bioassay are also included in Table 8. Mean survival relative to the Outer Harbor sediment ranged from 86±16.7% to 90±12.2%, compared to the open-lake reference area mean survival of 95±2.9%. The mean survival of the test organisms exposed to the Outer Harbor sediments was not more than 20% less, and was not statistically different than that associated with the reference area samples. Therefore, the Outer Harbor channel material met this guideline.

c. Elutriate Testing on River Channel Sediments. Elutriate test results on composited sediment samples LRB-1, LRB-2 and LRB-3 from 2005 are presented in Tables 11 through 14. Low releases of some metals and nutrients were evidenced in many of the sediment samples (Table 11). No releases of PAHs, PCBs or pesticides were measured at LRLs of 0.2, 0.5 and 0.1 µg/L, respectively (Tables 12, 13 and 14).

d. Final COC List. No final COCs were identified in the River Channel sediments. However, significant acute toxicity was indicated in sediments in Management Unit LRB-3. Further treatment and testing of this sediment sample indicated that the acute toxicity was not attributable to ammonia. The toxicity associated with Management Unit LRB-3 sediments may be related to a non-contaminant factor(s).

e. Quality Assurance(QA)/QC Documentation. QA/QC information and records on the data contained and used in this evaluation are available in EEI (2000; 2001 and 2005).

*Conclusion*

This evaluation has determined that:

a. Sediments dredged from the Lorain Harbor River Channel, as represented by Sites LR-4 through LR-9 (Figure 1) and corresponding Management Units LRB-1 and LRB-2 (Figure 2), meet Federal guidelines for open-lake placement.

b. Sediments dredged from near the upstream end of the Lorain Harbor River Channel, as represented by Sites LR-1 through LR-3 (Figure 1) and corresponding Management Unit LRB-3 (Figure 2), do not meet Federal guidelines for open-lake placement.

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**FIGURE 1. Sites for the 2001/2005 sediment sampling of the Lorain Harbor, Ohio, River Channel.**

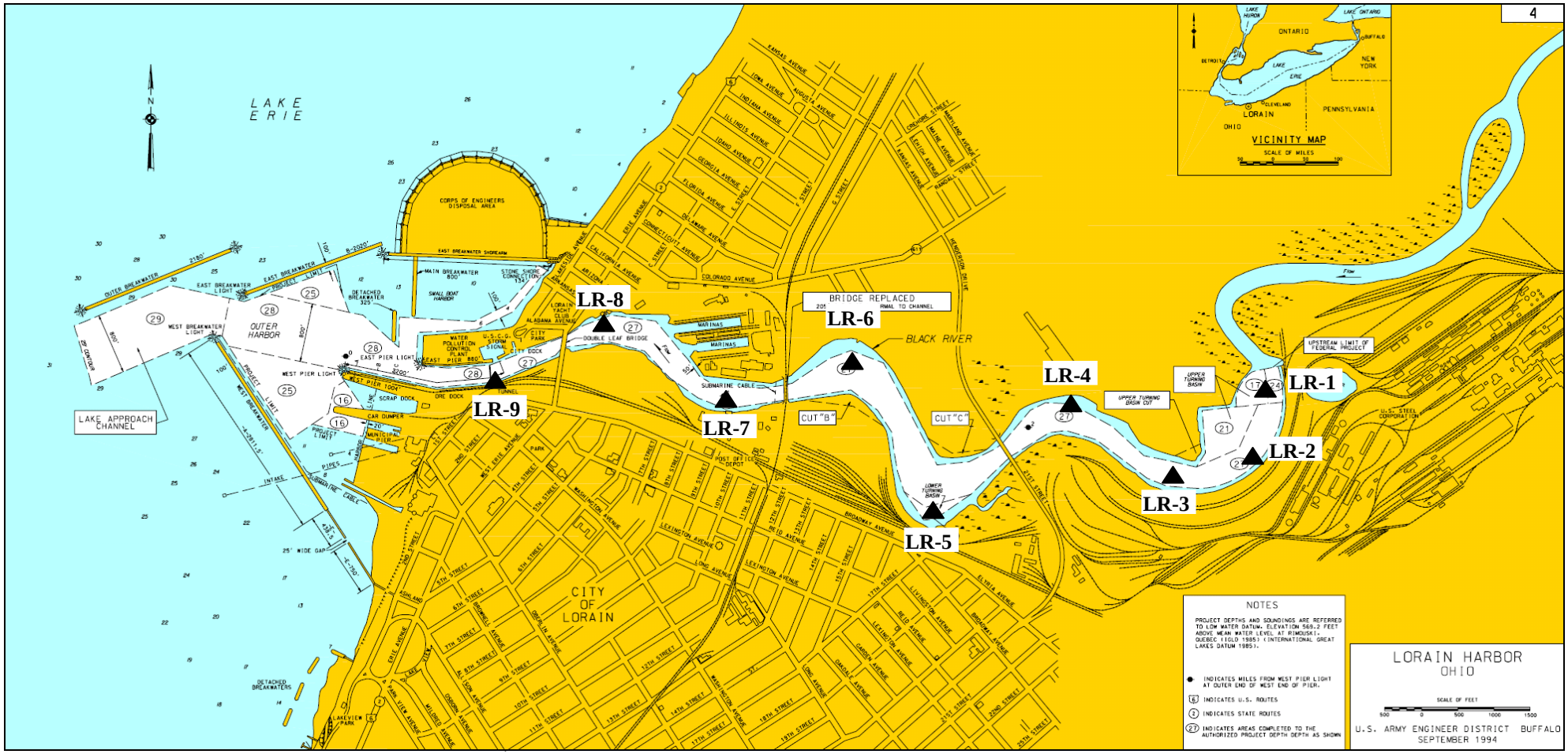

**FIGURE 2. Open-lake reference and placement area sediment sampling sites for Lorain Harbor, Ohio.**

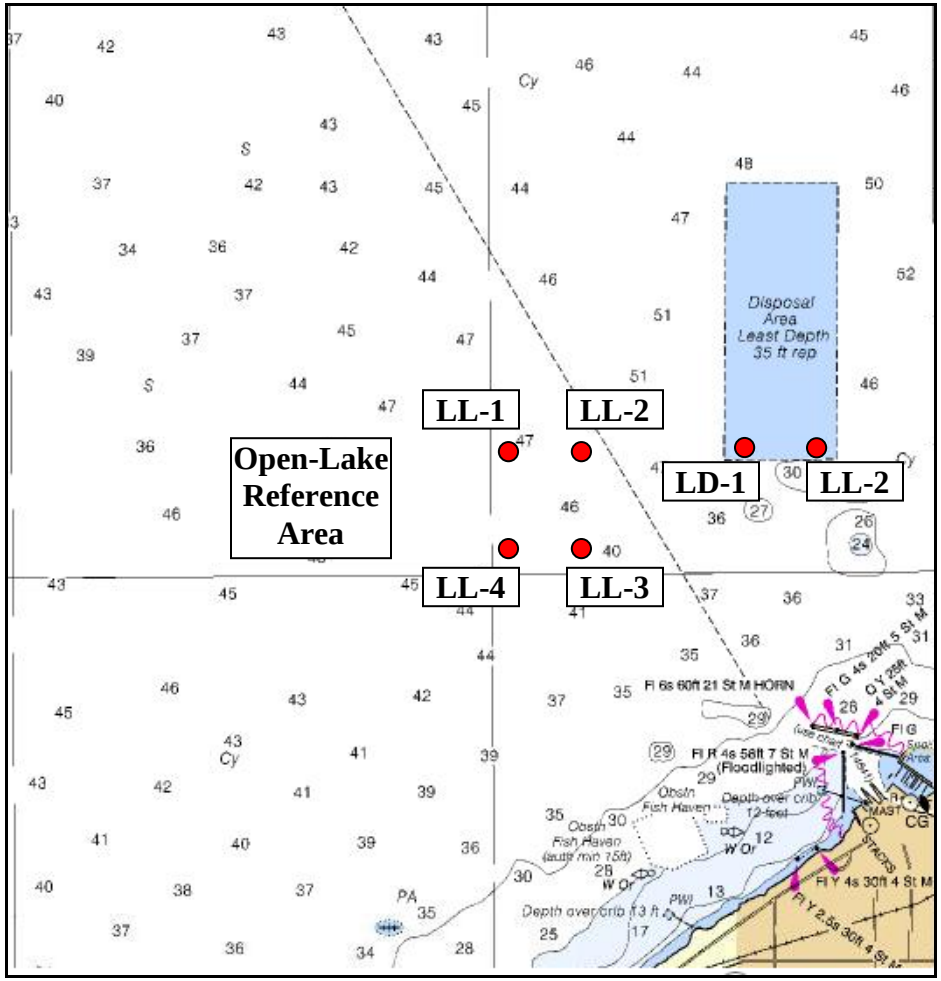

**FIGURE 3. Management Units for 2001/2006 River Channel composited sediment samples, Lorain Harbor, Ohio.**

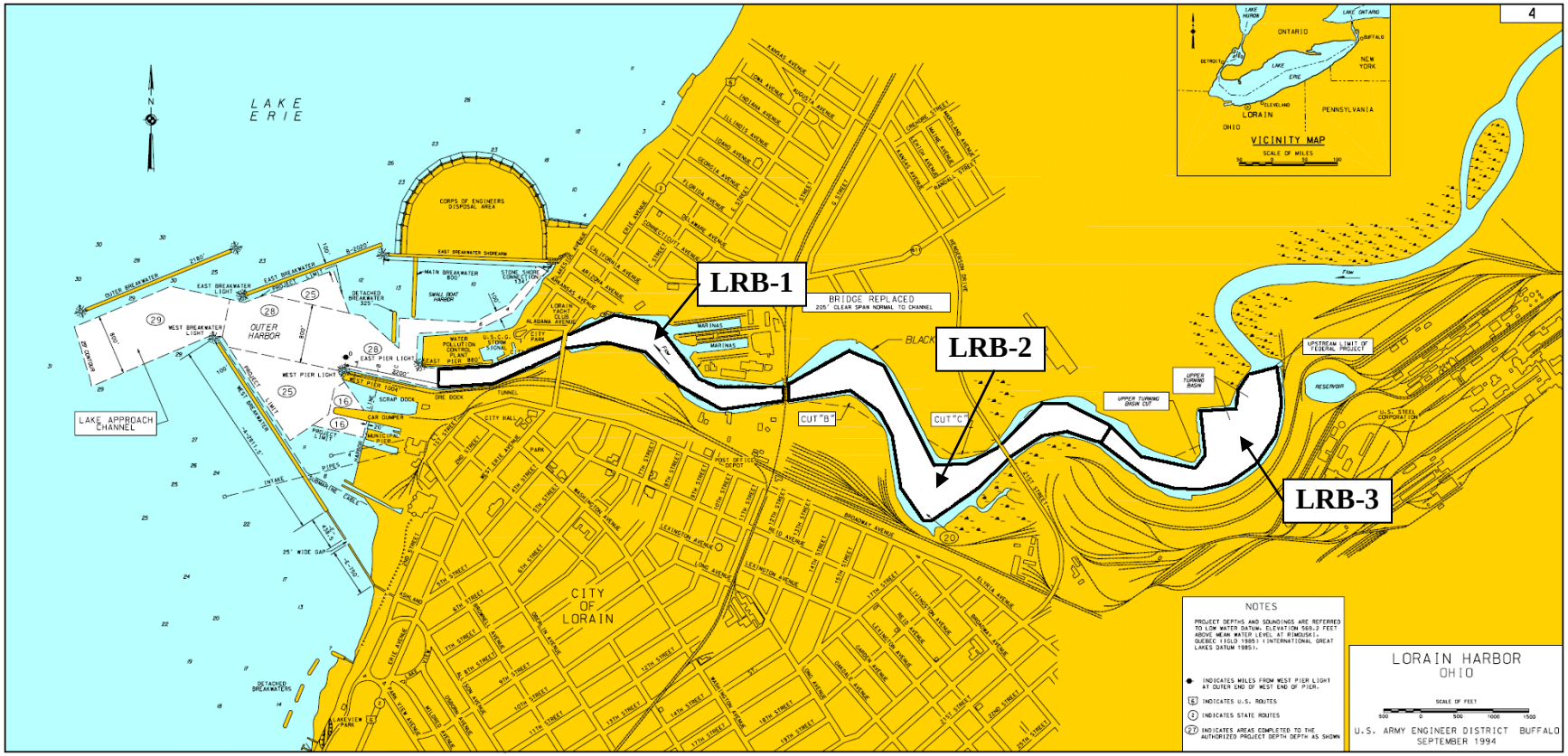

**FIGURE 4. Sum percentage of PAH compounds in Lorain Harbor, Ohio sediments, illustrating limited variation among the Outer Harbor and River Channel sectors of the harbor.**

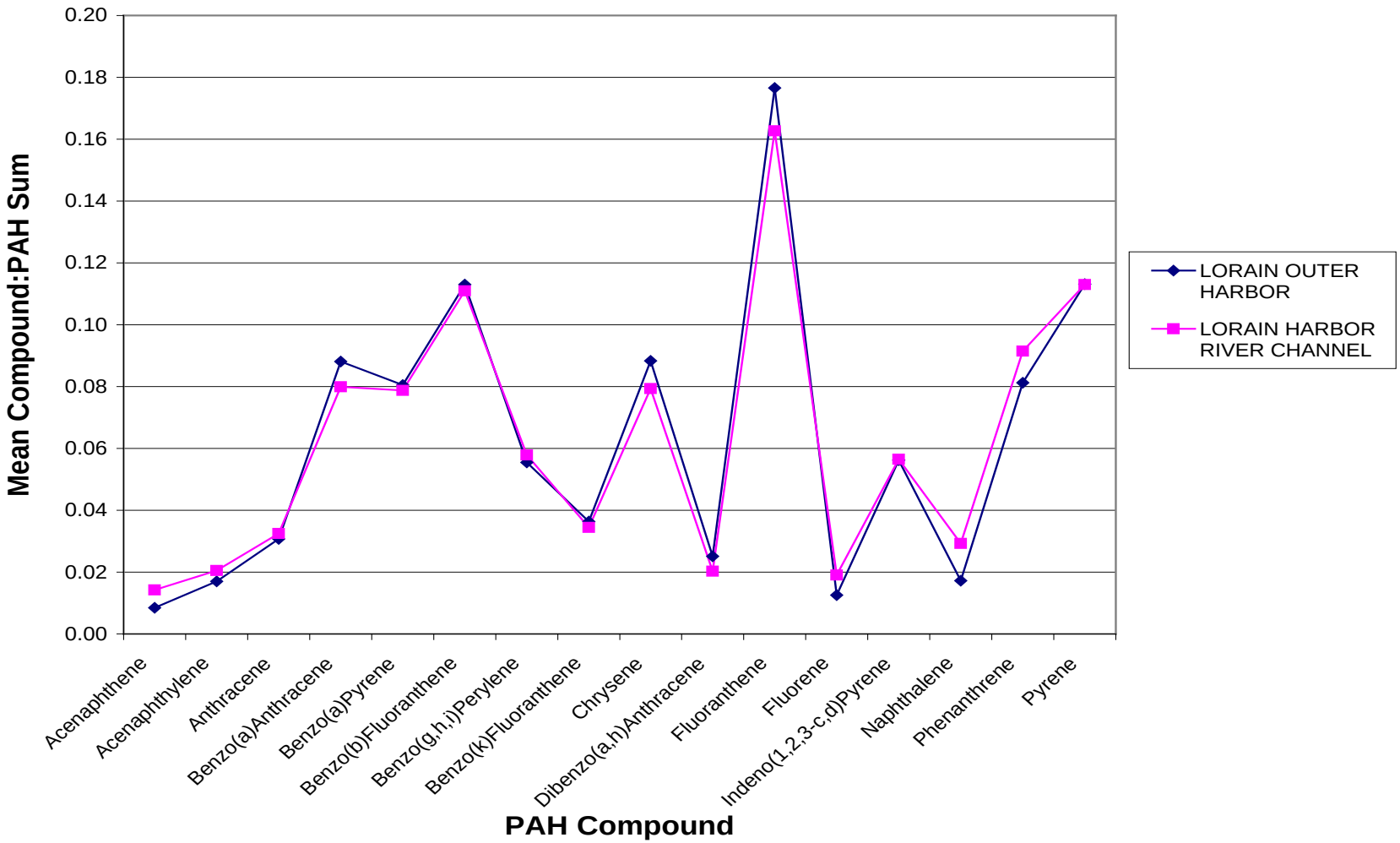

**FIGURE 5. Comparison of Lorain Harbor (River Channel and Outer Harbor) sediment PAH signatures, in terms of PAH:NaP ratios, to various source fingerprints obtained from Curran *et al*. (2000).**

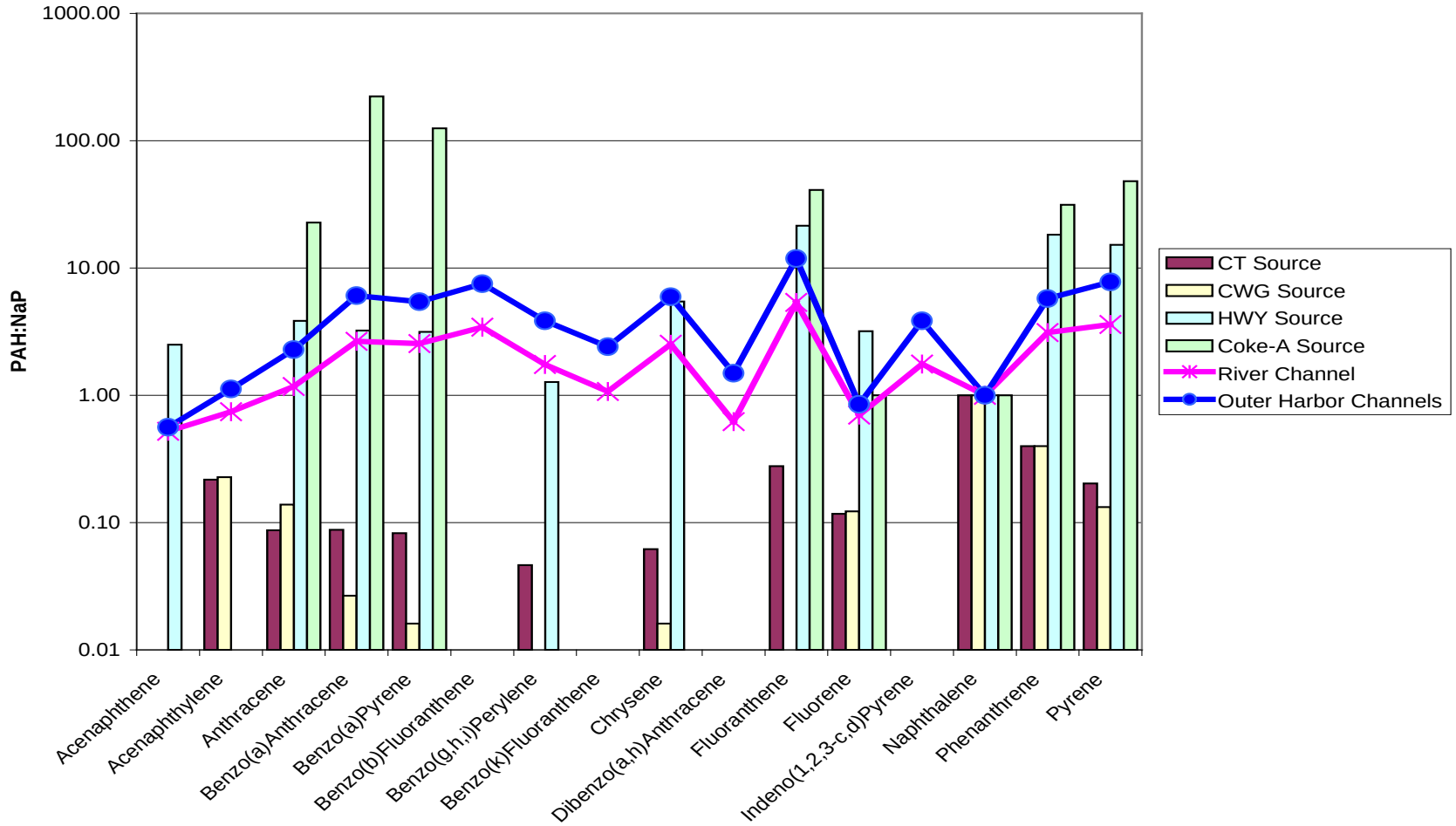

**TABLE 1. Particle size distribution of River Channel sediments, Lorain Harbor, Ohio (from EEI 2005).**

| Particle Size | River Channel Sediments | | | | | | | | | Open-lake Sediments | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | | | | | | | Reference Area Sampling Sites | | | | Placement Area Sampling Sites | |
| | LR-1 | LR-2 | LR-3 | LR-4 | LR-5 | LR-6 | LR-7 | LR-8 | LR-9 | LL-1 | LL-2 | LL-3 | LL-4 | LD-1 | LD-2 |
| Gravel | 0 | 1.4 | 0 | 0 | 0 | 0.1 | 0 | 1.3 | 5.1 | 0 | 0 | 0 | 0 | 7.2 | 5.3 |
| Sand | 33.9 | 10.7 | 6.5 | 10.2 | 2.1 | 4.4 | 5.9 | 14.9 | 47.6 | 5.0 | 16.0 | 8.1 | 0.7 | 75.4 | 81.9 |
| Silt | 41.3 | 39.1 | 56.2 | 55.4 | 51.7 | 42.7 | 29.4 | 50.7 | 23.7 | 39.9 | 34.9 | 27.0 | 49.5 | 4.3 | 3.7 |
| Clay | 24.8 | 48.8 | 37.3 | 34.4 | 46.2 | 52.8 | 64.7 | 33.1 | 23.6 | 55.1 | 49.1 | 64.9 | 49.8 | 13.1 | 9.1 |

**TABLE 2. Bulk inorganic analyses of River Channel sediments, Lorain Harbor, Ohio. Boldfaced values indicate concentrations that exceed open-lake reference area levels (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit)**

| Metals (mg/kg) | River Channel Sediments | | | | | | | | | Open-lake Sediments | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | | | | | | | Reference Area Sampling Sites | | | | Placement Area Sampling Sites | |
| | LR-1 | LR-2 | LR-3 | LR-4 | LR-5 | LR-6 | LR-7 | LR-8 | LR-9 | LL-1 | LL-2 | LL-3 | LL-4 | LD-1 | LD-2 |
| Aluminum | 8890 | 17700 | 13200 | 15400 | 15400 | 17500 | 172500 | 13100 | 10300 | 25500 | 28900 | 27900 | 21600 | 9760 | 4590 |
| Antimony | 0.724 | 1.39 | 0.841 | 0.855 | 1.03 | 1.31 | 1.17 | 1.32 | 0.947 | 1.43 | 1.98 | 1.51 | 1.03 | 1.85 | 2.32 |
| Arsenic | **7.53** | **10.7** | **10.3** | **10.2** | **10.8** | **11.2** | **9.83** | **12.1** | **9.84** | 7.67 | 7.51 | 7.37 | 7.22 | 13.1 | 8.12 |
| Barium | 39.8 | 64.4 | 54.3 | 60.1 | 59.2 | 66.8 | 65.5 | 65.8 | 54.4 | 104 | 102 | 107 | 95.4 | 52.3 | 32.1 |
| Beryllium | 0.358 | 0.597 | 0.491 | 0.539 | 0.568 | 0.692 | 0.613 | **2.72** | **4.03** | 1.03 | 1.02 | 1.06 | 0.973 | 1.19 | 0.509 |
| Cadmium | 2.43 | 3.92 | 2.28 | 2.71 | 2.69 | 3.71 | 2.77 | **14.8** | **8.68** | 2.38 | 2.37 | 2.27 | 2.12 | 15.5 | 5.74 |
| Chromium | 18.1 | 28.7 | 18.9 | 22.5 | 22.1 | 27.8 | 23.9 | **82.1** | 44.7 | 50.6 | 50.6 | 50.1 | 47.2 | 106 | 47.4 |
| Cobalt | 6.63 | 10.5 | 9.24 | 9.71 | 9.76 | 10.1 | 10.1 | 8.76 | 7.23 | 12.4 | 11.9 | 12.1 | 11.3 | 7.32 | 5.63 |
| Copper | 32.2 | 54.4 | 37.2 | 42.3 | 41.9 | 53.8 | 45.4 | **117** | **70.1** | 56.1 | 55.1 | 55.2 | 51.5 | 127 | 70.4 |
| Iron | 21500 | 41300 | 31900 | 32300 | 34000 | 38400 | 35200 | 42100 | 32200 | 37300 | 46600 | 41600 | 33400 | 57200 | 64200 |
| Lead | 20.1 | 38.1 | 23.4 | 27.7 | 27.2 | 37.9 | 32.3 | **82.9** | **56.1** | 54.7 | 55.1 | 51.9 | 49.1 | 74.4 | 33.7 |
| Magnesium | 2730 | 4340 | 3840 | 4220 | 4500 | 5720 | 4930 | 4330 | 7030 | 10900 | 10000 | 10200 | 9160 | 3500 | 3120 |
| Manganese | 409 | **930** | **636** | 554 | **603** | **617** | 552 | **590** | **796** | 570 | 533 | 506 | 432 | 664 | 575 |
| Mercury | 0.0611 | 0.124 | 0.114 | 0.0971 | 0.101 | 0.157 | 0.113 | 0.601 | 0.191 | 0.419 | 0.384 | 0.373 | 0.291 | 0.296 | 0.198 |
| Nickel | 23.1 | 31.1 | 25.5 | 27.2 | 27.9 | 30.4 | 29.8 | 40.1 | **56.9** | 51.9 | 51.8 | 51.8 | 49.1 | 40.3 | 24.7 |
| Selenium | 0.613 | 0.804 | 0.688 | 0.745 | 0.725 | 0.679 | 0.583 | 1.35 | 0.777 | 0.859 | 0.893 | 0.954 | 0.898 | 1.22 | 0.716 |
| Silver | 0.143 | 0.377 | 0.164 | 0.206 | 0.201 | 0.249 | 0.303 | **0.973** | **0.639** | 0.638 | 0.497 | 0.467 | 0.412 | 0.484 | 0.201 |
| Thallium | 0.317 | 0.431 | 0.351 | 0.401 | 0.416 | 0.459 | 0.407 | 0.605 | 0.501 | 1.16 | 0.531 | 0.565 | 0.445 | 0.418 | 0.301 |
| Vanadium | 17.4 | 24.1 | 20.2 | 23.5 | 23.9 | 25.3 | 24.9 | 21.3 | 17.6 | 42.1 | 40.5 | 42.4 | 38.1 | 23.1 | 17.9 |
| Zinc | 93.1 | 164 | 107 | 131 | 133 | 275 | 152 | **844** | **529** | 184 | 178 | 178 | 166 | 644 | 248 |

| Misc. (mg/kg) | LR-1 | LR-2 | LR-3 | LR-4 | LR-5 | LR-6 | LR-7 | LR-8 | LH-9 | LL-1 | LL-2 | LL-3 | LL-4 | LD-1 | LD-2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oil & Grease | **120** | 94.7 | 82.1 | 67.2 | 57.2U | 67.1 | 89.5 | **631** | **321** | 124U | 112 | 109U | 111U | 1470 | 801 |
| Phosphorus | 137 | 173 | 150 | 162 | 153 | 128 | 5.14 | 126 | 125 | 120 | 135 | 170 | 219 | 88.8 | 103 |
| TOC | 30300 | 34600 | 29300 | 29000 | 29400 | 30900 | 26600 | 36100 | 30500 | 14600 | 16600 | 13400 | 13300 | 24200 | 42800 |
| Cyanide | **0.573** | 0.219U | 0.463 | 0.31 | 0.406 | **0.862** | 0.474 | **1.67** | **4.26** | 0.468U | 0.538J | 0.477U | 0.473U | 3.26 | 4.22 |
| Ammonia | 183 | **444** | **284** | 249 | 214 | 189 | 225 | 113 | 73.2 | 203 | 249 | 191 | 181 | 68.3 | 68.1 |

**TABLE 3. Bulk polycyclic aromatic hydrocarbon (PAH) analyses of River Channel sediments, Lorain Harbor, Ohio. Boldfaced values indicate concentrations that exceed open-lake reference area levels (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit; J=Estimated value between the minimum detection limit and reporting limit)**

| PAHs (µg/kg) | River Channel Sediments | | | | | | | | | Open-lake Sediments | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | | | | | | | Reference Area Sampling Sites | | | | Placement Area Sampling Sites | |
| | LR-1 | LR-2 | LR-3 | LR-4 | LR-5 | LR-6 | LR-7 | LR-8 | LR-9 | LL-1 | LL-2 | LL-3 | LL-4 | LD-1 | LD-2 |
| Acenaphthene | **33.9** | **146** | **10.4** | **29.3** | **9.24** | **23.9** | **46.3** | **80.7** | **90.9** | 0.0711U | 0.0662U | 0.0639U | 3.56J | 288 | 281 |
| Acenaphthylene | **40** | **58.3** | 10.8 | **44.6** | 15.6 | **76.5** | **111** | **187** | **125** | 6.60JU | 7.11JU | 7.79J | 16.2 | 260 | 191 |
| Anthracene | **64.7** | **132** | **31.3** | **80.5** | **19.7** | **89.7** | **190** | **248** | **200** | 5.12J | 5.09J | 5.39J | 15.9 | 704 | 646 |
| Benzo(a)Anthracene | **181** | **296** | **111** | **246** | **74.4** | **199** | **438** | **459** | **386** | 15.6 | 15.9 | 19.0 | 47.2 | 1070 | 795 |
| Benzo(a)Pyrene | **181** | **298** | **113** | **254** | **88.0** | **188** | **391** | **444** | **342** | 15.0 | 16.1 | 18.9 | 48.1 | 936 | 657 |
| Benzo(b)Fluoranthene | **252** | **435** | **186** | **352** | **156** | **246** | **451** | **580** | **433** | 18.4 | 19.4 | 26.1 | 61.8 | 1130 | 767 |
| Benzo(g,h,i)Perylene | **130** | **286** | **109** | **156** | **90.9** | **116** | **183** | **289** | **217** | 11.8 | 11.8 | 16.2 | 39.9 | 561 | 382 |
| Benzo(k)Fluoranthene | **81.6** | **108** | **53.8** | **114** | **45.2** | **86.0** | **154** | **180** | **145** | 5.93J | 6.03J | 8.39J | 21.0 | 363 | 261 |
| Chrysene | **185** | **304** | **122** | **241** | **97.8** | **186** | **357** | **426** | **355** | 15.3 | 16.1 | 20.4 | 49.0 | 937 | 609 |
| Dibenzo(a,h)Anthracene | **47.2** | **70.8** | **32.7** | **58.9** | **29.9** | **50.5** | **69.6** | **113** | **88.7** | 0.1390J | 20.9 | 0.1250U | 28.4 | 215 | 148 |
| Fluoranthene | **426** | **593** | **216** | **554** | **161** | **344** | **897** | **899** | **745** | 28.4 | 29.4 | 32.3 | 89.3 | 2110 | 1700 |
| Fluorene | **45.5** | **130** | **13.0** | **38.7** | **11.1** | **44.6** | **94.9** | **120** | **133** | 0.0617U | 3.16J | 2.64J | 7.42J | 321 | 291 |
| Indeno(1,2,3-c,d)Pyrene | **135** | **240** | **91.3** | **168** | **75.6** | **130** | **210** | **309** | **230** | 11.8 | 11.9 | 15.4 | 38.2 | 618 | 420 |
| Naphthalene | **73.4** | **146** | **19.5** | **63.6** | **21.0** | **118** | **41.3** | **187** | **232** | 6.00J | 7.07J | 7.09J | 20.1 | 434 | 246 |
| Phenanthrene | **260** | **495** | **113** | **250** | **77.3** | **163** | **552** | **462** | **433** | 9.95 | 11.2 | 11.8 | 30.1 | 1130 | 947 |
| Pyrene | **257** | **511** | **189** | **323** | **152** | **199** | **520** | **615** | **478** | 20.3 | 21.5 | 21.6 | 59.3 | 1260 | 962 |
| TOTAL | **2390** | **4250** | **1420** | **2970** | **1120** | **2260** | **4710** | **5600** | **4630** | 170 | 204 | 213 | 576 | **12400** | **9300** |
| Naphthalene/total PAHs (%) | 3.1 | 3.4 | 1.3 | 2.1 | 1.8 | 5.2 | 0.88 | 3.3 | 5.0 | | | | | | |
| Fluoranthene:pyrene | 1.7 | 1.2 | 1.1 | 1.7 | 1.1 | 1.7 | 1.7 | 1.5 | 1.6 | | | | | | |

# TABLE 4. Acute equilibrium partitioning-based sediment benchmark toxic units (ESBTUs) specific to *H. azteca* for PAH compound mixture in LR-8 discrete sediment in the River Channel (based on EEI 2005).

| PAH compound | $C_{oc, PAHi, FAVi}$ ($\mu g/g_{OC}$)* | Concentration | | $C_{oc}$ ($\mu g/g_{OC}$) | $ESBTU_{FAVi}$ |
|---|---|---|---|---|---|
| | | PAH ($\mu g/g$) | TOC (% dec) | | |
| Acenaphthene | 3047 | 0.081 | 0.0305 | 2.645901639 | 0.000868363 |
| Acenaphthylene | 2807 | 0.187 | 0.0305 | 6.131147541 | 0.002184235 |
| Anthracene | 3684 | 0.248 | 0.0305 | 8.131147541 | 0.002207152 |
| Benzo(a)Anthracene | 5216 | 0.459 | 0.0305 | 15.04918033 | 0.002885196 |
| Benzo(a)Pyrene | 5988 | 0.444 | 0.0305 | 14.55737705 | 0.002431092 |
| Benzo(b)Fluoranthene | 6023 | 0.580 | 0.0305 | 19.01639344 | 0.003157296 |
| Benzo(ghi)Perylene | 6081 | 0.289 | 0.0305 | 9.475409836 | 0.001558199 |
| Benzo(k)Fluoranthene | 6789 | 0.180 | 0.0305 | 5.901639344 | 0.000869294 |
| Chrysene | 5235 | 0.426 | 0.0305 | 13.96721311 | 0.002668045 |
| Dibenzo(a,h)Anthracene | 6966 | 0.113 | 0.0305 | 3.704918033 | 0.000531857 |
| Fluoranthene | 4389 | 0.899 | 0.0305 | 29.47540984 | 0.006715746 |
| Fluorene | 3341 | 0.120 | 0.0305 | 3.93442623 | 0.001177619 |
| Indeno(1,2,3-cd)Pyrene | 6918 | 0.309 | 0.0305 | 10.13114754 | 0.001464462 |
| Naphthalene | 2391 | 0.187 | 0.0305 | 6.131147541 | 0.002564261 |
| Phenanthrene | 3698 | 0.462 | 0.0305 | 15.14754098 | 0.004096144 |
| Pyrene | 4328 | 0.615 | 0.0305 | 20.16393443 | 0.00465895 |
| **Total PAHs (16)** | | 5.6 | | | |
| **$\sum ESBTU_{FAV,16}$** | | | | | 0.04003791 |
| **Uncertainty factor**** | | | | | 3.6 |
| **$\sum ESBTU_{FAV,34}$** | | | | | **0.144136478** |

*Based on acute critical body burden of 13.9 μmol/g lipid for *Hyalalla azteca* (Kreitinger, personal communication; USEPA 2003).

**Based on conservative value for PAHs at 95% confidence interval (Hawthorne *et al.* 2006).

# TABLE 5. Acute ESBTUs specific to *H. azteca* for PAH compound mixture in LRB-3 composite sediments in the River Channel (based on EEI 2005).

| PAH compound | $C_{oc, PAHi, FAVi}$ ($\mu g/g_{OC}$)* | Concentration | | $C_{oc}$ ($\mu g/g_{OC}$) | $ESBTU_{FAVi}$ |
|---|---|---|---|---|---|
| | | PAH ($\mu g/g$) | TOC (% dec) | | |
| Acenaphthene | 3047 | 0.210 | 0.033 | 6.363636364 | 0.002088492 |
| Acenaphthylene | 2807 | 0.118 | 0.033 | 3.575757576 | 0.001273872 |
| Anthracene | 3684 | 0.247 | 0.033 | 7.484848485 | 0.002031718 |
| Benzo(a)Anthracene | 5216 | 0.592 | 0.033 | 17.93939394 | 0.003439301 |
| Benzo(a)Pyrene | 5988 | 0.600 | 0.033 | 18.18181818 | 0.003036376 |
| Benzo(b)Fluoranthene | 6023 | 1.176 | 0.033 | 35.63636364 | 0.005916713 |
| Benzo(ghi)Perylene | 6081 | 0.366 | 0.033 | 11.09090909 | 0.001823863 |
| Benzo(k)Fluoranthene | 6789 | 0.870 | 0.033 | 26.36363636 | 0.003883287 |
| Chrysene | 5235 | 0.651 | 0.033 | 19.72727273 | 0.003768342 |
| Dibenzo(a,h)Anthracene | 6966 | 0.039 | 0.033 | 1.181818182 | 0.000169655 |
| Fluoranthene | 4389 | 1.828 | 0.033 | 55.39393939 | 0.012621084 |
| Fluorene | 3341 | 0.235 | 0.033 | 7.121212121 | 0.002131461 |
| Indeno(1,2,3-cd)Pyrene | 6918 | 0.355 | 0.033 | 10.75757576 | 0.001555012 |
| Naphthalene | 2391 | 0.217 | 0.033 | 6.575757576 | 0.002750212 |
| Phenanthrene | 3698 | 1.205 | 0.033 | 36.51515152 | 0.009874297 |
| Pyrene | 4328 | 1.260 | 0.033 | 38.18181818 | 0.008822047 |
| **Total PAHs (16)** | | 9.969 | | | |
| **$\sum ESBTU_{FAV,16}$** | | | | | 0.065185734 |
| **Uncertainty factor**** | | | | | 11.5 |
| **$\sum ESBTU_{FAV,34}$** | | | | | **0.749635937** |

*Based on acute critical body burden of 13.9 μmol/g lipid for *Hyalalla azteca* (Kreitinger, personal communication; USEPA 2003).

**Based on conservative value for PAHs at 95% confidence interval (Hawthorne *et al.* 2006).

**TABLE 6. Bulk polychlorinated biphenyl (PCB) analyses of River Channel sediments, Lorain Harbor, Ohio (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit; J=Estimated value between the minimum detection limit and reporting limit)**

| PCBs (µg/kg) | River Channel Sediments | | | | | | | | | Open-lake Sediments | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | | | | | | | Reference Area Sampling Sites | | | | Placement Area Sampling Sites | |
| | LR-1 | LR-2 | LR-3 | LR-4 | LR-5 | LR-6 | LR-7 | LR-8 | LR-9 | LL-1 | LL-2 | LL-3 | LL-4 | LD-1 | LD-2 |
| PCB-1016 | 2.25U | 2.32U | 2.22U | 2.42U | 2.51U | 2.54U | 2.42U | 1.93U | 1.80U | 4.75U | 4.92U | 4.84U | 4.67U | 1.63U | 1.88U |
| PCB-1221 | 2.25U | 2.32U | 2.22U | 2.42U | 2.51U | 2.54U | 2.42U | 1.93U | 1.80U | 4.75U | 4.92U | 4.84U | 4.67U | 1.63U | 1.88U |
| PCB-1232 | 2.25U | 2.32U | 2.22U | 2.42U | 2.51U | 2.54U | 2.42U | 1.93U | 1.80U | 4.75U | 4.92U | 4.84U | 4.67U | 1.63U | 1.88U |
| PCB-1242 | 2.25U | 2.32U | 2.22U | 2.42U | 2.51U | 2.54U | 2.42U | 1.93U | 1.80U | 4.75U | 4.92U | 4.84U | 4.67U | 1.63U | 1.88U |
| PCB-1248 | 2.25U | 2.32U | 2.22U | 2.42U | 2.51U | 2.54U | 2.42U | 1.93U | 1.80U | 4.75U | 4.92U | 4.84U | 4.67U | 1.63U | 1.88U |
| PCB-1254 | 2.25U | 2.32U | 2.22U | 2.42U | 2.51U | 2.54U | 2.42U | 1.93U | 1.80U | 4.75U | 4.92U | 4.84U | 4.67U | 1.63U | 1.88U |
| PCB-1260 | 2.25U | 2.32U | 2.22U | 2.42U | 2.51U | 2.54U | 2.42U | 1.93U | 1.80U | 4.75U | 4.92U | 4.84U | 4.67U | 1.63U | 1.88U |
| PCB-1262 | 2.25U | 2.32U | 2.22U | 2.42U | 2.51U | 2.54U | 2.42U | 1.93U | 1.80U | 4.75U | 4.92U | 4.84U | 4.67U | 1.63U | 1.88U |

**TABLE 7. Bulk pesticides analyses of River Channel sediments, Lorain Harbor, Ohio. Boldfaced values indicate concentrations that exceed open-lake reference area levels (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit; J=Estimated value between the minimum detection limit and reporting limit)**

| Pesticides (µg/kg) | River Channel Sediments | | | | | | | | | Open-lake Sediments | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | | | | | | | Reference Area Sampling Sites | | | | Placement Area Sampling Sites | |
| | LR-1 | LR-2 | LR-3 | LR-4 | LR-5 | LR-6 | LR-7 | LR-8 | LR-9 | LL-1 | LL-2 | LL-3 | LL-4 | LD-1 | LD-2 |
| Alpha-BHC | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Beta-BHC | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.79 |
| Delta-BHC | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 4.75 |
| Gamma-BHC | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Heptachlor | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Aldrin | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.60 |
| Heptachlor Epoxide | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Endosulfan I | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Dieldrin | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 4.73 |
| 4,4'-DDT | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | **2.41** | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 5.56 |
| 4,4'-DDE | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 2.67 |
| DDD | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.77 |
| Endrin | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Endosulfan II | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.39 |
| Methoxychlor | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | **2.08** | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 15.9 |
| Toxaphene | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Alpha-Chlordane | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Gamma-Chlordane | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | **3.85** | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 4.91 |
| Endrin aldehyde | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |
| Endosulfan sulfate | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 2.04 |
| Endrin ketone | 1.35U | 1.39U | 1.33U | 1.44U | 1.40U | 1.52U | 1.45U | 1.16U | 1.08U | 1.90U | 1.97U | 1.94U | 1.87U | 0.979U | 1.13U |

**TABLE 8. Results of bioassays on Lorain Harbor, Ohio sediments (EEI 2001; 2005). Boldfaced values indicate that harbor sediments did not meet Federal guidelines for open-lake placement.**

| Sediment sample | Bioassay | | |
|---|---|---|---|
| | *H. azteca* | *C. dilutus* | |
| | Survival (mean %) | Survival (mean %) | Growth (mean dry weight, mg) |
| **Harbor, LB-1*** | 94±8.9 | 88±13 | 1.68±0.30 |
| **Harbor, LB-2*** | 96±5.5 | 90±12.2 | 1.71±0.09 |
| **Harbor, LB-3*** | 100±0 | 92±11 | 1.81±0.14 |
| **Harbor, LB-4*** | 88±17.9 | 86±16.7 | 1.68±0.25 |
| **River, LRB-1**** | 86±5.1 | 72±10.2 | 1.37±0.13 |
| **River, LRB-2**** | 94±2.4 | 72±6.6 | 1.73±0.11 |
| **River, LRB-3**** | **70±10.5** | **68±5.8** | 1.86±0.20 |
| **Reference Area*** | 90±6.3 | 95±2.9 | 1.72±0.23 |
| **Disposal Area*** | 10±17.3 | 48±25.1 | 0.30±0.10 |
| **Control*** | 100±0 | 96±5.5 | 1.24±0.20 |
| **Control***** | 100±0 | 96±6 | 1.33±0.13 |

*2005 data.
**2001 data compared to 2005 open-lake reference area data.
***2001 data.

**TABLE 9. Results of Lorain Harbor (Black River Channel) sediment *C. dilutus* bioassay (from ASCi 2006a). Boldfaced values indicate that harbor sediments did not meet Federal guidelines for open-lake placement.**

| Sediment sample | Measurement endpoint | |
|---|---|---|
| | Survival (mean %) | Growth (mean dry weight, mg) |
| **LRB-1** | 80±8.4 | 2.16±0.23 |
| **LRB-2** | 80±5.5 | 1.71±0.25 |
| **LRB-3** | **18±15.6** | **1.25±0.28** |
| **Reference Area** | 80±5.5 | 2.09±0.09 |
| **Control** | 84±8.9 | 1.37±0.06 |

**TABLE 10. Bulk PAH analyses of Outer Harbor sediments, Lorain Harbor, Ohio. Boldfaced values indicate concentrations that exceed open-lake reference area levels (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit)**

| PAHs (µg/kg) | Outer Harbor Sediments | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | | | | | | | | |
| | LH-1 | LH-2 | LH-3 | LH-4 | LH-5 | LH-6 | LH-7 | LH-8 | LH-9 | LH-10 | LH-11 |
| Acenaphthene | 7.85 | **20.2** | **11.6** | 5.75U | **9.3** | **27.5** | **9.72** | **27.6** | 7.54 | 5.42U | **38.9** |
| Acenaphthylene | **25.8** | **27.5** | **27.6** | 9.92 | 14.8 | **44.4** | **22.9** | **82.9** | **17.0** | 10.4 | **59.8** |
| Anthracene | **40.8** | **72.8** | **45.8** | **16.2** | **21.9** | **98.7** | **34.9** | **211** | **26.7** | 13.0 | **115** |
| Benzo(a)Anthracene | **127** | **146** | **130** | **52.7** | **89.9** | **248** | **110** | **439** | **87.7** | **43.9** | **375** |
| Benzo(a)Pyrene | **105** | **124** | **121** | **52.9** | **86.5** | **215** | **101** | **391** | **81.5** | 43.5 | **341** |
| Benzo(b)Fluoranthene | **143** | **185** | **176** | **75.0** | **159** | **283** | **131** | **469** | **102** | 59.7 | 515 |
| Benzo(g,h,i)Perylene | **51.2** | **71.7** | **65.8** | 33.0 | **75.5** | **176** | **75.4** | **258** | **58.5** | 33.0 | **275** |
| Benzo(k)Fluoranthene | **45.1** | **61.2** | **56.7** | **24.9** | **43.9** | **96.6** | **44.8** | **161** | **32.4** | 20.5 | **149** |
| Chrysene | **108** | **167** | **134** | **54.7** | **104** | **247** | **108** | **409** | **84.9** | 47.1 | **351** |
| Dibenzo(a,h)Anthracene | 27.7 | **33.6** | **35.6** | 20.4 | **33.2** | **56.7** | **30.7** | **90.9** | **30.3** | 18.8 | **76.8** |
| Fluoranthene | **224** | **357** | **255** | **104** | **184** | **545** | **223** | **775** | **178** | **92.8** | **692** |
| Fluorene | **12.6** | **34.4** | **17.0** | **7.39** | **13.2** | **47.6** | **13.0** | **51.0** | **10.9** | **7.17** | **45.2** |
| Indeno(1,2,3-c,d)Pyrene | **58.6** | **74.2** | **72.7** | 34.4 | **67.4** | **173** | **75.9** | **274** | **62.2** | 32.9 | **248** |
| Naphthalene | 15.6 | **35.4** | **31.0** | 15.0 | 18.1 | **59.3** | **22.2** | **56.4** | 16.1 | 12.2 | **24.2** |
| Phenanthrene | **85.9** | **193** | **110** | **43.7** | **87.2** | **270** | **93.3** | **346** | **78.5** | **39.3** | **409** |
| Pyrene | **133** | **213** | **157** | **64.6** | **170** | **307** | **129** | **434** | **105** | 56.0 | **601** |
| **TOTAL** | **1211** | **1816** | **1447** | **615** | **1178** | **2895** | **1225** | **4476** | **979** | **536** | **4316** |
| Naphthalene/total PAH (%) | 1.2 | 1.9 | 2.1 | 2.4 | 1.5 | 2.0 | 1.8 | 1.3 | 1.6 | 2.3 | 0.56 |
| Fluoranthene:pyrene | 1.7 | 1.7 | 1.6 | 1.6 | 1.1 | 1.8 | 1.7 | 1.8 | 1.7 | 1.6 | 1.2 |

**TABLE 11. Modified elutriate test results for metals on River Channel sediments, Lorain Harbor, Ohio (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit)**

| Metals (µg/L) | River Channel Sediments | | | | | |
|---|---|---|---|---|---|---|
| | Management Units | | | | | |
| | LRB-1 | | LRB-2 | | LRB-3 | |
| | total | filtered | total | filtered | total | filtered |
| Aluminum | 6720 | 281 | 8310 | 32.1 | 3760 | 139 |
| Antimony | 1.17 | 1.58 | 0.100U | 0.100U | 2.96 | 2.76 |
| Arsenic | 5.17 | 0.461 | 147 | 0.400U | 3.64 | 0.400U |
| Barium | 81.4 | 61.1 | 123 | 74.3 | 71.4 | 109 |
| Beryllium | 0.241 | 0.119U | 0.421 | 0.119U | 0.791 | 0.119 |
| Cadmium | 2.36 | 0.251 | 2.36 | 1.68U | 1.89 | 1.68 |
| Chromium | 14.6 | 4.71 | 17.8 | 2.91 | 19.6 | 1.84 |
| Cobalt | 4.46 | 2.67 | 7.44 | 2.58 | 0.701 | 1.19 |
| Copper | 14.3 | 3.35 | 24.1 | 2.56 | 17.8 | 3.74 |
| Iron | 8240 | 307 | 17600 | 78.6 | 3850 | 131 |
| Lead | 13.4 | 1.17U | 24.3 | 1.17U | 18.7 | 1.17U |
| Magnesium | 13100 | 11500 | 17500 | 15200 | 9660 | 9960 |
| Manganese | 742 | 135 | 1990 | 1030 | 341 | 98 |
| Mercury | 0.277 | 0.215 | 0.249 | 0.222 | 0.435 | 0.225 |
| Nickel | 11.9 | 3.78 | 15.3 | 3.71 | 10.1 | 1.91 |
| Selenium | 1.17U | 1.17U | 1.17U | 1.17U | 1.23 | 1.17U |
| Silver | 0.400U | 0.400U | 0.400U | 0.400U | 0.400U | 0.400U |
| Thallium | 0.601 | 0.491 | 0.481 | 0.301 | 5.87000 | 0.271 |
| Vanadium | 10.3 | 2.15 | 13.1 | 2.61 | 6.38 | 0.641 |
| Zinc | 50.3 | 12.2 | 97.1 | 5.15 | 114 | 6.69 |
| Misc (µg/L) | LRB-1 | | LRB-2 | | LRB-3 | |
| | total | filtered | total | filtered | total | filtered |
| Oil/Grease | 59.6 | 96.5 | 37.4 | 30.0U | 51.5 | 43.7 |
| Cyanide | 2.50U | 2.50U | 2.50U | 2.50U | 2.50U | 2.50U |
| Phosphorus | 160 | 30.0 | 380 | 50.0 | 80.0 | 20.0U |
| Ammonia | 10800 | 8760 | 9490 | 8960 | 3430 | 3500 |

**TABLE 12. Modified elutriate test results for PAHs on River Channel sediments, Lorain Harbor, Ohio (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit)**

| PAHs (µg/L) | River Channel Sediments | | | | | |
|---|---|---|---|---|---|---|
| | Management Units | | | | | |
| | LRB-1 | | LRB-2 | | LRB-3 | |
| | total | filtered | total | filtered | total | filtered |
| Acenaphthene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Acenaphthylene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Anthracene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Benzo(a)Anthracene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Benzo(a)Pyrene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Benzo(b)Fluoranthene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Benzo(g,h,i)Perylene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Benzo(k)Fluoranthene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Chrysene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Dibenzo(a,h)Anthracene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Fluoranthene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Fluorene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Indeno(1,2,3-c,d)Pyrene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Naphthalene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Phenanthrene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |
| Pyrene | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U | 0.200U |

**TABLE 13. Modified elutriate test results for PCBs on River Channel sediments, Lorain Harbor, Ohio (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit)**

| PCBs (µg/L) | River Channel Sediments | | | | | |
|---|---|---|---|---|---|---|
| | Management Units | | | | | |
| | LRB-1 | | LRB-2 | | LRB-3 | |
| | total | filtered | total | filtered | total | filtered |
| PCB-1016 | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U |
| PCB-1221 | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U |
| PCB-1232 | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U |
| PCB-1242 | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U |
| PCB-1248 | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U |
| PCB-1254 | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U |
| PCB-1260 | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U |
| PCB-1262 | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U | 0.500U |

**TABLE 14. Modified elutriate test results for pesticides on River Channel sediments, Lorain Harbor, Ohio (from EEI 2005). (NOTE: U=Not detected at or above the specified laboratory reporting limit)**

| Pesticides (µg/L) | River Channel Sediments | | | | | |
|---|---|---|---|---|---|---|
| | Management Units | | | | | |
| | LRB-1 | | LRB-2 | | LRB-3 | |
| | total | filtered | total | filtered | total | filtered |
| Alpha-BHC | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Beta-BHC | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Delta-BHC | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Gamma-BHC | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Heptachlor | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Aldrin | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Heptachlor Epoxide | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Endosulfan I | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Dieldrin | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| 4,4'-DDT | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| 4,4'-DDE | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| DDD | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Endrin | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Endosulfan II | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Methoxychlor | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Toxaphene | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Alpha-Chlordane | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Gamma-Chlordane | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Endrin aldehyde | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Endosulfan sulfate | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |
| Endrin ketone | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U | 0.100U |