UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

REPLY TO THE ATTENTION OF

FEB 01 2000

DE-9J

Mr. Hilton Frey, Manager
DuPont Specialty Chemicals
Corporate Remediation
6324 Fairview Road
Charlotte, North Carolina 28210

Re: EPA Comments
Sediment Characterization Study
DuPont - East Chicago, IN
IND 005 174 354

Dear Mr. Frey:

This letter is to inform you of the United States Environmental Protections Agency's (EPA) review of the Grand Calumet River Sediment Characterization Study (SCS), which was submitted to EPA by Exponent, Inc., in behalf of DuPont. The EPA has prepared and submitted comments to this report for your review.

After your review, please prepare a brief comment response letter. We can then schedule a conference call or meeting to discuss your responses in detail, if necessary. If you have any questions regarding these comments, please don't hesitate to call me at (312) 353-2720. Thank you for your cooperation in this matter.

US EPA RECORDS CENTER REGION 5
1003354

Sincerely yours,

Brian P. Freeman, Senior Chemist and Project Manager
Enforcement and Compliance Assurance Branch

cc: Frank Smith, DuPont

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U.S. EPA COMMENTS ON THE DRAFT SEDIMENT CHARACTERIZATION STUDY REPORT FOR THE DUPONT EAST CHICAGO FACILITY

The U.S. Environmental Protection Agency (EPA), Region 5 has received and reviewed the "Draft Sediment Characterization Study for the DuPont East Chicago Facility" prepared by Exponent, Inc., for E.I. DuPont de Nemours and Company (DuPont). In addition, the U.S. EPA reviewed the Draft DuPont Sediment Characterization Study (SCS), dated September 1999, to evaluate its technical adequacy and compliance with the applicable guidance and SCS Work Plan and to compare analytical results between DuPont and EPA split sediment samples that were collected from the Grand Calumet River (GCR) in October, 1998.

The following comments primarily focus on DuPont's physical and chemical data collected during the SCS, as well as an analytical data comparison between the sediment samples split between DuPont and EPA. DuPont provides sufficient information in the draft DuPont SCS report to accurately describe the environmental conditions that are present within the GCR.

GENERAL COMMENTS

1. DuPont should compare the draft SCS report analytical data with the Phase I Resource Conservation and Recovery Act facility investigation (RFI) data that will be collected over four quarters in 1999 and 2000 and discuss it in Phase I RFI report.

2. Throughout the draft SCS report, DuPont uses the "no-effect concentration" (NEC) calculated by Ingersoll and others (1996) as a means to evaluate the effects of sediment contaminants on ecological receptors. However, the use of

NEC concentrations to compare the effects of sediment contaminants within the GCR was not discussed in the approved SCS work plan. The use of NECs to evaluate exceedances of contaminants found in GCR sediment was not approved in that work plan, and as such, DuPont should provide justification on why NECs should be used for the ecological risk assessment associated with GCR sediments that are adjacent to DuPont.

3. DuPont should provide all laboratory quality assurance/quality control and data validation information for the SCS report.

4. In DuPont's SCS Work Plan, Appendix B, Page B-11, DuPont states that wetland Samples No. 1 and 2 will be analyzed for polynuclear aromatic hydrocarbons (PAH), pesticides, and polychlorinated biphenyls (PCB). However, DuPont did not provide this analytical data in the draft SCS report and it is unclear whether wetland samples were analyzed for PAHs, pesticides, and PCBs. DuPont should provide justification on why PAH, pesticide, and PCB analytical data for wetland Samples No. 1 and 2 were not included in the draft SCS report. In addition, GCR PCB methods have been refined somewhat in the last several months, such that interferences relating to oil and grease which previously caused excessive dilutions to be necessary (along with the subsequent elevated detection limits) have been greatly reduced by multiple treatments of sediment samples with sulfuric acid, in concert with florosil column cleanup.

SPECIFIC COMMENTS

1. **Section 2.4.1, Page 2-16, Paragraph 1**. DuPont states that their "outfalls account for approximately 50 percent of the organic nitrogen discharged to the river." DuPont should clarify this statement and provide data used to support its statement. Also, DuPont should identify the types and concentrations of organic nitrogen discharged to the GCR.

2. **Section 3.1, Page 3-3, Paragraph 1**. DuPont states that Industrial Disposal was located upstream of the facility, however, DuPont does not provide information as to what type

of industry that Industrial Disposal historically operated. DuPont should provide information, if available, on the type of business operations in which Industrial Disposal was engaged. If Industrial Disposal's operation is unknown, DuPont should clarify this information.

3. **Section 3.1, Page 3-3, Paragraph 3**. In Paragraph 3, DuPont discusses how maximum and average sediment loads were calculated to determine loading rates to the GCR. Specifically, DuPont states that "When an analyte was not detected, half the detection limit was used to calculate ... between these extremes." DuPont should provide a reference in the text that can be used to support its discussion on GCR loading rates.

4. **Tables 3-1, 3-2, and 3-5, Pages 3-4, 3-6, and 3-21, Respectively**. DuPont should provide a reference for the information presented in Tables 3-1, 3-2, and 3-5.

5. **Figures 3-1, 3-2, and 3-3**. DuPont should provide a reference for the information presented in Figures 3-1, 3-2, and 3-3.

6. **Page 3-24, Paragraph 1, Particulate (Sediment) Concentrations Table**. DuPont should provide a reference for the data presented in this table.

7. **Section 4.1.1.1, Page 4-10, Paragraph 0**. DuPont states that the "property on the south bank of the river adjacent to this transect was known for illegal dumping (Corps 1997)." DuPont should clarify and provide additional information on what type of illegal dumping activities occurred on the south bank near this transect, particularly, if the material present was a solid or hazardous waste, and if so, what variety(ies).

8. **Section 4.1.1.1, Page 4-17, Paragraph 0**. DuPont states that elevated lead concentrations in surface and near-surface sediments within the GCR appear to be associated with upstream sources and U.S.S. Lead, Inc. (USS Lead), which was downstream and adjacent to DuPont. DuPont has not provided sufficient information that would confirm this statement. If DuPont has references or a source for this information,

it should be provided. (ie. DuPont should provide additional information and references (such as historical sediment deposition rates or surface water chemical data) that would corroborate the statement that recent lead contamination of sediments is from an off-site source.

9. **Section 4.1.1.1, Page 4-18, Paragraph 2**. DuPont states that "zinc concentrations throughout the study area are attributable to the historical and ongoing sources from regional sources." Although this may be an accurate statement, DuPont, as referenced in the RFI and SCS work plans was also a historical contributor of zinc to the GCR. DuPont should acknowledge this fact, due to their referenced production of zinc ammonium chloride, chromated zinc chloride, zinc chloride, and zinc ore from 1902 to 1969.

10. **Section 4.1.2, Page 4-27, Paragraph 1**. DuPont uses the NEC calculated by Ingersoll and others (1996) for the *Hyallela azteca* bioassay, using nationwide data to compare metal, PAH, and PCB concentrations. The use of NECs may be acceptable by EPA, however, this was not approved by the EPA in the SCS work plan. DuPont should review the SCS work plan and provide justification for using NECs. In addition, DuPont should submit a copy of the Ingersoll and others (1996) article and corresponding NEC values that are discussed in the text and are presented in Tables 4-1 through 4-3 (see General Comment No. 2).

11. **Tables 4-1 and 4-2, Pages 4-28, 4-29, and 4-30**. DuPont should provide information or a reference on how NEC values for metals and PAHs presented in Tables 4-1 and 4-2 were derived (see Specific Comment 10).

12. **Table 4-4, Page 4-34**. DuPont should provide a reference for the data presented in Table 4-4.

13. **Section 4.2, Page 4-40, Paragraph 1**. DuPont states that "Until onsite mapping is possible, the NWI as modified by current aerial photography (shown in Figure 4-10) will have to be considered the best source of information on the extent of wetlands in the study area." DuPont should clarify whether it intends to conduct an on-site mapping

study of DuPont's wetlands.

14. **Section 4.3.2, Page 4-56, Paragraphs 1 through 3**. DuPont states that "Trophic state was assessed... in September 1998, so a TSI value cannot be calculated." In Section 2.4.1, Page
2-16, the text mentions that 50 percent of the organic nitrogen discharged to the GCR comes from DuPont's outfalls. DuPont does not provide a discussion on what happens to the GCR when DuPont's organic nitrogen discharge and the existing total phosphorous load in the GCR are combined. DuPont should provide information in Sections 4.3.2 and 6.8 on what the synergistic effect could be when organic nitrogen is discharged to the GCR, when total phosphorous is already present in quantities that can cause eutrophication or deplete oxygen.

15. **Section 4.4, Page 4-61, Bullet No. 1**. On Page 4-61, DuPont states that localized, subsurface sediment deposits of characteristically high levels of lead and mercury are present at Transects I and J. DuPont also states that elevated concentrations of mercury and lead are present in sub-surface sediments at Transects E and F and states that these levels may be attributable to DuPont's historical discharges. However, it is reasonable to conclude that contaminants at Transects I and J could also be attributable to DuPont's historical discharges. DuPont needs to provide more conclusive evidence to support the supposition that contamination of Transects I and J were largely not attributable to their own processes, or they should acknowledge that subsurface contamination at Transects I and J may also be attributable to DuPont.

16. **Section 5.4, Pages 5-10 and 5-11**. DuPont discusses sediment resuspension and entrainment in great detail, however, there is little or no technical discussion is provided in the SCS report text on actual sediment deposition rates that can be used to evaluate the historical deposition timeframe of contaminants. In addition, Section 5.5, Page 5-14 supports this comment, because DuPont states that "This difficulty points to the need for a better understanding of the potential for sediment resuspension and erosion at this site, which of necessity must be achieved experimentally

with these sediments." Therefore, DuPont should provide historical GCR information, if available, to determine sediment deposition rates. DuPont should also consider performing an experiment to determine GCR sediment deposition, resuspension, and erosion rates.

SPLIT-SAMPLE DATA COMPARISON SUMMARY BETWEEN EPA AND DUPONT SEDIMENT ANALYTICAL RESULTS

Table 1 presents analytical data comparison for metals, acid volatile sulfides, and simultaneously extracted metals (SEM). Table 2 presents the analytical data comparison for benzene, toluene, ethyl benzene, and xylenes (BTEX); PAHs; organochlorine pesticides; PCBs; and chlorinated herbicides. The deep core sediment sample at transect D, Station M was not analyzed for organic compounds.

Analytical data from both DuPont and EPA are generally comparable, except for the following analytes:

- Metals - for cadmium and molybdenum (see Table 1), the difference between EPA's and DuPont's three split samples varied between 3 to 10 times.
- SEM - for SEM mercury (see Table 1), the difference between the EPA and DuPont split sample, at Transect I, Station N (I-N), is 5 times.
- PAHs - for PAHs (see Table 2), the difference between EPA's and DuPont's two split samples (I-N and W-2) varies between 3 and 50 times.
- Organochlorine pesticides - Except for 4,4'-dichlorophenyldichloroethane (4,4'-DDD), no difference between the I-N split sediment sample is evident,

because organochlorine pesticides were not detected in either sample. EPA found 12.0J micrograms per kilogram (μg/kg) of 4,4'-DDD in the split sample; however, DuPont's 4,4'-DDD results for the split sample was less than the laboratory method detection limit (MDL). DuPont did not report organochlorine pesticide data for wetland Sample No. 002.

- PCBs - for PCBs (see Table 2), no difference between the I-N split sediment samples is evident because PCBs were not detected in either sample. DuPont did not report PCB data for wetland Sample No. 002.

- Chlorinated herbicide - 2,4-D was the only herbicide analyzed by EPA and DuPont. Both split samples were reported less than the MDL.

Except for the variations in PAH data, the analytical data indicate that sediment sample splits between EPA and DuPont were homogeneous; however an inference on variations in PAH data or statistical analysis from sample to sample cannot be made because DuPont's validated results and QA/QC data package were not included in the draft SCS report.

TABLE 1

TOTAL METAL, ACID VOLATILE SULFIDE, AND SIMULTANEOUSLY EXTRACTED METAL RESULTS FOR EPA AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES

Sediment Sample Location	Transect I, Station North	Transect D, Station Middle	W-2	Transect I, Station North	Transect D, Station Middle	W-2	W-2 Field Duplicate
Sediment Type	Shallow Core (10 to 20 cm)	Deep Core (upper horizon)	Wetland	Shallow Core (10 to 20 cm)	Deep Core (upper horizon)	Wetland	Wetland
Date Collected	10/05/98	10/02/98	10/07/98	10/05/98	10/02/98	10/07/98	10/07/98
	EPA Analytical Results			DuPont Analytical Results			
Total Metals (mg/kg)							
Antimony	25.6	1.3U	6.0U	28U	1.60J	2.60U	5.10U
Arsenic	310	7.9	28.7	310	5.8	29.1	28.9
Cadmium	30.8	0.70	2.7	3.40UR	0.066UR	0.310UJ	0.320UJ
Chromium	267	90.3	260	299	86	295	277
Copper	296	76.6	180	357	52.9J	209	207
Lead	3,330	112	524	3,200	103	605	553
Magnesium	3,840	3,100	4,250	4,410	3,860	5,650	5,120
Mercury	5.1	0.21	0.60U	6.1J	0.20J	0.532U	0.680U
Molybdenum	16.2	6.6U	30U	16	2.21U	20.4	19.9
Nickel	52.5	24.8	52.9	59	24.1	68	61.7
Silver	10.2	0.92	3.0U	14U	0.79U	3.1	3.0
Vanadium	59.2	6.6U	49.8	63J	5.46	56.1	52
Zinc	6,230	773	1,800	7,770	622	2,110J	2,000J
Acid Volatile Sulfides (mg/kg)							
Sulfide	2,870	NA	38J	1,810J	NA	33UJ	34UJ
Simultaneously Extracted Metals (mg/kg)							

TABLE 1

TOTAL METAL, ACID VOLATILE SULFIDE, AND SIMULTANEOUSLY EXTRACTED METAL RESULTS FOR EPA AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES (Continued)

Sediment Sample Location	**Transect I, Station North**	**Transect D, Station Middle**	**W-2**	**Transect I, Station North**	**Transect D, Station Middle**	**W-2**	**W-2 Field Duplicate**
Sediment Type	**Shallow Core (10 to 20 cm)**	**Deep Core (upper horizon)**	**Wetland**	**Shallow Core (10 to 20 cm)**	**Deep Core (upper horizon)**	**Wetland**	**Wetland**
Date Collected	10/05/98	10/02/98	10/07/98	10/05/98	10/02/98	10/07/98	10/07/98
	EPA Analytical Results			**DuPont Analytical Results**			
Arsenic	46	NA	17J	NR	NA	NR	NA
Cadmium	35.5	NA	2.8	27.3J	NA	2.9J	NA
Chromium	116	NA	83	NR	NA	NR	NA
Copper	104	NA	174	151	NA	189	NA
Lead	2,180	NA	693J	1,542	NA	515	NA
Mercury	0.01	NA	ND	0.002U	NA	0.015J	NA
Nickel	ND	NA	31	14.6J	NA	35.9	NA
Zinc	5,310	NA	1,520J	4,139	NA	1,504	NA

Reference: **EPA Contractor**, Tetra Tech EM Inc. 1998. "Data Validation Results for Sediment Samples Collected at E.I. DuPont deNemours and Company Chemical Manufacturing Plant." Submitted to U.S. Environmental Protection Agency, Region 5. EPA Contract No. 68-W4-0007, Work Assignment No. R05013. December 18.

Notes:

cm = Centimeter

J = Concentration is estimated because it is below the reporting limit or for quality control reasons

TABLE 1

TOTAL METAL, ACID VOLATILE SULFIDE, AND SIMULTANEOUSLY EXTRACTED METAL RESULTS FOR EPA AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES (Continued)

mg/kg = Milligrams per kilogram
ND = Not detected (detection limits are shown on analytical sheets in the appendix)
NA = Not analyzed
UJ = Target analyte was not detected; detection limit is estimated for quality control reasons

TABLE 2

ORGANIC RESULTS FOR EPA AND DUPONT COMPANY
SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES

Sample Location	Transect I, Station North	W-2	Transect I, Station North	W-2
Sediment Type	**Shallow Core (10 to 20 cm)**	**Wetland**	**Shallow Core (10 to 20 cm)**	**Wetland**
Date Collected	10/05/98	10/07/98	10/05/98	10/07/98
	EPA Analytical Results		**DuPont Analytical Results**	
Benzene, Toluene, Ethylbenzene, and Xylene (μg/kg)				
Benzene	660U	49UJ	7J	9U
Toluene	660U	49UJ	6J	9U
Ethylbenzene	660U	49UJ	6J	9U
Xylene	660U	49UJ	18	9U
Polynuclear Aromatic Hydrocarbons and Phenols (μg/kg)				
Acenaphthene	4,600J	260J	13,000	NR
Anthracene	7,000J	2,000U	22,000	NR
Benzo(a)anthracene	11,000J	500J	36,000	NR
Benzo(a)pyrene	5,800J	820J	19,000	NR
Benzo(b)fluoranthene	7,100J	1,100J	25,000	NR
Benzo(g,h,i)perylene	3,600J	770J	8,800	NR
Benzo(k)fluoranthene	1,800J	370J	5,100	NR
Chrysene	25,000	730J	79,000	NR
Dibenzo(a,h)anthracene	11,000U	2,000U	3,800J	NR
Fluoranthene	16,000	980J	50,000	NR
Fluorene	13,000	230J	23,000	NR
Indeno(1,2,3-c,d)pyrene	2,500J	690J	6,700	NR
2-Methynaphthalene	11,000U	240J	3,400J	NR
Naphthalene	1,300J	410J	3,800J	NR
Phenanthrene	73,000	600J	230,000	NR
Pyrene	31,000	840J	95,000	NR
4-Chloro-3-methylphenol	11,000U	2,000U	450U	NR
2-Chlorophenol	11,000U	2,000U	450U	NR
Dibenzofuran	11,000U	370J	1300J	NR
2,4-Dichlorophenol	11,000U	2,000U	900U	NR
2,6-Dichlorophenol	11,000U	2,000U	NR	NR
4,6-Dinitro-2-methylphenol	27,000U	5,000U	2,200U	NR
2,4-Dinitrophenol	27,000U	5,000U	2,700UJ	NR
Isophorone	11,000U	2,000U	NR	NR
2-Methylphenol	11,000U	2,000U	450U	NR
2-Nitrophenol	11,000U	2,000U	450U	NR
4-Nitrophenol	27,000U	5,000U	2,200U	NR

TABLE 2 (Continued)

ORGANIC RESULTS FOR EPA AND DUPONT COMPANY
SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES

Sample Location	Transect I, Station North	W-2	Transect I, Station North	W-2
Sediment Type	**Shallow Core (10 to 20 cm)**	**Wetland**	**Shallow Core (10 to 20 cm)**	**Wetland**
Date Collected	10/05/98	10/07/98	10/05/98	10/07/98
	EPA Analytical Results		**DuPont Analytical Results**	
Pentachlorophenol	11,000U	2,000U	2,200U	NR
Phenol	11,000U	2,000U	1,480J	NR
2,4,5-Trichlorophenol	11,000U	2,000U	900U	NR
2,4,6-Trichlorophenol	11,000U	2,000U	900U	NR
3- and 4-Methylphenol	11,000U	2,000U	900U	NR
Organochlorine Pesticides (μg/kg)				
4,4'-DDD	12J	10U	35UJ	NR
4,4'-DDE	4.5U	10U	35U	NR
4,4'-DDT	4.5U	12	35U	NR
alpha-BHC	4.5U	10U	18U	NR
beta-BHC	4.5U	10U	18U	NR
delta-BHC	4.5U	10U	18U	NR
gamma-BHC (Lindane)	4.5U	10U	18U	NR
Heptachlor	4.5U	10U	18U	NR
Aldrin	4.5U	10U	18U	NR
Heptachlor Epoxide	4.5U	10U	18U	NR
Organochlorine Pesticides (μg/kg) (Continued)				
Endosulfan I	4.5U	10U	18U	NR
Dieldrin	4.5U	10U	35U	NR
Endrin	4.5U	10U	35U	NR
Endosulfan II	4.5U	10U	35U	NR
Endosulfan Sulfate	4.5U	10U	35U	NR
Methoxychlor	8.7U	20U	180U	NR
Endrin Aldehyde	4.5U	10U	35U	NR
alpha-Chlordane	4.5U	10U	18U	NR
gamma-Chlordane	4.5U	10U	56R	NR
Toxaphene	180U	400U	1,800U	NR
Polychlorinated Biphenyls (μg/kg)				
Arochlor 1016	87U	200U	890U	NR
Arochlor 1221	87U	200U	890U	NR
Arochlor 1232	87U	200U	890U	NR
Arochlor 1242	87U	200U	890U	NR
Arochlor 1248	87U	1,100	890U	NR
Arochlor 1254	87U	590	890U	NR
Arochlor 1260	87U	200U	890U	NR

TABLE 2 (Continued)

ORGANIC RESULTS FOR EPA AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES

Sample Location	**Transect I, Station North**	**W-2**	**Transect I, Station North**	**W-2**
Sediment Type	**Shallow Core (10 to 20 cm)**	**Wetland**	**Shallow Core (10 to 20 cm)**	**Wetland**
Date Collected	10/05/98	10/07/98	10/05/98	10/07/98
	EPA Analytical Results		**DuPont Analytical Results**	
Chlorinated Herbicides (μg/kg)				
2,4-Dichlorophenoxyacetic acid	NA	80U	NR	200U and 210U (duplicate)

Reference: **EPA Contractor**, Tetra Tech 1998.

Notes:

J = Concentration is estimated because it is below the reporting limit or for quality control reasons
NA = Not analyzed
NR = Not reported
R = Data rejected
μg/kg = Micrograms per kilogram
U = Target analyte was not detected
UJ = Target analyte was not detected; detection limit is estimated for quality control reasons

REFERENCE

EPA Contractor, Tetra Tech EM Inc. 1998. "Data Validation Results for Sediment Samples Collected at E.I. DuPont deNemours and Company Chemical Manufacturing Plant." Submitted to U.S. Environmental Protection Agency (EPA), Region 5. EPA Contract No. 68-W4-0007, Work Assignment No. R05013. December 18.

Tetra Tech EM Inc.

200 E. Randolph Drive, Suite 4700 ◆ Chicago, IL 60601 ◆ (312) 856-8700 ◆ FAX (312) 938-0118

November 17, 1999

Mr. Allen Wojtas
Work Assignment Manager/Technical Advisor
U.S. Environmental Protection Agency Region 5
Enforcement and Compliance Assurance Branch (DE-9J)
77 West Jackson Boulevard
Chicago, IL 60604

Subject: **Technical Review Comments for the Draft Sediment Characterization Study and Split-Sample Data Comparison Summary for the DuPont East Chicago Facility Contract No. 68-W-99-018, Work Assignment No. R05805**

Dear Mr. Wojtas:

Tetra Tech EM Inc. (Tetra Tech) has reviewed the E.I. duPont de Nemours and Company (DuPont) "Draft Sediment Characterization Study" of the Grand Calumet River located in East Chicago, Indiana. An electronic copy of our review comments formatted in WordPerfect 6.1 has been sent to you by e-mail. The enclosed hard copy of the comments constitutes Tetra Tech's official deliverable.

If you have any questions regarding Tetra Tech's comments, please call me at (312) 856-8765 or Kurt Whitman at (414) 821-5894.

Sincerely,

Mary Wojciechowski
Project Manager

Enclosure

cc: Bernie Orenstein, EPA Regional Project Officer (letter only)
Edward Schuessler, Tetra Tech Regional Manager (letter only)
Art Glazer, Tetra Tech Program Manager
Kurt Whitman, Tetra Tech Site Manager

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TECHNICAL REVIEW COMMENTS ON THE DRAFT SEDIMENT CHARACTERIZATION STUDY REPORT FOR THE DUPONT EAST CHICAGO FACILITY

Under Contract No. 68-W-99-018, Work Assignment No. R05805, Tetra Tech EM Inc. (Tetra Tech) was tasked to technically review the "Draft Sediment Characterization Study for the DuPont East Chicago Facility" prepared by Exponent, Inc., for E.I. duPont de Nemours and Company (DuPont). Tetra Tech reviewed the Draft DuPont Sediment Characterization Study (SCS), dated September 1999, to evaluate its technical adequacy and compliance with the applicable U.S. Environmental Protection Agency (EPA) guidance and SCS Work Plan and to compare analytical results between DuPont and EPA split sediment samples that were collected from the Grand Calumet River (GCR) last October 1998.

Tetra Tech's technical review comments focus on DuPont's physical and chemical data collected during the SCS. DuPont provides sufficient information in the draft DuPont SCS report to accurately describe the environmental conditions that are present within the GCR. Tetra Tech's general and specific review comments are presented below, as well as an analytical data comparison between the sediment samples split between DuPont and EPA.

GENERAL COMMENTS

1. DuPont should compare the draft SCS report analytical data with the Phase I Resource Conservation and Recovery Act facility investigation (RFI) data that will be collected over four quarters in 1999 and 2000 and discuss it in Phase I RFI report.

2. Throughout the draft SCS report, DuPont uses the "no-effect concentration" (NEC) calculated by Ingersoll and others (1996) as a means to evaluate the effects of sediment contaminants on ecological receptors. However, the use of NEC concentrations to compare the effects of sediment contaminants within the GCR was not discussed in the EPA-approved SCS work plan. In addition, EPA did not approve the use of NECs to evaluate exceedances of contaminants found in GCR sediment. DuPont should provide justification to EPA on why NECs should be used for the ecological risk assessment associated with GCR sediments that are adjacent to DuPont.

3. DuPont should provide all laboratory quality assurance/quality control and data validation information for the SCS report.

4. In DuPont's SCS Work Plan, Appendix B, Page B-11, DuPont states that wetland Samples No. 1 and 2 will be analyzed for polynuclear aromatic hydrocarbons (PAH), pesticides, and polychlorinated biphenyls (PCB). However, DuPont did not provide this analytical data in the

draft SCS report and it is unclear whether wetland samples were analyzed for PAHs, pesticides, and PCBs. DuPont should provide justification on why PAH, pesticide, and PCB analytical data for wetland Samples No. 1 and 2 were not included in the draft SCS report.

SPECIFIC COMMENTS

1. **Section 2.4.1, Page 2-16, Paragraph 1**. DuPont states that their "outfalls account for approximately 50 percent of the organic nitrogen discharged to the river." DuPont should clarify this statement and provide data used to support its statement. Also, DuPont should identify the types and concentrations of organic nitrogen discharged to the GCR.

2. **Section 3.1, Page 3-3, Paragraph 1**. DuPont states that Industrial Disposal was located upstream of the facility, however, DuPont does not provide information as to what type of industry that Industrial Disposal historically operated. DuPont should provide information, if available, on the type of business operations in which Industrial Disposal was engaged. If Industrial Disposal's operation is unknown, DuPont should clarify this information.

3. **Section 3.1, Page 3-3, Paragraph 3**. In Paragraph 3, DuPont discusses how maximum and average sediment loads were calculated to determine loading rates to the GCR. Specifically, DuPont states that "When an analyte was not detected, half the detection limit was used to calculate ... between these extremes." DuPont should provide a reference in the text that can be used to support its discussion on GCR loading rates.

4. **Tables 3-1, 3-2, and 3-5, Pages 3-4, 3-6, and 3-21, Respectively**. DuPont should provide a reference for the information presented in Tables 3-1, 3-2, and 3-5.

5. **Figures 3-1, 3-2, and 3-3**. DuPont should provide a reference for the information presented in Figures 3-1, 3-2, and 3-3.

6. **Page 3-24, Paragraph 1, Particulate (Sediment) Concentrations Table**. DuPont should provide a reference for the data presented in this table.

7. **Section 4.1.1.1, Page 4-10, Paragraph 0**. DuPont states that the "property on the south bank of the river adjacent to this transect was known for illegal dumping (Corps 1997)." DuPont should clarify and provide additional information on what type of illegal dumping activities occurred on the south bank near this transect, particularly, if the material present was a solid or hazardous waste.

8. **Section 4.1.1.1, Page 4-17, Paragraph 0**. DuPont states that elevated lead concentrations in surface and near-surface sediments within the GCR appear to be associated with upstream sources and U.S.S. Lead, Inc. (USS Lead), which was downstream and adjacent to DuPont. This statement is misleading, because DuPont has not provided information that would confirm its belief that lead-contaminated surface and subsurface sediments are from upstream and USS Lead sources.

   DuPont also states in Section 5.5, Page 5-13, that it needs a better understanding to quantify

sediment entrainment. DuPont should provide additional information and references (such as historical sediment deposition rates or surface water chemical data) that would corroborate their belief that recent lead contamination of sediments is from an off-site source.

9. **Section 4.1.1.1, Page 4-18, Paragraph 2**. DuPont states that "zinc concentrations throughout the study area are attributable to the historical and ongoing sources from regional sources." Even though this statement is true, DuPont was also a historical contributor of zinc to the GCR. DuPont should acknowledge this fact, because DuPont produced zinc ammonium chloride, chromated zinc chloride, zinc chloride, and zinc ore from 1902 to 1969.

10. **Section 4.1.2, Page 4-27, Paragraph 1**. DuPont uses the NEC calculated by Ingersoll and others (1996) for the *Hyallela azteca* bioassay, using nationwide data to compare metal, PAH, and PCB concentrations. The use of NECs may be acceptable by EPA, however, this was not discussed in the SCS work plan. DuPont should review the SCS work plan and provide justification for using NECs. In addition, DuPont should submit a copy of the Ingersoll and others (1996) article and corresponding NEC values that are discussed in the text and are presented in Tables 4-1 through 4-3 (see General Comment No. 2).

11. **Tables 4-1 and 4-2, Pages 4-28, 4-29, and 4-30**. DuPont should provide information or a reference on how NEC values for metals and PAHs presented in Tables 4-1 and 4-2 were derived (see Specific Comment 10).

12. **Table 4-4, Page 4-34**. DuPont should provide a reference for the data presented in Table 4-4.

13. **Section 4.2, Page 4-40, Paragraph 1**. DuPont states that "Until onsite mapping is possible, the NWI as modified by current aerial photography (shown in Figure 4-10) will have to be considered the best source of information on the extent of wetlands in the study area." DuPont should clarify whether it intends to conduct an on-site mapping study of DuPont's wetlands.

14. **Section 4.3.2, Page 4-56, Paragraphs 1 through 3**. DuPont states that "Trophic state was assessed... in September 1998, so a TSI value cannot be calculated." In Section 2.4.1, Page 2-16, the text mentions that 50 percent of the organic nitrogen discharged to the GCR comes from DuPont's outfalls. DuPont does not provide a discussion on what happens to the GCR when DuPont's organic nitrogen discharge and the existing total phosphorous load in the GCR are combined. DuPont should provide information in Sections 4.3.2 and 6.8 on what the synergistic effect could be when organic nitrogen is discharged to the GCR, when total phosphorous is already present in quantities that can cause eutrophication or deplete oxygen.

15. **Section 4.4, Page 4-61, Bullet No. 1**. On Page 4-61, DuPont states that localized, subsurface sediment deposits of characteristically high levels of lead and mercury are present at Transects I and J. DuPont also states that elevated concentrations of mercury and lead are present in sub-surface sediments at Transects E and F and states that these levels may be attributable to DuPont's historical discharges. However, contaminants at Transects I and J could also be attributable to DuPont's historical discharges. In addition, DuPont's assertion that the subsurface deposits of lead and mercury from U.S.S. Lead's operation is plausible, however, DuPont did not provide conclusive evidence to support this supposition. Therefore, DuPont

should acknowledge that subsurface contamination at Transects I and J may also be attributable to DuPont.

16. **Section 5.4, Pages 5-10 and 5-11**. DuPont discusses sediment resuspension and entrainment in great detail, however, no technical discussion is provided in the SCS report text on actual sediment deposition rates that can be used to evaluate the historical deposition timeframe of contaminants. In addition, Section 5.5, Page 5-14 supports this comment, because DuPont states that "This difficulty points to the need for a better understanding of the potential for sediment resuspension and erosion at this site, which of necessity must be achieved experimentally with these sediments." Therefore, DuPont should provide historical GCR information, if available, to determine sediment deposition rates. DuPont should also consider performing an experiment to determine GCR sediment deposition, resuspension, and erosion rates.

SPLIT-SAMPLE DATA COMPARISON SUMMARY BETWEEN TETRA TECH AND DUPONT SEDIMENT ANALYTICAL RESULTS

Table 1 presents analytical data comparison for metals, acid volatile sulfides, and simultaneously extracted metals (SEM). Table 2 presents the analytical data comparison for benzene, toluene, ethyl benzene, and xylenes (BTEX); PAHs; organochlorine pesticides; PCBs; and chlorinated herbicides. The deep core sediment sample at transect D, Station M was not analyzed for organic compounds.

Tetra Tech and DuPont's analytical data are generally comparable, except for the following analytes:

- Metals - for cadmium and molybdenum (see Table 1), the difference between Tetra Tech and DuPont's three split samples varied between 3 to 10 times.
- SEM - for SEM mercury (see Table 1), the difference between the Tetra Tech and DuPont split sample, at Transect I, Station N (I-N), is 5 times.
- PAHs - for PAHs (see Table 2), the difference between Tetra Tech and DuPont's two split samples (I-N and W-2) varies between 3 and 50 times.
- Organochlorine pesticides - Except for 4,4'-dichlorophenyldichloroethane (4,4'-DDD), no difference between the I-N split sediment sample is evident, because organochlorine pesticides were not detected in either sample. Tetra Tech found 12.0J micrograms per kilogram (μg/kg) of 4,4'-DDD in the split sample; however, DuPont's 4,4'-DDD results for the split sample was less than the laboratory method detection limit (MDL). DuPont did not report organochlorine pesticide data for wetland Sample No. 002.
- PCBs - for PCBs (see Table 2), no difference between the I-N split sediment samples is evident because PCBs were not detected in either sample. DuPont did not report PCB data for wetland Sample No. 002.

- Chlorinated herbicide - 2,4-D was the only herbicide analyzed by Tetra Tech and DuPont. Both split samples were reported less than the MDL.

Except for the variations in PAH data, the analytical data indicate that sediment sample splits between Tetra Tech and DuPont were homogeneous; however an inference on variations in PAH data or statistical analysis from sample to sample cannot be made because DuPont's validated results and QA/QC data package were not included in the draft SCS report.

TABLE 1

TOTAL METAL, ACID VOLATILE SULFIDE, AND SIMULTANEOUSLY EXTRACTED METAL RESULTS FOR TETRA TECH EM INC. AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES

Sediment Sample Location	**Transect I, Station North**	**Transect D, Station Middle**	**W-2**	**Transect I, Station North**	**Transect D, Station Middle**	**W-2**	**W-2 Field Duplicate**
Sediment Type	**Shallow Core (10 to 20 cm)**	**Deep Core (upper horizon)**	**Wetland**	**Shallow Core (10 to 20 cm)**	**Deep Core (upper horizon)**	**Wetland**	**Wetland**
Date Collected	10/05/98	10/02/98	10/07/98	10/05/98	10/02/98	10/07/98	10/07/98
	Tetra Tech Analytical Results			**DuPont Analytical Results**			
Total Metals (mg/kg)							
Antimony	25.6	1.3U	6.0U	28U	1.60J	2.60U	5.10U
Arsenic	310	7.9	28.7	310	5.8	29.1	28.9
Cadmium	30.8	0.70	2.7	3.40UR	0.066UR	0.310UJ	0.320UJ
Chromium	267	90.3	260	299	86	295	277
Copper	296	76.6	180	357	52.9J	209	207
Lead	3,330	112	524	3,200	103	605	553
Magnesium	3,840	3,100	4,250	4,410	3,860	5,650	5,120
Mercury	5.1	0.21	0.60U	6.1J	0.20J	0.532U	0.680U
Molybdenum	16.2	6.6U	30U	16	2.21U	20.4	19.9
Nickel	52.5	24.8	52.9	59	24.1	68	61.7
Silver	10.2	0.92	3.0U	14U	0.79U	3.1	3.0
Vanadium	59.2	6.6U	49.8	63J	5.46	56.1	52
Zinc	6,230	773	1,800	7,770	622	2,110J	2,000J
Acid Volatile Sulfides (mg/kg)							
Sulfide	2,870	NA	38J	1,810J	NA	33UJ	34UJ
Simultaneously Extracted Metals (mg/kg)							
Arsenic	46	NA	17J	NR	NA	NR	NA
Cadmium	35.5	NA	2.8	27.3J	NA	2.9J	NA
Chromium	116	NA	83	NR	NA	NR	NA

TABLE 1

TOTAL METAL, ACID VOLATILE SULFIDE, AND SIMULTANEOUSLY EXTRACTED METAL RESULTS FOR TETRA TECH EM INC. AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES (Continued)

Sediment Sample Location	**Transect I, Station North**	**Transect D, Station Middle**	**W-2**	**Transect I, Station North**	**Transect D, Station Middle**	**W-2**	**W-2 Field Duplicate**
Sediment Type	**Shallow Core (10 to 20 cm)**	**Deep Core (upper horizon)**	**Wetland**	**Shallow Core (10 to 20 cm)**	**Deep Core (upper horizon)**	**Wetland**	**Wetland**
Date Collected	10/05/98	10/02/98	10/07/98	10/05/98	10/02/98	10/07/98	10/07/98
	Tetra Tech Analytical Results			**DuPont Analytical Results**			
Copper	104	NA	174	151	NA	189	NA
Lead	2,180	NA	693J	1,542	NA	515	NA
Mercury	0.01	NA	ND	0.002U	NA	0.015J	NA
Nickel	ND	NA	31	14.6J	NA	35.9	NA
Zinc	5,310	NA	1,520J	4,139	NA	1,504	NA

Reference: Tetra Tech EM Inc. 1998. "Data Validation Results for Sediment Samples Collected at E.I. DuPont deNemours and Company Chemical Manufacturing Plant." Submitted to U.S. Environmental Protection Agency, Region 5. EPA Contract No. 68-W4-0007, Work Assignment No. R05013. December 18.

Notes:

cm = Centimeter
J = Concentration is estimated because it is below the reporting limit or for quality control reasons
mg/kg = Milligrams per kilogram
ND = Not detected (detection limits are shown on analytical sheets in the appendix)
NA = Not analyzed
UJ = Target analyte was not detected; detection limit is estimated for quality control reasons

TABLE 2

ORGANIC RESULTS FOR TETRA TECH EM INC. AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES

Sample Location	Transect I, Station North	W-2	Transect I, Station North	W-2
Sediment Type	**Shallow Core (10 to 20 cm)**	**Wetland**	**Shallow Core (10 to 20 cm)**	**Wetland**
Date Collected	10/05/98	10/07/98	10/05/98	10/07/98
	Tetra Tech Analytical Results		**DuPont Analytical Results**	
Benzene, Toluene, Ethylbenzene, and Xylene (μg/kg)				
Benzene	660U	49UJ	7J	9U
Toluene	660U	49UJ	6J	9U
Ethylbenzene	660U	49UJ	6J	9U
Xylene	660U	49UJ	18	9U
Polynuclear Aromatic Hydrocarbons and Phenols (μg/kg)				
Acenaphthene	4,600J	260J	13,000	NR
Anthracene	7,000J	2,000U	22,000	NR
Benzo(a)anthracene	11,000J	500J	36,000	NR
Benzo(a)pyrene	5,800J	820J	19,000	NR
Benzo(b)fluoranthene	7,100J	1,100J	25,000	NR
Benzo(g,h,i)perylene	3,600J	770J	8,800	NR
Benzo(k)fluoranthene	1,800J	370J	5,100	NR
Chrysene	25,000	730J	79,000	NR
Dibenzo(a,h)anthracene	11,000U	2,000U	3,800J	NR
Fluoranthene	16,000	980J	50,000	NR
Fluorene	13,000	230J	23,000	NR
Indeno(1,2,3-c,d)pyrene	2,500J	690J	6,700	NR
2-Methynaphthalene	11,000U	240J	3,400J	NR
Naphthalene	1,300J	410J	3,800J	NR
Phenanthrene	73,000	600J	230,000	NR
Pyrene	31,000	840J	95,000	NR
4-Chloro-3-methylphenol	11,000U	2,000U	450U	NR
2-Chlorophenol	11,000U	2,000U	450U	NR
Dibenzofuran	11,000U	370J	1300J	NR
2,4-Dichlorophenol	11,000U	2,000U	900U	NR
2,6-Dichlorophenol	11,000U	2,000U	NR	NR
4,6-Dinitro-2-methylphenol	27,000U	5,000U	2,200U	NR
2,4-Dinitrophenol	27,000U	5,000U	2,700UJ	NR
Isophorone	11,000U	2,000U	NR	NR
2-Methylphenol	11,000U	2,000U	450U	NR
2-Nitrophenol	11,000U	2,000U	450U	NR
4-Nitrophenol	27,000U	5,000U	2,200U	NR
Pentachlorophenol	11,000U	2,000U	2,200U	NR
Phenol	11,000U	2,000U	1,480J	NR
2,4,5-Trichlorophenol	11,000U	2,000U	900U	NR
2,4,6-Trichlorophenol	11,000U	2,000U	900U	NR
3- and 4-Methylphenol	11,000U	2,000U	900U	NR
Organochlorine Pesticides (μg/kg)				

TABLE 2 (Continued)

ORGANIC RESULTS FOR TETRA TECH EM INC. AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES

Sample Location	Transect I, Station North	W-2	Transect I, Station North	W-2
Sediment Type	Shallow Core (10 to 20 cm)	Wetland	Shallow Core (10 to 20 cm)	Wetland
Date Collected	10/05/98	10/07/98	10/05/98	10/07/98
	Tetra Tech Analytical Results		DuPont Analytical Results	
4,4'-DDD	12J	10U	35UJ	NR
4,4'-DDE	4.5U	10U	35U	NR
4,4'-DDT	4.5U	12	35U	NR
alpha-BHC	4.5U	10U	18U	NR
beta-BHC	4.5U	10U	18U	NR
delta-BHC	4.5U	10U	18U	NR
gamma-BHC (Lindane)	4.5U	10U	18U	NR
Heptachlor	4.5U	10U	18U	NR
Aldrin	4.5U	10U	18U	NR
Heptachlor Epoxide	4.5U	10U	18U	NR
Organochlorine Pesticides (μg/kg) (Continued)				
Endosulfan I	4.5U	10U	18U	NR
Dieldrin	4.5U	10U	35U	NR
Endrin	4.5U	10U	35U	NR
Endosulfan II	4.5U	10U	35U	NR
Endosulfan Sulfate	4.5U	10U	35U	NR
Methoxychlor	8.7U	20U	180U	NR
Endrin Aldehyde	4.5U	10U	35U	NR
alpha-Chlordane	4.5U	10U	18U	NR
gamma-Chlordane	4.5U	10U	56R	NR
Toxaphene	180U	400U	1,800U	NR
Polychlorinated Biphenyls (μg/kg)				
Arochlor 1016	87U	200U	890U	NR
Arochlor 1221	87U	200U	890U	NR
Arochlor 1232	87U	200U	890U	NR
Arochlor 1242	87U	200U	890U	NR
Arochlor 1248	87U	1,100	890U	NR
Arochlor 1254	87U	590	890U	NR
Arochlor 1260	87U	200U	890U	NR
Chlorinated Herbicides (μg/kg)				
2,4-Dichlorophenoxyacetic acid	NA	80U	NR	200U and 210U (duplicate)

Reference: Tetra Tech 1998.

Notes:

J = Concentration is estimated because it is below the reporting limit or for quality control reasons

NA = Not analyzed

TABLE 2 (Continued)

ORGANIC RESULTS FOR TETRA TECH EM INC. AND DUPONT COMPANY SEDIMENT CHARACTERIZATION STUDY SPLIT SAMPLES

NR	= Not reported
R	= Data rejected
μg/kg	= Micrograms per kilogram
U	= Target analyte was not detected
UJ	= Target analyte was not detected; detection limit is estimated for quality control reasons

REFERENCE

Tetra Tech EM Inc. 1998. "Data Validation Results for Sediment Samples Collected at E.I. DuPont deNemours and Company Chemical Manufacturing Plant." Submitted to U.S. Environmental Protection Agency (EPA), Region 5. EPA Contract No. 68-W4-0007, Work Assignment No. R05013. December 18.

Comments on DuPont Draft SCS Dated September 17, 1999

Executive Summary

1. The Executive Summary (page ES-5) states that none of the constituents of interest (COIs) are associated with current DuPont activites. This statement is inconsistent with past groundwater monitoring data, which does show COIs discharging to the River. In addition, EPA has reportedly determined that aluminum, copper, mercury and zinc exhibit the reasonable potential to exceed water quality standards based on the existing DuPont discharge (see page 3-20). As such, this statement should be modified.

2. The Executive Summary (page ES-5) also states that a localized, subsurface sediment deposit that contains elevated levels of arsenic, copper, mercury and lead is present at Transects E and F, but that it is physically isolated due to overlying deposits of other materials which are high in oil and grease, among other constituents. Recognizing that the objective is to restore the River to achieve designated uses, and that the existing sediment overlying the subject deposit impairs beneficial uses, most likely requiring removal, the deposit in question will then be exposed to both human and ecological receptors. Depending on conditions, at least arsenic will be readily available.

3. The high concentrations of lead and mercury at Transects I and J (page ES-7) may be attributable to historical releases from DuPont, since Transect I is upstream of any known direct discharges from U.S.S. Lead. No support is provided for the statement within the report.

4. On page ES-10, arsenic should be added to the list of constituents most likely to be associated with impairment of beneficial uses.

5. On page ES-12, the statement that sufficient data exist to characterize conditions in the study area may not be accurate. Additional data would be very useful to further identify the locations of the more contaminated sediments containing arsenic, mercury, lead, zinc and chrome which are attributable to historical activities at DuPont.

6. On page ES-12, the statement that constituents that could be attributed to DuPont operations are buried by sediments is not completely accurate. There are sufficient concentrations of many constituents in surface sediment adjacent to DuPont which pose risks to human health and the environment.

Background

7. The first sentence in the third paragraph should be stricken. In that same paragraph, the last sentence should be changed to say that the flow in the East Branch is primarily once-through non-contact cooling water, and wastewater ...

8. In the Section on industrial history on page 2-6, please revise the report to state that lead refining operations occurred at the site from until 1972, when the facility was converted to a

secondary lead smelter. It ceased operations in December 1985. (Source: U.S. EPA Statement of Basis for U.S.S. Lead Refinery, May 1996.)

9. Table 2-1 should include zinc. The column for metals should probably be separated to Metals and Trace Metals. At least arsenic, barium, chromium, copper, lead, and zinc were not trace metals, but were major raw materials or products. Alternatively, include them under the heading Major Inorganics.

Chemical Mass Loadings

10. The report states that PCS loading data were not available after January 1998. PCS data are available for at least all major facilities (and some minor facilities) for all months after January 1998 through December 1999.

Chemical Conditions, Processes and Potential Effects

11. At page 4-2, revise the report to state that Transect I is adjacent to DuPont, but upstream of the U.S.S. Lead facility.

12. The distributions of metals in the sediments adjacent to DuPont would seem to indicate a need for additional sampling specifically related to metals of concern between Transects D through I, to further isolate the extent of contamination in this reach related to historical DuPont operations. Specific constituents should include, arsenic, copper, chromium, mercury, lead and zinc.

13. The distribution of zinc in the sediments in the vicinity of Dupont would appear to indicate that Dupont is both a historical and current source of zinc; the distribution of zinc in the vivinity of DuPont seems to contradict the assertion in the report that it is from upstream sources.

14. DuPont has compared metal, PCB and PAH concentrations to no-effect concentrations calculated by Ingersoll et. al. (1996) for the *Hyalella azteca* bioassay using nationwide data. This comparison should be updated using the site-specific information developed by Ingersoll in January 1999 for the West Branch of the Grand Calumet River (GCR), which is based on much more data, and where probable-effects concentrations (PEC) were also calculated. See An Assessment of Sediment Injury in the West Branch of the Grand Calumet River, January 1999, by Ingersoll and MacDonald, copy available upon request. Table 10 (attached) is a summary of consensus-based SECs for the contaminants of concern in the West Branch GCR. Both threshold-effects concentrations (TEC) below which no effects are expected, and PECs, above which adverse impacts are predicted, are shown. Using the new information, it can be seen that the results for arsenic, for example, are drastically changed, with only one result below the TEC, and 12 (out of 27) results above the PEC.

15. Similarly, the wetland information (table 4-6) should be updated using the new information developed by Ingersoll and MacDonald.

16. The overall conclusions in this section of the report need to be updated based on the TECs and PECs developed for the Grand Calumet River by Ingersoll and MacDonald.

17. The conclusions related to Transects I and J are not supportable by the evidence presented. The source of the contaminants at Transect I is more than likely from DuPont (being upstream from U.S.S. Lead) and the source at Transect J is also likely to be from DuPont from contaminants which passed Kennedy avenue, which is known to be scoured by CSO discharges, more than likely moving sediments downstream to be deposited between Transects I and J.

Impaired Beneficial Uses

18. The use impairments due to arsenic in the sediment is not discussed in this Section. It should be added.

19. The discussion on relationship on releases from DuPont is unsupported by the information in the report and should be modified. For example, there are 12 out of 27 surface samples of arsenic which exceed the calculated PECs. In that there are no known ongoing sources of arsenic from upstream of DuPont, the conclusion must be drwn that there is an ongoing or historical release from DuPont which is still exposed and impacting human health and the environment.

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12. The distributions of metals in the sediments adjacent to DuPont would seem to indicate a need for additional sampling specifically related to metals of concern between Transects D through I, to further isolate the extent of contamination in this reach related to historical DuPont operations. Specific constituents should include, arsenic, copper, chromium, mercury, lead and zinc.

13. The distribution of zinc in the sediments in the vicinity of Dupont would appear to indicate that Dupont is both a historical and current source of zinc; the distribution of zinc in the vivinity of DuPont seems to contradict the assertion in the report that it is from upstream sources.

14. DuPont has compared metal, PCB and PAH concentrations to no-effect concentrations calculated by Ingersoll et. al. (1996) for the *Hyalella azteca* bioassay using nationwide data. This comparison should be updated using the site-specific information developed by Ingersoll in January 1999 for the West Branch of the Grand Calumet River (GCR), which is based on much more data, and where probable-effects concentrations (PEC) were also calculated. See An Assessment of Sediment Injury in the West Branch of the Grand Calumet River, January 1999, by Ingersoll and MacDonald, copy available upon request. Table 10 (attached) is a summary of consensus-based SECs for the contaminants of concern in the West Branch GCR. Both threshold-effects concentrations (TEC) below which no effects are expected, and PECs, above which adverse impacts are predicted, are shown. Using the new information, it can be seen that the results for arsenic, for example, are drastically changed, with only one result below the TEC, and 12 (out of 27) results above the PEC.

15. Similarly, the wetland information (table 4-6) should be updated using the new information developed by Ingersoll and MacDonald.

16. The overall conclusions in this section of the report need to be updated based on the TECs and PECs developed for the Grand Calumet River by Ingersoll and MacDonald.

17. The conclusions related to Transects I and J are not supportable by the evidence presented. The source of the contaminants at Transect I is more than likely from DuPont (being upstream from U.S.S. Lead) and the source at Transect J is also likely to be from DuPont from contaminants which passed Kennedy avenue, which is known to be scoured by CSO discharges, more than likely moving sediments downstream to be deposited between Transects I and J.

Impaired Beneficial Uses

18. The use impairments due to arsenic in the sediment is not discussed in this Section. It should be added.

19. The discussion on relationship on releases from DuPont is unsupported by the information in the report and should be modified. For example, there are 12 out of 27 surface samples of arsenic which exceed the calculated PECs. In that there are no known ongoing sources of arsenic from upstream of DuPont, the conclusion must be drwn that there is an ongoing or historical release from DuPont which is still exposed and impacting human health and the environment.

ATTACHMENT I
SCOPE OF WORK TO CHARACTERIZE SEDIMENTS IN THE GRAND CALUMET RIVER AND ADJACENT WETLANDS

Purpose

The purpose of this Sediment Characterization Study (SCS) is to further determine the nature and extent of site related constituents in portions of the Grand Calumet River and adjacent wetlands, and to gather necessary data to support if necessary the Sediment Remediation Alternatives Report (SRAR). Recognizing that unknown or poorly understood variables are inherent in investigations of complex systems, the SCS will be completed in a phased approach. This approach allows data to be collected in a logical and scientific manner.

Scope

The Sediment Characterization Study consists of the following tasks. Completion of these tasks should enable the project purpose as described above to be achieved.

1. Task I—Sediment Characterization Study Work Plan

   This work plan will consist of the following components:

   A. Project Management Plan

   B. Sampling Plan

   C. Quality Assurance Project Plan

   D. Data Management Plan

   E. Health and Safety Plan

   F. Community Relations Plan

2. Task II—Sediment Characterization Area Investigation

   A. Environmental Setting

   B. Contamination Characterization

3. Task III—Analysis and Conclusions of Sediment Characterization Study Area Investigation

   A. Data Analysis

   B. Discussion of Evaluation

4. Task IV—Reports

   A. Progress

   B. Draft and Final SCS Report

Each of these tasks are described in more detail in the following text.

Task I—Sediment Characterization Study Work Plan Requirements in the Study Area

DuPont shall prepare a SCS Work Plan (SCSW). The SCSW shall include the development of a work plan for a study to be conducted within the study area, defined as the reach of the Grand Calumet River and adjacent wetlands contiguous with and downstream of the Facility from approximately Cline Avenue to the east to the easternmost limit of the confluence of the Grand Calumet River and the Indiana Harbor Canal to the west (see Figure 1). The investigation will include sample points upstream and downstream of the Facility, as needed, to determine the extent of the site related constituents. The SCSW shall include the following.

A. *Project Management Plan*

Respondent shall prepare a Project Management Plan which will include a discussion of the technical approach, schedules, budget, and personnel. The Project Management Plan also will include a description of the qualifications of personnel performing or directing the SCS, including contractor personnel. This plan shall document the overall management approach to the SCS and shall include a list of any necessary permits, and the time frames for obtaining the permits.

B. *Sampling Plan*

A Sampling Plan (SP) for the area of the study to be characterized will be prepared that documents the data collection strategy to be used during the investigation to characterize the environmental setting, and potential contamination, to ensure that the information, data, and resulting decisions are technically sound, statistically valid, and properly documented. The SP can consider past data collection efforts by other parties, and integrate those efforts into its decision-making process.

The SP shall document to the extent practical, the locations to be sampled and, as appropriate the types of samples (e.g. composites, grabs) and number of samples to be collected. Justification should be provided for sample types, locations, and numbers. The Respondent shall prepare the plan for approval by U.S. EPA.

1. The Sampling Plan shall briefly discuss, as appropriate:
   a. Sampling Approach
      I. Identify sampling locations, depth, etc.;
      ii. Identify media to be sampled;
      iii. Identify types of samples (e.g. composites vs. grabs), and the number of samples to be collected; and
      iv. Identify ancillary data needs, if any.
2. Graphical Displays

   The following may be presented in graphical format (e.g. area, plan maps, or subsurface profiles-color is optional).

   a. Sampling location and/or sampling grid.
   b. Boundaries of sampling area.

C. *Quality Assurance Project Plan (QAPjP)*

Respondent shall prepare a QAPjP plan to document monitoring procedures, sampling, field measurements and sample analyses performed during the investigation. The QAPjP shall be used to characterize the environmental setting and contamination within the study area, so as to ensure that data collected are technically sound, statistically valid, and properly documented.

(DuPont will show evidence of recent performance audits to U.S. EPA on the laboratories selected by Respondent). U.S. EPA reserves the right to conduct laboratory audit(s) on the laboratory(ies) selected by Respondent. U.S. EPA also highly recommends that a pre-QAPjP meeting be held prior to submission of the QAPjP.

D. *Data Management Plan*

Respondent shall develop and initiate a Data Management Plan to document and track investigation data and results from SCS investigations. This plan shall identify and establish data documentation materials and procedures, project file requirements, and project-related progress reporting procedures and documents. The plan shall also provide a format to be used to present the raw data and conclusions of the investigation.

1. Data Record (kept by Respondent, but available on request)

   The Data record shall include the following:

   a. Unique sample or field measurement code;
   b. Sampling or field measurement location determined using GPS technology and sample or measurement type;
   c. Sampling or field measurement raw data;
   d. Laboratory analysis ID number;
   e. Property or component measured;
   f. Result of analysis (e.g., concentration); and.
   g. Unsorted (raw) data.
   h. Chain of Custody

2. Tabular Display

   The following data shall be presented in tabular displays:

   a. Results for each constituent where a response was measured;
   b. Data reduction for statistical analysis, if applicable;
   c. Sorting of data by potential stratification factors (e.g., location, soil layer, topography); and
   d. Compilation of sorted data in GIS format or other compatible system.

3. Graphical Displays

   Additional data may be presented in graphical formats (e.g., bar graphs, line graphs, area or plan maps, isopleth plots, cross-sectional plots or transects, depiction in three dimensional graphs, etc.):

   a. Display sampling location and sampling grid;
   b. Indicate boundaries of sampling area;
   c. Display levels of contamination at each sampling location;
   d. Display geographical extent of contamination;
   e. Display contamination levels, average, and maxima; and
   f. Illustrate change in concentration in relation to distance from the source (i.e., outfalls), time, depth or other parameters.

D. *Community Relations Plan*

A plan will be prepared for the dissemination of information to the public regarding the study activities and results developed in accordance with the RCRA Expanded Public Participation Plan (60 FR 63417, December 11, 1995).

E. *Health and Safety Plan*

A Health and Safety Plan for all field activity will be prepared, although it does not require review and approval of U.S. EPA. The Health and Safety Plan shall be developed as a stand alone document, although it may be submitted as part of the work plan.

Task II— Sediment Characterization Area Investigation

Implementation of the tasks as described in the work plan should lead to: characterization of the Environmental Setting in the Grand Calumet River and adjacent wetlands; definition as to the degree and extent of contamination; and identification of potential receptors. The investigations should also result in data of adequate technical content to support the development and evaluation if necessary of remediation alternatives during the SRAR for the Sediment Characterization Area.

A. *Environmental Setting*

Information relative to the physical characterization of the River is imperative to understanding contaminant fate and transport. During the investigation data collection will focus on obtaining the following information:

1. Sediments

   Sediments are defined as geological material which either naturally occurs or is man-induced. Characterization shall, as appropriate, include but not be limited to, the following information:

   a. Qualitatively describe the depositional area;

b. Thickness profile;

c. Description of the physical characteristics of sediments using general geological terms;

d. Physical and chemical parameters.

2. Water

Since the majority of flow within the Eastern Branch of the Grand Calumet River consists of industrial discharges it is important to understand the historical nature of the sources of discharges. Characterization shall include but not be limited to the following:

a. Sources

b. Flow profiles

c. Drainage basins

d. Groundwater influence

3. Wetlands

Respondent shall characterize the adjacent wetlands in the study area to determine the impact from the River. Characterization shall include the following:

a. Extent of wetlands;

b. Type of wetlands;

c. Physical and chemical parameters.

B. *Contamination Characterization*

Data collected shall include time and location of samples, media sampled, concentrations of contaminants found, conditions during sampling, and the identity of the individuals performing the sampling and analysis. The investigation shall address the following topics with regards to the contamination in the study area:

1. Sediment Contamination

a. A description of the vertical and horizontal extent of contamination:

b. Specific contaminant concentrations; and

c. A qualitative assessment as to the potential migration/availability of contaminants within the sediment.

Task III—Analysis and Conclusions for Sediment Characterization Area (SCA) Investigation

An analysis and list of conclusions for the Sediment Characterization Area investigation based on its results will be prepared. The objective of this task shall be to ensure that the investigation data are

sufficient in quality (e.g., quality assurance procedures have been followed) and quantity to describe the nature and extent of contamination, potential threat to human health and the environment, and support if necessary the SRAR.

A. *Data Analysis*

SCA investigation data will be analyzed and a report on the type and extent of contamination present at the SCA will be prepared. Data gaps will be identified and a Phase II investigation will be provided where necessary to meet the project objectives. The report shall describe the extent of contamination (qualitative/quantitative) in relation to the natural or expected levels indicative for the area as well as conclusions and recommendations of the sediment characterization program.

Task IV—Reports

A. *Work Plan*

The Task I Work Plan shall be submitted to U.S. EPA within 100 days after the effective date of the Order.

B. *Progress Reports*

Bi-monthly progress reports shall be provided to U.S. EPA that contain at a minimum the following information:

1. A description and estimate of the percentage of the Sediment Characterization Study (SCS) completed;
2. Summaries of all findings;
3. Summaries of all changes made in the SCS during the reporting period;
4. Summaries of all contacts with representatives of local community public interest groups or State government during the reporting period;
5. Summaries of all problems or potential problems encountered during the reporting period;
6. Action being taken to rectify problems;
7. Changes in key personnel during the reporting period;
8. Projected work for the next reporting period; and

Copies of daily reports; inspection reports, laboratory/monitoring data, etc., will be maintained at the facility for review purposes.

C. *Draft and Final SCS Reports*

The SCS Report which incorporates information developed in Tasks II and III shall be developed in draft form for U.S. EPA review. The SCS Report shall be developed in final format after comments are received on the Draft SCS Report. The Final SCS Report will be used to support the SRAR, as needed.

Four (4) copies of all deliverables shall be provided by the Respondent to U.S. EPA and IDEM.

Facility Submission Summary

A summary of the information requirements contained in the Sediment Characterization Study is presented below:

[illegible]	[illegible]
Sediment Characterization Work Plan (Task I)	100 days after effective date of Consent Order
Draft SCS Report (Tasks II and III)	Contingent on schedule approved in work plan
Final SCS Report (Tasks II and III)	Contingent on schedule approved in work plan
Progress Reports	Bi-monthly Status Reports to begin 120 days after effective date of Consent Order

DuPont Specialty Chemicals
Barley Mill Plaza-Bldg. 27
Lancaster Pike and Rt. 141
Wilmington, DE 19805

DuPont Specialty Chemicals

March 18, 1998

Mr. Allen Wojtas
U.S. EPA, Region 5
Waste Pesticide and Toxics Division
Enforcement and Compliance Assurance Branch
77 West Jackson Boulevard, DRE-9J
Chicago, Illinois 60604-3590

Attn: DuPont-East Chicago Project Coordinator

RE: Sediment Characterization Study Work Plan

Dear Mr. Wojtas:

Enclosed is DuPont's response to the comments provided by your office on the Sediment Characterization Work Plan submitted by DuPont. We are hopeful that the proposals contained within the responses are acceptable to the agency and other stakeholders who offered comments to the work plan. As we discussed, DuPont will move forward with modifications to the work plan where mutual agreement has been reached. In addition, DuPont will be available for a conference call or a meeting to discuss those comments which may require further clarification.

Upon resolution of the work plan comments, the project QAPP can be completed and submitted for review. I will call you later next week to confirm a time to discuss our pathforward for the Sediment Characterization Work Plan.

Sincerely,

J Hilton Frey / DEE.

J Hilton Frey
Project Director
DuPont Corporate Remediation Group

cc: Kathy Shelton, DuPont CRG
File

Responses to Comments on the "Sediment Characterization Study (SCS) Work Plan for the DuPont East Chicago Facility"

General comments

Reference will be made to the Grand Calumet River System early in the work plan. To simplify reference to the Grand Calumet River thereafter, the acronym "GCR" will be used in most instances.

Specific comments

1. Section 2.1, Page 2-1, Paragraph 2.

Available information on the historical outfalls will be summarized from the Current Conditions Report (CCR) (CH2M HILL 1997). A figure showing the locations of the historical outfalls and the existing outfalls (adapted from Figure 3-5 in the CCR) will be added to the work plan. It should be recognized, however, that detailed information is not available on the length of service for each outfall and the types of chemicals discharged through each outfall. It is known that the historical outfalls were abandoned and replaced with three permitted outfalls in 1973. Text will be added that describes which manufacturing processes discharged to specific outfalls. A list of the types of chemicals used in manufacturing processes at the facility is provided in Table 3-1 of the CCR and was considered in identification of the constituents of interest (COIs) for analysis.

Cross ref WP to TABLE 3-1 of CCR

The outfalls for the two current permitted discharges will be distinguished in the figure from the historical outfalls. Currently, Discharge 003 consists of process wastewater and stormwater collected within the active manufacturing area. Discharge 004 is an emergency discharge point for stormwater runoff in case the wastewater treatment system reaches its maximum capacity during a storm event.

2. Section 2.3.1, Page 2-4, Paragraph 4.

Sediment chemistry data tables from Hoke et al. (1993) and the Corps (1997) will be reproduced in an appendix to the work plan. A map showing the locations of the stations sampled by Hoke et al. (1993) will be included; the authors provide no information on the sampling depths, although all samples were surface grabs. The data tables provided by the Corps (1997) include only summary statistics (e.g., minimum, maximum, numbers of detections within various ranges); no information is provided on sampling locations or sampling depths.

USX. Hoke 1993 [illegible] Corps - not relevant?

3. Section 2.3.2, Page 2-5, Paragraph 1.

A list of the water quality parameters measured by the USGS (1987) will be included in the work plan. Of most interest to the DuPont investigation is the fact that the surface water concentrations of copper, iron, lead, nickel, and zinc were all lower at Kennedy Avenue (downstream of DuPont) than at Cline Avenue (upstream of DuPont). The data tables (including results for 35 parameters at 22 stations) could be reproduced in an appendix to the work plan, if necessary.

4. Figure 2-3, Page 2-6.
The requested changes will be made. It should be noted that the figure was based on 1986 data and that it was indicated that more recent data would be acquired as part of Phase 1 of the SCS.

5. Section 3.1, Page 3-3, Paragraph 1.
References will be added to substantiate the statement that polycyclic aromatic hydrocarbon (PAH) compounds are generally metabolized by fish and do not accumulate in their tissues. The statements in this paragraph were included only as examples, and therefore DuPont does not believe that a detailed discussion of the factors affecting bioaccumulation is warranted.

6. Section 3.2, Page 3-6, Paragraph 2.
A list of the water quality parameters measured in surface water by the USGS (1987) will be provided (see response to comment on Section 2.3.2, Page 2-5, Paragraph 1 above).

7. Section 3.2, Page 3-6, Paragraph 3.
References will be added to substantiate the statement that the biologically active zone of the sediments is typically the uppermost 10 cm or less.

8. Section 3.2, Page 3-6, Paragraph 3.
The bullets referred to in this comment summarize processes and conditions shown in the conceptual model (Figure 3-2). The title of that figure indicates that it describes "existing physical/chemical processes." Because loadings from historical outfalls are not ongoing, they are not considered to be "existing processes." However, the figure will be modified by adding a note that the "older sediments" contain chemicals discharged historically to the river from various permitted and unpermitted sources, including historical DuPont outfalls as well as multiple upstream sources.

9. Figure 3-1, Page 3-7.
The current number of combined sewer overflows (CSOs) in Gary will be verified with the Gary Sanitary District and the inconsistencies between these two figures will be resolved. The "actual flow" from the Gary Sanitary District sewage treatment plant presumably varies on a daily basis. The flow of 60 million gallons per day (mgd) is reportedly being used by the Indiana Department of Environmental Management (IDEM) for wasteload allocation purposes.

10. Figure 3-2, Page 3-8.
The figure will be modified to show both permitted sources (including CSOs) and unpermitted sources (including storm drains).

11. Table 4-1, Page 4-2.
The table will be revised to indicate that the source of information on the municipal sewage treatment plants will be either the municipalities or IDEM.

12. Section 4.3, Page 4-5, Paragraph 1.
The hydrologic model has been constructed and calibrated. The sediment transport modeling for cohesive sediments is being revised to handle changes in shear elevations. The Corps of Engineers estimates that the sediment modeling will be completed by April, 1998.

13. Section 5.3.1, Page 5-2, Paragraph 3.
The Phase I Groundwater Assessment (CH2M HILL 1990) and Table 3-1 in the CCR (CH2M HILL 1997) include the most complete list of chemicals potentially used at the DuPont facility. These sources have been previously submitted to the U.S. EPA.

14. Section 5.3.1, Page 5-2, Paragraph 3.
A cross reference will be provided to Section 2.3.1, where the existing chemical data on sediments are discussed, and to the new appendix reproducing sediment chemistry data tables from the earlier reports (see response to comment on Section 2.3.1, Page 2-4, Paragraph 4 above).

15. Section 5.3.1, Page 5-2, Paragraph 5.
The discussion of the rationale for the placement of the sediment transects will be expanded, noting in particular the inferred depositional/erosional characteristics of each area and the proximity to historical and existing discharges from the DuPont facility. The recommendations in this comment were evaluated and the following responses are offered:

a. Transect A will be moved downstream of Cline Avenue, as requested.

WANT W/ TO CLARIFY.

b. Clarification is requested regarding the historical stormwater disposal practices that are alleged to have impacted the groundwater recharging that section of the reach and what impact the groundwater may be causing. DuPont has proposed additional activities to further characterize groundwater flow in this area of the facility as part of the RCRA Facility Investigation (RFI) and believes these data will assist in determining the need for an additional transect in this area.

c. One additional transect (comprised of surface and near-surface sediment samples from a station on the north side of the river, a deep core sample from the middle of the river, and a surface sediment sample from a station on the south side of the river) will be added approximately half way between Kennedy Avenue and Transect J, to investigate the degree of sediment contamination downstream of the DuPont facility and upstream of the U.S.S. Lead outfall. It should be noted that the Harbison-Walker wastewater outfall and a CSO are located upstream of this transect and may be potential sources of contamination found in this area.

d. The locations of existing and historical DuPont outfalls and of groundwater monitoring wells near the river will be added to Figure 5-1.

16. Table 5-1, Pages 5-3 and 5-4.

a. Reference to the target analyte list (TAL) will be removed from "metals" to avoid confusion. The metals to be analyzed include all of those listed (Sb, As, Cd, Cr, Cu, Pb, Mg, Hg, Mo, Ni, Pb, Ag, Zn), for the reasons described in the rationale column.

b. Measurement of the concentrations of acid volatile sulfide (AVS) and simultaneously extracted metals (SEM) provide an indication of whether these metals are likely to be biologically available. If the molar concentration of AVS exceeds the molar concentration of the total SEM, these metals are likely to be tightly bound in insoluble metalsulfide compounds, and therefore unavailable for release into sediment pore water or surface water.

c. Organochlorine pesticides are listed as COIs because they were present in previous sediment samples collected from the GCR. The purpose for including these types of compounds as COIs is to allow for additional understanding of their distribution within the study reach sediments. The sample collected earlier on behalf of U.S. Steel was located on the south side of the river bank along the Harbison-Walker property and was reportedly collected from the upper 18–24 in. of saturated sediment below the vegetative zone. It is presumed that this sample would be representative of relatively new sediment deposits. Potential sources for the dioxins and furans found in this sample may include: runoff from upstream areas historically treated with organochlorine pesticides, discharges from municipal wastewater treatment plants and CSOs to the GCR, and wastewater discharges from upstream industrial sites.

Considering the difficulty in identifying a source for the dioxins and furans and the lack of knowledge regarding reach-specific hydraulic processes, DuPont has proposed to investigate the distribution of COIs that would be indicative of a dioxin source(s), such as organochlorine pesticides or polychlorinated biphenyls (PCBs), rather than exhaust financial resources on limited analyses for dioxins and furans.

d. In Table 5-1, the rationale for the measurement of chemical oxygen demand (COD) will be changed to "Indicator of discharges from certain industrial facilities."

e. In Table 5-1, the rationale for the measurement of dissolved oxygen will be modified to state "Low dissolved oxygen concentrations found in historical surface water sampling; indicator of current sewage discharges and/or a high sediment oxygen demand."

17. Table 5-1, Pages 5-3 and 5-4.
The COI list was developed based on the following criteria:
Primary criteria

- Constituents listed in the ACO;
- Chemicals that have the potential to cause the impaired uses identified within the GCR;

Secondary Criteria

- Chemicals potentially associated with either current or historical industrial wastewater discharges to the GCR;
- Chemicals present in sediment samples previously collected from the GCR, and;
- Chemicals used in the manufacturing processes at the DuPont facility as well as the characteristics of these chemicals (i.e., mobility, toxicity, and persistence in the environment).

Several compounds listed within the CCR (CH2M HILL 1997) were not included as preliminary COIs because their characteristics were such that they would not be expected to cause an impaired use or it was determined that an analytical methodology was not available to detect them in the sediment matrix.

Additional justification will be added to the work plan for specific COIs, as necessary.

18. Figure 5-1, Page 5-5.
Additional discussion will be included in the text explaining the rationale for the transect and station locations. Consideration was given to presumed sediment deposition conditions in the GCR. However, there is little definitive evidence of existing sediment deposition conditions, and therefore they must be inferred from the river's channel slope and plan form. For example, in a river bend, the highest current velocities are typically found along the outside of the bend, creating an environment more conducive to erosion than deposition. In contrast, the inside of a river bend is generally an area with slower current velocities and is more conducive to deposition. This leads to steeper slopes along the outside of the channel in a river bend, and more gentle slopes along the inside of the channel in a river bend, a pattern confirmed in the channel cross sections reported by Floyd Browne Associates (1993). Unlike a more natural river, however, whose course in constantly shifting by erosion of the outer banks of river bends and by deposition along the inner banks, the GCR must be in a quasi-steady state with regard to deposition and erosion because its course is relatively constant. Substantial reductions in flow within the GCR that have occurred as a result of industrial source control have likely reduced flow velocities and made the entire GCR more prone to deposition than in the past.

The comment regarding a presumed gap between the shallow and deep sediment cores is apparently based on a misunderstanding of the intent of the deep sediment cores. "Deep" only referred to the depth of penetration of the sediment core. The entire sediment column retained within the deep sediment core will be divided into 2–3

horizons per core for chemical analyses. The shallowest sediment horizon to be sampled from each deep sediment core will extend from the sediment-water interface to the top of the next sediment horizon to be sampled; there will be no gaps left unsampled. Sediment samples submitted for analysis will represent composite samples collected over the entire depth of each horizon. Additional discussion of this sampling strategy will be included in the text to avoid confusion.

19. Section 5.3.1, Page 5-6, Paragraph 1.
The seep referred to in this comment was located immediately adjacent to the Chrome Outfall near monitoring well MW-5. It is not clear, given the historical river discharge rates, how contamination from this seep could have impacted wetlands upstream of this point. In addition, DuPont has proposed that surface and subsurface soil samples will be collected as part of the RFI from eight locations upstream of the referenced seep in the area where river sediment was disposed during the straightening of the GCR in 1956.

20. Section 5.3.1, Page 5-6, Paragraph 1.
Exact locations for the wetland sediment samples were not specified in the work plan; instead, it was indicated that the locations will be determined on the basis of a field reconnaissance, using the following criteria:

- Within the 100-year flood plain
- A hydraulic connection or channel is observed between the river and the sampling location
- Sediments at the sampling station are either under water or show evidence of having been submerged within the last year.

Basing the sampling locations on these criteria is believed to make it more likely that wetland sediment samples will be indicative of inputs from the river than would be the case if the locations were selected a priori. Also for this reason, it is not considered worthwhile to link the wetland sediment sampling locations to the river transects because they serve completely different purposes.

Table 5-2 was correct in indicating a total of six wetland sediment samples, but the text (p. 5-11) was incorrect because two (not one) sediment samples will be collected from the DuPont wetland. Table 5-2 will be corrected, however, to indicate that the two sediment samples from the DuPont wetland will be analyzed for the full analyte list, while the sediment samples from the Harbison-Walker and U.S.S. Lead wetlands will only be analyzed for the short analyte list.

21. Section 5.3.2.1, Page 5-8, Paragraph 3.
This comment is apparently based on a misunderstanding. Each of the five stations where shallow cores are to be collected will include analysis of surface (0–10 cm) sediment samples. Adding these five samples to the twenty stations at which only surface sediment samples will be collected yields the total of 25 surface sediment

samples referred to in the text. Additional sediment samples will now be included in the work plan as a result of other comments, and care will be taken to ensure consistency in the numbers of samples specified in the text, tables, figures, and appendices throughout the work plan.

22. Section 5.3.2.1, Page 5-8, Paragraph 3.
The basis for this comment is the same misunderstanding as in the preceding comment. As shown in Table 5-2, two of the five shallow core stations (i.e., those on Transects A and I) will include analyses of the surface (0–10 cm) sediment samples for the full analyte list. Adding these two samples to the eight stations at which only surface sediment samples will be collected and analyzed for the full analyte list yields the total of 10 surface sediment samples referred to in the text.

23. Section 5.3.2.2, Page 5-8.
It is recognized that collection and sectioning of the shallow sediment cores as described in the work plan will present a logistical challenge given the expected nature of the sediments in the GCR. Nevertheless, the value of the information to be gained from these samples is sufficiently great that effort should be expended to attempt to collect them. A subcontractor with experience sampling sediments in the GCR is being considered for the sediment coring, and, given their expertise, there is a reasonable expectation of success. A pilot sampling study is planned to demonstrate whether such sampling is indeed feasible. In the event that collection of these shallow sediment horizons is infeasible, it may be necessary to collect and analyze only surface sediment samples in lieu of the shallow core samples. This fall-back position would obviously limit the interpretation of the resulting data as currently intended, but this limitation could not be avoided if the samples simply cannot be collected.

24. Section 5.3.2.2, Page 5-8, Paragraph 5, and Table 5-2, Page 5-9.
In response to this comment, DuPont proposes the addition of near-surface (10–20 cm and 20–30 cm) samples at the north and south ends of Transects E and G. In addition, the near-surface sediment samples previously proposed for the north and south ends of Transect H will be moved to Transect I, with only surface sediment samples now proposed for the north and south ends of Transect H. Also, as discussed earlier in response to the comment on Section 5.3.1, Page 5-2, Paragraph 5, a new transect (comprised of surface and near-surface sediment samples from a station on the north side of the river, a deep core sample from the middle of the river, and a surface sediment sample from a station on the south side of the river) will be added approximately half way between Kennedy Avenue and Transect J. Finally, near-surface (10–20 cm and 20–30 cm) samples will be added at the south end of Transect J. The addition of all of these samples should address the concern expressed in this comment.

25. Section 5.3.2.3, Page 5-11, Paragraph 2.
Previous sediment coring in this reach of the GCR by Floyd Browne Associates (1993) indicated that the depth to native sediments varied between approximately 4 ft and 11 ft, with a typical depth of 6–8 ft. Vibracoring to be conducted as part of the SCS will attempt to penetrate to native sediment. After the sediment cores are collected, they will be cut open and examined by a geologist and screened with an organic vapor detector. If observations of sediment grain size, color, sheen, odor, presence of organic vapors, or other characteristics suggest distinct differences over the length of the sediment core, up to three horizons will be identified for sampling. The horizons identified for sampling will be continuous (i.e., there will be no gaps between horizons), and will extend from the sediment-water interface down to the depth of the native sediments. If the sediment core appears to have no distinct horizons, it will be divided into equal horizons between the surface and the depth of the native sediments. The maximum depth for an individual horizon will be 4 ft (i.e., the core will be divided into two equal horizons if it is 8 ft in length or less, or three equal horizons if it is greater than 8 ft in length). Sediment samples for analyses will be composited from subsamples collected over the length of each horizon. The basis for the decisions regarding sampling horizons will be recorded in a field notebook.

26. Section 5.3.2.3, Page 5-11, Paragraph 2.
The list of analytes in the text will be made consistent with the list of analytes in Table 5-2.

27. Section 5.3.2.3, Page 5-11, Paragraph 2.
In response to this comment, DuPont will amend the sampling program to include the long list of analytes (with the exception of benzene, toluene, ethylbenzene, and xylene [BTEX]) in the deep core sediment samples from Transects B, G, and I. The presence of BTEX would be expected to be very limited as a result of volatilization over time and biological degradation of the compounds, and therefore BTEX will not be included among the analyses.

28. Section 5.3.2.4, Page 5-11, Paragraph 3.
Information on historical dredging of the GCR is very limited. However, the available information indicates that dredging occurred only at the mouth of the Chrome Outfall. The disposition of the dredged sediments could not be ascertained from the information currently available. Additonal dredging did occur during the construction of Interstate 90 some time around 1956. The final wetland sediment sample locations will be mutually agreed upon between the U.S. EPA and DuPont prior to initiation of sampling activities.

29. Section 5.3.2.4, Page 5-11, Paragraph 4.
As indicated earlier in the response to the comment on Section 5.3.1, Page 5-6, Paragraph 1, Table 5-2 will be corrected to indicate that the two sediment samples from the DuPont wetland will be analyzed for the full analyte list, while the sediment samples

from the Harbison-Walker and U.S.S. Lead wetlands will only be analyzed for the short analyte list.

30. Section 5.3.3, Pages 5-11 and 5-12, Paragraph 5.
Attachment I (Scope of Work to Characterize Sediments in the Grand Calumet River and Adjacent Wetlands) to the U.S. EPA's Corrective Action Order specifies that characterization of the river sediments and wetland sediments should include their physical and chemical parameters, but the required characterization of surface water only includes sources, flow profiles, drainage basins, and groundwater influence. There is no requirement for a characterization of surface water physical and chemical parameters. DuPont's intent in sampling surface water, as stated in the work plan, is to determine the concentrations of COIs in the general vicinity of the DuPont facility, to determine the trophic state of the East Branch of the GCR and its potential effect on plant and animal life, to provide an indication of the loading of COIs to the study area from upstream sources, and to determine the effect of rainfall events on overall water quality. DuPont will be investigating the potential for groundwater discharges to the GCR from the facility through the RFI.

The phrase "from each location" in the last sentence in the top paragraph on page 5-12 will be replaced with "during each event."

31. Section 5.3.3, Page 5-12, Paragraph 1.
Aluminum and manganese are common, naturally occurring metals in soil and their detection in groundwater is not unusual. In addition, they are not generally associated with adverse effects on biota and therefore would be unlikely to be causes of impaired uses. Furthermore, DuPont only intends to collect surface water samples at an upstream location (see response to comment on Section 5.3.3, Pages 5-11 and 5-12, Paragraph 5 above), so contributions of aluminum and manganese to the GCR from the facility could not be assessed. For these reasons, addition of aluminum and manganese to the list of surface water analytes is unwarranted.

32. Section 5.3.4, Page 5-12, Paragraph 4.
DuPont's interest in abandoned historical outfalls that may have predated the National Pollutant Discharge Elimination System (NPDES) is initially limited to those outfalls on DuPont property. Readily available information on existing permitted discharges to the GCR have been considered, and additional research into historical discharges on other properties will be completed at a later date if warranted.

33. Appendix A, Section 5.2, Page A-7.
The requested change will be made.

34. Appendix B, Section 1, Page B-1, Paragraph 2.
In revising the work plan, attention will be given to ensuring consistency in the numbers of samples in the text, figures, tables, and appendices, especially considering the samples that will be added in response to comments.

35. Appendix B, Table B-3, Page B-9.
Reference in this table to "distilled water" will be changed to "distilled/deionized water," as requested.

36. Appendix B, Page B-10, Paragraph 4.
Reference will be made to the new methanol preservation requirement for volatile organic compound analyses, as requested.

37. Appendix B, Page B-10, Paragraph 5.
The intent was that only archived samples were to be frozen; samples that are to be immediately analyzed will be stored at 4°C until analysis. The text will be rewritten to clarify this distinction.

38. Appendix B, Page B-10, Paragraph 6.
The text will be revised to indicate that immediately upon retrieval of the grab sample, subsamples will be removed and transferred to appropriate sample containers for analyses of volatile constituents. A geologist will then describe the remaining sediments as they are removed from the grab and transferred to a stainless steel bowl, noting any stratification that may be present. Prior to compositing the sediments in the stainless steel bowl and subsequent collection of the remaining subsamples for analyses, the sediments in the bowl will be photographed, recognizing that they will not be totally undisturbed. It is not feasible to photograph the sediments prior to their removal from the grab.

39. Appendix B, Page B-11, Last Paragraph.
The text will be revised to indicate that immediately upon removal of the split core liner, subsamples from throughout each horizon of interest in these shallow cores will be removed and transferred to appropriate sample containers for analyses of volatile constituents. A geologist will then describe the remaining sediments within each horizon of interest and photograph them before they are removed from the core liner and transferred to a stainless steel bowl for compositing and collection of the remaining subsamples for analyses.

40. Appendix B, Page B-12, Last Paragraph.
Unlike the grab samples and shallow core samples that were the subject of the preceding two comments, detailed description of the deep sediment cores by a geologist need not be completed prior to collection of the samples for analyses. The reason for this difference is that broad horizons (up to 4 ft in depth) are expected to be targeted and subsamples will need to be removed for compositing from multiple locations within each horizon, leaving much of the sediment core intact in the lower half of the core tube. For the purposes of establishing the appropriate horizons for analyses, a cursory examination of the sediment core will be made immediately after opening of the core tube, but the detailed description of the undisturbed sediments remaining in the core tube can be completed after subsampling.

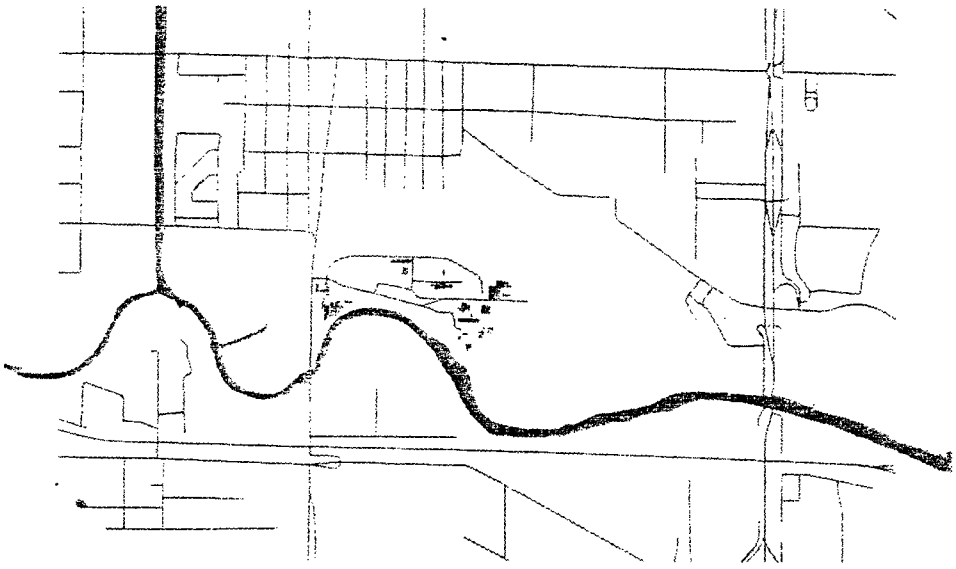
41. Attachment B1, SOP 2, Page 2-8.
Spray paint had been included in the list for marking the outside of 55-gal drums used to hold contaminated waste materials. It will be removed from the list, as requested.

42. Attachment B1, SOP 5, Page 5-2.
The section on groundwater sampling will be removed, as requested.

43. Attachment B1, SOP 5, Page 5-3.
The requested change will be made; the trip blank vials will be filled before the vials are delivered to the site.

Overview Proposed Sediment Characterization Study for the DuPont East Chicago Plant

Meeting September 25, 1997



Prepared for

E.I. du Pont de Nemours and Company

Prepared by

PTI Environmental Services

OVERVIEW

- Impaired uses
- Conceptual model
- Information needs
- Study design

SUBSTANCES POTENTIALLY RESPONSIBLE FOR ALLEGED USE IMPAIRMENTS

	Alleged Use Impairment	Substance(s) Potentially Responsible												Substance(s) Present in:		
		Metals	Mercury	PCBs	Chlorinated Pesticides	Dioxins and Dioxin-Like Compounds	PAHs	Oil and Grease	Nutrients	Grain Size	Other Sediment Conventional Parameters	Fecal Coliform Bacteria	Dissolved Oxygen	Surface Water	Sediments	Organisms
i	Restrictions on Fish and Wildlife Consumption		X	X	X									S	~~S~~ P	P
ii	Tainting of Fish and Wildlife Flavor							X						S	S	P
iii	Degradation of Fish and Wildlife Populations	X	X	X				X		X	X		X	P	P	S
iv	Fish Tumors or Other Deformities			X			X							S	S	P
v	Bird or Animal Deformities or Reproductive Problems				X	X								S	S	P
vi	Degradation of Benthos	X	X	X	X		X	X	X	X	X		X	S	P	S
vii	Restrictions on Dredging Activities	X	X	X			X	X						S	P	--
viii	Eutrophication or Undesirable Algae								X					P	S	--
ix	Restrictions on Drinking Water Consumption (or Taste and Odor Problems)							X				X		P	S	--
x	Beach Closings											X		P	--	--
xi	Degradation of Aesthetics							X	X					S	--	--
xii	Added Cost to Agriculture or Industry	X	X	X			X	X						S	P	--
xiii	Degradation of Phytoplankton and Zooplankton Communities	X						X	X				X	P	S	--
xiv	Loss of Fish and Wildlife Habitat							X	X	X	X		X	S	S	--
Data to be acquired in SCS field sampling and laboratory analyses		SW, Sed	SW, Sed	Sed	Sed		Sed	SW, Sed	SW, Sed	Sed	Sed	SW	SW			

Footnotes on following page.

EXISTING CONDITIONS IDENTIFIED AS BEING RESPONSIBLE FOR THE ALLEGED USE IMPAIRMENTS

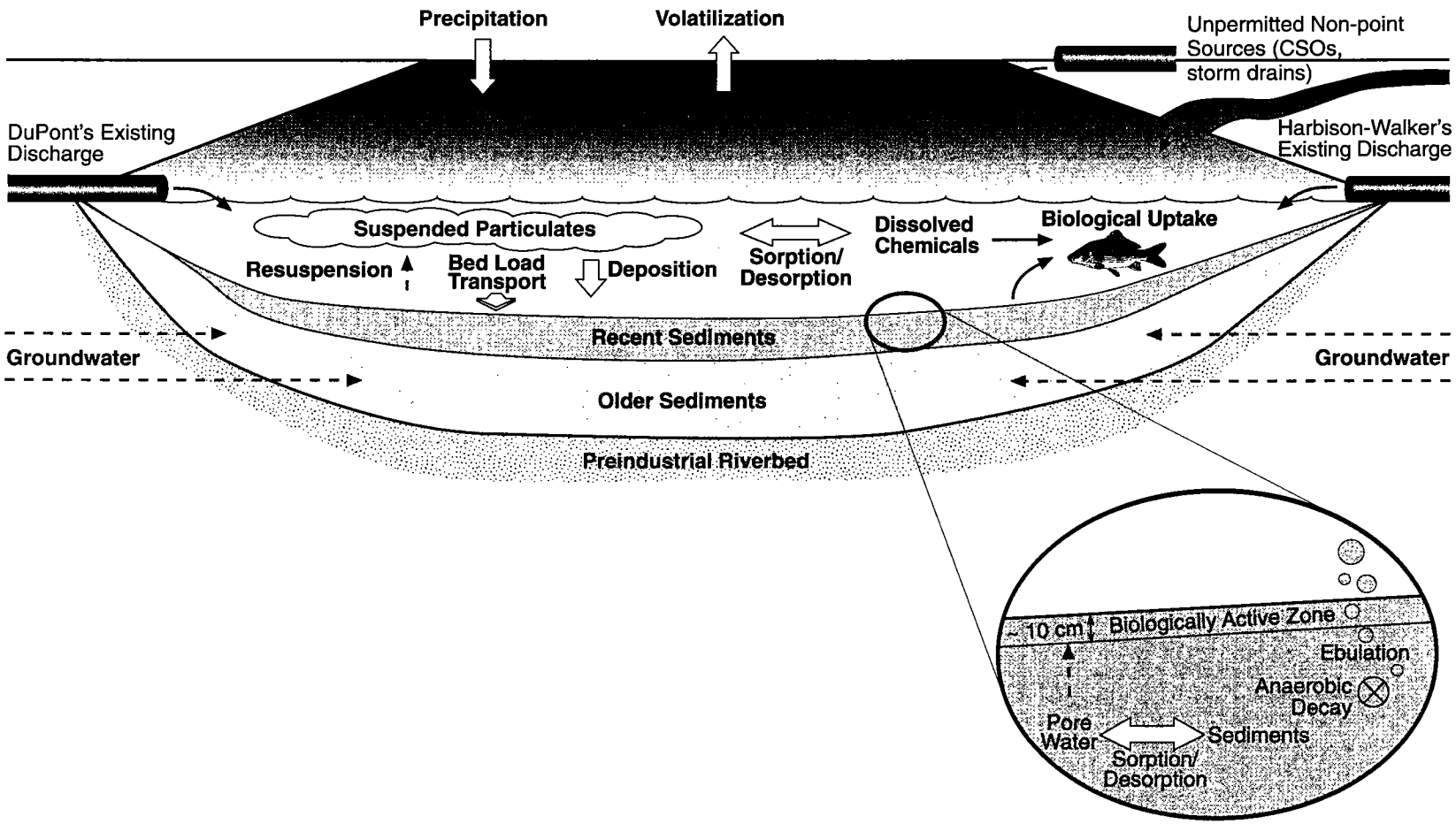
	Alleged Use Impairment	Existing Conditions[a]
i	Restrictions on Fish and Wildlife Consumption	Advisory against eating any fish from the Grand Calumet River or the Indiana Harbor Canal. No known restrictions on wildlife consumption.
ii	Tainting of Fish and Wildlife Flavor	Tainting of fish is said to have occurred. No evidence of tainting of wildlife.
iii	Degradation of Fish and Wildlife Populations	Pollution-tolerant species of fish and benthic invertebrates are dominant. Stable, self-reproducing populations of native fish species are largely absent.
iv	Fish Tumors or Other Deformities	Carp from the Grand Calumet River and the Indiana Harbor Canal have eroded fins, swollen eyes, swollen abdomens, deformed lower jaws, and bloody fins.
v	Bird or Animal Deformities or Reproductive Problems	Limited bird and animal deformities in Grand Calumet River System and Lake George. Reproductive impairment in birds inhabiting or feeding in the area.
vi	Degradation of Benthos	Pollution-tolerant benthic species are dominant. Sediments have been shown to be toxic to, or avoided by, other organisms.
vii	Restrictions on Dredging Activities	Concern regarding sediment contamination has precluded navigational dredging in recent years.
viii	Eutrophication or Undesirable Algae	Nutrient loadings to the Grand Calumet River promote excessive phytoplankton production. Phytoplankton species typical of eutrophic environments are dominant. Water clarity and dissolved oxygen problems exist.
ix	Restrictions on Drinking Water Consumption (or Taste and Odor Problems)	Water quality of the Grand Calumet River and the Indiana Harbor Canal clearly would not support its use as a public water supply. Local area is provided with drinking water from Lake Michigan, so this is not a significant issue.
x	Beach Closings	Swimming is not recommended in the Grand Calumet River and the Indiana Harbor Canal because of poor water quality. Beaches along Lake Michigan have been closed because of coliform bacteria, but the source of the bacteria is not certain.
xi	Degradation of Aesthetics	Oil and grease apparent on the water surface, river banks, and emergent vegetation. Debris litters the river banks and benthic habitats.
xii	Added Cost to Agriculture or Industry	Concern regarding sediment contamination has precluded navigational dredging in recent years. Shipping capacity has been reduced by 15 percent, resulting in increased shipping costs.
xiii	Degradation of Phytoplankton and Zooplankton Communities	Phytoplankton counts are very low in nearshore Lake Michigan waters off Indiana Harbor.
xiv	Loss of Fish and Wildlife Habitat	Loss of appropriate physical habitat characteristics and structure diminishes the usability of the habitat by native fish species. Lack of suitable food organisms limits the ability of fish to survive in the Grand Calumet River and Indiana Harbor Canal.

[a] Summarized from the Stage I remedial action plan (RAP) (IDEM 1991) and the draft Stage II RAP (IDEM 1996).

xv Pollution of Lake Michigan by Contaminated Sediments — Various estimates of contaminated sediments loading to L.M. & associated pollutant loads.

Note: PAH - polycyclic aromatic hydrocarbon
PCB - polychlorinated biphenyl
P - primary (of primary importance in impairment of the specified use)
S - secondary (of secondary importance in impairment of the specified use, or more typically, serving as a source of the substance to the primary medium)
SW - surface water
Sed - sediment
SCS - sediment characterization study

Conceptual Model of Existing Physical/Chemical Processes Affecting Chemical Fate and Transport in the River Adjacent to the DuPont East Chicago Plant



DRAFT - September 25, 1997

PTI ENVIRONMENTAL SERVICES

CHEMICAL CONDITIONS AND PROCESSES IN SURFACE WATER AND SURFACE SEDIMENT OF THE GRAND CALUMET RIVER

Condition/Process	Information Needed	Data Source	Interpretive Method
Surface Water			
Potential to Cause Adverse Biological Effect	T, DO, nutrients, COI concentrations	SCS, IDEM	Numerical comparison
	Biological effects criteria	EPA, IDEM	
Trophic State	DO, nutrient concentrations	SCS, IDEM	Trophic index calculation
Sorption/Desorption	Dissolved and total metals and TSS concentrations	SCS	Calculate partition coefficients
Sediments			
Potential to Cause Adverse Biological Effects	Grain size, TOC, nutrients, COI concentrations	SCS	Numerical comparison
	Effects criteria	Literature	
Potential to Bioaccumulate	TOC, PCB, mercury, chlorinated pesticide concentrations in sediment	SCS	Numerical comparison
	PCB, mercury, chlorinated pesticides, lipid concentrations in tissue	Other investigations	
Metal Bioavailability	AVS and SEM concentrations	SCS	Calculate AVS/SEM molar ratio
Natural Recovery	COI concentrations in surface sediment	SCS	Compare to historical sediment data
	COI concentrations in subsurface sediment	SCS	Compare to surface sediment data
	Sediment mass balance	SCS/COE	Sediment transport model, loading calculations

Note: AVS - acid-volatile sulfide
COE - U.S. Army Corps of Engineers
COI - chemical of interest (metals, organic chemicals, oils and grease)
DO - dissolved oxygen
EPA - U.S. Environmental Protection Agency
IDEM - Indiana Department of Environmental Management
PCB - polychlorinated biphenyl
SCS - sediment characterization study → TO BE DONE BY DUPONT
SEM - simultaneously extracted metals
T - temperature
TOC - total organic carbon
TSS - total suspended solids

CHEMICAL MASS LOADING TO THE GRAND CALUMET RIVER

Source/Process	Information Needed	Data Source	Interpretive Method
Upstream Sources			
Industrial Point Sources	COI concentrations	IDEM, USGS	Load calculations
	Flow rate	IDEM, USGS	
Municipal STP	COI concentrations	IDEM	Load calculations
	Flow rate	COE POTW	
Groundwater	COI concentrations	Other investigations	
	Regional groundwater loading	Other investigations	
Storm Drains/CSOs	COI concentrations	Other investigations	
	Flow rate	Other investigations	
DuPont Sources			
Groundwater	COI concentrations	RFI	Numerical/analytical modeling
	Hydraulic gradient	RFI	
	Hydraulic conductivity	RFI	
	Partition coefficients	Literature	
Outfall	COI concentrations	IDEM, DuPont	Load calculations
	Flow rate	IDEM, DuPont	
Buried Sediments	Groundwater flow	RFI	Numerical/analytical modeling
	Hydraulic conductivity (sediments)	SCS	
	COI concentrations in surface sediments	SCS	
	Partition coefficients	Literature	
Net Source Loading Between Cline Ave. and Kennedy Ave.	COI concentrations in upstream surface water	SCS	Load calculations and comparisons
	Upstream flow rate	SCS — IDEM, USGS, COE	
	COI concentrations in downstream surface water	SCS — IDEM	
	Downstream flow rate	SCS	

Note: COE - U.S. Army Corps of Engineers
COI - chemical of interest (metals, organic compounds, oil and grease)
CSO - combined sewer overflow
IDEM Indiana Department of Environmental Management
RFI - RCRA facility investigation
SCS - sediment characterization study
STP - sewage treatment plant
USGS - U.S. Geological Survey

Advective flow thought to be

PARTICLE AND CHEMICAL TRANSPORT IN THE GRAND CALUMET RIVER

Condition/Process	Information Needed	Data Source	Interpretive Method
Suspended Solids Transport	TSS concentration	SCS, USGS, other investigations	Loading calculation
	Flow rate, depth	SCS, COE	
	Suspended sediment grain size	SCS, COE, USGS	
	Water surface slope	SCS, COE	
Dissolved and Particulate Chemical Transport	Dissolved and total metal concentrations	SCS	Loading calculation
	Flow	COE	
Sediment Resuspension and Deposition	Grain size	SCS	Resuspension calculation
	Flow velocity	COE	
	Water surface slope	SCS, COE	
Net Sedimentation/Scour	Accumulation records	Other investigations	Mass balance calculations, sediment transport model, comparison with wetland topography
	Dredging records	COE	
	Hydrographic records	USGS	

Note: COE - U.S. Army Corps of Engineers
SCS - sediment characterization study
TSS - total suspended solids
USGS - U.S. Geological Survey

KEY STUDY ELEMENTS (Phase 1)

- **Sediment chemistry**
  - Surface
  - Near surface
- **Surface water chemistry**
  - Base flow
  - Storm event
- **Wetlands description**
  - DuPont wetlands
  - Adjacent wetlands

J. Great Lakes Res. 22(3):495–511
Internat. Assoc. Great Lakes Res., 1996

A Comparison of Sediment Toxicity Test Methods at Three Great Lake Areas of Concern

G. Allen Burton, Jr.,[1,8] Christopher G. Ingersoll,[2] LouAnn C. Burnett,[3,9] Mary Henry,[4,10] Mark L. Hinman,[5,11] Stephen J. Klaine,[5,12] Peter F. Landrum,[6] Phillipe Ross,[3,13] and Marc Tuchman[7]

[1]*Institute for Environmental Quality*
Wright State University
Dayton, Ohio 45435

[2]*Midwest Science Center*
National Biological Service
Columbia, Missouri 65201

[3]*Illinois Natural History Survey*
Champaign, Illinois 61820

[4]*National Biological Service*
University of Minnessota
St. Paul, Minnessota 55108

[5]*Memphis State University*
Memphis, Tennessee 38152

[6]*Great Lakes Environmental Research Laboratory*
Ann Arbor, Michigan 48105

[7]*Great Lakes National Program Office*
U.S. Environmental Protection Agency
Chicago, Illinois 60604

ABSTRACT. *The significance of sediment contamination is often evaluated using sediment toxicity (bioassay) testing. There are relatively few "standardized" test methods for evaluating sediments. Popular sediment toxicity methods examine the extractable water (elutriate), interstitial water, or whole (bulk) sediment phases using test species spanning the aquatic food chain from bacteria to fish. The current study was designed to evaluate which toxicity tests were most useful in evaluations of sediment contamination at three Great Lake Areas of Concern. Responses of 24 different organisms including fish, mayflies, amphipods, midges, cladocerans, rotifers, macrophytes, algae, and bacteria were compared using whole sediment or elutriate toxicity assays. Sediments from several sites in the Buffalo River, Calumet River (Indiana Harbor), and Saginaw River were tested as part of the U.S. Environmental Protection Agency's (USEPA) Assessment and Remediation of Contaminated Sediments (ARCS) Project. Results indicated several assays to be sensitive to sediment toxicity and able to discriminate between differing levels of toxicity. Many of the assay responses were significantly correlated to other toxicity responses and were similar based on factor analysis. For most applications, a test design consisting of two to three assays should adequately detect sediment toxicity, consisting of various groupings of the following species: Hyalella azteca, Ceriodaphnia dubia, Chironomus riparius, Chironomus tentans, Daphnia magna, Pimephales promelas, Hexagenia bilineata, Diporeia sp., Hydrilla verticillata, or Lemna minor.*

INDEX WORDS: *Great Lakes, fresh water, bioassay, toxicity, sediments.*

INTRODUCTION

Sediment toxicity testing is a recent approach used in ecological risk assessments. The first sediment tests were developed because of concerns over dredged material contamination and its suitability for open-water disposal by the U.S. Army Corps of Engineers (USCOE), in the late 1960s and early 1970s. There was relatively little testing until the 1980's, with a dramatic increase in the past few years (Burton 1991). The science has progressed quickly because of the methodological similarities to the more traditional water column and effluent toxicity tests. The USEPA is developing approaches for managing contaminated sediments and method standardization that will undoubtedly result in an

[8]To Whom Correspondence May Be Addressed
Current Addresses:
[9]University of Illinois Div. of Environ. Health & Safety, Urbana, IL
[10]National Biological Service, Arlington, VA
[11]Exxon Biomedical Sciences, East Millstone, NJ
[12]ENTOX/TIWET, Clemson University, Pendleton, SC
[13]Biology Department, The Citadel, Charleston, SC

even greater amount of sediment testing and research in the near future (Southerland *et al.* 1992).

The objective of a sediment toxicity test is to determine whether sediment is harmful to aquatic organisms. The tests measure interactive toxic effect of complex contaminant mixtures in sediment. These tests do not require knowledge of specific pathways of interactions among sediment and test organisms (Kemp and Swartz 1988). Toxicity testing of sediment can be used to: (1) determine the relationship between toxic effects and bioavailability, (2) investigate interactions among contaminants, (3) determine spatial and temporal distribution of contamination, (4) evaluate hazards of dredged material, (5) rank areas for clean up, and (6) estimate the effectiveness of remediation and management. Sediments spiked with known concentrations of contaminants can be used to establish cause and effect relationships between chemicals and biological responses.

Tests that have been used to evaluate the toxicity of freshwater sediments include: (1) microbial enzyme systems and bacteria, (2) algae, (3) macrophytes, (4) amphipods, (5) midges, (6) mayflies, (7) cladocerans, (8) oligochaetes, and (9) fish (Burton 1991). The choice of the test organism has a major influence on the ecological relevance, success, and interpretation of the test. Furthermore, no one species is best suited for all applications over the wide range of sediment characteristics.

Various methods have been developed to evaluate sediment toxicity. These procedures range in complexity from short-term lethality tests that measure effects of individual contaminants on single species to long-term tests that determine the effects of chemical mixtures on the structure and function of communities. The evaluated sediment phase may include whole sediment, suspended sediment, elutriates, or sediment extracts (Lamberson *et al.* 1992, Burton 1991). For a review of sediment toxicity test methods, their strengths and limitations, and considerations related to sampling and testing of sediments, see Burton (1992).

Currently, there are ASTM standard guides for several of the test species used in this study, e.g., E1706-95c, E1391-94, E1525-94a. In addition, the USEPA has recently standardized test methods for *Hyalella azteca*, *Chironomus tentans*, and *C. riparius*, and the bioaccumulation assay using *Lumbriculus variegatus* (USEPA 1994). The U.S. Army Corps of Engineers and the USEPA also have test methods for dredged material evaluations (USEPA-USCOE 1994). These standard test procedures may vary slightly from those used in this ARCS study.

A primary objective of the ARCS study was to determine which toxicity assays efficiently identified sediment contamination in the Great Lakes. In the ARCS study, a multi-biological level approach was taken, using assays representative of multiple trophic levels which had been successfully used in studies of sediment contamination.

METHODS

A detailed description of the toxicity test methods is presented in Burton *et al.* (1989) and Ingersoll *et al,* (1993). Sample site descriptions and sediment collection methods are described in detail in Ingersoll *et al.* (1993). Briefly, sediments were collected using a ponar sampler. A minimum of 5 composites were used for each station and mixed using a cement-mixer. Sediments were subsampled following mixing and distributed to high density polyethylene bottles (2 to 4 L). Sediments were kept in ice chests on ice until sampling was completed (within 2 days) and then shipped via overnight express to the participating laboratories. Upon sample receipt, sediments were refrigerated until test initiation (typically within 2 weeks of receipt). A Quality Assurance Project Plan was developed, which included reference toxicant testing, laboratory audits and data checks.

The sampled sediments and elutriates were tested with a variety of species. Toxicity assays were conducted with organisms from in-house cultures (exception was field-collected *Hexagenia* and *Diporeia*), and purchased rotifer cysts and Microtox. Culture health was routinely monitored by measuring reproductive rates and conducting reference toxicant testing. Test species included: (1) fathead minnow (*Pimephales promelas*, < 24 h old, whole sediment), (2) cladoceran (*Daphnia magna* and *Ceriodaphnia dubia*, < 24 h old, elutriates or whole sediment) neonates, (3) amphipods (*Hyalella azteca*, 7–14 d old, and *Diporeia* spp., adults, (formerly *Pontoporeia hoyi*), whole sediment), (4) midges (*Chironomus riparius* and *Chironomus tentans*, 8–12 d, second to third instar, whole sediment), (5) mayflies (*Hexagenia bilineata*, juvenile instars, elutriates, and whole sediment), (6) duckweed (*Lemna minor*, mature plants, whole sediment), (7) macrophyte (*Hydrilla verticillata*, mature plants, whole sediment), (8) rotifers (*Brachionus calciflorus*, < 24 h old, elutriates), (9) microbial enzymes (whole sediment, elutriates) and Microtox (elutriates), and (10) algae (*Selenastrum capricornutum*, log-phase growth, elutriates) (Table 1). In situ colonization of artificial substrates (3M Corp.

TABLE 1. Sediment toxicity tests evaluated in the ARCS program.

Biological Level	Test Organism/Community	Duration	Endpoints	Phase
Fish	*Pimephales promelas*	7 day	Larval survival/weight	S
		7 day	Embryo-larval survival, length, terata	S
Zooplankton	*Daphnia magna*	48 hour	Survival	S,E
		7 day	Survival/Reproduction (3 brood)	S
	Ceriodaphnia dubia	7 day	Survival/Reproduction (3 brood)	E
	Brachionus sp	24 hour	Survival	E
Benthic Invertebrate	*Hyalella azteca*	7 day	Survival	E
		14, 28 day	Survival, length, antenna segment number, sexual maturation	S
	Diporeia spp.	28 day	Survival	S
		5 day	Preference/avoidance, survival	S
	Chironomus tentans	10 day	Survival, length/weight	S
	Chironomus riparius	14 day	Survival, length/weight	S
	Hexagenia bilineata	10 day	Survival	S,E
			Molting frequency	S,E
	Rapid Bioassessment III (artificial substrates)	(10)	Community indices	S
Phytoplankton	*Selenastrum capricornutum*	48, 96 hour	Growth	E
		24 hour	14°C uptake	E
Macrophyte	*Lemna minor*	4 day	Growth (frond number)	S
			Chlorophyll a	S
			Biomass (wet weight)	S
	Hydrilla verticillata	10 day	Chlorophyll a	S
			Dehydrogenase activity	S
			Shoot length	S
			Root length	S
			Peroxidase	S
Microbial	Microtox ® (*Photobacterium phosphoreum*)		Luminescence	E
	Alkaline phosphatase (sediment community)		Enzyme activity	S
	Dehydrogenase (sediment community)		Enzyme activity	S
	β-Galactosidase (sediment community)		Enzyme activity	S
	Glucosidase (sediment community)		Enzyme activity	S

Note: E – elutriate
S – whole sediment

Summary: Total toxicity test types – 25
Single species tests – 20
Community tests – 5
Total endpoints – 55 (duplicate endpoints in solid and elutriate phases, counted as one)
Single-species endpoints – 41

polymer coiled web mesh) by benthic invertebrates at each site was also evaluated.

With the exception of Microtox, all assays were conducted in replicate. Most assays were conducted with ten to twenty organisms in triplicate test beakers, however, the mayfly, *C. tentans*, and short-term chronic cladoceran assays were conducted with one organism per 10 replicates.

Because of the large water volumes required for this test battery, the decision was made by the GLNPO ARCS Toxicity-Chemistry Work Group to test elutriates instead of interstitial water. All laboratories processed their elutriates in the same manner. A 1:4 mixture of sediment to test water was shaken for 30 minutes and then allowed to settle for 1 hour. The supernatant was then centrifuged for 15 min at 10,000 × g to reduced suspended solids. The centrifuged sample was used for testing. However, in the algal growth assay, elutriates were also filtered via a 0.45 micron cellulose-acetate filter to remove any remaining particulates.

Whole-sediment toxicity assays were conducted with macrobenthos in static or water-renewal systems at temperatures of 20 to 25°C. Sediments were placed in the test beakers and overlying water was gently added, typically resulting in a sediment to overlying water ratio of 1:4. Test organisms were randomly added within 24 h and the test initiated. Exposure water was typically moderately hard (hardness 134 mg/L as $CaCO_3$; alkalinity 1.2 to 1.3 mM 60 to 65 mg/L as $CaCO_3$); pH 7.8 to 8.0; conductivity 300 μmhos/cm; sulfate 72 mg/L). Dissolved oxygen, temperature, alkalinity, pH, conductivity, and water hardness were measured either daily or at test initiation and termination, depending on the parameter. See Burton *et al.* (1989) and Ingersoll *et al.* (1993) for additional detail.

Data Analysis

Data are summarized several different ways to allow for evaluations of the following questions: (1) does Station (sample) A differ from Station B?; (2) does Site 1 differ from Site 2?; (3) how sensitive are the measured endpoint responses?; and, (4) how well does the assay discriminate between different levels of toxicity (does Treatment A differ from Treatment B)? Data were analyzed using replicate data, arithmetic means of each assay by station, arithmetic means of each assay by site, or arithmetic means over all sites (using both station means and replicate data).

By conducting all assays on split samples which were collected and processed in the same manner, statistical relationships could be established with high statistical confidence. The assay responses were evaluated and compared by several methods, as described below:

- Sensitivity: comparison of the test response to the control response. Responses were then grouped into categories, (1) 20 to 50% difference and (2) 20 to 100% difference from the control. A relatively insensitive assay would show small differences from the control (e.g., near 20%) and sensitive assays would show large differences (e.g., greater than 50%). The number of responses falling within each grouping was then used to compare the relative sensitivity between assays. In addition, the variability and range of these responses were determined.
- Discrimination: the ability of the assay to detect differing degrees of toxicity between samples. It is important when defining the spatial extent of contamination to be able to ascertain whether sediment samples vary in toxicity. A statistical test was conducted (Kruskal-Wallis) which was used to determine the degree to which the sediment samples (each station) were different from each other within a test site (e.g., Buffalo River). The more statistically significant the difference was between samples, the more discriminatory the assay was.
- Redundancy: The degree of similarity of the responses from different assays was measured using correlation analyses (parametric and non-parametric) and by grouping the assay responses into patterns, through factor analysis. A high degree of correlation or pattern (grouping) similarity implies that the assays were responding in a similar manner. These analyses were conducted across all sites to better meet the study objective of determining which assays were best (in terms of predictive power) for Great Lakes studies. If the assays are producing similar information then it is less important that each be conducted, unless a weight-of-evidence approach is being used. It is, perhaps, of greater importance that a range of assays be employed which respond differently to varying types of sediment contamination (i.e., which show different response patterns and groupings). This approach will increase the likelihood that any detrimental effects on the aquatic ecosystem are being detected.

Data analyses were made using appropriate parametric or non-parametric correlation and m

comparison analyses. Correlation analyses, sensitivity determinations and groupings, discriminatory analyses, and principal component analysis were generated using a SAS computer package.

Raw data and summary statistics are presented in Burton *et al.* (1989) and Ingersoll *et al.* (1993). The data have also been entered into the USEPA's Office of Marine and Estuarine Protection ODES database and have received a quality assurance validation from the USEPA (USEPA 1994a).

RESULTS AND DISCUSSION

The principal objectives of the study were to determine: (1) which assays were the most sensitive to the presence of contaminated sediments, (2) which assays discriminated best between differing degrees of sediment contamination, and (3) were the assays responding in similar (e.g., significantly correlated) or dissimilar patterns. As each test sampling was a unique sampling event, sediment toxicity varied widely between stations and sites. Therefore, the degree of assay sensitivity and comparability with other assays varied with each sampling event. The data summaries provide a weight-of-evidence approach for identifying trends in assay responses. It is likely that conclusions from this study may change with additional testing of contaminated sites.

Combined Site Sediment Toxicity—Sensitivity

The assays were ranked by comparing each assay replicate to the control and grouping response into: (1) effects greater than 50% difference from the control and (2) effects between 20 and 50% different from the control (Table 2). Groupings were divided into inhibitory and stimulatory responses. In the "Effect Level" column of Table 2, the percentage of samples classified as toxic are listed. They are then ranked by their relative degree of toxicity (% effect level) in the "Site Rank" column. The assay responses were ranked against each other. Equal effect levels received equal rankings. The "Composite Rank" was the average mean value of the four site rank values (with the associated range).

Several benthic species were very responsive to sediment toxicity. Preference behavior by *Diporeia* was the most sensitive endpoint of effects, being affected by 90% of the samples. Behavior would be expected to be a responsive sublethal measure, but the ecological significance of a behavioral response is difficult to interpret. *Hexagenia bilineata* endpoints comprised 4 of the top 15 inhibitory measures, with survival and molting being affected in both elutriate and whole-sediment exposures. Unfortunately, the number of data points used in the mayfly assays was only 16 and many of these samples were stored for several months before testing which makes comparisons to *H. bilineata* suspect. The *Hydrilla verticillata* assay produced primarily stimulatory responses with a maximum of 88% of the samples being affected in the peroxidase assay and 75% of the samples inhibiting root growth (and stimulated in 10% of the samples).

The 11 assays ranked in Table 2 comprised 43 response endpoints. The remainder of the assays and endpoints were deleted from this ranking because there was either insufficient data or the controls were not appropriate for the sensitivity calculation used in the ranking process (e.g, microbial enzymes or artificial substrate colonization). Only the *H. verticillata* peroxidase and the *H. azteca* 14 d antenna length endpoints did not show any test responses in greater than 50% of the samples.

Combined Sediment Toxicity—Discrimination

A ranking of the discriminatory power of 53 of the 97 endpoints is listed in Table 3. The discriminatory ability measures how well the assay response detects varying levels of sediment toxicity. This ability is expressed using levels of statistical significance, or p values. The smaller the p value, the higher the level of statistical significance, or difference between samples/stations. Some assay data were not available or could not be analyzed by this procedure, so p values do not exist for all responses at all sites. The p value average, the range of p values, and the number of sites (1 to 4) for which discrimination analysis was conducted, must all be considered in the relative ranking. It is misleading, in some cases, to only consider the p value average, if it only came from one site or highly significant p values (e.g., $p = 0.0001$) were offset by very high p values (e.g., $p = 1.0$). For example, the first two endpoints were not considered reliable as they were only reported for one site.

The photosynthetic and indigenous microbial responses would be expected to be good discriminators since they can exhibit both inhibitory and stimulatory responses, giving them a wider range of response than just 0 to 100%, as with conventional test responses. Indeed, the *S. capricornutum* growth at 48 h (average p value of 0.0213) and at 96 h (average p value of 0.0150) were among the best discriminatory

TABLE 2. Ranking of most sensitive assay endpoints.[a]

Assay[b]	Rank	Effect Level[c] 20–100%	Effect Level[c] 20–50%	Site[d] Ranks IH	BR	SR1	SR3	Composite Avg. (Range)
php.s	1	90	6	1=[e]	3	5	1	2.5 (1–5)
xs.e	2	75	0	1=	1	1	20=	5.75 (1–20)
vr.s	3	75 (10)[f]	35	1=	11=	3	2	4.25 (1–11)
xm.e	4	69	13	1=	4	2	20=	6.75 (1–20)
dr.s	5	64	44	6	7	6	8	6.75 (6–8)
Hx14	6	60 (23.3)	1.7	1=	2	17	7	6.75 (1–17)
flw.s	7	58	34	3	8	8	10	7.75 (3–10)
M45.5	8	54	12	2	9	23=	–	11.3 (2–23)
hs.s	9	51	16	1=	5	10	17=	8.25 (1–17)
M45.15	10	50	4	1=	10	23=	–	11.3 (1–23)
Ct10	11	50	12	1=	26=	–	4	10.3 (1–26)
cr.s	12	50	13	10=	18	4	3	8.75 (3–18)
xs.s	13	50	19	1=	17	19=	6	10.75 (1–19)
Cr14	14	47	10	1=	6	15	19=	10.25 (1–19)
xm.s	15	44	6	1=	11=	19=	20=	12.75 (1–20)
phs.s	16	43	27	14	14	7	9	11.6 (7–14)
Hs14	17	35.5	9.2	1=	13	19	20=	13.25 (1–20)
Ctl	18	30.8	30.8	5	12	–	20=	12.3 (5–20)
fet.s	19	31	21	4	17	11	20=	13.0 (4–20)
cr.e.100	20	31	3	7	26=	14	14	15.25 (7–26)
vs.s	21	29 (52)	29	9	23	13	15	12.5 (5–23)
cs.s	22	26	0	16	21	20	11	17.0 (11–21)
fes.s	23	21	13	8	22	27=	17=	18.5 (8–27)
ds.48.s	24	19	9	12	26=	12	20=	17.5 (12–23)
cs.e.100	25	18	0	17	24	16	16	18.25 (16–24)
vd.s	26	17.5 (70)	5	21=	16	25	5	16.75 (5–25)
Hs28	27	15	5	–	–	19=	18	18.5 (18–19)
vc.s	28	15 (53)	11	20=	20	9	20=	17.75 (9–20)
M100.5	29	14	7.4	–	26=	28=	12	22.0 (12–28)
fls.s	30	14.5	9.2	13	19	28=	19=	19.75 (13–28)
Hl14	31	13.3	13.3	10=	15	25	20=	17.5 (10–25)
lb.s	32	12 (36)	1	11	21	28=	20=	20.0 (11–28)
M100.15	33	11.1	3.7	–	26=	27=	13	22.0 (13–27)
Hx28	34	10 (2.5)	5	–	–	20	19=	19.5 (19–20)
Hl28	35	10	7.5	–	–	18	20=	19.0 (18–20)
ds.s	36	8	0	18	25	24	19=	21.5 (18–25)
fel.s	37	7	7	15	26=	28=	20=	22.25 (15–28)
Crl	38	6.6 (16.7)	3.3	–	26=	17	20=	21.0 (17–26)
Ha28	39	5	5	–	–	21	20=	20.5 (20–21)
lf.s	40	3 (36)	3	19=	26=	28=	20=	23.25 (19–28)
lc.s	41	2 (25)	2	20=	26=	28=	20=	23.25 (20–28)
Ha14	42	0	0	21=	26=	27=	20=	23.5 (20–27)
vp.s	43	0 (87.5)	0	21=	26=	28=	20=	23.75 (20–28)

[a] Ranking based on SAS sensitivity groupings using individual replicate data (not station means). Missing endpoints were not included due to lack of true control values for determining sensitivity (Response – Control/Control) or data were too limited.

[b] See facing page.

[c] Percentage of values showing effects ranging from 20 to 100 % or 20 to 50 % of the control response.

[d] IH, Indiana Harbor; BR, Buffalo River; SR1; Saginaw River survey no. 1; SR#, Saginaw River survey no. 3. Based on mean value of station replicates.

[e] = , Same rank level as another measurement endpoint.

[f] (x) = additional percentage of responses stimulated greater than 20% over the control response. Value not considered in ranking.

Footnote b, Table 2, continued from facing page.

Test Response Endpoints and Codes *.

Code	Response
a.as	amphipods, % (artificial substrate)
ap	alkaline phosphatase activity
BR1	Buffalo River, first sample period
c	control
c14.e.50	*Selenastrum capricornutum* C-14 uptake (24 h 50% elutriate)
c.as	chironomids, % (artificial substrate)
cr	*Ceriodaphnia dubia* reproduction (7 d, 3 brood)
cs	*Ceriodaphnia dubia* survival (7 d, 3 brood)
cr.e.100	*Ceriodaphnia dubia* reproduction (7 d 100% elutriate)
cs.e.100	*Ceriodaphnia dubia* survival (7 d 100% elutriate)
Cr14	*Chironomus riparius* survival (14 d)
Crl	*Chironomus riparius* length (14 d)
Ct10	*Chironomus tentans* survival (10 d)
Ctl	*Chironomus tentans* length (10 d)
dh.s	dehydrogenase activity in sediment
dr	*Daphnia magna* reproduction (7 d, 3 brood)
ds	*Daphnia magna* survival (7 d, 3 brood)
ds48	*Daphnia magna* survival (48 h exposure)
.e	elutriate phase exposure
f.as	flatworms, % (artificial substrate)
fel	*Pimephales promelas* embryo larval length (7 d)
fes	*Pimephales promelas* embryo larval survival (7 d)
fet	*Pimephales promelas* embryo larval terata (7 d)
fls	*Pimephales promelas* larval survival (7 d)
flw	*Pimephales promelas* larval weight (7 d)
ga	galactosidase activity
gl	glucosidase activity
h.as	hydra numbers, % (artificial substrate)
hs7	*Hyalella azteca* survival (7 d)
Hs14	*Hyalella azteca* survival (14 d)
Hl14	*Hyalella azteca* length (14 d)
Ha14	*Hyalella azteca* antenna length (14 d)
Hx14	*Hyalella azteca* sexual maturation (14 d)
Hs28	*Hyalella azteca* survival (28 d)
Hl28	*Hyalella azteca* length (28 d)
Ha28	*Hyalella azteca* antenna length (28 d)
Hx28	*Hyalella azteca* sexual maturation (28 d)
ic.m	Invertebrate Community Index mayfly, % (artificial substrate)
ic.to	Invertebrate Community Index tolerant organisms, % (artif. substr.)
ic.tr	Invertebrate Community Index, taxa richness (artif. substr.)
IH1	Indiana Harbor, first sample period
lb	*Lemna minor* biomass (4 d)
lc	*Lemna minor* chlorophyll a (4 d)
lf	*Lemna minor* frond number (4 d)
m.e.50	Microtox 50% dilution (15 min)
mr.e.50	Microtox QA check on stored rotifer samples, 50% dilution (elutriate)
M100.5	Microtox 100% (5 min)
M100.15	Microtox 100% (15 min)
M45.5	Microtox 45% dilution (5 min)
M45.15	Microtox 45% dilution (15 min)
o.as	oligochaete number (artificial substrate)
php	*Pontoporeia hoyi (Diporeia spp.)* preference (5 d)
phs	*Pontoporeia hoyi (Diporeia spp.)* survival (20 d)
r2d	Rapid Bioass. Protocol Phase II, % contrib. dominant family (artif. subs.)
r2.ec	Rapid Bioassessment Protocol Phase II, EPT/Chironomidae (artif. subs.)
r2f	Rapid Bioassessment Protocol Phase II, Family Biotic Index (artif. subs.)
r2.tr	Rapid Bioassessment Protocol Phase II, taxa richness (artif. substr.)
r.e.50	rotifer (*Brachionus sp.)* survival 24 h 50% elutriate)
.s	solid phase exposure
s.48.e.100	*Selenastrum capricornutum* growth (48 h 100% elutriate exposure)
s.96.e.100	*Selenastrum capricornutum* growth (96 h 100% elutriate exposure)
SR1	Saginaw River, first sample period
SR3	Saginaw River, third sample period
sag.b	Saginaw R. macroinvertebrate biomass (artificial substrate)
vc	*Hydrilla verticillata* chlorophyll
vd	*Hydrilla verticillata* dehydrogenase
vp	*Hydrilla verticillata* peroxidase
vr	*Hydrilla verticillata* root length
vs	*Hydrilla verticillata* shoot length
xm	*Hexegenia bilineata* molting frequency (10 d)
xs	*Hexegenia bilineata* survival (10 d)
z.as	zebra mussel number (artificial substrate)
*	Some codes in the dataset are combinations of the above codes, such as:

c (control) + assay code + .s (solid phase) or + .e (elutriate) + # (% sample, e.g., 100, 71.4, 57, 50, 28.6, 15, 12.5, 10.2 or 6.25). Assays which are capitalized were conducted by the USFWS (National Biological Service).

TABLE 3. Discriminiatory table.

Toxicity Test (Endpoint)[a]	Discriminatory Rank[b]	Average *P* Value[c]	Standard Deviation	Significant Surveys[d]	Range of *P* Values
Hydra (numerical percent, artificial substrate)	1	0.0069	N.A.[e]	1/1	
Saginaw River macroinvertebrates (biomass, artificla substrate)	2	0.0069	N.A.[e]	1/1	
Brachionus sp. (50-percent elutriate, 24-hour survival)	3	0.0071	0.0048	4/4	0.0018-0.0134
Ceriodaphnia dubia (100-percent elutriate, 7-day reproduction)	4	0.0083	0.0110	4/4	0.0001-0.0233
Chironomus riparius (14-day length)	5	0.0116	0.0050	3/3	0.0063-0.0162
Selenastrum capricornutum (100-percent elutriate, 96-hour growth)	6	0.0150	0.0097	4/4	0.0037-0.0273
Sediment microbial community (dehydrogenase activity)	7	0.0152	0.0170	2/2	0.0032-0.0273
Pimephales promelas (7-day larval weight)	8	0.0198	0.0180	4/4	0.0061-0.0463
Selenastrum capricornutum (100-percent elutriate, 48-hour growth)	9	0.0213	0.0155	3/3	0.0084-0.0329
Rapid Bioassessment Protocol Phase II (Family Biotic Index, artificial substrate)	10	0.0240	0.0113	3/3	0.0291-0.0319
Hyalella azteca (28-day length)	11	0.0298	0.0176	3/3	0.0129-0.0481
Sediment microbial community (glucosidase activity)	12	0.0331	0.0314	2/3	0.0050-0.0670
Selenastrum capricornutum (50-percent elutriate, 24-hour 14°C uptake)	13	0.0507	0.0736	3/4	0.0013-0.0158
Daphnia magna (7-day reproduction)	14	0.0570	0.1136	3/4	0.0001-0.2274
Sediment microbial community (galactosidase activity)	15	0.0647	0.0529	2/2	0.0273-0.1021
Flatworms (numerical percent, artificial substrate)	16	0.0675	0.0726	2/3	0.0223-0.1513
Lemna minor (4-day cholrophyll a)	17	0.0676	0.0547	3/4	0.0086-0.1266
Amphipods (numerical percent, artificial substrate)	18	0.0707	0.0488	1/3	0.0284-0.1223
Pimephales promeles (7-day embryo larval terata)	19	0.0826	0.1404	3/4	0.0020-0.2929
Rapid Bioassessement Protocol Phase II (percent contributing dominant family, artificial substrate)	20	0.0870	0.0965	2/3	0.0302-0.1984
Microtox (50-percent dilution, 15 minute)	21	0.0890	0.0060	0/3	0.0833-0.1017
Hyalella azteca (14-day survival)	22	0.1049	0.1441	2/3	0.0173-0.2712
Hydrilla verticillata (10-day peroxidase)	23	0.1051	0.0000	0/1	
Hyalella azteca (28-day survival)	24	0.1098	0.1137	1/3	0.0169-0.2366
Hyrdrilla verticillata (10-day shoot length)	25	0.1182	0.0270	0/4	0.0922-0.1479
Oligochaetes (number, artificial substrate)	26	0.1397	0.2051	2/3	0.0116-0.3763
Rapid Bioassessement Protocol Phase II (taxa richness, artificial substrate)	27	0.1407	0.0977	1/3	0.0290-0.2107

Ceriodaphnia dubia (7-day survival)	28	0.1452	0.1698	2/4	0.0001-0.3402
Hyalella azteca (28-day sexual maturation)	29	0.1639	0.2102	1/3	0.0463-0.5296
Sediment microbial community (alkaline phosphatase activity)	30	0.1712	0.2671	2/3	0.0032-0.4712
Hyalella azteca (28-day antenna segment number)	31	0.1726	0.2391	2/3	0.0219-0.4483
Hyalella azteca (14-day length)	32	0.1805	0.1372	1/3	0.0277-0.2930
Pimephales promelas (7-day embryo larval length)	33	0.1808	0.1928	2/4	0.0183-0.3766
Ceriodaphnia dubia (7-day reproduction)	34	0.1914	0.3613	3/4	0.0002-0.7329
Ceriodaphnia dubia (elutriate, 7-day survival)	35	0.1930	0.2234	2/4	0.0001-0.4060
Lemna minor (4-day biomass)	36	0.2017	0.2509	1/4	0.0452-0.5743
Chironomus riparius (14-day survival)	37	0.2091	0.3290	3/4	0.0245-0.7017
Daphnia magna (7-day survival)	38	0.2441	0.2865	2/4	0.0001-0.5527
Diporeia spp. (5-day preference)	39	0.2671	0.2441	2/4	0.0539-0.8296
Daphnia magna (48-hour survival)	40	0.2764	0.2212	1/4	0.0272-0.4060
Hyallela azteca (14-day sexual maturation)	41	0.2765	0.2425	1/3	0.0463-0.5296
Hyalella azteca (14-day antenna segment number)	42	0.3120	0.3849	1/3	0.0262-0.7496
Pimephales promelas (7-day larval survival)	43	0.3172	0.4498	2/4	0.0161-0.9716
Diporeia spp. (28-day survival)	44	0.3182	0.4398	2/4	0.0233-0.9576
Hydrilla verticillata (10-day chlorophyll)	45	0.3720	0.1783	0/4	0.1931-0.6110
Chironomids (numerical percent, artificial substrate)	46	0.3633	0.4987	1/2	0.0105-0.7161
Pimephales promelas (7-day larval survival)	47	0.3815	0.3122	1/4	0.0159-0.7580
Lemna minor (4-day frond number)	48	0.3824	0.3065	1/4	0.0427-0.7863
Rapid Bioassessment Protocol Phase II (EPT/Chironomidae, artificial substrate)	49	0.4191	0.5078	0/3	0.0593-1.0000
Hyalella azteca (7-day survival)	50	0.4742	0.00000	0/4	0.0713-1.0000
Hydrilla verticillata (10-day dehydrogenase)	51	0.4988	0.3647	0/3	0.1125-0.8371
Zebra mussels (numbers, artificial substrate)	52	0.5080	0.6958	1/2	0.0160-1.0000
Hydrilla verticillata (10-day root length)	53	0.5826	0.3152	0/4	0.2521-0.8769

[a]All toxicity tests were conducted with whole sediment unless indicated otherwise. Some endpoints lacked adequate data for ranking.
[b]Discriminatory ranks based on the average *P* value for pairwise statistical comparisons of all station responses with the control response.
[c]Average of *P* values for the surveys analyzed.
[d]Number of surveys with significant Kruskal-Wallis *P* value ($P \leq 0.05$) per total number of surveys where that endpoint was analyzed.
[e]Not applicable since standard deviation cannot be done on one sample.

assays over four sites. However, of the other photosynthetic endpoints, only *L. minor* chlorophyll a production showed significant differences at three sites. Frond number and biomass showed differences at only one site and *H. verticillata* endpoints did not detect any significant differences.

The indigenous microbial responses were better discriminators than these later two photosynthetic surrogate species with significant differences observed at two or three of the three sites analyzed. They ranked from high to low discriminatory ability, in order, as: dehydrogenase, glucosidase, galactosidase, and alkaline phosphatase.

Several of the benthic macroinvertebrate community indices that were sampled using artificial substrates were good discriminators. The top two listed in Table 2 (hydra and biomass) cannot be reliably evaluated as they only were analyzed or determined for one site. The Family Biotic Index, however, was highly discriminatory ($p = 0.0291$ to 0.0319) at all three sites. The second best discriminator in this group of endpoints was percent flatworm composition, showing differences at two of three sites. Two other endpoints showing this level of discrimination, but with slightly lower p values, were percent contributing dominant family and percent oligochaete composition.

Of the other toxicity test species which were evaluated, several endpoints were good discriminators among the nonbenthic species. Survival of the benthic species *Hyalella azteca, C. riparius*, and *Diporeia* did not rank high in discriminatory ability at the four sites. However, chronic endpoints of length and sexual maturation were highly discriminatory at a minimum of one test site. The *C. riparius* length ($p = 0.0116$) and *H. azteca* 28 d length ($p = 0.0298$) were significant at all three sites tested. The best nonbenthic invertebrate endpoints were ranked as follows: the rotifer, *Brachionus* survival, *C. dubia* reproduction (elutriate), and *P. promelas* larval weight, showing differences at all four sites. The rotifer assay showed significant discrimination at all four sites, however, the data are questionable, for comparison purposes, due to storage of sediment for 12 months before testing. Five endpoints had significant p values at 75% of the sites, including: *S. capricornutum* ^{14}C-uptake, *D. magna* reproduction, *P. promelas* embryo- larval terata (visible abnormalities), *C. dubia* reproduction (whole sediment), and *C. riparius* survival. Some other endpoints showed highly significant p values at two of four sites, but had high p values at others, such as *C. dubia* survival (whole sediment), *P. promelas* embryo larval length, *C. dubia* reproduction (whole sediment) and survival (elutriate), and *D. magna* survival (whole sediment). In summary, there were several assay endpoints which proved to be highly discriminatory of degrees of sediment toxicity. This is a critically important assay trait when attempting to define the spatial extent of site contamination. The nonbenthic assays tended to be more discriminatory than the benthic assays and should be included in any test battery for this reason.

Summary of Assay Sensitivity and Discriminatory Ability

While the *Diporeia* preference and avoidance endpoints were the most sensitive overall, this assay is one of the least developed (Gossiaux *et al.* 1993). The survival endpoint for this organism was relatively insensitive (ranked from 7 to 14 in the four surveys) and *Diporeia* must be collected from the field for testing. The ecological significance of behavior endpoints, such as avoidance/preference is difficult to evaluate at this time. However, *Diporeia* is of critical importance in the Great Lakes. This characteristic alone indicates the assay should be given high priority for additional methods development and testing.

Hexagenia bilineata exhibited sensitive responses at most test sites with endpoint responses ranging from 1 to 9. The Kruskal Wallis test could not be run with this data set. Previous discriminatory analysis using a different procedure whereby the geometric mean is divided by the arithmetic mean indicated the molting endpoint to be relatively discriminatory (rank = 5), however survival was not discriminatory (rank = 21). Surprisingly, the elutriate exposures were, for *H. bilineata*, more sensitive than the whole-sediment assays. The sensitivity of *H. bilineata* in the ARCS project may have resulted from the prolonged storage of sediment before testing. The inability to continuously culture mayflies in the laboratory has limited their routine use in sediment testing. Mayflies may also be sensitive to grain size in whole-sediment exposures (ASTM 1995).

An elutriate assay was to be evaluated with the nematode *Pangrellus redivivus* (Samoiloff *et al.* 1980). The culture was lost during the project. Consequently the rotifer, *Brachionus calyciflorus*, survival assay was testing in place of nematodes (Snell and Persoone 1989). Unfortunately, the assays had to be conducted after prolonged sediment storage (up to 12 months). As with the *Hexagenia* assay, comparison of sediment effects on rotifers to the other assays

tenuous because of potential toxicity artifacts caused by sediment storage. The rotifer was insensitive but was discriminatory in elutriate exposures.

Hyalella azteca responses were highly variable, depending on the time of exposure (7 to 28 d) and the endpoint measured, with rank levels ranging from 1 to 27. The advantages to conducting sediment tests with *H. azteca* are: (1) the animals can be cultured in the laboratory, (2) testing and culturing methods have been standardized, (3) effects on survival, growth, or sexual maturation can be monitored in 7- to 28-d exposures, (4) *H. azteca* are insensitive to grain size of the sediment (Ankley *et al.* 1996), (5) *H. azteca* ranked number 4 in the combined ranking of sensitivity and discriminatory ability for 14 d survival, and (6) they correlated well with other assay responses and covered three of the four unique pattern groupings identified over all the test sites.

The midges *C. tentans* and *C. riparius*, as *H. azteca*, showed a wide range of sensitivity and discriminatory ability over the test sites, but ranked relatively high overall. Control survival for the *Chironomus* sp. was typically lower than the other test species. The advantages to conducting sediment tests with midges are: (1) the animals can be cultured in the laboratory, (2) testing and culturing methods have been standardized, and (3) effects on survival and growth can be monitored in 10- to 14-d exposures. The *C. riparius* assay responses described two of the four unique pattern groupings observed at the ARCS sites.

Tests with the aquatic macrophyte *Hydrilla* have been conducted by very few laboratories. Some of the measured endpoints used in this assay proved to be sensitive (root growth, ranked 1–11), but the endpoints were not discriminatory. *Hydrilla* represents a unique level of biological organization and should be considered in future assessments if adequate resources are available for testing. The *Lemna* (duckweed) assay also measures a unique biological level of organization that is of importance to ecosystem functioning. The assay by design cannot be highly sensitive to sediment contaminants since the plants float on the surface of the water. Therefore, *Lemna* are only exposed to contaminants that are water soluble or associated with colloidal suspended particles.

Hall *et al.* (1996, this issue) reported problems conducting elutriate toxicity tests using the 24-h ^{14}carbon assimilation with algal assay. Interpretations of toxicity using *Selenastrum capricornutum* were complicated by variable nutrient and inorganic carbon concentrations in the elutriate samples. All of the elutriate samples tested stimulated carbon assimilation of *Selenastrum capricornutum* in one or more of the dilutions. Attempts to modify the algal medium to provide unlimited nutrients were not successful. An algal medium that supports greater growth potential should be developed in order to evaluate the toxicity of environmental samples with high concentrations of nutrients to algae.

The Microtox assay response was relatively sensitive (overall rank of 8; Table 2). It was well correlated with other assay responses. Other strengths of the Microtox assay are rapid response and small volume requirements. Microtox is recommended as a screening tool for evaluating freshwater and marine sediment, and can be used to quickly process a large number of samples. The bioluminescence response is relatively sensitive to many contaminants and is often correlated with responses of other test species. The simplicity, degree of standardization, and ability to test interstitial water, elutriates, and whole sediment makes Microtox a versatile and relevant assay. However, no one assay should be used as the sole toxicity method, since the assay can produce false negatives or false positives.

The indigenous assays included benthic macroinvertebrate indices from artificial substrates and microbial enzyme activities of sediment samples. These data could not be analyzed for sensitivity with the above data sets because of the lack of controls for comparisons. Several endpoints for these assays proved to be highly discriminatory (Table 3). The percent tolerant species and percent chironomid composition indices were highly correlated with toxicity assay responses. Both of these assays represent unique levels of biological organization. Microbial enzyme and benthic colonization assays evaluate indigenous organisms, not surrogate species and, therefore, there are reduced uncertainty in data extrapolations.

Measured Endpoint Response Pattern Similarities–Redundancy

Principal component analysis (PCA) was conducted on the data set to determine if there were similar groupings of responses among assays. This procedure illustrates which endpoints produce similar or unique response patterns. In the PCA, the data undergo an orthogonal transformation, so the factors are independent of each other. The results of the analysis are presented as separate factors, each of which explains one response pattern. The percent contribution of each variable (endpoint) to each re-

sponse pattern (factor) is listed in Table 4. Variables contributing similar levels to a factor are grouped as being similar. There can be no missing data for any variable; that is, the number of data points must be equal. So, there were only 20 endpoints (Table 4) out of 97 possible endpoints that met these data requirements.

The statistical analysis revealed four groupings of unique response patterns. Group 1 consisted of *H. azteca* length (14 or 28 d), antenna number (14 or 28 d), and sexual maturation (28 d); *C. riparius* survival; *D. magna* reproduction; *L. minor* frond growth; and *C. dubia* reproduction. Group 2 included *C. dubia* survival, *C. riparius* length, *H. azteca* sexual maturation (14 d), and *P. promelas* larval weight. Three endpoints comprised the third grouping, including *H. verticillata* root length, *Diporeia* (*P. hoyi*) preference, and *H. azteca* survival (14 d). *Hexagenia bilineata* survival and molting explained the fourth pattern of responses. All of the endpoints included in these groupings were whole sediment exposures.

TABLE 4. Principal component analysis of ARCS sites.

	Factor[a]			
Assay	1	2	3	4
Chironomus riparius 14 d survival	.97			
Chironomus tentans 10 d length	.96			
Hyalella azteca 28 d antenna length	.95			
H. azteca 28 d length	.94			
H. azteca 14 d antenna length	.94			
Daphnia magna 7 d reproduction	.92			
Lemna minor 4 d frond	.90			
H. azteca 14 d length	.86			
H. azteca 28 d survival	.63			
Ceriodaphnia dubia 7 d reproduction	–.74			
H. azteca 28 d sexual maturation	–.94			
C. dubia 7d survival		.85		
C. riparius 14 d length		.83		
H. azteca 14 d sexual maturation		–.70		
Pimephales promelas 7 d larval weight		–.71		
Hydrilla verticillata 10 d root length			.92	
Diporeia 5 d preference			.78	
H. azteca 14 d survival			–.60	
Hexagenia bilineata 10 d survival				.91
H. bilineata 10 d molting frequency				.72

These findings suggest that responses within each group are producing similar and redundant information. If a test battery were to be selected that detected each type of toxicity response pattern (Factors 1 to 4), one assay consisting of two or more endpoints could provide unique information for multiple groupings. For example, the *H. azteca* 14 d assay consisting of survival, length, antenna number, and sexual maturation endpoints is representative of three unique response patterns, while only *H. bilineata* describes the fourth pattern. Both the *C. dubia* and *C. riparius* assays can be used to explain factors 1 and 2. Use of these assays would enable each unique response pattern to be covered with fewer organism types.

Correlations Between Assay Responses

Correlating the endpoint responses (both laboratory assays and community structure) to detect similar response patterns is another useful method to evaluate data redundancy and provide field validation of toxicity assays. All measured endpoints were correlated with each other and the top ten correlations evaluated based on the r^2 and p values.

The numbers of significant correlations between assay responses vary with the degree of site contamination. Indiana Harbor was the worst contaminated (Nelson *et al.* 1996) and most toxic site of the three surveyed. Indiana Harbor had the highest number of significant (greater than or equal to $p = 0.05$) correlations. The Buffalo River samples exhibited less contamination and toxicity compared to the other sites and had the fewest correlations. The Saginaw River No. 1 survey had a moderate level of toxicity. There was little toxicity observed in the Saginaw 3 sediments.

A review of the best 10 correlations for each assay (93 endpoints) at each site showed 72% of the endpoints had more than 10 significant correlations and 77% had endpoint correlations with r^2 greater than 0.80. Endpoints with the fewest correlations included *H. verticillata* root and shoot growth (no significant correlations), *L. minor* biomass and benthic taxa richness (two correlations), percent flatworms and microbial galactosidase activity (three correlations), *D. magna* 7 d survival (four correlations), and *L. minor* chlorophyll *a* (five correlations). The response patterns among assays was similar for sediments collected from the Indiana Harbor and Saginaw No. 1 surveys. Since there were only three samples collected in the Saginaw No. 1 survey, correlations would be similar, particularly since one

sample (station no. 6) was very toxic. The endpoints with the highest average correlation (r^2 value) were (in rank order) Microtox, *C. tentans* length, and % chironomids and % tolerant species in the artificial substrate samples. Fewer significant correlations were noted a second survey of the Saginaw River that had more samples and less toxicity associated with the samples. The high number of significant correlations between laboratory toxicity assay responses and some artificial substrate benthic macroinvertebrate endpoints (e.g., % tolerant species and % chironomids) provides a high degree of field validation for the laboratory assays.

When assessing sediment toxicity it is important to consider effects on both benthic and nonbenthic species, since there may be interactions between sediment and overlying water compartments and between benthic and nonbenthic species. Of the nonbenthic species, the *P. promelas* and cladoceran assays are the most commonly used in sediment testing. Fish and cladocerans feed on the sediment surface during whole sediment exposures, which increases their exposure. When toxicity response patterns were compared between benthic and non-benthic species there were many significant correlations. The 7-d assays with *C. dubia, D. magna*, and *P. promelas* larval growth were significantly correlated with 10 to 70% of the benthic responses. The endpoint responses of *H. azteca* were significantly correlated with 10 to 80% of the nonbenthic responses, and *C. tentans* and *C. riparius* responses were correlated with greater than 60 and 70%, respectively, of the nonbenthic responses. The indigenous sediment microbial enzyme activities correlated with 10 to 70% of the nonbenthic endpoints.

For non-dredged material applications it is preferable to conduct liquid-phase toxicity tests with interstitial water. Toxicity tests with interstitial water are better than elutriates for evaluating the potential *in situ* effects of contaminated sediment on aquatic organisms (Ankley *et al.* 1991). Elutriate tests are most appropriately used in dredged material evaluations because they mimic disposal conditions. Elutriate samples are typically less toxic than either whole-sediment or interstitial water samples (Sasson-Brickson and Burton 1991, Ankley *et al.* 1991).

CONCLUSIONS

The process of selecting the optimal assay(s) for use in an ecosystem assessment is not simple or straight forward. The optimal assay can only be selected when the objectives of the study and associated data quality objectives have been defined and there is a reasonable understanding of the physical, chemical, and biological characteristics of the study site.

A number of useful assays have been evaluated in freshwater and marine studies (Burgess and Scott 1992, Burton 1991, Lamberson *et al.* 1992, Burton and Scott 1992). It is apparent from these previous studies and the current one that no one assay, indicator, or measured response (endpoint) is superior to all others. The rankings of sensitivity and discriminatory ability varied between test sites. However, the overall rankings give an indication of which assays tend to be the most useful. To reduce uncertainty and reduce the chance of obtaining false positive or false negative results, it is important to test more than one species. The importance of testing multiple species increases with the importance of protecting the ecosystem and the need to define "significant" contamination in the "gray" (marginally contaminated) zone.

Each assay provides information that is unique to that species and the life process measured (e.g., survival, growth). Some of assay responses are similar to each other, thus provide duplicative (redundant) information. If this similarity between assay response patterns occurs at several test sites, then some of the similar assays could be deleted from a test battery, using other criteria for assay selection, e.g., cost, resource requirements, difficulty. Resources might be put to better use by deleting assays that produce redundant information and measuring unique toxicant response patterns, such as observed in the PCA analyses (Table 4). However, if one wants to take a "weight-of-evidence" approach, use of assays which respond similarly to contaminated sediments may provide additional effect information. This increases the uncertainty, however, that a realistic comprehensive assessment of ecosystem effects is being attained. A toxicity survey which is too limited in scope may produce false positive or false negative results and thereby faulty conclusions. It may be more important to conduct fewer assays with more samples to better define the spatial and temporal variability in sediment contamination.

Other critical factors to consider in selection of the test responses are relative abilities at detecting sediment toxicity (i.e., sensitivity) and measuring level of toxicity (i.e., discrimination). Sediment toxicity appeared to relate well to the relative degree of chemical contamination at these sites. To relate these assay responses to chemical contaminant levels requires detailed analyses (described in In-

gersoll *et al.* 1996, and USEPA 1994b). Sediment contamination can vary dramatically within and between sites. Additional analyses are required to determine if the endpoints listed in Table 1 are responding to contaminants associated with sediments or to physical (e.g., grain size) or non-contaminant chemical characteristics, (e.g., interstitial water hardness). An assay that was sensitive and discriminatory at one site will not necessarily respond in a similar fashion at another site.

Integrative studies should use a water column and benthic species in whole-sediment exposures as resources permit. Useful water column assays are 7-d early life stage exposures with fathead minnows (*Pimephales promelas* larval growth or embryo-larval growth and terata (abnormalities) and 7-d survival) and reproduction assays with *Ceriodaphnia dubia* or *Daphnia dubia*. Both of these cladoceran assays were recently developed as ASTM methods (ASTM 1995). Benthic assays that were most successful were: (1) 7- to 28-d survival, growth, and development test with *Hyalella azteca*, (2) 10- to 14-d survival and growth assays with *Chironomus tentans* or *Chironomus riparius*, and (3) the 10-d survival and molting assay with *Hexagenia bilineata*. Methods for testing sediment with the amphipod *Diporeia* spp. (formerly *Pontoporeia hoyi*) have been recently described (ASTM 1995). Survival and sediment avoidance or preference of *Diporeia* are monitored in 28 and 5 d exposures, respectively (Burton *et al.* 1989).

The choice of the appropriate endpoint (response) to measure is important to the assessment process. All toxicants do not affect the same metabolic processes and result in the same effects since they have differing modes of action and target receptors. Some toxicants may interfere with processes essential for reproduction or growth. Relative species sensitivity frequently varies among contaminants. For example, Reish (1988) reported the relative toxicity of six metals (As, Cd, Cr, Cu, Hg, and Zn) to crustaceans, polychaetes, pelecypods, and fishes and concluded that no one species or group of animals was the most sensitive to all of the metals. Differences in contaminant types and concentrations between sites likely contributes to differences in species responses; however, the present study sites were each contaminated with a wide range of PAHs and metals.

Contaminants may also stimulate a process due to interruption of a feed-back mechanism or they may be essential nutrients at low concentrations (e.g., selenium). Stimulation at low concentrations of toxicant exposure (hormesis) is often reported in the literature. Some responses are much more sensitive than others (e.g., enzyme inhibition vs. lethality), and should not necessarily be weighted equally in evaluating the importance of effects. Therefore, a battery of tests are required to identify toxic sediment samples.

A critical issue that is not directly addressed with laboratory toxicity tests is the ecological significance of the measured endpoints. As discussed above, there were many significant correlations between laboratory responses and benthic community structure patterns. The relationship to chemical contaminant levels was less distinct, possibly due to differing bioavailability levels. However, general trends were evident between extremely contaminated or slightly contaminated sites and test species effects. The most sensitive toxicity endpoint in the ARCS project was the avoidance or preference behavior of *Diporeia*, a common amphipod in the Great Lakes. Behavior is often a sensitive indicator of sublethal responses. What is not known is whether or not the preference for one sediment over another would alter the population, community, or ecosystem to any degree that constitutes short- or long-term impairment. These issues are best resolved by a "weight-of-evidence" approach whereby other toxicity endpoints and community analyses are considered along with chemical and physical characteristics.

For most applications, a minimum test battery consisting of two to three assays should be evaluated. These recommendations are for waters in the United States and are based on the above characteristics and on comparison studies where multiple species have been used simultaneously in sediment contamination investigations (Burton 1991, Burton *et al.* 1989, Burton and Scott 1992, Giesy *et al.* 1988, Giesy and Hoke 1990, Hoke *et al.* 1990, Ingersoll *et al.* 1993, Chapman *et al.* 1992, Long and Buchman 1989).

It appears from these data that several measured endpoints would be useful for routine sediment contamination assessments. Results from the statistical analyses indicate two test species (with four measured endpoints) could be used to describe the three major toxicity response patterns observed at the ARCS test sites (Table 4). The endpoints that could be selected vary in their sensitivity, discrimination of toxicity, relationship to other assay responses and benthic community indices, and other strengths and weaknesses.

The following recommendations for selection of

optimal assays in future assessment of contaminated Great Lakes sediment are based on sensitivity, discrimination, and similarity analyses and on their strengths and weaknesses associated with each method. It is evident that the optimal assays vary between sites and this variation cannot be confirmed *a priori*. The PCA analysis provides an approach for selection of assays to be included in a test battery. Species can be chosen with endpoints representing each of the major response pattern groupings identified in Table 4, to better ensure that the many varied and potentially adverse species responses are being evaluated. Many of the assays that appeared best in the PCA analysis and in the sensitivity and discriminatory analyses have also been demonstrated to be good indicators of sediment toxicity in previous assessments (Burton 1991). Based on the current study, the minimal test battery recommended for Great Lakes sediment toxicity studies should consist of two species, four measurement endpoints, and represent three of the four major response pattern groups (Table 5). This enables some flexibility in the choice of the test species which may be based on other descision criteria, such as resource requirements, laboratory expertise or organism availability, need for sensitivity or discriminatory power, or other characteristics.

TABLE 5. Optimal groupings for test battery.[1]

Group 1:	a. *Hyalella azteca* 14 d survival, length and sexual maturation b. *Ceriodaphnia dubia* 7 d survival and reproduction, or *Chironomus riparius* 14 d survival and length, or *Daphnia magna* 7 d survival and reproduction, or *Pimephales promelas* 7 d larval survival and weight, or *Diporeia (Pontoporeia hoyi)* 5 d avoidance/ preference, or *Hexagenia bilineata* 10 d survival and molting frequency.
Group 2:	a. *C. dubia* or *C. riparius* (endpoints listed above) b. *Diporeia* or *H. bilineata*
Group 3:	a. *D. magna* b. *P. promelas* c. *Diporeia* or *H. bilineata*
Reconnaissance Surveys: Microtox	

[1]Based on Principal components analysis, sensitivity, discriminatory ability, and correlation with other measurement endpoints.

The first test battery option consists of two species. The only assay whose endpoints characterized three of the four response patterns was the *H. azteca* 14 d test, consisting of survival, length, and sexual maturation. Unfortunately, measuring amphipod length accurately requires use of digitizing microscope equipment. Perhaps dry weight could be measured instead of length. Furthermore, antennal segment number is a good predictor of *H. azteca* length. While 14-d tests were conducted with *C. riparius* and *H. azteca*, the USEPA (1994a) described methods for testing amphipods and midges in 10-d exposures, monitoring survival and growth. In combination with this amphipod, any of five different assays should be tested, including: *C. dubia* 7-d survival and reproduction, or *C. riparius* 14-d survival and length, or *P. promelas* 7-d larval growth, or *Diporeia* 5-d preference, or *H. bilineata* 10-d survival and molting assay.

The second test battery option consists of two species (Table 5). The first is either *C. dubia* or *C. riparius*. The second species should be *Diporeia* or *H. bilineata*. The third option for a test battery should consist of three species (Table 5). The first is *D. magna*, the second is *P. promelas*, and the third is either *Diporeia* or *H. bilineata*.

There is some degree of confidence in the conclusions reached from the large ARCS toxicity data set (7,600 data points), that organisms that were relatively sensitive or discriminatory at three or four of the sites in the ARCS project would probably be sensitive or discriminatory at other sites. It should be noted that those assays which are recommended based on the ARCS study are similar to those recommended in other North American studies by the International Joint Commission (1988), Giesy and Hoke (1990), Giesy *et al.* (1988, 1989), Kemble *et al.* (1994), Burton *et al.* (1989), USEPA (1994), and ASTM (1995). There have been no studies comparing sediment toxicity test methods that were as comprehensive as the present study.

Additional assays could be used in these test batteries, and additional measured responses will strengthen the weight-of-evidence, reducing uncertainty. Many of the assays that ranked high in the ARCS project have been used successfully in other studies of sediment toxicity. The *C. tentans* 10-d assay was not included in the minimal test batteries, due to data limitations in the discriminatory analyses. However, the growth endpoint was shown to be

a sensitive response measure in this and other studies and should be considered as useful assay. In addition, data requirements prevented principal component analysis of some useful assays such as *D. magna* and *P. promelas* 7-d assays. So a variety of toxicity assays exists, representing differing biological levels, which are sensitive and discriminatory. Evaluations of sediment using laboratory toxicity tests and benthic community structure indices, combined with physico-chemical characterization of the test site will allow for an integrated "weight-of-evidence" assessment approach which can be used to provide evidence of contaminant-induced degradation to aquatic communities.

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Rapid Sediment Assessment: Indicator Analysis and Screening Analysis Approaches

Joseph E. Rathbun, Laura Lang Huellmantel,[1] Mary Tracy,[2] V. Elliott Smith, and Kristen Ahlgren

AScI Corporation-Environmental Survey Division
15300 Rotunda Drive, Suite 307
Dearborn, Michigan 48120

ABSTRACT. *Efficiently characterizing the distribution of contaminated and toxic sediments in rivers and harbors is usually limited by the expense of conventional chemical and toxicological analyses. Two approaches were developed to address this problem; the indicator analysis approach, used in the ARCS project, and the screening analysis approach, here applied to a sediment assessment project on the Ottawa River (Toledo, Ohio). The indicator analysis approach utilized two suites of analyses; 23 conventional toxicological and chemical analyses performed on a subset of samples, and 11 rapid, inexpensive chemical and toxicological assays performed on many samples, including those analyzed using the conventional analyses. Predictive correlation equations were generated using step-wise linear regression, and these equations were used to calculate values for the conventional analyses for samples on which they were not performed. This approach generated statistically strong predictive equations, as well as a "weight of evidence" data set useful for evaluating relative sediment contamination. The equations, however, were very site-specific, and sometimes contained terms which were counter-intuitive, and the approach failed if the data sets contained too many "non-detect" or 100% mortality values. The screening analysis approach measured total PCBs by enzyme immunoassay (EIA) and 18 elements by x-ray fluorescence spectroscopy (XRF). These analyses correlated very strongly with gas chromatography (GC) and atomic absorption spectroscopy (AA), respectively, and their production rates and costs were far superior. A low bias was observed in the EIA data, compared to the GC data, possibly due to inefficient EIA extraction of the oily sediments, or to a mismatch between the PCB mixtures in the sediment and used as a calibrator for the EIA. XRF data for Cr, Cu, Mn, Ni, Sb, and Zn exhibited a positive bias compared to AA, while Cd and Pb did not. This was probably due to metal-specific variations in the contribution of mineral matrix-associated metal to the acid-digestible metal quantified by AA. Both EIA and XRF can be performed in the field, to produce near-real time data to guide sampling. Detection limits of the PCB EIA (0.12 μg/g DW) and of XRF (typically 5 to 15 μg/g DW) are adequate for most sediment assessment projects. Of the two approaches, screening analyses are recommended for the rapid, cost-effective characterization of contaminated sediments.*

INDEX WORDS: *Sediment, rivers, enzyme immunoassay, x-ray fluorescence, Saginaw River, Buffalo River, Indiana Harbor, Ottawa River*

INTRODUCTION

Most of the Great Lakes Areas of Concern (AOCs) have been industrialized for decades, and subject to a variety of degrading alterations, including discharges of metals, petroleum by-products, halogenated organic compounds, domestic wastes, and other pollutants; altered sedimentation patterns due to watershed deforestation; and artificial rearrangement of their bedded sediments from dredging, ship traffic, and shoreline construction. The result is that the ecosystems of the Great Lakes AOCs, and sediments in particular, possess a heterogeneous mosaic of chemical and physical characteristics that reflect a multitude of historical anthropogenic alterations. This heterogeneity makes even a general inventory of sediment quality very difficult.

Most previous studies of contaminated sediments in AOCs usually include a limited number of chemical assays and even fewer toxicity tests, performed on surficial sediment samples from a small number

[1]Deceased.
[2]Present Address: Wayne State University, Department of Biological Sciences, Detroit, Michigan 48202

of stations (< 25). Conventional chemical and biological assays are relatively expensive, time-consuming, and often require large volumes of sediment, and few projects have the resources to analyze enough samples to adequately characterize, or to create meaningful contour maps of contaminant distributions, for significant portions of a river or other water body. In addition, many studies devote great effort to reducing laboratory analytical error, even though non-representative sampling and subsampling can be more much significant sources of data variance in environmental assessment studies (Mason 1992, van Ee *et al.* 1990).

In situations where there are insufficient resources to adequately characterize a study area using conventional chemical and toxicological analyses, two approaches have the potential to fill in data gaps at relatively low cost: indicator analyses (performed during the ARCS Program), and screening analyses (developed since ARCS ended, and the recommended approach). The indicator analysis approach utilizes a two-phased study design: (1) performing detailed, conventional chemical and toxicological assays at a limited number of stations (master stations) from throughout the study area, and (2) performing a set of quick, less-expensive assays ("indicator" analyses) at a large number of stations, including the master stations. Multivariate statistics are then used to establish relationships between the indicator analysis data and the more detailed conventional assays, and these predictive correlation equations are used to calculate endpoint data for the conventional assays for samples on which they were not performed. In effect, the indicator approach is a modeling exercise.

Conversely, the screening analysis approach directly measures contaminant concentrations or toxicity endpoints, using rapid, inexpensive analytical techniques more commonly applied to soils. The screening analysis approach described here utilizes two analytical techniques that were not routinely applied to sediment studies when the ARCS project was designed: enzyme immunoassays to quantify organic contaminants, and x-ray fluorescence spectroscopy to quantify metals. These assays are faster and cheaper than conventional analyses like gas chromatography and atomic absorption spectrophotometry, and just as accurate and precise. Their major limitations are 1) higher detection limits; 2) potential matrix interferences; 3) potentially lower extraction efficiencies for the immunoassays; and 4) recognition and acceptance by some regulatory agencies.

METHODS

Indicator Analyses

The indicator analyses used in the ARCS Program (Table 1) are rapid, low-cost analyses chosen with the following considerations in mind: environmental relevance; probable correlation with conventional analyses; production rate and cost; and regulatory relevance. The metals, total and volatile solids, total organic carbon, sediment grain size, pore water ammonia, and the Microtox® bioassay produced a direct measure of sediment composition, contamination, or toxicity. The remaining analyses were thought likely to be correlated to other variables of environmental importance (e.g., bioavailability, petroleum or organohalogen contamination, etc.). A more detailed discussion of the

TABLE 1. ARCS indicator analyses.

Analyte(s)	Matrix	Method
Conductivity	Pore water	Wheatstone bridge electrode
pH	Whole sediment	Selective ion electrode
Total solids	Whole sediment	Dried at 60°C
Volatile solids	Whole sediment	Ashed at 550°C
Grain size (5 fractions)	Whole sediment	Wet sieved
Microtox® toxicity	Elutriate	Bacterial luminescence
Metals (Cd, Cr, Cu, Fe, Ni, Pb, and Zn)	Whole sediment	Inductively coupled emission spectroscopy
Ammonia	Elutriate	Selective ion electrode
Total organic carbon	Whole sediment	Combustion/thermal conductivity
Solvent extractable residue	Whole sediment	Solvent extraction/gravimetry
Organohalogens (Br and Cl)	Solvent extract	Neutron activation

indicator analysis approach is contained in U.S. EPA (1994b).

The indicator analyses were applied to all 320 samples collected in 1989 and 1990 from the three ARCS study areas (95 samples from Indiana Harbor; 112 samples from Buffalo River; 113 samples from Saginaw River), both surficial and vibrocore samples, including the master station grab samples at which the conventional analyses were performed (32 stations total; 7 at Indiana Harbor, 10 at Buffalo River, and 15 at Saginaw River). Correlation equations comparing the indicator analysis data set to concentrations of 9 organic contaminants and selected endpoint data from 14 bioassays (Table 2) were calculated using stepwise linear regression analyses, using SAS® statistical software.

Screening Analyses

The screening analyses described below were used in the first phase of a planned three-phase sediment assessment project on the Ottawa River, near Toledo (Lucas County), Ohio, in 1994. Eighty-four samples were collected from the lower 18 kilometers of the river by personnel from the Ohio Environmental Protection Agency using a hand-held vibrocoring unit. The cores were subsampled in the field by visible horizon, and analyzed by EIA and XRF. A subset of the samples was analyzed by conventional techniques, described below, to confirm the results of the screening analyses.

Enzyme Immunoassays

Enzyme immunoassays (EIAs) are biochemical analyses originally developed to quantify viruses, bacteria and proteins in the clinical and veterinary fields. EIAs were adapted to quantifying environmental contaminants about 20 years ago, and are now available for measuring a wide variety of organic pesticides, herbicides, and industrial chemicals. Recent reviews of environmental applications of EIAs are Gruessner *et al.* (1995), Meulenberg *et al.* (1995), Van Emon and Gerlach (1995), and U.S. EPA (1994a).

Wet sediment samples were extracted in 30-mL HDPE bottles, by combining 2.0 grams of sediment with 15 grams of sodium sulfate and 10.0 mL spectro grade methanol. The extraction bottles contained five stainless steel ball bearings, and were shaken on a wrist shaker for 3 minutes. The sediment/sulfate mixture was allowed to settle, and the overlying methanol extract was decanted into the lower base of a syringe filter, and filtered to remove particles. Filtered extracts were stored in 4-mL amber glass vials at 4°C until analysis. Reagents, materials, and general instructions from Millipore Envirogard® total PCBs test kits, which utilize anti-

TABLE 2. Conventional analyses modeled using the indicator analysis approach.

Bioassay	Duration	Endpoint
Microtox®	15 min.	EC_{50}
Daphnia magna	48 hr.	EC_{50}
Selenastrum capricornutum	24 hr.	EC_{50}
Chironomus riparius	14 d.	% Survival
Chironomus riparius	14 d.	Growth
Chironomus tentans	10 d.	% survival
Chironomus tentans	10 d.	Growth
Ceriodaphnia dubia	7 d.	% Survival
Diporeia sp.	20 d.	% Survival
Hexagenia limbata	10 d.	% Survival
Hyalella azteca	28 d.	% Survival
Hyalella azteca	28 d.	Growth
Hyalella azteca	14 d.	Growth
Pimephales promelas	7 d.	% Survival

Chemical Analyses

Total PCBs	Total TCDFs	Phenanthrene
Total TCDDs	2,3,7,8-TCDF	Fluoranthene
2,3,7,8-TCDD	Pyrene	Benzo(a)pyrene

body-coated test tubes, were used to analyze the extracts. This particular test kit is optimized for Aroclor 1248. Extract color was quantified at 450 nm. A fully quantitative procedure was performed, rather than the "semiquantitative," range-finding procedure often employed with EIAs: a four-point calibration curve of diluted Aroclor 1248 standards, created daily, was used to calculate sample concentrations. A methanol system blank was analyzed each day, as was a standard reference material (Aroclor 1248 in soil; Environmental Resource Associates). Ten percent of the samples were analyzed in replicate. Previous experimental studies indicated that extract cleanup is unnecessary, even for oily sediments. PCB concentrations were normalized to sample dry weight.

Twenty-seven samples were also analyzed by gas chromatography by another laboratory chosen by the Ohio EPA, using CLP laboratory protocols (Soxhlet extraction, both acid and gel permeation chromatography (GPC) clean up, gas chromatography/electron capture detector). The GC data were reviewed by a quality assurance group, who chose a single data set from among the acid-cleaned and GPC-cleaned values, and these results were compared to those generated by the EIA.

X-Ray Fluorescence Spectroscopy

X-ray fluorescence (XRF) is a non-destructive fluorescence spectroscopic technique which quantifies elements in solid or liquid samples by exciting the sample atoms with x-rays and measuring the resulting fluorescence. The energy of this emitted fluorescence is characteristic of each element and its intensity is proportional to the element's concentration. Standard XRF is appropriate for quantifying elements from potassium to uranium (except for the Nobel gases), and this can be expanded to include sodium through chlorine by performing the analysis under vacuum. XRF units can be laboratory-based or field-portable. XRF has apparently not been previously applied to sediments, but references describing its application to soil assessments include U.S. EPA (1993) and Helland and McCall (1993).

The XRF analyzer used in this study was a Spectrace Model 6000, a laboratory-based unit. Wet sediment samples were air-dried overnight, pulverized in a polyethylene bag with a rubber mallet (as per NIST, 1990), and analyzed for 18 elements (Ag, As, Ba, Br, Ca, Cd, Cr, Cu, Fe, Hg, K, Mn, Ni, Pb, Sb, Se, Ti, and Zn). A data analysis program, Fundamental Parameters, was used to account for matrix effects, resolve analyte interferences and identify and quantify the elements in the samples. Ten percent of the samples were analyzed in replicate. NIST standard reference materials were also analyzed.

Twenty-seven samples were also analyzed for Cd, Cr, Cu, Mn, Ni, Pb, Sb, and Zn by atomic absorption spectroscopy by another laboratory chosen by the Ohio EPA, and these results were compared to those generated by XRF. Details of the screening analyses and confirmatory analyses are available in the Ottawa River Quality Assurance Project Plan (Ohio EPA 1994).

Confidence intervals around the r^2 values for both the indicator and the screening analysis data sets were calculated using Hotelling's modification of the z-transformation, as described in Sokal and Rohlf (1981).

RESULTS AND DISCUSSION

Indicator Analysis Approach

The indicator analyses were comparatively rapid and most could be performed by a single technician. They were also relatively inexpensive; material and supply costs for all 11 indicator analyses combined were approximately $100 per sample (U.S.; 1991). This is less than the cost of any one of the conventional analyses for which endpoints were modeled.

Viewed as stand-alone information, the indicator assay data showed that sediments from the three ARCS study sites exhibited a wide range of contamination, with the Saginaw River the least contaminated and Indiana Harbor the most contaminated (Table 3). Only pore water conductivity and sediment pH failed to show this pattern. Some specific observations from Table 3 include:

- The mean ammonia concentration in the sediment elutriates from Indiana Harbor, 24 mg/L, caused significant mortality in fathead minnow (*Pimephales promelas*) and cladoceran (*Ceriodaphnia dubia*) toxicity tests of sediment pore water from the Lower Fox River/Green Bay watershed in Wisconsin (Ankley *et al.* 1990), and exceeded the LC_{50} values for several amphibian species (Hecnar 1995).
- The greatly elevated TOC and extractable residue values found at Indiana Harbor are indicative of the extreme amounts of oil found in these sediments. Indeed, some volatile solid samples from this site ignited when combusted in a muffle furnace.

TABLE 3. Mean values for selected indicator parameters in sediment core samples.

Analyte	Saginaw River #2[a]	Saginaw River #3[b]	Buffalo River #3[c]	Indiana Harbor #2[d]
Ammonia (mg/L)	11	11	19	24
Conductivity (µS/cm)	2,200	2,200	3,000	2,500
pH	7.13	7.12	7.24	7.27
Total organic carbon (% DW)	2.0	2.2	2.4	9.1
Cd (µg/g DW)	1.3	2.2	4.6	10
Cr (µg/g DW)	48	64	210	450
Cu (µg/g DW)	42	47	162	261
Fe (% DW)	1.3	1.4	4.8	12
Ni (µg/g DW)	21	28	42	79
Pb (µg/g DW)	44	41	300	790
Zn (µg/g DW)	134	150	650	3,300
Microtox® (EC_{50})	98	96	72	38
Extractable Residue (µg/g DW)	750	1,000	4,600	20,000

[a]Lower 16 kilometers of the river.
[b]Vicinity of the Bay City waste water treatment plant.
[c]Lower 15 kilometers of the river, plus the Buffalo Ship Canal.
[d]Lower 5 kilometers of the Grand Calumet River, plus Indiana Harbor.

• The Microtox® test results suggest that sediments from Indiana Harbor were substantially more toxic than sediments from the other study areas. In general, the Microtox® results reflected the chemical results; increasing chemical contamination was associated with increasing toxicity (data not presented here).

The vibrocore sampling, while fairly costly and time-consuming, yielded information unavailable from traditional surficial grab sampling. Many cores exhibited increasing contamination and toxicity with depth, with highly contaminated and toxic material up to 4 meters beneath the water:sediment interface. For example, 50 % of the cores from the Buffalo River ended in what was visually characterized as black, oily silt. This material contained elevated concentrations of metals (e.g., Pb = 1,590 µg/g DW and Cu = 951 µg/g DW) and volatile solids (up to 19.8% DW), and was also toxic (50% of the deepest samples had an EC_{50} < 50 percent elutriate). Some of the cores from the Buffalo River, in the vicinity of the "Buffalo Color Peninsula," exhibited thick upper and lower layers of black, oily silt separated by a 0.3 to 0.6-meter layer of clean clay. This unexpected situation may be due to historic slumping of dredged clay sediments from the along river bank, where they were sometimes discharged prior to construction of the Times Beach confined disposal facility, and subsequent deposition of additional oily sediments. Cores from near the Bay City waste water treatment plant discharge in the Saginaw River contained a 0.2 to 0.5-meter layer of black, oily silt beneath approximately 0.3 meter of cleaner surficial sand. The oily silt exhibited metals concentrations 3-15 times higher than those in the overlying sand (e.g., Cd = 19 vs. 1.3 µg/g DW; Cr = 590 vs. 40 µg/g DW; Pb = 180 vs. 32 µg/g DW). In general, the most contaminated sediments in most of the cores from the Saginaw and Buffalo Rivers were found well below the water:sediment interface. This distribution is often observed in Great Lakes AOCs when there has been recent success in controlling contaminant discharges from point sources. In contrast, Indiana Harbor sediments were typically most contaminated in the upper portions of the cores, suggesting continuing contaminant inputs.

Correlation Between Indicator and Conventional Analyses

The stepwise linear regression statistics applied to the indicator analysis and conventional chemical and toxicological analyses usually yielded statistically significant correlation equations (Table 4). Where equations could be generated, the r^2 values ranged from 0.9001 to 1.0000, and all p values were less than 0.05. Most of the equations were simple; i.e., contained three or fewer correlative terms. Overall, the most common correlates were various metals, the organohalogens, extractable

TABLE 4. Selected correlation equations derived from the ARCS application of the indicator analysis approach.

Saginaw River

Chironomus tentans growth = 13.5 + Cl (0.064) – Pb (0.012)
r^2 = 0.9237; 95% CI = 0.361–0.980; p = 0.0211; n = 7

Total PCB = –497 + Cl (334)
r^2 = 0.9492; 95% CI = 0.658–0.984; p = 0.0001; n = 9

Buffalo River

Hexagenia % survival = 165 – Br (732) + < 38 μm GS (0.65)
r^2 = 0.9669; 95% CI = 0.203–0.994; p = 0.0331; n = 5

2,3,7,8–TCDF = –2.59 + Cr (0.068) + pH (0.664) – VS (0.320)
r^2 = 0.9098; 95% CI = 0.548–0.970; p = 0.0016; n = 10

Indiana Harbor

Pimephales promelas % survival = 108 – Pb (0.074)
r^2 = 0.9753; 95% CI = 0.000–0.998; p = 0.0124; n = 4

Phenanthrene = –28,400 + Cr (112) + Pb (86.6) – Ni (1600)
r^2 = 0.9817; 95% CI = 0.760–0.994; p = 0.0042; n = 7

GS = grain size fraction Cl = organochlorine
VS = volatile solids Br = organobromine

residue, and Microtox® toxicity. Correlation equations could not be generated for certain conventional analyses, especially chemical analyses which yielded mostly "no detect" data, or bioassays which exhibited no effects, or near-100% mortality in most samples.

Figure 1 shows the strong relationship between predicted and measured pyrene in Indiana Harbor master stations sediments. Predicted vs. measured Microtox® data from all of the ARCS master stations were also in good agreement (Fig. 2), although the very strong r^2 value was heavily influenced by 16 stations (mostly from the Saginaw River) which exhibited virtually no toxicity.

The predictive equations were not always readily interpretable, however, and sometimes were counter-intuitive. In the Buffalo River, for example, the equation predicting *Hyalella azteca* growth (14 day) was:

Hyalella growth = 1.77 + NH_3 (0.007)
(r^2 = 0.9269; 95% CI = 0.028-0.988; p = 0.0086; n = 5)

However, there is no apparent reason why increasing sediment elutriate ammonia concentration would increase the growth of *Hyalella*.

In most cases, the predictive equations were not universally applicable between AOCs, probably due to site-specific variations in contaminant occurrences and distributions, bioavailability, etc. For example, the predictive equations for the Microtox® test endpoint in the three ARCS study areas were:

Buffalo River EC_{50} = 119 – (587 × organobromine) – (0.127 × Pb)
(r^2 = 0.9700; 95% CI = 0.810-0.990; p = 0.0001; n = 10)

Saginaw River EC_{50} = 106 - (10.5 × Cd)
(r^2 = 0.9943; 95% CI = 0.970–0.998; P = 0.0001; n = 14)

Indiana Harbor EC_{50} = 59.3 – (0.117 × Cu) – (0.008 × Pb)
(r^2 = 0.9432; 95% CI = 0.460–0.986; P = 0.0032; n = 7)

Apparently the regression equations were often indicative of correlative rather than causative relationships among the variables. This was especially true for the bioassay equations. This does not diminish their predictive capabilities, but does weaken or even prevent their use in identifying the cause of the observed chemical distribution or toxic response.

In a few instances, however, the regression equations did suggest possible causative relationships that might not have been otherwise apparent. For example, the most frequent correlate in the predictive equations for the bioassay endpoint data from the Buffalo River was organobromine (four of nine

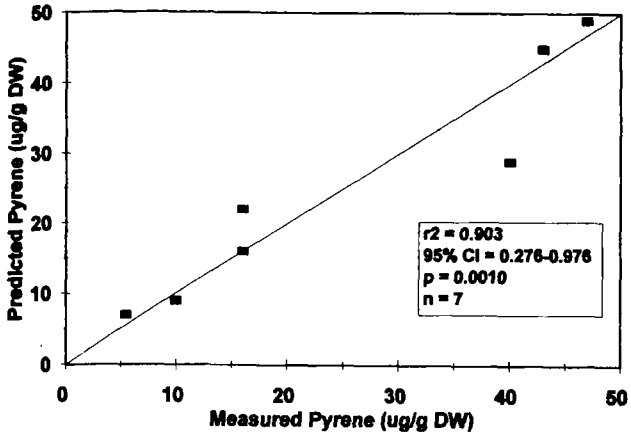


FIG. 1. Comparison of measured and predicted pyrene in Indiana Harbor sediments.

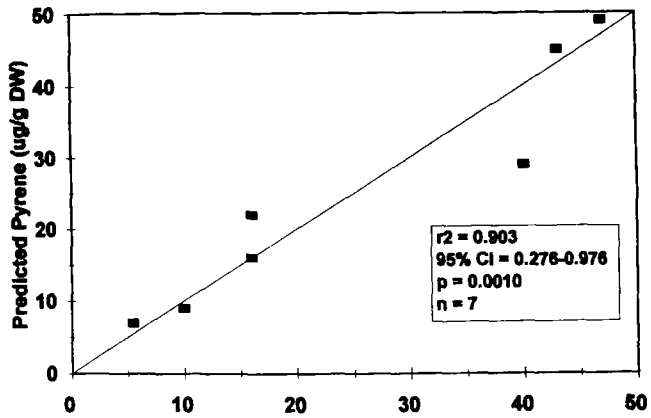


FIG. 2. Comparison of measured and predicted Microtox® EC_{50} values in sediment elutriate from all three ARCS harbors.

equations). Some of the dyes produced by a local chemical industry are believed to have been brominated, and certain brominated textile dyes are known to be mutagenic (Friedman *et al.*, 1980).

Because Microtox® was performed both as an indicator analysis on all of the ARCS stations and as a conventional analysis on the master stations, the accuracy of the predicted Microtox® values could be evaluated. For evaluation purposes, the EC_{50} values were divided into three categories: low toxicity (EC_{50} > 70% elutriate), intermediate toxicity (EC_{50} = 30–70 % elutriate), and high toxicity (EC_{50} < 30% elutriate), and comparisons were made between the calculated and measured values from each master station. If there was no predictive power to the correlation equations, by chance only one-third of the calculated EC_{50} values would be expected to occur in the same category as the measured value. The results (Table 5) indicate fairly good agreement between the predicted and measured EC_{50} values, especially for the Saginaw River and Indiana Harbor samples. The predicted values also exhibited a desirable, conservative bias, with most of the "incorrect" values indicating a higher toxicity than was actually measured.

A potential criticism of the ARCS application of the indicator analysis approach, not fully considered at the time, is that the correlation equations were generated using data from surficial sediment samples, and then used to model chemical concentrations and bioassay endpoints in subsurface sediments. This may have been inappropriate, given potential differences in contaminant bioavailability, sediment physiochemical properties, etc., between surficial and subsurface sediments. In retrospect, some master station samples should have been subsurface sediments, and used to generate a separate set of correlation equations.

TABLE 5. Comparison between predicted and measured Microtox® EC_{50} values.

ARCS Site	Percent of predicted values in same toxicity category	Percent of predicted values in higher category (false positive)	Percent of predicted values in lower category (false negative)
Buffalo River	47.3	47.3	5.4
Saginaw River	71.6	11.2	17.2
Indiana Harbor	58.9	35.8	5.3

Finally, a severe weakness of the ARCS application the indicator analysis approach, also not fully appreciated at the time, was the inadequate number of stations at which both the indicator and conventionally analyses were performed (master stations). To achieve acceptable confidence intervals around the r^2 values generated by correlation analysis, it is necessary to analyze 25 to 30 split samples (compare the n and CI values in the text, in Table 4 and on Figures 1 through 4). Only 7 to 15 master station samples were analyzed from the ARCS harbors.

Screening Analysis Approach

Both the EIA for total PCBs and XRF for metals proved to be excellent tools for rapidly analyzing a large number of sediment samples in a short time. Table 6 lists pertinent aspects of the two analyses. The production rates and supply costs of both assays are superior to conventional analyses such as gas chromatography or atomic absorption spectroscopy. The detection limits of these screening analyses are higher than GC or AA (or ICP), but are adequate for most sediment assessment projects. Accuracy and precision of EIA and XRF are comparable to their conventional equivalents. These screening analyses are also more "environmentally friendly" than their conventional equivalents. EIA wastes consist of a small mass of extracted sediment and a small volume of non-hazardous methanol, and the reagents can be disposed of down a sanitary sewer, while a typical solid:liquid extraction procedure for GC analysis utilizes several hundred milliliters of hazardous solvents. XRF is a non-destructive technique and does not require any sample preparation besides drying and perhaps grinding, while a typical digestion procedure for AA or ICP analysis generates hazardous acid fumes and wastes.

Figure 3 shows the correlation between total PCBs by EIA and GC, and Figure 4 shows the correlation between XRF and AA for cadmium and chromium, for the Ottawa River samples. Both screening analyses exhibited a strong correlation with their conventional counterparts. The PCB data are presented on a log:log plot, because of the great range of the data (< 0.01 to ~ 3,000 μg/g DW), and because so many of the values were low (less than 5 μg/g DW). The GC/ECD data in Figure 3 are a combination of acid-cleaned and GPC-cleaned sample values, selected by the analytical QA group as best representing the "true" PCB values in the sediments. Although the correlation between the two analyses was good, a low bias was observed for the EIA data. Two factors, singly or in combination, may have contributed to this result. First, the high oil content of many of these samples may have reduced the efficiency of the EIA's methanol "shake"

TABLE 6. Performance of total PCB enzyme immunoassay and X-ray fluorescence for analyzing sediment samples from the Ottawa River, Ohio.

	Total PCB Immunoassay (Quantitative procedure)	X-Ray Fluorescence (18 element scan)
No. samples/8 hr. day (1 technician)	~ 15	~ 20
Supplies cost per sample (U.S.)	~ $15	~ $5
Mean percent recovery of standard reference material	104 %	Varies with element; typically 95 to 105 %
Mean relative percent deviation (RPD) for replicate samples	26 %	Varies with element; typically 10 to 25 %
Method detection limit	0.120 μg/g DW	Varies with element; typically 5–15 μg/g DW
Average system blank value	0.092 μg/g DW	*

*Blanks are not typically analyzed by XRF, but acid-washed sand yields values below the method detection limit for most elements of toxicological concern.

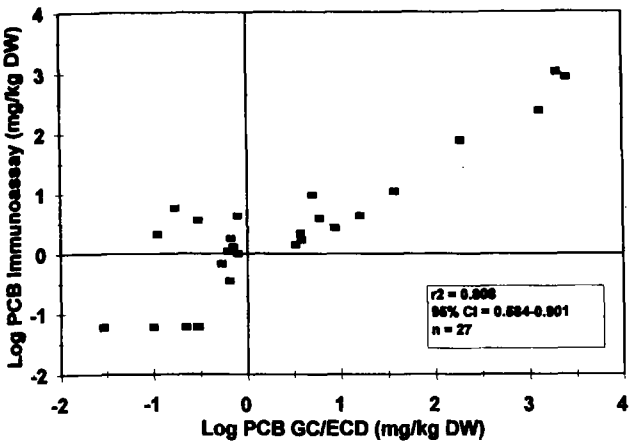
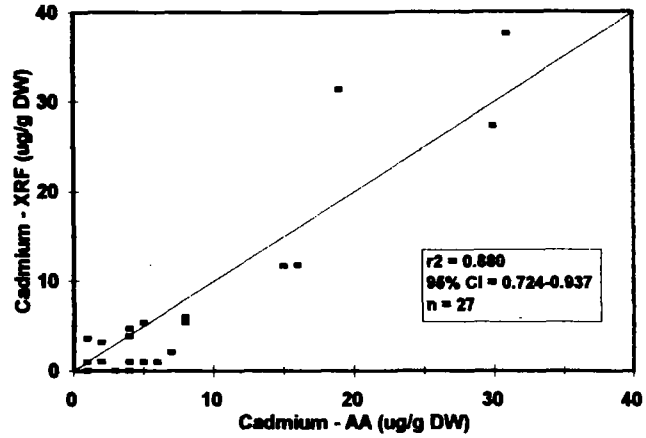


FIG. 3. Comparison of Ottawa River sediment total PCB concentrations determined by gas chromatography and quantitative enzyme immunoassay.



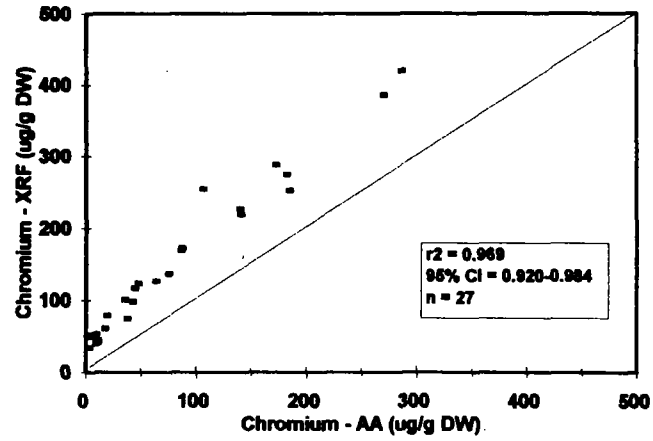


FIG. 4. Comparison of Ottawa River sediment cadmium and chromium concentrations determined by atomic absorption spectroscopy and energy dispersive X-ray fluorescence.

extraction, relative to the presumably more rigorous Soxhlet extraction used in the laboratory procedure. Second, this EIA is known to be 32% less sensitive to the Aroclor mixture, 1242, identified as predominant in these Ottawa River sediments, compared to the Aroclor 1248 to which it is calibrated (Millipore test kit instruction pamphlet). It is possible to calculate a site-specific "correction factor," after the confirmatory data are available, to adjust for observed biases in the EIA data. It should be noted, however, that the difference between the two GC data sets (acid-cleaned and GPC-cleaned) was comparable to the differences between either GC data set and the EIA data. This observation calls into question the common assumption that GC analysis produces data that are more reliable than EIA data.

A positive bias was observed in the XRF chromium data (Fig. 4), as well as for antimony, copper, manganese, nickel, and zinc analyzed by both XRF and AA for this project. This is not surprising given that XRF quantifies the "total" metal in a sample (including that incorporated into the mineral matrix), while the acid digestion used to create a sample for AA (or ICP) analysis contains only the "acid-digestible" metal fraction. No bias was apparent in the cadmium or lead XRF data, however, and other applications of XRF to sediment and soil samples have shown that the magnitude and even direction of bias in XRF data is site- and element-specific. Both Figures 3 and 4 illustrate two points: (1) the importance of verifying the results of screening analyses by analyzing an adequate number of split samples (25 to 30 is recommended) by conventional techniques, and (2) the strength of the correlation between screening and conventional analysis results that may be expected. It should be noted that samples chosen for confirmatory analyses should approximate the range of contaminant concentrations observed in the entire data set. This argues for subjectively selecting the confirmatory samples after the screening analyses are completed, rather than choosing them randomly before sampling begins.

Finally, both EIA and XRF can be performed in the field, providing near-real time data for guiding sampling personnel (although the fully quantitative EIA procedure described here requires more train-

ing and experience than the "semiquantitative" technique often used in the field). These methods are also ideal for generating sufficient data for detailed contaminant 2-D contour mapping or 3-D contour modeling at a reasonable cost (e.g., O'Meara *et al.* 1994).

CONCLUSIONS AND RECOMMENDATIONS

Both the indicator analysis and the screening analysis approaches are useful for analyzing a large number of sediment samples quickly and cheaply, so that more expensive and time-consuming conventional chemical and toxicological assays can be focused on selected samples that are most likely to be of greatest concern (such as delineating "hot spot" boundaries). As a group, the indicator analyses provided a "weight of evidence" data set that permitted ranking the ARCS study areas, and stations within each study area, in terms of overall contamination. The indicator analysis approach also generated predictive correlative equations which were statistically strong, and occasionally suggested causal relationships that were not otherwise apparent (e.g., the correlation between organobromine concentrations and several bioassay endpoints in the Buffalo River). Finally, the indicator approach can be used to predict results for chemical or toxicological parameters for which screening analyses are not (yet) available. The correlative equations produced by the indicator analysis approach were very site-specific, however, and sometimes contained correlative terms which were counter-intuitive. Also, an excessive number of chemical nondetects or bioassay 100% mortality data in the conventional analyses prevents calculation of regression equations. On the whole, the indirect indicator analysis approach is not recommended for characterizing the distribution of contaminated and/or toxic sediment deposits.

The screening analysis approach, utilizing rapid analyses like enzyme immunoassays for quantifying organic contaminants and x-ray fluorescence spectroscopy for quantifying metals, is recommended. The accuracy and precision of these assays are comparable to their conventional equivalents, and they generate less hazardous wastes; their production rates and cost are far superior; they are easily performed in the field, providing near-real time data to guide sampling; they are probably the most cost-effective way to generate sufficient data for 2-D and 3-D contour models; and their admittedly higher detection limits are acceptable for most sediment quality assessments. Best of all, they provide direct measurements of contaminant concentrations rather than predicted concentrations. Given sufficient resources, it is always better to measure something than to model it.

One limitation of EIAs is the potentially variable efficiency of the standard methanol "shake" extraction technique. A more efficient but still rapid field extraction procedure, like one of the new automated solvent extraction systems, would improve the quality of the EIA data and its comparability to confirmatory GC analyses. It is highly recommended that the same extract be used for both EIA and confirmatory GC analyses, to maximize the comparability of the two data sets.

It would be desirable to add one or more rapid bioassays to a suite of screening chemical analyses. Microtox® analysis of whole sediment or sediment elutriate or pore water seems the best technique at present, though additional rapid bioassays would be desirable, since no single bioassay can be expected to be sensitive to the full range of potential toxins present in environmental samples (U.S. EPA 1994b). This issue deserves more attention.

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This paper is dedicated to the memory and spirit of Laura Lang Huellmantel. She was an outstanding scientist and even finer person, and all who knew her are the poorer for her loss. Peace, dear friend.

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Technical Considerations in Sediment Quality Surveys

V. Elliott Smith, Joseph E. Rathbun, Stephen G. Rood,[1] and Laura L. Huellmantel[2]

AScI Corporation - Environmental Survey Division
15300 Rotunda Drive, Suite 307
Dearborn, Michigan 48120

[1] Camp Dresser & McKee
One Woodward Avenue, Suite 1500
Detroit, Michigan 48226

ABSTRACT. *Previously in the ARCS Program (Assessment and Remediation of Contaminated Sediments), the authors helped the U. S. EPA to evaluate and refine techniques for conducting sediment quality surveys through investigation of several Great Lakes harbors. This involved outfitting a field team with specialized equipment including a survey vessel, collecting core samples for field and laboratory analysis, and testing various approaches for screening and mapping sediment contamination. Since ARCS, 3 more years of sediment surveys have provided a basis for updating some of the technical recommendations found in the ARCS Guidance Document* (USEPA *1994b). Although these additional suggestions are meant to be general in nature, they may apply best to harbors in the Great Lakes area. Given the fairly high level of certainly now achieved in most laboratory data, more widespread attention to the details of sampling and processing sediments can improve overall certainty about the occurrence and extent of contamination. In order to achieve representative sampling, survey designs should include stages of intelligence gathering and field reconnaissance which help to focus sampling on areas of both average and extreme contamination. For accurate position-finding in the field a variety of technologies are available, but real-time, differential GPS (global positioning system) has the most advantages overall. Vibrocoring is an effective, economical method for collecting intact sediment cores up to 6 m long. Procedures are described for sub-sampling and documenting strata in sediment cores. Screening methods of chemical analysis, such as immunoassays and x-ray fluorescence, provide on-site results which are useful for refining survey designs in the field.*

INDEX WORDS: *Sediment contamination, screening analysis, vibrocoring, core sampling, Great Lakes.*

INTRODUCTION

The USEPA (1994a) has recently proposed a national strategy to manage the problems of contaminated sediments occuring at numerous sites throughout much of the U. S. The risks these sediments pose to ecosystems and human health are still unclear, since many factors are involved. Bioavailability of contaminants is one key issue, and this is partly a matter of contaminant distribution as well as chemical conditions. Unfortunately, there is still a shortage of good information on where and how contaminants become associated with sediments. A thorough understanding of this relationship is the key to diagnosing sediment problems and solving them efficiently. It is important to map contaminant deposits accurately as well as characterize them. In one sense the sediment quality issue has become a question more of spatial than of chemical analysis. Now that chemical laboratories routinely perform standardized analyses with a fair degree of certainty, most of the remaining uncertainty about the occurrence of sediment contamination is due to unrepresentative sampling (van Ee *et al.* 1990, Mason 1992).

There is still much uncertainty about the occurrence and extent of contamination in aquatic sediments, especially in harbors and other disturbed areas. One reason is that natural associations of contaminants with sediment particles are governed by a variety of physical and chemical factors. Another is that sediments in most urbanized harbors have experienced a complex history of physical disruption and water pollution events in addition to the dynamic processes that normally complicate river bottoms. As a result the occurrence of contaminant deposits

[2]Deceased.

in these sediments can be highly variable and difficult to sample representatively (Lyman *et al.* 1987). Added to this complexity is the practical difficulty of sampling underwater substrates of any kind.

Perhaps the biggest problem with most sediment surveys is the failure to achieve representative sampling. While the laboratory data may represent the samples with a high degree of certainty, there is often little or no certainty that the samples represent the sediment environment. In vertical profiles (cores) of Great Lakes harbor sediments the most contaminated material is often found a meter or so below the surface, reflecting historical trends of water pollution in those areas. The majority of sediment chemistry data on record is based on grab samples of surficial sediments, which are less likely than core samples to represent the full range of sediment quality in many harbors.

It is most important to understand where and how certain contaminants are distributed in sediments in order to make intelligent choices about remedial actions, if any. Such decisions are driven not only by regulatory concerns, but also by the growing interest in reclaiming for public use old industrial sites around harbors. In some cases it will not be acceptable in the long run to leave stable deposits of contaminated sediments undisturbed, whether or not they represent a hazard in that form.

In the ARCS field program, we evaluated various tools and techniques for systematically mapping contamination in river harbor sediments. These approaches were generally described in the ARCS Guidance Document (USEPA 1994b). Since the ARCS surveys ended in 1993, our group has continued to use these methods and develop others for sampling, characterizing, and mapping sediment contamination, primarily in the field.

The purpose of this paper is to supplement the ARCS guidelines by suggesting some additional techniques which we have found to be useful in sediment quality surveys. This commentary departs somewhat from the usual discipline of journal articles, but we hope that in this form it will best complement the Guidance Document and help in the practice of sediment investigations. More comprehensive reviews of sediment survey technology and methods will be found elsewhere (Mudrock and MacKnight 1991, Baudo 1990).

Survey Planning

Survey planning often does not get the attention it deserves. In the case of sediment surveys, there has been a historical tendency to conduct underwater sampling somewhat haphazardly. Surveys can vary in purpose from a general reconnaissance designed to detect contamination gradients, to intensive sampling of small deposits for purposes of 3-dimensional mapping. . The important thing is to recognize what the intended use of the survey results will be. Will the survey result in representative data of known quality? Will the data quality be adequate to meet the survey objectives? The EPA and other agencies have established formal procedures for developing data quality objectives (DQOs) and quality assurance (QA) guidelines for technical projects. These are discussed at some length in the ARCS Document (USEPA 1994b).

In planning the ARCS surveys of Great Lakes harbors we considered the known distributions of sediment contaminants, based on historical data for grab samples. We prepared horizontal profiles of sediment quality which served to indicate likely sources and sinks of contamination. Also, we reviewed historical maps and aerial photography dating from the 1950s and 1960s, which revealed changes in harbor development and use during the period of highest contaminant loadings. Historical information on industrial sites, dumps and outfalls can be useful to identify former sources and types of contamination which may have accumulated in nearby sediments. For example, the Sanborn fire insurance maps, dating from the mid 1800s, are available for many urban harbors in the U. S. We have also noted in aerial views where ships were once moored at dredged sites which are now silted in. Buried deposits of higher-level contamination would be expected in such areas, and this has often proved to be true.

To a limited degree in ARCS, we also used acoustic (sub-bottom) profiling techniques to help focus sampling on silt deposits where contaminants are more likely to accumulate. Probing with a pole is another more economical technique for locating soft deposits in shallow water. Through a combination of historical review and field reconnaissance, one can locate more probable areas of contamination for systematic sampling and mapping. Whenever possible, we recommend that the survey plan include some preliminary sampling and analysis before the bulk of sampling occurs. As discussed below, recent advances in the technology of field positioning and screening analysis have made it possible to refine planning and design of sampling as the survey progresses. This can result in greater certainty that laboratory results are representative

of sediment quality and contaminant distribution. Considering the potentially high cost of any sediment remediation, this increased certainty can yield substantial savings.

Sampling Designs

Principles of soil sampling design have been developed, based on the laws of probability, which result in defensible data of known quality (Gilbert 1987, Mason 1992). These geostatistical principles apply equally to aquatic sediments. One advantage of working with silty sediments is that grain size tends to be smaller and less variable than for typical soils; therefore, the effect on minimum sample size is diminished. On the other hand, contaminant "layering" in the vertical dimension tends to be more complex and variable as a result of episodic pollution events in the water column over time. Moreover, sediment deposits in rivers, particularly those bordering dredged channels, are often curvilinear features which can be difficult to sample and map systematically.

Since most surveys are limited by considerations of effort and cost, simple random sampling is usually not feasible for a sediment sampling design. Given that contaminants in harbor sediments are more highly associated with silts than with sand, clay, or gravel, it makes sense to restrict most of the sampling to those substrates within the areas of interest. However, the location of these priority areas may be identified first by probing or sampling at regular intervals in a grid pattern.

In the reconnaissance phase of ARCS sampling a predetermined number of grab sampling points was distributed at fairly regular intervals along the river axis. At each point the nearest silt deposit was located and sampled. The results of this area reconnaissance indicated more contaminated sub-areas where a more detailed site reconnaissance with judgmental core sampling was planned in each case. Finally, based on the site results a more intensive coring survey was planned to carry out 3-dimensional mapping of selected deposits, as part of a remediation planning study. The latter sampling, which followed an approximate grid pattern, was an example of the systematic sampling approach (Mason 1992).

In summary, the ARCS survey approach represented a hybrid of systematic and judgmental sampling, based on historical review and field reconnaissance. It was also constrained somewhat by our technical limitations at the time. Appropriate technology is an important asset in sediment quality surveys, as will be discussed below.

Field Positioning

Determining one's location accurately in the field, which is necessary for any systematic sampling, is a particular problem in boat surveys. Reproducible sampling requires absolute position accuracy of +/- 3 to 5 meters and the capability to navigate to predetermined points on a map. Several different positioning technologies are available, including Loran-C, radar, range-azimuth, microwave, and satellite global positioning systems (GPS). Each has its limitations; conditions around urban-industrial harbors may impose certain constraints on use. Namely, bridges, buildings, power lines and the topography itself often interfere with laser beams, radio waves or microwave signals; access and security may be problems for any shore-mounted transmitters.

At the outset of the ARCS program we considered all of the position-finding technologies above. For a combination of reasons "differential" GPS or DGPS was the positioning method of choice, even though the satellite system was not fully operational at the time. In DGPS, correction factors generated by one satellite receiver at a known point are used to calibrate the position data acquired by a second receiver on the sampling vessel. Some government and commercial DGPS services now provide these corrections routinely from land or satellite-based transmitters. During ARCS, the capability to navigate in real-time to map points was not available to us until late in the program. However, shore references were often used to reach approximate points, which were then located accurately with DGPS in a post-navigation mode.

Since ARCS, the performance of DGPS systems has improved greatly, and the technique has been widely adopted for survey use on land and water. It usually offers the best combination of accuracy, reliability, flexibility and cost for continuous positioning in the field. Location outputs from DGPS, expressed as geographical or state plane coordinates, can be used efficiently to prepare distribution maps of any on-site measurements.

Sampling Methods

For many years sediment investigators have used a variety of grab and core sampling tools, which over the years have changed little in design (APHA

1985). Typically, surficial samples (0-.2 m sediment depth) have been collected with Ekman, Ponar, van Veen, or other grab samplers of the clamshell type. Box corers are sometimes used for collecting undisturbed samples of upper level sediments. Although long core (over 1 meter) sampling is routine for offshore sediments, it has been less commonly used to profile harbor sediments, especially in the Great Lakes. As a result, the variability of buried contamination in these harbor sediments was not widely appreciated until recent years. Also, in past decades water pollution was considered a more immediate problem than "in-place" sediment pollution. Even now there is still no comprehensive understanding of the risks posed by contamination buried in sediments. Nevertheless, intelligent consideration of risks must be based on realistic information about where, what and how much contamination is present. Appropriate tools and methods for core sampling these deposits are fundamental for sediment quality assessment.

Vibrocore Sampling

Vibrocoring (or vibracoring) technology was developed some years ago mainly for marine geotechnical applications. In principle, a submersible vibrator motor driven by electrical, pneumatic or hydraulic power is mounted on a thin-walled metal core tube. As the vibrating tube penetrates water-saturated material like sediments, it easily displaces particles on both sides of the wall. The rapid vibrations help to reduce tube wall friction, usually without disrupting the core interior. A largely undisturbed column of sediment is collected within the tube, where it is retained during tube withdrawal by a leaf-type core catcher at the lower end, and a check valve at the upper.

Vibrocoring is more effective than gravity coring for sampling layered, compacted sediments, as are found in most harbors. The smaller vibrocorers are usually faster and less expensive to deploy than drilling rigs or impact corers. Since the vibrocorer hangs from a cable, it is generally more suitable for use from an anchored boat than are rigid probe and drilling systems. For ARCS we initially developed our own vibrocorer system, which we later replaced with a more effective commercial version. The latter was designed to collect intact cores up to 6 m long and 10 cm in diameter. Liners tubes of polycarbonate or butyrate plastic were used within core tubes to simplify handling of intact, contaminated cores.

A 10 m sampling vessel, the R/V Mudpuppy, was built especially for ARCS sediment surveys (Fig. 1). Since it was designed to support a range of survey activities, the Mudpuppy is a more elaborate vessel than is needed for vibrocoring alone. In our vibrocoring work since ARCS we have used an 8 m pontoon boat with a 5 m high draw works for lifting cores through a central hole in the deck. Two portable generators power the vibrocorer, winch and other tools. A variety of other boats and even boom trucks have been used to deploy vibrocoring equipment.

Two problems that may occur when coring contaminated sediments are commonly referred to as compression and rodding effects. Either or both may be invoked to explain situations where the core length collected is apparently less than the core tube penetration in the sediment. Compression, one assumes, might occur when gas bubbles, especially within the more fluid upper core, are released by vibrations and the core compacts somewhat on withdrawal. In fact we sometimes do observe gas bubbles emerging around the tube during initial stage of vibrocoring. On the other hand, we have also observed small bubble cavities or voids remaining in the upper core immediately after collection. Whether or not the compression effect is a significant factor in core volume changes probably depends a great deal on physical properties of the sediment.

Rodding can occur when the bearing strength of sediment, which normally increases with depth, suddenly decreases relative to wall friction inside the core tube. Alternatively, debris may become wedged in the tube, partly blocking it. In any case, the sediment column stops moving within the tube, and both form a solid rod which pushes through the softer layer without collecting it. This might occur, for example when soft, oily sediments underly a stiff layer of clay. However, during ARCS when we encountered this situation in Buffalo Harbor sediments, vibrocoring did successfully collect alternating layers of dense clay and oily silt.

Clearly, there is still much to be learned about core sampling of contaminated sediments. Suffice to say that some core distortion can occur no matter how a core tube is introduced into sediment. Most often, however, the interior of vibrocores we collect resembles a solid, undisturbed column of sediment, usually with distinct zones of color and texture visible along its axis. We have often documented this in photographs (Fig. 2).

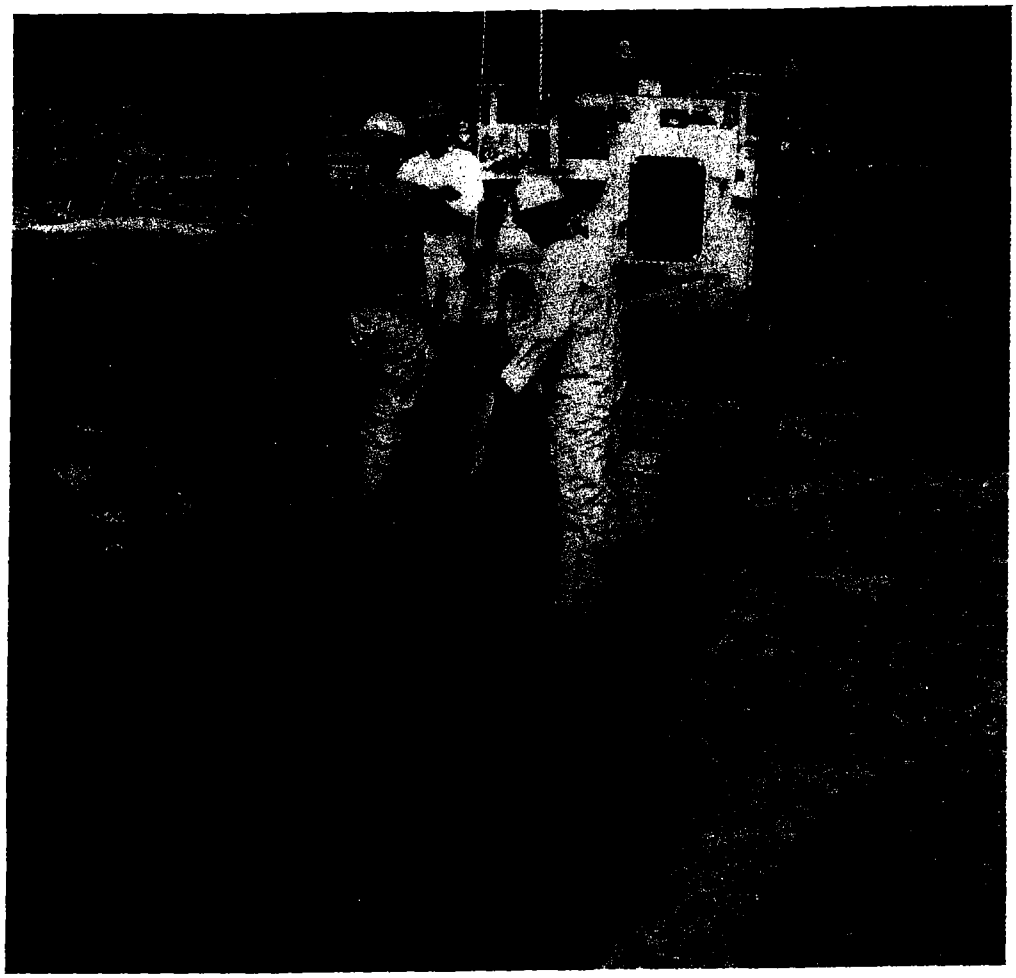

FIG. 1. **R/V Mudpuppy** ***retrieving a vibrocore from the Buffalo River, NY.***

Core Processing

During ARCS we initially processed cores on the deck of the Mudpuppy to simplify the decontamination process. This has two major disadvantages, however. One is that core documentation and subsampling may be impossible under some weather conditions. Furthermore, the processing work uses valuable sampling time which is always at a premium. We now prefer to set up a separate core processing facility in a secure location central to the sampling area. Access to local power and water is highly desirable, but the operation can be self-contained if necessary.

Processing begins as soon as the core is collected. Vibrocores are often collected in plastic liners, usually made of cellulose acetate butyrate (CAB) or polycarbonate. Using these liners in vibrocore tubes helps to protect core integrity. When fresh cores are brought on board the survey vessel they should be kept in a near-vertical position as the liner is unloaded from the core tube. The uppermost sediment layer (15-20 cm) is nearly always fluid or gelatinous, and is easily disturbed if the tube is laid down horizontally. Once the clear liner containing the core is unloaded, the overlying water can be drained off the core through a small hole drilled just above the sediment-water interface. Then the liner can be cut off and capped to keep the uppermost soft sediment in place. With the core (whole or in segments) capped and taped securely at both ends, it can be transported horizontally with little risk of disturbing it or exposing personnel to hazardous sediment. Cores in sealed liners, protected from air,

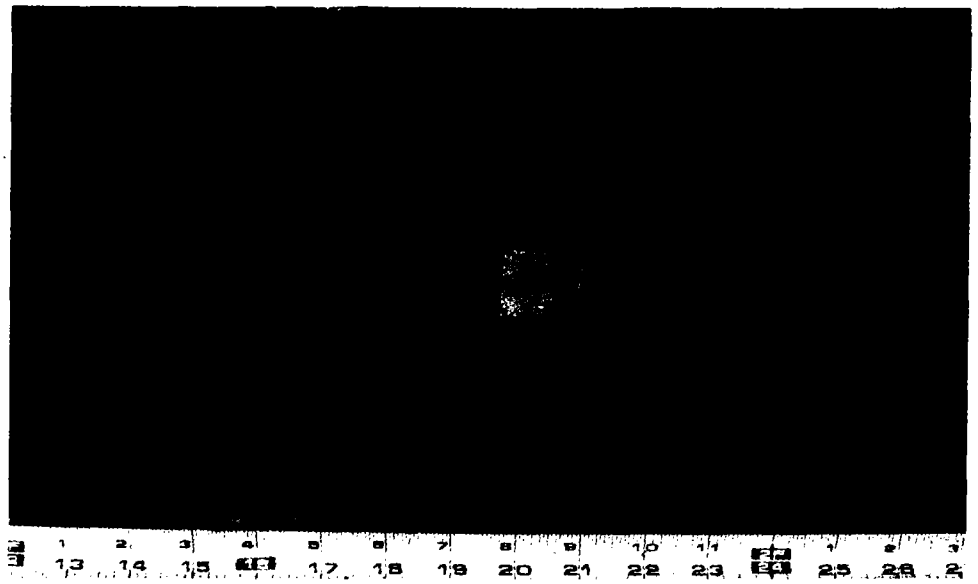

FIG. 2. Bisected portion of sediment vibrocore with dark zones of oily silt.

light and temperature changes, are least likely to deteriorate before samples can be taken. Of course, it is essential to label all cores as to station and date, and to mark the sequence and orientation of core segments.

Before the core itself can be split open lengthwise, the plastic liner wall (about 2 mm thick) must be cut through along opposite sides, without cutting significantly into the underlying sediment. Both CAB and polycarbonate are extremely tough and difficult to cut by hand with a blade. Circular saws and routers can cut the plastic easily, but they are dangerous to use and tend to contaminate the core with plastic chips. The best cutting tool we have found is a vibrating (reciprocating) saw of the type used to cut sheet metal or plaster casts. The vibrating action creates little plastic debris and does not endanger softer materials like human skin.

With the liner cut open along both sides, the core itself can be cut in half longitudinally with thin, rectangular pieces of stainless steel about 15 by 30 cm long. Ideally, each vertical cut along the core segment is made with a separate, precleaned blade. This prevents having to clean and decontaminate one blade repeatedly — not an insignificant problem with oily sediments. The radial cuts along the core axis do not smear adjacent zones of sediment, which normally lie across the core axis. With practice the user can produce a smooth, evenly cut surface along the core, which photographs well and reveals small details of structure.

Core Documentation

With cores encased in plastic liners it is convenient to describe and photograph a longitudinal section of the whole core before it is disturbed by subsampling. Such a record can be useful in accounting later for chemical zones and their boundaries within the core. For example, oily layers are often associated with higher concentrations of organics and metals. The lowest concentrations are typically found in sand or clay zones.

We have developed two different color photography systems for documenting core profiles. When cores (in liners) must be processed far from the collection point, they are usually cut and capped for transport in convenient segments of about 1.5 m. At the processing facility we split the core lengthwise and photograph both halves of it in overlapping frames, using a track-mounted camera and lighting system. A measuring tape (advanced for each core interval) lies beside the core and appears in each photograph, as does a label identifying the core. Prior to photography we also record a visual description of the core on a log sheet, noting intervals of different color, consistency and structure, as well as inclusions of a biological or industrial nature. Decisions about subsampling intervals are made at

this point, and these marks made on the core surface appear in the photographs. The redundancy of this procedure is intentional; it is desirable to have a thorough record of the intact core, including the unsampled zones.

In working with segmented cores as above, it may be advisable to reassemble all of the split segments on one surface before selecting the subsamples. Zones of interest may bridge two or more segments. Later on, photographs can also be assembled into composite views of whole cores. This is particularly useful for comparing zones in multiple cores.

The other photography system we use is designed for photographing whole split cores, regardless of length. It consists of a camera and light source mounted in a box which has a rectangular area cut out of the base on opposite sides. The box is moved along the split core step-wise, with the core passing through its cut out base. This design insures that overlapping photographs can be taken easily with a constant focus, light source and field of view.

When automatic exposure cameras are used the usually dark sediment photographs best with medium speed color film against a dark background. Depending on the type and orientation of lighting, suitable filters can be used to achieve realistic color and to minimize reflected glare from wet surfaces.

Sub-sampling Cores

After core documentation is complete the bisected core is ready for subsampling, according to whatever criteria the study plan requires. Initially in ARCS we subsampled cores at predetermined 0.6 m intervals, regardless of core content or structure. Our logic at the time was that any remedial dredging could not be done reliably at smaller increments than this. Later, as we came to recognize the complexity of core zonation, we wanted to understand how sediment contaminants were actually distributed, in anticipation of more refined remediation techniques in the future.

Currently, we often select for subsampling a core interval of 10-25 cm which represents a visibly discrete zone of sediment. Each sample is collected from the undisturbed center of the core interval by cutting out a narrow strip with a stainless steel spatula. Both exposed halves of the core are sampled equally until a sufficient volume of sediment is collected. The combined material is usually homogenized by stirring it in a stainless steel mixing bowl until it is visibly homogeneous. Portions of this homogenate are then bottled separately for various types of analysis.

Prior to analysis, sediments are generally stored in air-tight containers, under refrigeration (or frozen) in the dark. The analytical "shelf life" of sediments according to quality assurance guidelines (USEPA 1986) may or may not be meaningful with respect to particular analytes and sediments. If it is essential to verify a particular analyte's stability in stored sediment, a time series of samples can be analyzed during the period of storage.

Appropriate containers for sediment samples are usually wide mouth glass jars with Teflon®-lined lids, when organic compounds are the priority of analysis, or polyethylene jars (so-called "linear" PE), when metals are the priority. Different cleaning methods are used for each, according to EPA guidelines. When bottling samples it is helpful to use an oversized container — say, twice the sediment volume — so that the sample can be easily remixed in its jar before any aliquot is removed. One possible disadvantage, however, is that the sample is more exposed to air and oxidation during storage.

Frequently, silty sediments below the surficial mixed zone are anoxic when collected, as a result of organic decay. Some components, such as iron and other metals, are in a chemically reduced state. With exposure of sediments to air, rapid oxidation begins to occur and the rusty color of precipitated iron may be observed in samples after some time in storage. Other important properties such as bioavailability and toxicity of contaminants can change drastically with oxidation. If it is desireable to maintain the natural reduced condition of sediment cores for study purposes, they should be kept sealed in the tube liner until the core can be opened under controlled conditions (under nitrogen) in the laboratory. Possibilities exist for measuring anaerobic properties of collected sediment through prearranged ports in the liner wall.

Field Screening Analysis

In many sediment quality studies the field sampling and laboratory analysis are disconnected in time and space. Unfortunately, results obtained long after the survey can have no possible influence on sampling design. By the same token, blind analysis can be wasted on samples of no particular interest. Field screening helps to link the two phases by making interim results available on the site. Screening data for selected contaminants can provide

feedback needed to refine the sampling as it progresses. For example, if "hot spots" are located by field screening, further sampling can be focused on them immediately. Figure 3 illustrates a core profile of contaminant and toxicity measurements which can all be done in a mobile laboratory facility.

Recent advances in analytical technology have increased the use of both screening and standard methods of analysis in the field. More and more contaminant analyses are being done in mobile laboratories on site without significant loss of data quality. While the reliability of most screening results still must be verified in the laboratory, screening can offer big advantages of timeliness and cost. During ARCS we analyzed for certain "indicator" contaminants, as described in the accompanying article (Rathbun *et al.* 1996). Since ARCS we have often used two field screening techniques in our mobile laboratory: enzyme immunoassays (EIA) for selected organics, and energy dispersive x-ray fluorescence (XRF) for metals and other elements. With one operator, each can provide 25 or more analyses per day. The XRF method is particularly efficient since it produces data for 18 elements at a time.

Although careful use of XRF and immunoassays can yield reliable data, both methods are regarded by USEPA as semiquantitative: 10 per cent or more of sediment samples must also be analyzed by an EPA-recommended SW-846 method (USEPA 1986). However, when screening and laboratory results have differed in practice (as they inevitably will), few studies have probed the sources of variation (Johnson and Van Emon 1994). Oily sediment is a notoriously difficult matrix to analyze by screening and standard methods alike. One should not assume that all laboratory data are necessarily "true" values and that screening data are "off" by the observed difference. Moreover, less accurate screening data can still be useful as long as the bias is known and consistent. In any case, field screening methods can serve much the same purpose as the first level of diagnostics does in medical science: they help to focus our attention on the main problems, which more rigorous methods can then illuminate in detail.

Sediment Remote Sensing

The technology to remotely sense contaminants in sediments has great appeal for two reasons: representative sampling of a site demands a certain density and distribution of samples; sampling and analysis are usually constrained by cost and other non-scientific realities. A sediment core represents only a narrow vertical slice of the deposit, which may consist of many horizontal layers or zones of contamination. Are these zones intermittant or are

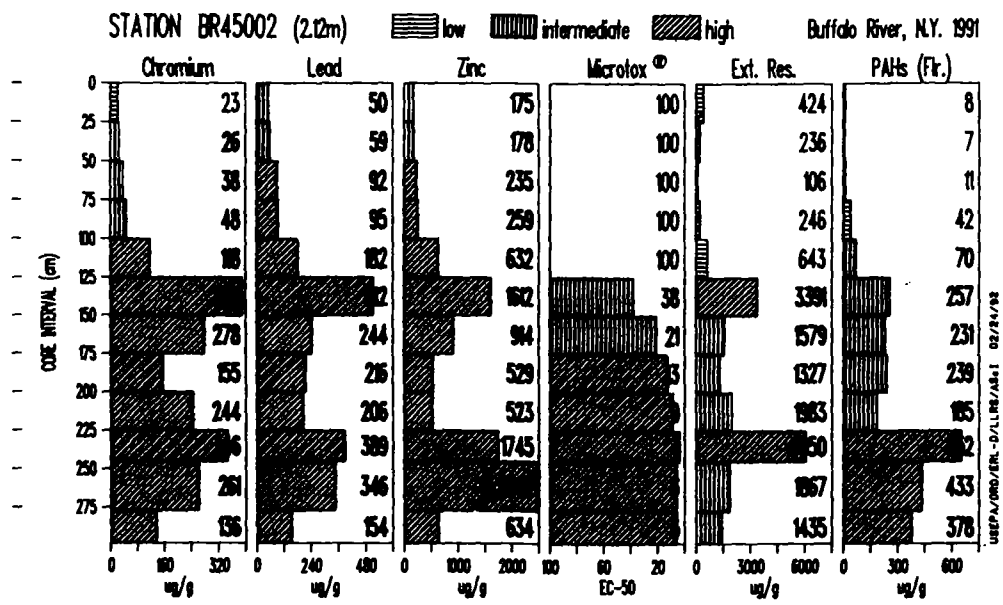

FIG. 3. Vertical profiles of contaminants and toxicity for a sediment core. Note increases below 1 m core depth.

they continuous between adjacent cores? Can some contaminant-related property of the zones be sensed remotely, in lieu of more costly sampling and analysis? Remote sensing could provide the means to map contaminant layers over an entire area. It might be useful to know, for example, the quality of sediments exposed by dredging to a certain depth.

The technique of acoustic impedence (or sound reflectance) profiling is promising in this regard, if its potential to sense contaminated sediments can be realized. The Army Corps of Engineers, in its ongoing development of acoustic techniques to support dredging, has used acoustic profiling successfully to characterize zones of uncontaminated marine sediments by means of density differences (McGee *et al.* 1995). Since oil affects sediment density and is commonly associated with other pollutants, there may be some prospect of sensing contaminant zones, if only indirectly.

Another sensing technique applied to intact cores has been used to locate the lower boundary of contamination, based on changes in the magnetic properties of sediment (Versteeg *et al.* 1995). In principle, the magnetic mineral content of sediments increases with other forms of industrial contamination.

Data Analysis and Mapping

Sediment contaminants are clearly a 3-dimensional problem, given that extreme variations can be seen in some vertical profiles in harbors. Some of these long buried deposits may be exposed eventually by dredging or development. Visualizing them through techniques of data mapping and modeling can help us to anticipate environmental problems that might occur.

As discussed in the ARCS Document and elsewhere (USEPA 1994b, Baudo 1990), computer mapping programs are available which make it relatively simple to create 2- and 3-dimensional contour maps using "point" data from discrete samples. Typically, the process involves using an algorithm such as kriging to prepare an interpolated data set on a grid. Contours or isopleths are then generated from the gridded data.While these are only simulations of reality, they can at least indicate gradients and potential "hot spots" where further sampling may be needed. Three-dimensional contouring or data modeling may require relatively large data sets representing hundreds of samples. However, the added focus that it can bring to a costly remediation effort can make this worthwhile. In an ARCS-related study in the Buffalo River, New York, we used 3-dimensional software (Geologic Modeling Program, Dynamic Graphics Inc.) to visualize concentration zones of contaminants in sediment for approximately 100 measurements from ten cores (Fig. 4).

As a data screening tool, contour mapping is most useful when conducted during the course of a sediment quality survey, while there is still some opportunity to refine the sampling design. This approach is practical, however, only if reliable screening data can be produced quickly in the field. The strategy of collecting and contouring data repeatedly in the field is used routinely in the oil exploration business. More such field reconnaissance in environmental projects would increase the certainty that contaminant data thoroughly represent the site.

Field Precautions

Health and safety concerns in sediment surveys should never be limited to contaminant issues. Physical hazards can pose a much greater threat to personnel who perform demanding work with power equipment on open boats under sometimes adverse conditions in the field. While the required use of protective equipment, such as "moon suits," gloves, visors, etc., does minimize exposure to contaminants, it can also cause clumsiness, heat stress, fatigue and confusion. The wearer can then become more accident-prone. One of the important purposes of field reconnaissance is to perform a thorough "mental" survey of the site, anticipating all hazards that staff may encounter on the job. All appropriate precautions can then be included in the health and safety plan.

When handling and processing contaminated sediment cores, much trouble can be avoided and time saved by thorough preparation of the staff, the decontamination procedures and the work space itself. The forms of contamination most prevalent in aquatic sediments tend to be less volatile, less water soluble and more persistent by nature. Examples are the semivolatile cholorocarbons (like PCBs), the polynuclear hydrocarbons (like PAHs), and heavy metals. As with any potentially hazardous material, harbor sediments must be handled with caution. Certain toxic constituents, such as hydrogen sulfide, can pose an immediate threat to human health.

Usually it is best to process contaminated cores out of the weather, but in a well ventilated space. A cargo truck, open at the rear, can serve this purpose. Although weathered underwater sediments do not typically contain much highly volatile material like

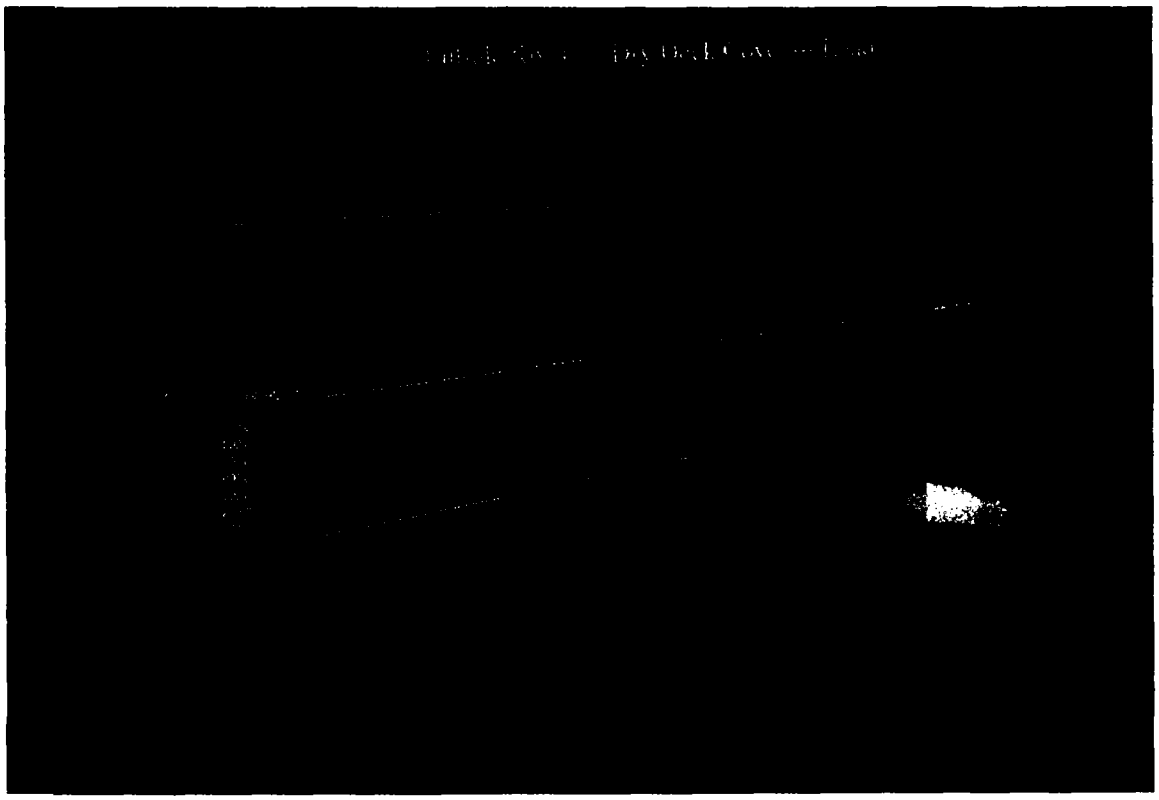

FIG. 4. Data model of lead distribution in sediments at Buffalo River site. Transparent view reveals probable zones of highest concentration.

solvents, oil is often present and its odor may be noticeable when cores are first cut open. As mentioned above, other organic and metal contaminants tend to be more concentrated in the oiliest sediments, which adds to their toxic potential. With oily sediment it is more difficult to control contamination at the processing facility. A good practice is to tape polyethylene film over all work surfaces, including the floor and walls.

Processing staff usually dress in full protective clothing, to include impervious coveralls, rubber boots and gloves. Whether or not to use respirators is a site-specific decision to be made by responsible parties. At least safety glasses or face shields are always essential. All waste is disposed of properly, with separate drums provided for wash water, excess sediment and solid waste (clothing, paper, core liners). When all excess sediment has been collected at the end of the survey, it is customary to take one or more composite samples for analysis to determine the correct disposal means.

The above summary of precautions is by no means complete. Many features of any health and safety plan are necessarily specific to the site, the season and other considerations.

CONCLUSIONS

In our present view, sharpened with hindsight, the ARCS effort was a significant step forward in some aspects of sediment surveying. First, the results of our coring and contaminant profiling in Great Lakes harbors revealed much about the complexity of contaminant distribution. This led to a greater emphasis on field reconnaissance and screening analysis as a way to focus sampling for more meaningful results. It has become increasingly apparent in our experience since ARCS that sediment surveys which involve collecting only a few, intuitive grab samples are unlikely to yield any realistic appraisal of sediment quality, overall.

For detailed, systematic mapping of contaminants in sediments, it is essential to have accurate positioning and the capability to navigate to predetermined points. Recent advances in differential GPS have made this process easier and more affordable.

Position accuracies of +/- 3 m are realistic and desirable for most sediment sampling.

Vibrocoring with submersible equipment seems to us the most versatile method for collecting intact cores of various sediments, at least in Great Lakes waters. However, it would be a useful exercise to directly compare the performance of different coring techniques for different sediment types in the field.

Processing cores on site should include carefully documenting any visible zonation, since oily layers in particular may correspond to contaminant zones. Proper subsampling and handling techniques are essential to preserve sample quality.

Sampling designs can be refined onsite through sample analysis and data mapping in the field. Rapid screening methods, such as immunoassays and x-ray fluorescence, are useful if selected results are confirmed by standard methods.

Until now, concerns about quality assurance in sediment assessment work have been focused almost entirely on laboratory data quality, rather than on sampling errors as an important source of uncertainty. More thorough, representative sampling can yield the most benefit per effort in terms of improved data quality and better decision-making.

ACKNOWLEDGMENTS

We dedicate this paper to the memory of our late coauthor, good friend, and admired colleague, Laura Lang Huellmantel. We also wish to thank the many field and laboratory staff of numerous institutions who contributed to the ARCS survey effort.

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DuPont Engineering
Barley Mill Plaza - Bldg. 27
Lancaster Pike & Rte. 141
Wilmington, DE 19805

DuPont Engineering

June 25, 2002

Mr. Brian P. Freeman
Corrective Action Project Manager
U.S. Environmental Protection Agency – Region V
77 W. Jackson Blvd., DE-9J
Chicago, IL 60604-3590

RE: Environmental Indicator Determination Report – Current Human Exposures Under Control (CA725)

Dear Mr. Freeman:

We told you earlier this year that DuPont would be submitting an evaluation of the environmental indicator (EI) "current human exposures under control." We understand that the responsibility for EI determinations resides with the U.S. EPA and do not presume to usurp EPA authority or role. However, we believe that pulling together relevant data and using the EPA guidance and score sheet will facilitate an appropriate, timely determination. We have enclosed three copies of this EI Determination Report for your review.

Our report concludes that releases or the potential for releases identified from Resource Conservation and Recovery Act (RCRA) correctives action units at the DuPont East Chicago facility do not constitute a significant threat to human health. Reasonably expected exposures above screening levels were found to be acceptable, i.e., did not exceed U.S. EPA acceptable risk levels. As a result, a positive EI determination was reached for EI CA 725.

If you have any questions, please feel free to call me at (704) 362-6628 or Alan Egler at (302) 892-1296.

Sincerely,

Hilton Frey (APE)

J. Hilton Frey
DuPont Corporate Remediation Group
Project Director

cc: Chris Myer, IDEM
Ross Austin, DuPont
Alan Egler, URS Diamond
Dana McCue, URS Diamond

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Internat. Assoc. Great Lakes Res., 1996

Assessing Contamination in Great Lakes Sediments Using Benthic Invertebrate Communities and the Sediment Quality Triad Approach

Timothy J. Canfield,[1] F. James Dwyer,[1] James F. Fairchild,[1] Pamela S. Haverland,[1] Christopher G. Ingersoll,[1] Nile E. Kemble,[1] David R. Mount,[2] Thomas W. La Point,[3] G. Allen Burton,[4] and M.C. Swift[5]

[1]*Midwest Science Center*
National Biological Service
4200 New Haven Road
Columbia, Missouri 65201

[2]*Mid-continent Ecological Division-Duluth*
U.S. Environmental Protection Agency
6201 Condon Boulevard
Duluth, Minnesota 55804

[3]*ENTOX/TIWET*
Clemson University
One TIWET Dr.
Box 709
Pendleton, South Carolina 29670–0709

[4]*Wright State University*
Institute for Environmental Quality
Dayton, Ohio 45435

[5]*University of Minnesota*
Monticello Ecological Research Station
Box 500
Monticello, Minnesota 55362

ABSTRACT. *Sediments in many Great Lakes harbors and tributary rivers are contaminated. As part of the USEPA's Assessment and Remediation of Contaminated Sediment (ARCS) program, a number of studies were conducted to determine the nature and extent of sediment contamination in Great Lakes Areas of Concern (AOC). This paper describes the composition of benthic invertebrate communities in contaminated sediments and is one in a series of papers describing studies conducted to evaluate sediment toxicity from three AOC's (Buffalo River, NY; Indiana Harbor, IN; Saginaw River, MI), as part of the ARCS Program. Oligochaeta (worms) and Chironomidae (midge) comprised over 90% of the benthic invertebrate numbers in samples collected from depositional areas. Worms and midge consisted of taxa identified as primarily contaminant tolerant organisms. Structural deformities of mouthparts in midge larvae were pronounced in many of the samples. Good concurrence was evident between measures of laboratory toxicity, sediment contaminant concentration, and benthic invertebrate community composition in extremely contaminated samples. However, in moderately contaminated samples, less concordance was observed between the benthos community composition and either laboratory toxicity test results or sediment contaminant concentration. Laboratory sediment toxicity tests may better identify chemical contamination in sediments than many commonly used measures of benthic invertebrate community composition. Benthic measures may also reflect other factors such as habitat alteration. Evaluation of non-contaminant factors are needed to better interpret the response of benthic invertebrates to sediment contamination.*

INDEX WORDS: *Oligochaeta, Chironomidae, Great Lakes, sediment quality triad, sediment contaminants.*

INTRODUCTION

Benthic macroinvertebrate abundance, community composition, and ecological function have long been used to characterize water quality in freshwater ecosystems. Numerous studies have documented changes in benthic invertebrate community composition resulting from sediment contamination (Cook and Johnson 1974; Rosenberg and Wiens 1976; Hilsenhoff 1982, 1987; Waterhouse and Farrell 1985; Clements *et al.* 1992). Most of these studies have examined the responses of benthic macroinvertebrates in stony riffle areas of streams and rivers, and provide only limited assessment in soft sediments (which typically accumulate elevated levels of contaminants). This study evaluated how benthic invertebrate community composition measures can be used in the context of a Sediment Quality Triad (SQT) approach (Chapman 1992) to assess and discriminate between contaminated and uncontaminated sediments.

The aquatic ecosystem is linked together by virtue of interdependent trophic levels. Organisms near or in the sediment can be adversely affected by contaminants (USEPA 1994). When assessing sediment contamination, it may not be adequate to study single components of the ecosystem (Burton 1991). Ecological risk assessments of sediment contamination using laboratory toxicity tests, sediment contaminant concentration, and measures of benthic macroinvertebrates as indicators of sediment quality may provide a more definitive assessment (Burton 1991, USEPA 1993, Canfield *et al.* 1994).

The spatial and temporal distribution of benthic organisms may reflect the degree to which chemicals in sediments are bioavailable and toxic. Field surveys of invertebrates may provide an important component of biological assessments of toxicity associated with contaminated sediments for several reasons: (1) macroinvertebrates are abundant, relatively sedentary, easy to collect, and ubiquitous across a broad array of sediment types; (2) benthic organisms complete all or most of their life cycle in the aquatic environment serving as continuous monitors of sediment quality; and (3) assessment of indigenous populations may be useful for quantifying resource damage (Cook 1976, Pratt and Coler 1976, Davis and Lathrop 1992). The usefulness of benthic invertebrate field studies for assessing sediment contamination has been limited by several factors: (1) benthic invertebrate community composition has been difficult to relate to individual chemical concentrations; (2) in addition to contaminants benthic invertebrates respond to biotic and abiotic factors; and (3) large numbers of samples are typically needed to address the high variance associated with distribution of benthos.

This paper is one in a series of papers in this issue describing studies conducted to evaluate the contamination of sediments from three Great Lakes tributaries: Buffalo River, NY; Indiana Harbor, IN; and Saginaw River, MI. These are 3 of 42 areas in the Great Lakes basin that have been identified as Areas of Concern (AOC) by the International Joint Commission (Fox and Tuchman 1996; IJC 1987, 1988a, 1988b). This study is part of a five year project conducted by the Great Lakes National Program Office (GLNPO) of the U.S. EPA for the assessment and Remediation of Contaminated Sediments (ARCS) in the Great Lakes (Fox and Tuchman 1996). The objectives of this paper are to: (1) describe the distributions and abundances of benthic invertebrates in sediment depositional areas; (2) assess the toxicity of contaminated sediments in these three AOCs using measures of benthic invertebrate community composition; (3) evaluate sources of variability in sampling benthic invertebrate communities; and (4) evaluate the reliability of benthic invertebrate assessments of sediments in an SQT approach. The SQT is used as an effects based approach to integrate data from chemical and physical analyses, whole-sediment laboratory toxicity tests and benthic community measures. We used sediment chemical and physical analyses and whole sediment laboratory tests to identify those benthic community indices which best correspond with sediment contamination.

MATERIALS AND METHODS

Sampling Locations

Stations were selected for assessing whole-sediment toxicity, sediment contaminant concentration, and benthic macroinvertebrate communities based on evidence that contaminants in sediments could be deleterious to resident aquatic biota (Fox and Tuchman 1996). All three ARCS sites: Indiana Harbor (IH1, August), Buffalo River (BR1, October), and Saginaw River (SR1, December) were sampled once in 1989. Saginaw River (SR3) was sampled again in June 1990 (USEPA 1993). Seven stations were sampled both in Indiana Harbor and Saginaw River while 10 stations were sampled in the Buffalo River. For a description of individual sampling station locations see USEPA (1993, 1994). A Global Positioning System was used to locate sampling stations.

Sediment Collection, Handling, and Storage

Benthic invertebrates and bulk sediment samples for chemistry and toxicity assessments were collected with a stainless steel standard ponar grab (23 × 23 cm, 529 cm^2 area). Five sediment grabs were taken within an area of about 100 m^2 at each sampling station. In an effort to minimize disturbance of the sediments and associated invertebrates, benthic samples were taken before the collection of sediment samples for chemistry and toxicity testing. Samples were sieved in the field through an ASTM No. 30 sieve (533 μm). Material retained by the sieve was transferred to 500-mL glass jars, preserved with 10% buffered formalin, and transported to the laboratory.

Sediment samples for chemical analyses and toxicity testing were collected from the upper 10 to 20 cm of sediment at Indiana Harbor, Buffalo River, and the first sampling at Saginaw River. A Van Veen Grab (41× 51 cm) was used for the second sampling at Saginaw River. Each sample was a composite of 15 to 100 L of sediment/station. Sediments were homogenized for 15 min in a cement mixer and sub-samples of sediments were placed in high-density polyethylene containers. The samples were shipped on ice to testing laboratories via overnight mail, and inventoried and stored at 4°C in the dark (USEPA 1993).

Taxonomic Identification

In the laboratory, benthos samples were placed in a sieve (250 μm) and rinsed thoroughly with tap water to remove formalin and excess silt or mud prior to sorting. The samples were drained of excess water, returned to the original jars, filled with 95% ethanol, and allowed to soak for at least 24 h to facilitate extraction of volatile compounds. Each sample was rinsed again with tap water to remove the ethanol and volatiles. The samples were placed in a 4-L wide-mouth jar and agitated with tap water to float the invertebrates and lighter detrital material while leaving the gastropods (snails), bivalves (clams), and heavier material to settle to the bottom of the jar. Sample aliquots were sequentially removed from the jar to sort the benthic invertebrates.

A binocular dissecting microscope (4× to 12× power) was used to sort the organisms. Invertebrates were sorted and enumerated into the following broad categories: Oligochaeta, Chironomidae, Bivalvia, Gastropoda, Ephemeroptera, Odonata, Plecoptera, Hemiptera, Megaloptera, Trichoptera, Coleoptera, Diptera, Hirudinea, and Amphipoda. Benthic samples were used to estimate macroinvertebrate abundance (number/m^2), species composition, and taxa richness. Finer taxonomic identification was made using the following taxonomic keys: Wiederholm 1983, Merritt and Cummins 1984, Pennak 1989, Thorp and Covich 1991. Oligochaetes were identified to genus and species (when possible) by Mark Wetzel at Invertaxon, Urbana, IL. Clams were identified to genus and species by Jeff Garner at the Aquatic Resources Center, Franklin, TN. Chironomidae (midges) were identified to genus at the Midwest Science Center, and confirmations were made by Leonard Ferrington, University of Kansas, Lawrence, KS.

Midge larvae were examined for mouthpart deformities which included various types of asymmetry, missing teeth, extra teeth, fusion among teeth, and labial separation (Saether 1970, Hamilton and Saether 1971, Hare and Carter 1976, Warwick *et al.* 1987, Warwick 1989). Individual midge were mounted on slides using CMCP 10 mounting media and examined for deformities in the mentum and ligula (Tanypodinae only) under 40× or higher power. Occurrence of deformities was expressed as a proportion of the total number of midges observed at each station.

Physical and Chemical Characterizations of Sediment

Physical characteristics measured in sediments included: (1) sediment particle size, (2) total organic carbon, and (3) inorganic carbon. Chemical constituents analyzed included: (1) chlorinated pesticides, (2) polychlorinated biphenyls (PCB's), (3) select polynuclear aromatic hydrocarbons (PAH's), (4) polychlorinated dioxins and furans, (5) organometals, (6) simultaneously extracted metals (SEM) and acid volatile sulfide (AVS), and (7) total metals. All chemical analyses on sediment samples were provided by Battelle Laboratory, Sequim, WA. For additional information on the chemical and physical characteristics of the sediments as well as methods of analysis, see USEPA (1993).

Statistical Analyses

Statistical analysis was performed with the Statistical Analysis System (SAS) computer package for personnel computers (Statistical Analysis System 1988). Benthic invertebrate abundance between AOCs were analyzed with a nested analysis of variance (ANOVA) with a mean separation by Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$ (Snedecor and Cochran 1982). Benthic in-

vertebrate abundance and physical and chemical data were compared with a Spearman Rank correlation procedure ($\alpha \leq 0.05$) and multivariate regression statistics. If not reported, statements of statistical significance indicate ≤ 0.05.

Sediment Quality Triad

The SQT is a weight of evidence approach which incorporates measures of sediment chemistry, sediment toxicity, and benthic community composition to evaluate sediment quality (Chapman *et al.* 1992). Investigators have evaluated SQT data using several procedures including scoring, multiple regression, and principal component analyses (Cross *et al.* 1991, Chapman 1992). In the present study, toxicity, benthos, and chemistry data were scored using procedures developed by Kreis (1988), and data were plotted using procedures described by Chapman *et al.* (1991). Values for individual variables were arithmetically scored proportionally between 1 and 100 (e.g., 1 is indicative of the lowest concentration/least toxic/best benthos observed, least impacted, and 100 is the most impacted). Scoring the data retains proportional differences between measurements and results in an identical range for all variables. More than one variable may be used for a particular SQT component (e.g., *Hyalella azteca* survival and growth). In these instances, Kreis (1988) recommended: (1) scoring each individual variable among stations, (2) summing the scored values for each station and SQT component, and (3) re-scoring (between 1 and 100) the sums. This results in scores between 1 and 100 for each SQT component. Scores can be plotted on tri-axial graphs (Fig. 1).

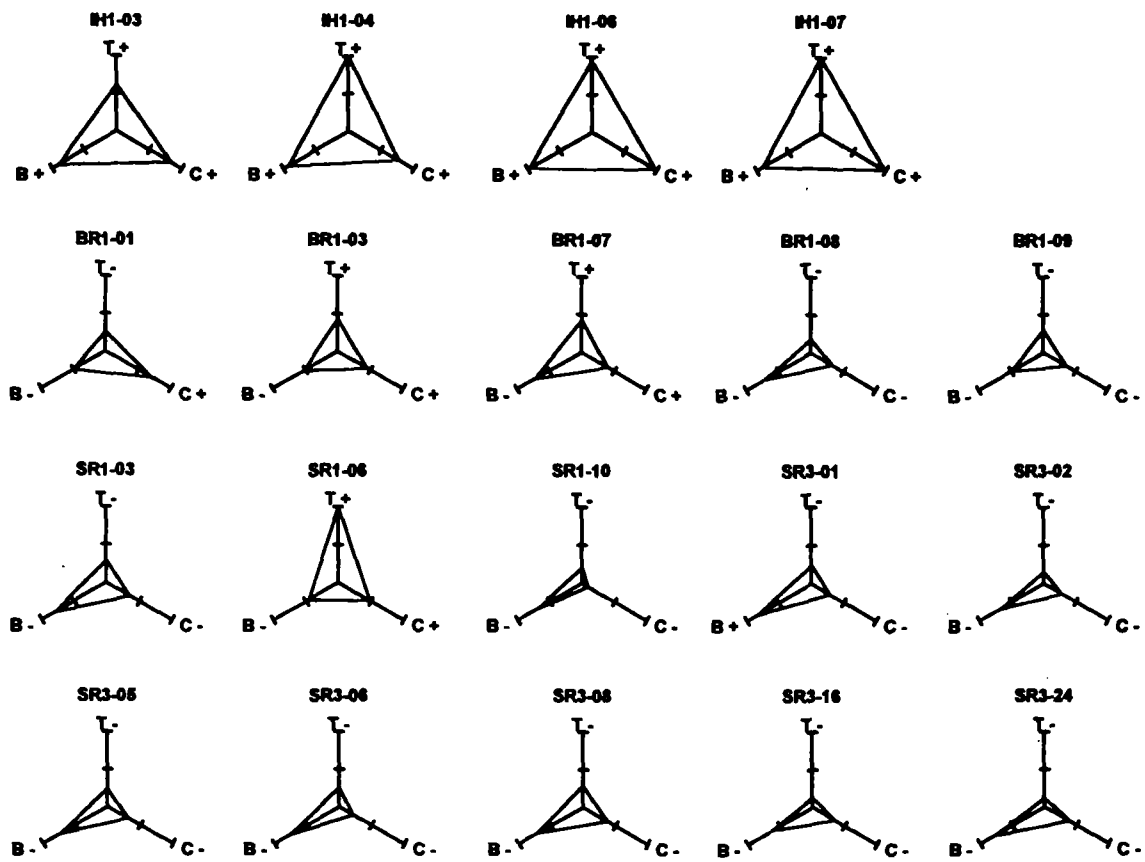

FIG. 1. Sediment Quality Triad for Great Lakes samples. T = Toxicity, with the scores based on Hyalella azteca *28 d growth and survival, C = Chemistry, with the scores based on the SERM-Q, B = Benthos, with the scores based on the midge biotic index – taxa richness metric. A "+" for toxicity indicates a score > 30, a "+" for chemistry indicates a score > 39, and a "+" for benthos indicates a score > 80.*

Benthic Indices

Several benthic indices were evaluated to determine which would be most useful indicators of sediment contamination. The evaluation was based on data from the three Great Lakes AOCs and data from a study of the upper Clark Fork River and Milltown Reservoir in Montana (Canfield *et al.* 1994). The greater number of stations across a broad range of contamination provides a more robust data set and a better opportunity to interpret the effects of contaminated sediments on benthic communities.

Benthic indices evaluated were: (1) total taxa richness, (2) chironomid genera richness, (3) chironomid mouthpart deformities, (4) chironomid biotic index, (5) chironomid/oligochaete ratio, and (6) oligochaete biotic index. The Hilsenhoff Index of Biotic Integrity was used to calculate a biotic index for both the midges and oligochaetes. Species sensitivity within a genera was obtained primarily from those assigned by Hilsenhof (1982, 1987) and secondarily by Lenat (1993).

Guidelines have not been well developed for distinguishing impacts of contaminant effects on benthos collected from soft sediments in either streams or lakes. A quadrant frequency analysis (essentially a frequency analysis to identify correct classification and Type I and Type II error) was conducted in order to evaluate which benthic indices were most sensitive to elevated contaminant concentration. In this analysis, scores for benthos indices are plotted against scores for chemical contamination in sediments. Quadrants were then defined which identified the following: (A) low chemical concentration and benthos adversely impacted (Type II error, false negative), (B) elevated chemical concentration and benthos not adversely impacted (Type I error, false positive), (C) low chemical concentration and benthos not adversely impacted, and (D) elevated chemical concentration and benthos adversely impacted. Various combinations of benthic indices were evaluated by adding the individual scores and re-scoring. This analysis was conducted for all possible combinations of the six scored benthic indices listed above.

Chemical Indices

To evaluate the chemistry portion of the SQT, eight of nine Effect-Range Median (ERM) sediment effect concentrations, as defined by Long and Morgan (1991) and calculated by Ingersoll *et al.* (1996), were used. These ERM's classified laboratory toxicity correctly > 70% of the time in 28-d tests with *Hyalella azteca*. The ERMs used included: cadmium, chromium, nickel, lead, zinc, chrysene, benzo(a)pyrene, and benzo(g,h,i)perylene. In the present study, calculations for the ninth ERM (total PCBs) could not be made or used because total PCBs were not determined for the Great Lakes data set. For a complete discussion of the sediment effects concentrations, see Ingersoll *et al.* (1996).

Associations between degree of sediment contamination and benthic indices or laboratory toxicity were evaluated in two ways. First, benthic indices or laboratory toxicity data were plotted against the single greatest or maximum ERM quotient (MERM-Q; Q = concentration of a chemical in a sediment sample / ERM for that chemical). The second approach plotted the sum of the ERM Quotients (SERM-Q) for all eight chemicals in a sample. Each ERM-Q was then scored from 1 to 100 as previously described above.

Sediment Toxicity Tests

Whole-sediment toxicity studies were conducted at 32 of the 44 stations. Of all the species tested, *Hyalella azteca* were one of the most sensitive test organisms, and survival and growth were the most sensitive endpoints (Burton *et al.* 1996, Ingersoll *et al.* 1996). Therefore, the *Hyalella azteca* 28-d growth and survival endpoints were used as laboratory measures of toxicity. Each sediment sample was designated as toxic or not toxic depending on whether survival or growth was significantly lower than the controls (Kemble *et al.* 1994, Ingersoll *et al.* 1996, USEPA 1993). By plotting both the toxicity scores and whether a sample was toxic or not toxic to *H. azeteca*, a MERM-Q score of 43 was determined as the location for the vertical quadrant line, corresponding to the MERM-Q above which no nontoxic sites were observed (i.e., Fig. 2a). The horizontal quadrant line was drawn at a score for laboratory toxicity of 30 corresponding to the greatest laboratory score above which there were no non-toxic samples observed. Using the same rationale, we evaluated the SERM-Q and laboratory toxicity data. The vertical quadrant line was drawn at a SERM-Q of 39 and the horizontal line at the laboratory toxicity score of 30 (i.e., Fig. 2b). This selection procedure for establishing quadrant lines may be less environmentally protective since some of the samples that had a MERM-Q score less than 43 and a SERM-Q score less than 39 were toxic to

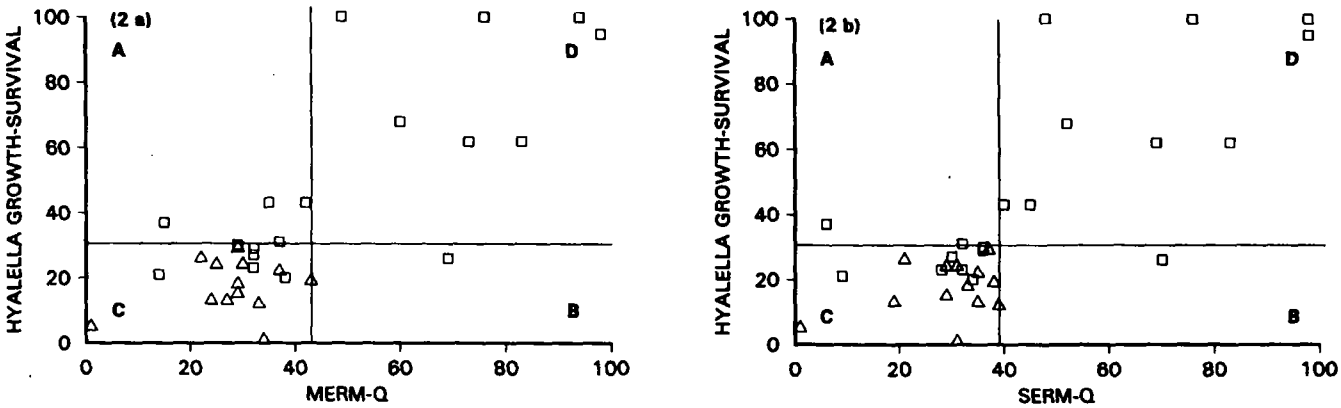

FIG. 2. Quadrant analysis with **Hyalella azteca** *toxicity tests using: (A) the MERM-Q; and (B) the SERM-Q. Quadrants are labeled: A: false negative (Type II error), B: false positive (Type I error), C: non-impacted, (low chemistry, low toxicity response), and D: impacted, (high chemistry, high toxicity response). A square indicates toxic samples and a triangle indicates non-toxic samples in* **Hyalella azteca** *toxicity tests as identified by USEPA (1993).*

Hyalella azteca in the laboratory studies (Kemble *et al.* 1994, Ingersoll *et al.* 1996).

Scores of various benthic indices and all combinations of scores were plotted against the MERM-Q or against the SERM-Q (i.e., Fig. 3). The position of quadrant lines for benthic indices were determined by: (1) plotting the data, (2) drawing the vertical quadrant line at 43 for the MERM-Q or 39 for the SERM-Q, (3) evaluating the distribution of the data and selecting a benthic score (horizontal quadrant line) which maximized the number of points in quadrants which would be considered "correctly classified" and minimized the number of stations with "Type I, false positive" and "Type II, false negative" error results. Quadrant analysis was also used to compare benthic indices and laboratory toxicity results.

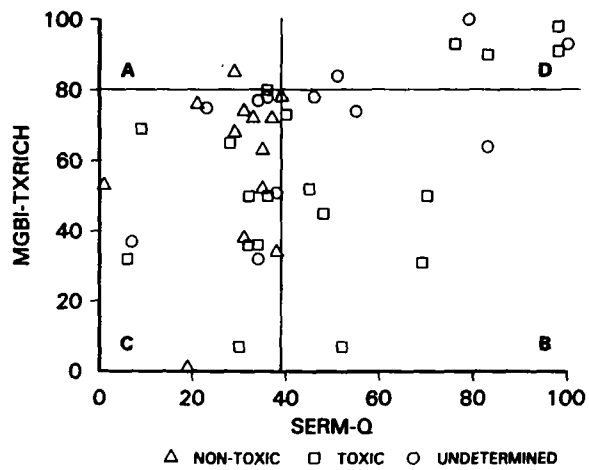

FIG. 3. Quadrant analysis of the combined score of the midge biotic index and total taxa richness with the SERM-Q score. Quadrants are labeled: A: false negative (Type II error), B: false positive (Type I error), C: non-impacted, (low chemistry, low benthos response), and D: impacted, (high chemistry, high benthos response). A square indicates toxic samples and a triangle indicates non-toxic samples in the **Hyalella azteca** *toxicity tests as identified by USEPA (1993). A circle indicates samples for benthos data which were not evaluated in laboratory toxicity testing.*

RESULTS AND DISCUSSION

Benthic Invertebrates

Abundance

Mean benthic invertebrate abundance (number/m^2) ranged from 609/m^2 at station IH1- 07 to a maximum of 493,917/m^2 at station IH1-10 (Table 1). Except for station IH1-10, mean total

TABLE 1. Mean abundance data (number/m², standard error in parentheses) for major benthic invertebrate groups in the Buffalo River (BR1), Indiana Harbor (IH1), Saginaw River first sampling (SR1), and Saginaw River second sampling (SR3). Data are mean values for five replicates.

Station	Oligochaeta	Chironomidae	Total
BR1-01	2,714 (1,045)	197 (60)	3,013 (1,190)
BR1-02	7,394 (1,389)	110 (44)	7,530 (1,419)
BR1-03	7,059 (1,712)	151 (46)	7,536 (1,787)
BR1-04	8,407 (989)	386 (37)	9,461 (1,210)
BR1-05	6,403 (1,920)	11 (8)	6,445 (1,927)
BR1-06	19,157 (2,756)	114 (44)	19,418 (2,809)
BR1-07	14,496 (1,838)	26 (11)	14,708 (1,839)
BR1-08	16,220 (2,254)	181 (19)	16,473 (2,248)
BR1-09	1,984 (492)	287 (86)	2,294 (553)
BR1-10	3,092 (860)	2,771 (1,633)	6,067 (2,423)
IH1-03	3,765 (1,618)	0 (0)	3,791 (1,623)
IH1-04	5,935 (2,090)	0 (0)	6,025 (2,081)
IH1-05	5,198 (1,742)	0 (0)	5,307 (1,788)
IH1-06	1,501 (915)	0 (0)	1,501 (915)
IH1-07	552 (272)	0 (0)	609 (255)
IH1-08	2,903 (1,430)	0 (0)	2,907 (1,435)
IH1-10	493,887 (180,680)	0 (0)	493,917 (180,676)
SR1-02	6,418 (761)	238 (77)	6,664 (822)
SR1-03	6,974 (242)	121 (22)	7,129 (239)
SR1-04	3,621 (515)	45 (18)	3,686 (511)
SR1-06	1,682 (432)	11 (5)	1,709 (437)
SR1-07	5,954 (365)	87 (14)	6,056 (377)
SR1-09	1,478 (204)	363 (79)	1,890 (287)
SR1-10	813 (630)	61 (55)	888 (693)
SR3-01	4,944 (863)	2,204 (372)	7,152 (1,194)
SR3-02	3,735 (648)	23 (9)	3,780 (658)
SR3-05	2,861 (244)	144 (35)	3,047 (227)
SR3-06	302 (108)	15 (7)	321 (114)
SR3-08	820 (240)	360 (105)	1,157 (296)
SR3-16	3,538 (253)	389 (45)	3,977 (240)
SR3-24	805 (203)	125 (36)	941 (238)

abundance values were less than 20,000/m², with abundance values at 22 of 31 stations less than 7,000/m². Overall mean abundance values for the Buffalo River were two to three times higher than Indiana Harbor (excluding Station IH1-10) and the Saginaw River. Oligochaetes were numerically dominant at all locations. Midges comprised the majority of the remaining benthic community at 20 of 31 stations with Unionidae comprising the majority of the community at seven of the remaining locations.

Benthic invertebrates from the Buffalo River exhibited a wide range of abundance, while Indiana Harbor (excluding station IH1-10) and Saginaw River showed a fairly narrow range in terms of abundance values. Many of the grab samples from Indiana Harbor had large remnants of snail and clam shells. The stations sampled were depositional areas and the shells may have washed in from up stream, but the possibility that resident snail and clam communities at these locations have died off can not be excluded. Samples from Indiana Harbor had a very depauperate benthic invertebrate community compared to either Buffalo River or the Saginaw River. Except for the two midge collected

at IH1-10, no other aquatic insect orders were present in the samples from Indiana Harbor. Oligochaete abundance accounted for 51 to 100% of the community across all stations sampled (USEPA 1993). Combined oligochaete and midge abundance accounted for 92 to 100% of the total benthic invertebrate community at all stations, with the remainder of the benthic community abundance coming from the Mollusca, Diptera, Coleoptera, and Trichoptera (USEPA 1993).

Mean oligochaete abundance ranged from 552/m^2 at station IH1-07 to 493,887/m^2 at station IH1-10 (Table 1). The abundance values of oligochaetes closely paralleled the overall abundance values, which is not surprising since the oligochaetes made up greater than 90% of the total abundance values in 24 of 31 stations. Overall mean abundance of oligochaetes was 2.5 times higher in the Buffalo River samples compared to Indiana Harbor (excluding station IH1-10) and the Saginaw River samples.

Oligochaete abundance was lowest at stations IH1-07 (junction of Lake George Branch and Grand Calumet Branch) and IH1-06 (main channel), and highest at station IH-01-10. Sediments from station IH1-07 generally had the highest concentrations of metals and organic contaminants (USEPA 1993) with station IH1-06 having the next highest concentration of metals and organic contaminants. Oligochaete abundance was extremely high at station IH1-10, approaching 1,000,000/m^2 in individual grab samples. A reason for the higher abundances may be the high density of aquatic vegetation present at IH1-10. Large amounts of vegetation were most likely present because station IH1-10 was on the upstream side of a low clearance bridge, which tended to minimize the amount of disturbance caused by boat traffic (Joe Rathbun, ASCI Corporation, Grosse Ile, MI, personal communication). The vegetation most likely provided a habitat which collected decaying plant material resulting in a considerable amount of bacterial activity, the primary food source for oligochaete worms.

Mean midge abundance ranged from zero at several stations to 2,771/m^2 at station BR1-10 in the Buffalo River (Table 1). Except for stations BR1-10 and SR3-01, all midge abundance was less than 500/m^2. Overall mean abundance of midge was similar among Buffalo River samples and samples from the second collection in the Saginaw River, while overall mean abundance of midge was very low in samples from the first sampling of the Saginaw River and in Indiana Harbor.

Community Composition

The oligochaete communities were similar among all three AOCs. Oligochaetes were comprised of 2 families (Tubificidae and Naididae), 7 genera, and 13 species (USEPA 1993). Samples from the Buffalo River and Saginaw River had 7 to 8 species of tubificids and naidids, while Indiana Harbor had 8 tubificid species. *Limnodrilus* spp., considered tolerant of organic and metal contamination (Kennedy 1965, Brinkhurst *et al.* 1972, Burt *et al.* 1991), was the most common genus at all sites except stations BR1-01 and BR1-10. Contaminant intolerant species such as *Rhyacodrilus* spp. or *Stylodrilus heringianus* (Brinkhurst and Cook 1974, Spenser 1980) were never collected in any samples.

The midge community was comprised of 12 genera within 4 subfamilies (Chironomini, Tanipodinae, Tanytarsini, and Orthocladinae). Samples from the Buffalo and Saginaw rivers had midges from three subfamilies, while Indiana Harbor had one subfamily and one genus. The Buffalo River had the highest number of midge genera (11), while the Saginaw River had seven genera. *Procladius* spp. was the most abundant genera in 17 of 31 stations, with *Chironomus* spp. and *Cryptochironomus* spp. most abundant in eight of the remaining locations.

The midge community in the Buffalo River, Indiana Harbor, and Saginaw River consisted primarily of genera tolerant to organic enrichment (i.e., nutrient addition: Hilsenhoff 1982, 1987; Bode 1988). An exception was *Tanytarsus* spp. at stations BR1-10 and SR3-08 which reportedly is found in less organically enriched environments (Krieger 1984). *Procladius* spp., *Chironomus* spp., and *Cryptochironomus* spp. are generally considered to be the most frequently encountered chironomid genera in heavily enriched environments (Cook and Johnson 1974, Krieger 1984, Plafkin *et al.* 1989). These genera were generally the most frequently collected chironomids in the Buffalo River, while *Procladius* spp. and *Chironomus* spp. were the most common in the Saginaw River. *Cricotpus* spp. was the only genus found in Indiana Harbor samples and is typically considered one of the most tolerant midges of organic and inorganic contamination (Winner *et al.* 1980, Clements *et al.* 1988).

The Mollusca (snails and clams) and aquatic insects (excluding midges) in all the samples were few and comprised a small part (< 3%) of the numbers collected (USEPA 1994). The Mollusca and aquatic insects were found to be inconsequential in any analyses that were performed. For this reason

no further discussion of these groups will be addressed in this paper. For a more detailed discussion see USEPA (1993).

Estimates of abundance of benthic invertebrates made in the present study are most likely conservative because of the use of the ponar grab sampler (Resh 1979) and the mesh size (500 m) used to sieve invertebrates (Brinkhurst 1974, Resh 1979, Heushelle 1982). Water is displaced as a ponar sampler nears the sediment surface, causing small organisms and surface dwellers to be potentially pushed out of the way of the sampler (Flannagan 1970, Howmiller 1971, Howmiller and Beeton 1971, Millbrink and Wiederholm 1973). The effect of this type of disturbance is not easily quantified and was not estimated in this study. Samples were sieved through a 500 μm brass screen upon collection in the field. A 500 μm size screen is good at separating the benthic invertebrates from the sediments, but many smaller organisms such as small chironomids and naidids (oligochaete worm) tend to pass through the sieve (Brinkhurst 1974, Resh 1979, Heushelle 1982). A more appropriate method may be to sieve samples through a 500 μm mesh screen followed by a 250 μm screen to collect organisms that pass through a 500 μm mesh screen (Burt *et al.* 1991, Dr. Ralph Brinkhurst, Aquatic Resources Center, Franklin TN, personnel communication). By not using this method, the abundance of midge and oligochaetes may have been underestimated. However, any bias caused by the grab sampler or mesh size used should be consistent across all samples.

Midge Deformities

The frequency of mouth part deformities in midge larvae community ranged from a minimum of 0% at Stations BR1-05 and SR1-06 to a maximum of 100% at Station IH1-10 (Table 2). The lowest mean percentage of deformities was from Buffalo River samples (7%), followed by the first sampling of Saginaw River (13%), the second sampling of Saginaw River (17%), and Indiana Harbor (100%). Some deformities were present in chironomids collected in 19 of 42 samples in Buffalo River, 17 of 29 in the first sampling of Saginaw River, 23 of 30 in the second sampling of Saginaw River, and two of two in Indiana Harbor.

Different midge genera exhibit different levels of susceptibility or tolerance to contaminants (Hamilton and Saether 1971; Hare and Carter 1976; Warwick 1985, 1988; Wiederholm 1984; Diggins and Stewart 1993). Some genera are quite intolerant of contamination and are eliminated from locations with relatively low levels of contaminants, while other genera such as *Procladius* spp., *Chironomus* spp., and *Cryptochironomus* spp. are more tolerant and may persist in contaminated areas (Warwick 1985, Bode 1988). An association between in-

TABLE 2. Comparison of percent chironomid deformities for each area of concern (AOC).

Station	Number of Midges	Percent Deformities
BR1-01	52	8
BR1-02	29	7
BR1-03	32	6
BR1-04	102	5
BR1-05	3	0
BR1-06	30	7
BR1-07	7	14
BR1-08	48	4
BR1-09	76	17
BR1-10	210	7
MEAN	10	8 ± 1.5
IH1-10	2	100
SR1-02	63	14
SR1-03	32	15
SR1-04	12	25
SR1-06	3	0
SR1-07	23	13
SR1-09	96	16
SR1-10	6	17
MEAN	7	14 ± 2.8
SR3-01	334	2
SR3-02	6	14
SR3-05	38	23
SR3-06	4	25
SR3-08	94	16
SR3-16	103	21
SR3-24	33	16
MEAN	7	17 ± 2.9
Overall occurence among individual replicate grabs		
Buffalo River (19/42)		45
Indiana Harbor (1/1)		100
Saginaw River 1 (17/29)		59
Saginaw River 3 (23/30)		77

creased sediment contamination and the presence of midge deformities has been documented by many investigators (Hamilton and Saether 1971, Warwick 1985, Tennessen and Gottfried 1983, Cushman 1984, Wiederholm 1984, Diggins and Stewart 1993). Deformities include: thickening of the exoskeleton, enlargement and darkening of the head capsule, asymmetry in mouth parts, missing or fused lateral teeth, and antennal deformities. None of the specimens examined in the present study exhibited antennal deformities. Mouthpart deformities occurred primarily in *Procladius* spp. and *Chironomus* spp. Other chironomid genera did not often display mouth part deformities. It is possible that these individuals died before developing morphological abnormalities.

The occurrence of deformities in midges reportedly is less than 1% in non-impacted communities (Wiederholm 1984, Warwick *et al.* 1987). Several investigators have suggested that frequency of deformities in the range of 5 to 25% or greater is indicative of moderate to severe sediment contamination (Wiederholm 1984, Warwick *et al.* 1987). Based on this criterion, deformities in midges collected from sediments in all three AOCs sampled indicate moderate to severe contamination. Only two midge larvae were collected from Indiana Harbor (Station 10) and both had morphological deformities. The low frequency of deformities in the Buffalo River indicates less severe contamination than either Indiana Harbor or the Saginaw River. Interestingly the occurrence of deformities was consistently high at the Saginaw River stations, suggesting that contaminants may have been present and bioavailable at sufficient concentrations to impact the midge community at most stations. Although the occurrence of these deformities may be associated with contamination in the sediments, the limited number of samples made comparisons difficult. We examined the frequency of deformities exhibited by the midge *Chironomus riparius* exposed in laboratory sediment toxicity tests (USEPA 1993). Deformities in the laboratory-exposed midge were generally less than the deformity levels found in field-collected samples. A more specific study, designed to determine the relations between specific contaminants and midge mouthpart deformities using multi-generation exposures to determine if continual exposure over time causes higher observed deformities than single generation exposure of midge, is needed before deformities of midge can be readily used as a monitoring tool.

Variation in Benthic Invertebrate Grab Samples

Variation in the estimate of benthic invertebrate abundance in grab samples was partitioned into three components: (1) location variability, defined as the difference in benthic invertebrate estimates between AOCs; (2) station variability, defined as differences in benthic estimates among stations within a particular AOC; and (3) replicate variability, defined as differences in abundance estimates between individual replicates at each station.

Variance components (Nested Analysis of Variance; Snedecor and Cochran 1982) identified that combined station and replicate variability accounted for 74 to 99% of the variability in the estimates for all major groups (Table 3). Variability among locations contributed 1 and 26% of the variation of chironomids and oligochaetes, respectively. Station variability explained almost 50% of the variability in the estimates of oligochaete abundance (Table 3), with variability associated with location and sampling each accounting for 25% of the remaining variability. Replicate variability (62%) and station variability (37%) accounted for nearly all the variability in the estimates of midge abundance.

It is important to identify sources of variability so that a meaningful interpretation of the data can be made (Collins and Sprules 1983) and so future studies can be designed to address major sources of variation. The results of the variance partitioning indicates that station and replicate variability accounted for most of the variability in the taxa estimates. It is not uncommon for station to station variance to account for a considerable amount of the variation in estimates of invertebrate abundance (Lewis 1978, Threlkeld 1983). Differences between stations may be due to: (1) variation in locations relative to contaminant sources, (2) variation in substrate composition and structure which affect colonization by invertebrates, (3) variation in depth

TABLE 3. Percentage of total variance in benthic invertebrate abundance estimates partitioned among various sources.[1] Variance estimates are based on invertebrates collected with a ponar grab sampler.

Taxa	Location	Station	Replicate
Abundance			
Oligochaete	26.0	49.0	25.0
Chironomid	1.0	37.0	62.0

which may determine the impact of wave action or shipping traffic on invertebrates, or (4) other unmeasured variables.

Variance associated with location was significant in the estimates of oligochaetes but was minimal in the estimates of midge. The abundance of benthic invertebrates was quite similar. This is not unexpected, considering all three AOCs sampled have received substantial inputs of contaminants from industrial and municipal sources and the bulk of the community at all three locations consists of oligochaetes. Future studies would be improved if a relatively unimpacted reference area could be identified and sampled.

A substantial portion of the variation in invertebrate abundance was associated with variation among replicate grab samples. Invertebrate abundance estimates could vary by as much as 68% between successive grabs depending on the taxon. Benthic invertebrate populations often exhibit a patchy distribution in the sediment (Elliott 1977). In most studies with benthic invertebrates, it is desirable for this variance component to be kept as low as possible either by collecting additional replicates or if possible reducing variation among replicates.

Partitioning of the variance into different components indicates that future studies might provide better data if: (1) smaller size grabs were taken, but with more grabs to try to minimize the influence of a patchy benthic invertebrate distribution and (2) more stations were sampled in a given location in an attempt to obtain stations which would better sample across the gradient of contamination concentrations and habitat types. The main reasons for limiting the number of grabs taken from an area of concern is the time and cost associated with processing the samples. By taking smaller samples, but still taking the same area of sample, the processing time would be shorter and the variance between grabs should be reduced.

Sediment Quality Triad

To compare the relations between sediment contamination and benthic invertebrate community structure across a broad range of contaminant levels, we combined the data from the Great Lakes sites with data in the literature from the Clark Fork River and Milltown Reservoir (Kemble *et al.* 1993). Spearman rank correlations for whole sediment physical and chemical characteristics with benthic invertebrate community measures were strongest for select organic chemicals, chromium, and nickel (Table 4). Additionally, percent sand showed a negative correlation, and total organic carbon (TOC) was positively correlated with several of the benthic community measures. Although several significant correlations were evident between benthic community measures and sediment contaminant concentration, most of the correlations explained less than 10 to 50% of the overall variation in these responses. Spearman rank correlation was used to compare these associations because of potential problems associated with a non-normal distribution of data. While rank correlation analysis can be used to demonstrate association among variables, this type of ranking of data eliminates proportional relationships among variables. Thus, this ranking can not be used to evaluate dose response relationships. For example, a plot of the ranked data between midge genera richness and benzo(g,h,i)perylene shows a strong rank correlation ($r = 0.77$, Fig. 4a), but a plot of the raw data indicates a weak linear relationship between the two variables (Fig. 4b). Specifically, no consistent response is observable at the lower concentration of benzo(g,h,i)perylene, thereby providing very little discriminatory ability. For these reasons, we evaluated benthic community and laboratory toxicity data using a quadrant classification approach (Figs. 2 and 3; Tables 5 and 6).

Quadrant classification explained a high percentage of laboratory toxicity (Fig. 2). Quadrants identified using the MERM-Q score of 43 and a laboratory toxicity score of 30 had a combined incidence of false positive and false negative error of 19% (Fig. 2a). Quadrants identified using a SERM-Q score of 39 and laboratory toxicity score of 30 had a combined incidence of false positive and false negative error of 16% (Fig. 2b). With the laboratory toxicity data, we have identified toxic and nontoxic samples using well defined toxicity endpoints (*Hyalella azteca* growth and survival). When the number of incorrectly classified samples is considered to include both quadrants identified as false positive and false negative error as well as the number of toxic samples in the no-effect quadrant, the actual error rate is 37% for both of the ERM-Q scoring approaches.

There was a consistent relationship between the MERM-Q score and the SERM-Q score (Fig. 5a). The MERM-Q score accounted for either the majority of the toxic compounds in a sample or was representative of a class of toxic compounds which were the primary contaminants in a sample. Therefore, the results of using either the MERM-Q score or the SERM-Q score are nearly identical. The re-

TABLE 4. Spearman rank correlation for whole sediment measured cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), zinc (Zn), chrysene (CHRY), benzo(a)pyrene (BAP), benzo(g,h,i)perylene (BGHIP), conductivity (COND), dissolved oxygen (DO), total organic carbon (TOC), acid volatile sulfide (AVS), percent sand (PSAND) with oligochaete biotic index (OLBI), midge biotic index (MGBI), midge-oligochaete ratio (MGOLRAT), midge deformities (MGDFRM), midge genera richness (MGRICH), taxa richness (TXRICH), midge biotic index-taxa richness (MGB-TX), midge biotic index-midge genera richness (MGB-MGR), midge-oligochaete ratio-midge biotic index-midge genera richness (MGO-MGB-MGR), midge oligochaete ratio-taxa richness-midge genera richness (MGO-TX-MGR), and midge biotic index-taxa richness-midge genera richness (MGB-TX-MGR). Significant correlations are designated with an asterisk (*) ($P \leq 0.05$).

	OLBI	MGBI	MGOLRAT	MGDFRM	MGRICH	TXRICH	MGB-TX	MGB-MGR	MGO-MGB-MGR	MGO-TX-MGR	MGB-TX-MGR
Cd	–0.09	0.15	0.26	0.15	0.05	–0.01	0.04	0.04	0.09	0.07	0.01
Cr	0.04	0.49*	0.46*	0.53*	0.69*	0.60*	0.60*	0.65*	0.64*	0.65*	0.66*
Ni	–0.02	0.41*	0.48*	0.43*	0.68*	0.53*	0.51*	0.59*	0.60*	0.63*	0.61*
Pb	–0.05	0.28	0.45*	0.27	0.26	0.17	0.23	0.26	0.32*	0.28	0.22
Zn	–0.10	0.23	0.27	0.21	0.03	0.00	0.10	0.09	0.14	0.07	0.04
CHRY	0.09	0.53*	0.47*	0.57*	0.70*	0.63*	0.64*	0.68*	0.68*	0.66*	0.70*
BAP	0.07	0.53*	0.51*	0.54*	0.68*	0.62*	0.64*	0.69*	0.68*	0.65*	0.70*
BGHIP	0.19	0.57*	0.49*	0.58*	0.77*	0.70*	0.72*	0.75*	0.72*	0.72*	0.77*
COND	0.64*	0.22	–0.08	0.30	0.34*	0.36*	0.33*	0.35*	0.30	0.28	0.35*
DO	0.38*	0.35*	–0.52*	–0.18	–0.26	–0.20	–0.26	–0.28	–0.31	–0.29	–0.23
TOC	0.03	0.32*	–0.22	0.44*	–0.27	0.25	0.33*	0.32*	0.30*	0.27	0.31*
AVS	0.36*	–0.05	0.01	–0.29	–0.32*	–0.39*	–0.27	–0.29	–0.27	–0.32*	0.37*
PSAND	0.11	0.37*	0.33*	–0.35*	–0.43*	–0.35*	–0.43*	–0.49*	–0.52*	–0.41*	–0.48*

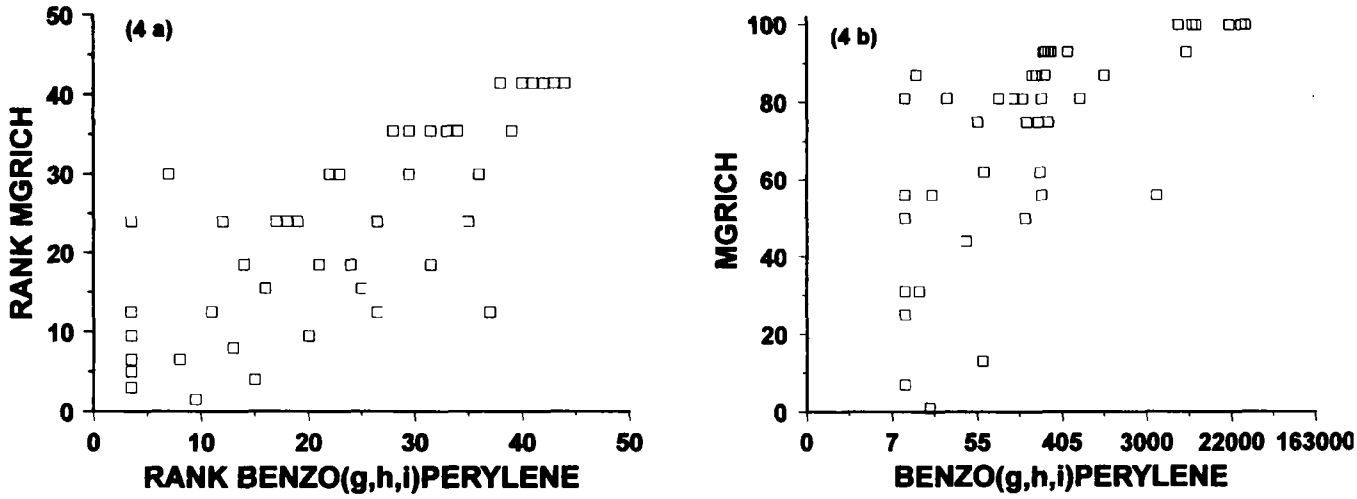

FIG. 4. Midge genera richness and benzo(g,h,i)perylene for A: rank data, and B: raw data.

TABLE 5. Summary of quadrant analysis for scores of individual benthic measures, scores of the sum ERM quotients (SERM-Q: concentration of a chemical in sediment sample / ERM for that chemical) and scores of laboratory toxicity. The benthos quadrant score is the score which maximized the number of points in quadrants which would be considered "correctly classified" and minimized both the incidence of false negative error (low chemical concentrations and benthos adversely impacted) and false positive error (high chemical concentrations and benthos not adversely impacted).

Benthic indice	Benthos Quadrant score	Sum ERM-Q (Quadrant score 39) % False positive and False negative error	Laboratory Toxicity (Quadrant score 30) % False positive and False negative error
Midge deformities (%)	75	27	34
Midge richness	81	34	45
Midge biotic index	81	32	43
Taxa richness	75	27	48

TABLE 6. Identification of benthic indices included in the combined benthic metric and summary of quadrant analysis for the SERM-Q as a score of chemical contamination and score of laboratory toxicity. Quadrant score is the score which maximized the number of points in quadrants which would be considered "correctly classified" and minimized the incidence of false negative error (low chemical concentrations and benthos adversely impacted) and false positive error (high chemical concentrations and benthos not adversely impacted).

Number of Benthic Indices in Score	Benthos Quadrant Score	Error-sum ERM-Q (%)	Olig. biotic index	Midge-olig. ratio	Midge biotic index	Midge deformities	Midge richness	Taxa richness	Error-laboratory toxicity (%)
2	80	25			X			X	30
3	81	25		X	X			X	32
3	81	25		X			X	X	36
3	81	21			X		X	X	32
3	80	25		X	X		X		36
total				3	4		3	4	

sults obtained with the SERM-Q score will be discussed since the SERM-Q score does slightly better than the MERM-Q score and the SERM-Q score is a better estimate of the overall level of contamination. Furthermore, there was a good correspondence between the SERM-Q score and the number of ERM exceedances (defined as the number of ERMs exceeded in an individual sample) for each sample (Fig. 5b). This correspondence shows a consistency between the approach used by Ingersoll *et al.* (1996) to evaluate sediment contamination and the SERM-Q score procedures in this paper.

Toxic sediment samples, as shown by an altered benthic community composition, have been previously identified (USEPA 1993, Canfield *et al.* 1994). However, the benthic indices in these previous evaluations were specific to samples collected from a particular area. In the present study, a broad-scale approach was used to determine benthic indices indicative of chemical contamination by using sediment samples collected from broad geographical areas and classification of benthos samples as impacted or non-impacted was not done *a priori*. For this reason, samples were considered classified

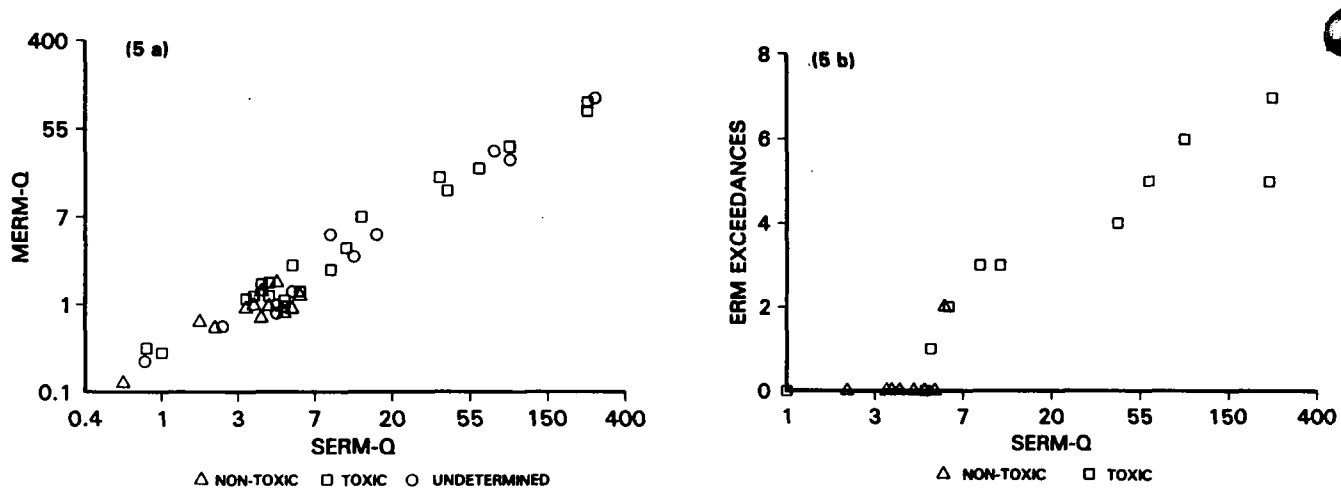

FIG. 5. Relations between: (A) the SERM-Q and the MERM-Q; (B) the SERM-Q and the number of ERM exceedances. A square indicates toxic samples and a triangle indicates non-toxic samples in the **Hyalella azteca** *toxicity tests as identified by USEPA (1993). A circle indicates samples for benthos data which were not evaluated in laboratory toxicity testing.*

as incorrect only if they were in the false positive or false negative error quadrants.

No midge larvae were found at six locations which were highly contaminated with PAHs and metals. Hence, percentage of midge deformities and the midge biotic index could not be calculated for these six stations. The absence of midge larvae suggests that the presence/absence of midges may be a useful indicator of sediment contamination. For this study, the absence of midges was equivalent to the worst-case values for these indices. This assumption was supported by the high concentrations of PAHs and metals at these stations. Stations without midge larvae were assigned a score of 100 for these indices.

Four of the six benthic community indices (midge biotic index, midge richness, percent midge deformities, and taxa richness) provided some degree of discrimination among sediment samples with differing degrees of contamination (Table 5). The oligochaete biotic index and oligochaete/midge ratio provided little discrimination between contaminated or uncontaminated sediments. Percent midge deformities and total taxa richness had the smallest combined false positive and false negative error rates for the SERM-Q score (Table 5). The benthic score required to obtain this degree of discrimination was always greater than 75. When quadrant classification was used relative to laboratory sediment toxicity testing, percent midge deformity and midge biotic index had the smallest combined false positive and false negative error rate (Table 5).

In addition to assessments using single indices, two and three combined scores of benthic indices were evaluated which provided the best quadrant classification (smallest combined false positive and false negative error). We have not included or discussed the various combinations of four to all six indices since the accuracy of classification did not increase with combinations of more than three benthic indices.

Quadrant classification using the SERM-Q score for several of the combined benthic indices reduced the false positive and false negative error rate to 21–25%, less than any of the individually scored benthic indices (Table 6). We restricted the combinations so that the benthos score required to minimize false positive and false negative error was no greater than 80 to 81 since we were unable to identify a combined benthic score of less than 80 which minimized both false positive and false negative error. Midge biotic index and taxa richness were most frequently associated with the combinations which had the smallest error (Table 6). Quadrant classification with the combination of midge biotic index/taxa richness to laboratory toxicity produced the smallest incorrect classification (30%) of false positive and false negative samples (Fig. 6).

Benthic community indices and sediment laboratory toxicity corresponded to grossly contaminated samples. The absence of midges appears to be indicative of a grossly contaminated sample. A requirement of a score of 75 to 81 for either a sing

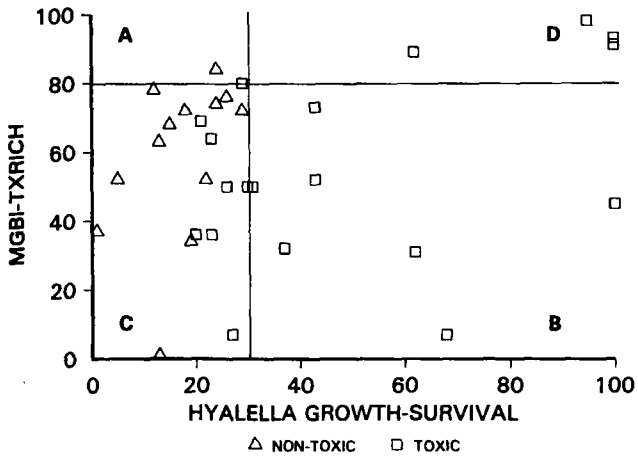

FIG. 6. Quadrant analysis with the combined rank of the midge biotic index and total taxa richness with the* Hyalella azteca *toxicity score. Quadrants are labeled: A: false negative (Type II error), B: false positive (Type I error), C: non-impacted, (low toxicity, low benthos response), and D: impacted, (high toxicity, high benthos response). A square indicates toxic samples and a triangle indicates non-toxic samples in* Hyalella azteca *toxicity tests as identified by USEPA (1993).

or combined benthic indices to be classified as affected, suggests they are highly variable in less contaminated samples. This result is not unexpected and may result from not measuring the appropriate chemistry or abiotic factors over time for the benthos exposed in the field.

While use of chemical measures alone to assess sediment quality ignores the potential ability of natural systems to mitigate the effects of contamination above background levels, only those chemicals which are measured at the time of sampling can be evaluated. Biological measures are used to determine the significance of chemical contamination or the potential interactive effects of multiple contaminants. Laboratory toxicity studies conducted under controlled conditions measure evidence of toxicity using well-defined and interpretable end points (USEPA 1994, ASTM 1995). However, the number of taxa amenable to laboratory testing is limited and it is often difficult to identify ecological relevance of a laboratory result. We think that benthic invertebrate indices should be representative of *in- situ* conditions of sediments. However, variation in characteristics of benthic communities is typically great, so that many samples are required to make accurate measures of community distributions. Benthic invertebrate community composition is affected by biotic and abiotic factors unrelated to contamination and their populations may vary seasonally and spatially, all of which may reduce their value in assessing chemical contamination.

In the present study, laboratory sediment toxicity studies were more closely related to contaminated sediments than measures of benthic inverebrate community composition responses. However, risk assessments based on these results may be overprotective and force requirements that may not be necessary for environmental protection. Conversely benthic indices only identified grossly contaminated samples with any consistency (requiring scores of 75 or greater to classify a sample as impacted) and may underestimate the sensitivity of the benthos to contaminants. Moreover, grossly contaminated samples, as identified by benthic indices, were samples typically associated with other ecological effects such as bioaccumulation of contaminants in aquatic organisms or disappearance of water- column organisms (International Joint Commission 1987, 1988a, 1988b). Therefore the use of these benthic indices may be redundant if they only identify contaminated locations where other ecological effects have already been documented. An ability to identify expected benthic invertebrate community composition from relatively uncontaminated sediments (Reynoldson *et al.* 1995) is necessary before we can fully assess the effects of sediment contamination on the benthic invertebrate community. Other indices such as the Ephemeroptera-Plecoptera-Trichoptera (EPT) index which are useful in running waters (Plafkin *et al.* 1989) may prove to be more useful with data exhibiting low concentrations of contaminants and may be helpful in discriminating unimpacted benthic communities.

The tri-axial graphs of SQT data were used to illustrate geographical trends and magnitude in differences in sediment toxicity, chemistry, and benthos among stations (Fig. 1). Typically, a symmetrical triangle indicates similar ranking using sediment contaminant concentration, toxicity, and benthos community composition (Station IH-06). A larger triangle indicates a more severely degraded site. Since the criterion for impacted and non-impacted was defined by the quadrant analyses, we have identified impacted legs of the Triad with a "+" and non-impacted legs of the Triad with a "–". For this paper, legs of the SQT are based on *Hyalella azteca* 28 d growth and survival (toxicity

scores), the SERM-Q score (chemistry scores), and combined midge biotic index - taxa richness metric (benthos scores). The SQT plots show that Indiana Harbor samples were the most consistently degraded (pluses" for all three legs) and Saginaw River samples were the least impacted (almost all three legs showing "minuses"). Fourteen of 19 samples (74%) showed good agreement (either all "+++" or all "– – –" for the three legs) among all three measures. In four of 19 (21%) comparisons, laboratory toxicity and sediment contaminant concentration were in agreement but without a matching benthos response. This relatively high correspondence among laboratory toxicity, chemistry, and benthic results from using a score of 80 to classify impacted benthic sites. This assumption may underestimate benthic responses at lower levels of contamination.

Reasons for a lack of agreement between benthic indices and other components of the SQT may be that: (1) measures used for assessing benthic communities in soft sediments may not adequately discriminate between degrees of sediment contamination; (2) benthic invertebrates could be impacted by non-contaminant factors (i.e., habitat); (3) spatial or temporal differences in sediment contamination affected the laboratory and benthic measures differently; (4) samples for laboratory toxicity and sediment contaminant concentration came from a composite sample while benthic measures were made on individual grab samples; or (5) unquantified contaminant factors may be the driving force behind the observed benthic community composition.

Chapman *et al.* (1992) listed three assumptions for using the SQT approach: (1) toxicity tests are appropriate indicators of relevant toxic modes of action, (2) benthic community composition is an appropriate indicator of effects *in situ*, and (3) measured chemicals in sediment are appropriate indicators of overall chemical contamination. In the present study, the first assumption was met since the *Hyalella azteca* whole-sediment toxicity tests is among the most sensitive sediment toxicity test currently available (USEPA 1994, ASTM 1995). Additional studies are needed to better evaluate the second assumption and establish both empirical association and cause-and-effect relationships between benthic indices and chemical contamination in sediment. Three specific questions need to be addressed: (1) Is there a consistent relationship between measured changes in taxa richness, chironomid genera richness, chironomid mouthpart deformities, and chironomid biotic index with sediment chemical concentrations in depositional sediments? (2) Can a cause-effect relationship be identified between sediment contamination and measured changes in these benthic indices? and (3) How do non-contaminant factors influence these benthic indices? Studies are needed to determine which measures of sediment contamination best represents the bioavailable fraction of the contaminants in the sediment. Temporal and spatial differences in the bioavailability of contaminants also need to be addressed to determine the most appropriate time and methods for the sampling benthos and the sediment contaminant concentration.

CONCLUSIONS

Oligochaetes and midges comprised over 90% of the benthic invertebrate numbers collected from all stations in the three Great Lakes. Additional evaluations of the benthic community at reference sites are necessary to determine if the dominance by oligochaetes and midges is common in uncontaminated sediments and to determine the influence of non-contaminant factors to the benthic community. These results suggest that sediments from Indiana Harbor were least suitable for benthic invertebrates. The Buffalo River had the largest number of benthic taxa (33), followed by the Saginaw River (20) and Indiana Harbor (14).

Chironomid deformities were pronounced in samples from all three AOCs. The Buffalo River consistently had the lowest occurrence of deformities, while midge deformities were more prevalent in the Saginaw River. The two midge larvae collected from Indiana Harbor were both deformed. Overall, the frequency of deformities at all three AOC locations indicates that sediments were moderately to severely contaminated.

Variation of invertebrate abundance among stations and replicates within stations accounted for most of the overall variance explained by ANOVA. Variance among locations was significant in the estimation of oligochaete abundance, but was minimal in the estimation of abundance of the remaining taxa abundance. With most of the variance in benthic community estimates associated with station and replicates, future studies should sample more stations and take more replicates using smaller grab samples in order to increase resolution of comparisons among study sites.

At the more severely contaminated locations, both quadrant analyses and SQT plots showed concurrence between measures of laboratory toxicity

sediment contaminant concentration and benthic invertebrate community composition. However, there was less similarity between the benthos and either laboratory toxicity or sediment contaminant concentration at low and moderately contaminated sites. Quadrant analyses demonstrated that the sediment laboratory toxicity test may be more sensitive in screening sediment contamination than benthic community composition indices.

Additional studies are needed to evaluate specific chemical contaminants, biotic, and abiotic factors controlling the composition of benthic communities in sediments. Sediment contaminant concentration and physical variables need to be analyzed from splits of samples from which invertebrates are collected to overcome problems associated with benthic invertebrate patchiness and heterogenous contaminant deposition.

At best, we had one sample from either the Saginaw River or the Buffalo River that could be considered reference sample. Additional data need to be included in this evaluation for samples that score out as low chemistry (0 to 10 range) to evaluate if non-toxic samples can be consistently identified with measures of benthic invertebrate community composition. Studies designed to examine the composition of benthic invertebrate communities in reference sediments are needed to characterize the expected composition of communities in non-impacted areas and to determine measures of benthic invertebrate community composition that will be sensitive enough to identify the effects of low contaminant levels.

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Prepared for

E.I. du Pont de Nemours and Company
Wilmington, Delaware

Exponent™

Draft

Sediment Characterization Study for the DuPont East Chicago Facility

Prepared for

E.I. du Pont de Nemours and Company
Barley Mill Plaza, Building 27
Routes 141 and 48
Wilmington, Delaware 19805

Prepared by

Exponent
15375 SE 30th Place, Suite 250
Bellevue, Washington 98007

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Acronyms and Abbreviations

AOC	area of concern
AVS	acid-volatile sulfide
AWQC (CCC)	ambient water quality criteria (criterion continuous concentration)
BOD	biochemical oxygen demand
BTEX	benzene, toluene, ethylbenzene, and xylenes
CCR	Current Conditions Report
cfs	cubic feet per second
COD	chemical oxygen demand
COI	constituent of interest
Corps	U.S. Army Corps of Engineers
CSO	combined sewer overflow
DuPont	E.I. du Pont de Nemours and Company
EPA	U.S. Environmental Protection Agency
Gary STP	Gary Sanitary District sewage treatment plant
GCR	Grand Calumet River
Grasselli	Grasselli Chemical Company
IDEM	Indiana Department of Environmental Management
IGLD	international Great Lakes datum
IHC	Indiana Harbor Canal
IJC	International Joint Commission
mgd	million gallons per day
NEC	no-effect concentration
NPDES	National Pollutant Discharge Elimination System
NWI	National Wetlands Inventory
Order	Administrative Order on Consent
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCS	permit compliance system
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
SCS	sediment characterization study
SEM	simultaneously extracted metals
STP	sewage treatment plant
TCFM	trichlorofluoromethane
TDS	total dissolved solids
TSI	trophic state index
TSS	total suspended solids
USGS	U.S. Geological Survey
USX	U.S. Steel–Gary Works

Executive Summary

This report describes the results of the sediment characterization study (SCS) specified by the Resource Conservation and Recovery Act (RCRA) Administrative Order on Consent (Order) 5-RCRA-97-007, dated June 25, 1997. The SCS addresses that portion of the East Branch of the Grand Calumet River (GCR) that is adjacent to and downstream of E.I. du Pont de Nemours and Company's (DuPont's) East Chicago facility. This study area constitutes a portion of the Indiana Harbor Canal (IHC), GCR, and nearshore Lake Michigan area of concern (AOC) designated by the International Joint Commission. The SCS is focused on those processes and conditions that affect sediment quality, but includes a general assessment of water quality.

DuPont's objectives for the SCS are as follows:

- To meet the intent of the Order by investigating the presence of constituents that may be related to the DuPont facility in sediments of the study area and specific wetlands
- To develop a conceptual understanding of physical and chemical processes that affect constituent distributions in the study area
- To collect information on beneficial uses that are alleged to have been impaired in the study area, as well as information that will contribute to an understanding of the causes of those impaired uses
- To collect information on past and present constituent loading to the East Branch that will contribute to an understanding of how those constituents have contributed to the impaired uses.

The SCS is designed to further an understanding of the specific conditions and causative agents contributing to the 14 impaired beneficial uses identified in the remedial action

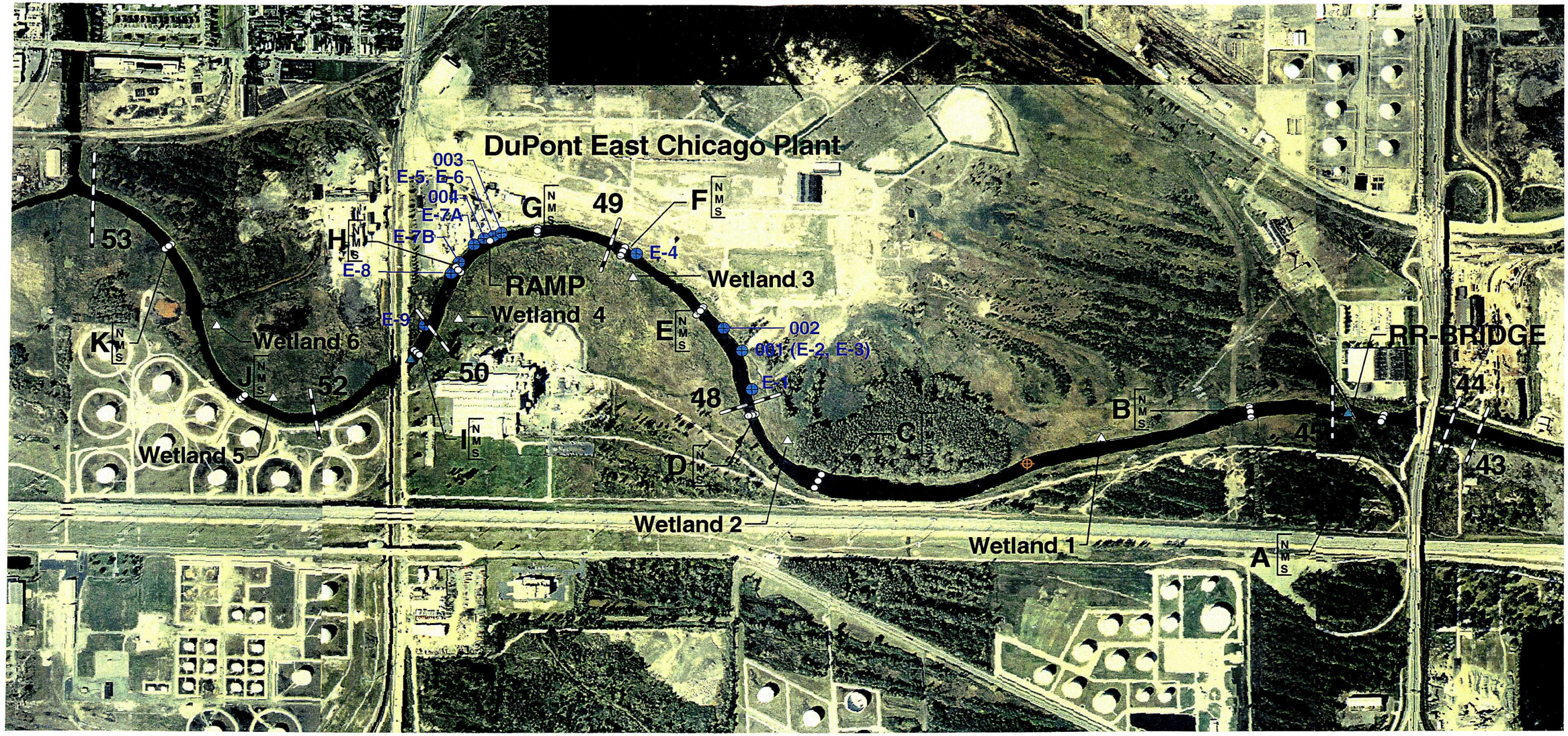
plan for the larger AOC, and to characterize conditions in the study area in the context of those impaired uses. The conditions and processes of greatest interest were organized into three general categories: source loading, chemical conditions and processes, and sediment transport. The results of the SCS and their implications for impaired uses are summarized below.

As part of the SCS, sediment and surface water samples were collected from the study area in 1998 and 1999. Three types of sediment samples were collected on 11 transects (Figure ES-1):

- **16 Surface Sediment Samples**—Surface samples represented the upper 10 cm of sediment.
- **11 Short Cores (36 samples)**—Short cores represented three depth horizons: 0–10 cm, 10–20 cm, and 20–30 cm.
- **11 Deep Cores (38 samples)**—Deep cores were collected as deep as the vibracorer would penetrate (i.e., refusal), which varied from location to location. Three horizons were sampled from each deep core. At some locations, native sediments were not reached.

Transects A, B, C, and D are positioned upstream of historical DuPont outfalls. Transects E, F, G, and H are adjacent to DuPont's historical outfalls. Transects I, J, and K are adjacent and downstream of the U.S.S. Lead facility.

In addition to the sediment samples, wetland and surface water samples were collected. Wetland samples were collected at six stations, and surface water samples were collected at one station (Figure ES-1). Twenty-four-hour time series of surface water samples were collected at two high-flow and two low-flow events.



LEGEND

- Stilling wells
- Wetlands stations
- Sediment stations
- Surface water station
- DuPont historical outfalls
- Floyd Browne sediment transects

0 100 200 300 Meters

Figure ES-1.
SEDIMENT AND SURFACE WATER STATIONS, HISTORICAL DUPONT OUTFALLS, AND CURRENT INDUSTRIAL FACILITIES

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 86001058.001 0501
Date prepared: 8/18/99
Prepared by: D. Gadsden
/calumet/projects/SCS_899.apr

Exponent

Source Loading

The GCR/IHC system was and continues to be a conveyance for industrial discharges. An evaluation of current chemical loading to the East Branch of the Grand Calumet was conducted to provide a better understanding of the processes controlling chemical distributions in surface water and sediment. Ongoing loading of chemicals is of particular interest because sources of problem chemicals must be adequately controlled if sediment remediation is to occur. In the absence of adequate source controls, accumulating particles will recontaminate surface sediments. Consequently, source control is a necessary action that should precede sediment cleanup.

Based on the available loading data for National Pollutant Discharge Elimination System (NPDES)-permitted facilities, ongoing loading of copper, chromium, lead, mercury, zinc, and oil and grease have the potential to adversely affect sediment quality downstream from their source(s). According to data from 1989 to 1998, the primary sources of these chemicals are U.S. Steel–Gary Works (USX) and the Gary sewage treatment plant (STP). Combined sewer overflows and storm drains are also expected to adversely affect sediment and water quality, although less quantitative information exists for these sources. The elevated concentrations of chromium, lead, zinc, and oil and grease in surface sediments corroborate these findings.

None of the constituents of interest (COIs) identified for the SCS are associated with current DuPont activities, and COIs are not included in DuPont's NPDES permit. A localized, subsurface sediment deposit that contains elevated levels of arsenic, copper, mercury, and lead is present at Transects E and F. This deposit may be associated with historical releases from DuPont; however, the physical isolation of this deposit substantially reduces or eliminates the potential for exposure to human or ecological receptors. The low permeability of the sediments limits any potential advective transport of dissolved constituents, and the elevated levels of acid-volatile sulfide (AVS) present in surface sediments bind with mobile forms of divalent copper, mercury, lead, and zinc.

Chemical Conditions and Processes

An evaluation of chemical conditions in the surface water and sediment of the East Branch of the Grand Calumet was conducted to provide a better understanding of the processes affecting chemical distributions, bioavailability, persistence, and potential biological effects. Sediments are the primary focus of this investigation. Surface water conditions have a much faster response time to environmental variables and can be considered a "snapshot" of conditions. Sediments, on the other hand, represent the integrated record of decades of releases.

The vertical distribution of chemicals in sediments can be used to reconstruct their release history (i.e., in general, older releases are buried, newer releases are surficial). Non-native sediments of 2 ft to more than 15 ft in thickness are present in the East Branch from Cline Avenue with the junction of the IHC. These accumulated sediments appear to reflect the industrial history of the waterway. In the study area, there are several distinctive features:

- A localized, subsurface deposit is present adjacent to the DuPont facility and may be attributable to historical releases from DuPont. This deposit contains elevated concentrations of arsenic, copper, mercury, and lead and is covered with approximately 2 ft of more recently deposited sediments with lower concentrations of these metals. The physical isolation of these historical deposits substantially reduces or eliminates potential exposure to human and ecological receptors.

- A localized, very thick (i.e., 15-ft) deposit is present at Transect C that contains high concentrations of chromium and oil and grease. The extraordinary depth of contaminated sediment at this location suggests that the underlying native material may actually have been excavated prior to the deposition of this material. This portion of the river reach

was relocated during construction of Interstate 90. It is also a location where historical dumping was alleged to have occurred (Corps 1997). The nature of the wastes at this location is similar to those observed in the uppermost reach of the East Branch adjacent to USX. The high concentrations of oil and grease indicate that DuPont was not a source of this material at this location, which is well upstream of DuPont wastewater discharges.

- A localized, subsurface deposit is present at Transects I and J. This deposit has characteristically high concentrations of lead and mercury and may be attributable to historical releases from U.S.S. Lead, which was active from 1914 to late 1985.

- Elevated concentrations of oil and grease, chromium, lead, and zinc are found in the surface and near-surface sediments, suggesting a recent or ongoing source. The extremely elevated concentrations of oil and grease pose a risk to benthic infauna on the basis of physical disturbance alone. Constituents of oil and grease (i.e., polycyclic aromatic hydrocarbon [PAH]) exceed no-effect concentration (NEC) values at all locations tested.

- Surface sediment concentrations of chromium, lead, nickel, and zinc exceed NEC values throughout most of the study area. Simultaneously extracted metals and AVS results suggest that lead, nickel, and zinc (and other divalent metals) in surface sediments are bound to the AVS fraction at many locations. Of the metals, chromium may pose the greatest potential risk to aquatic organisms, followed by lead and zinc.

These results are consistent with previous investigations of the GCR and IHC.

The Nature Conservancy has recognized the DuPont wetlands and natural area tract as a unique resource in the region on the basis of floristic integrity and wildlife usage.

However, on the margins of the GCR, this tract has become dominated by aggressive, generally exotic vegetation (i.e., cattails [*Typha* spp.], common reed [*Phragmites australis*], and purple loosestrife [*Lythrum salicaria*] that must be actively controlled to maintain the biotic integrity of the tract. The distribution of metals and oil and grease in wetland soil samples and the extent of unvegetated channel banks visible on the aerial photographs demonstrates the extent of historical (i.e., pre-1985) connection between the channel and the wetlands. Contaminated wetland soils are gradually being buried by a buildup of plant debris as the channel narrows to adjust to the current lower base flow regime.

Surface water results indicate dissolved metals are below ambient water quality criteria (criterion continuous concentration), suggesting that the high concentrations of metals in sediment do not adversely affect water quality (at least under the flow conditions observed). The East Branch receives sufficient nutrient load to be eutrophic, at least during a portion of the year.

Sediment Transport

Sediment dynamics play a critical role in controlling current and future sediment quality in the East Branch of the GCR. The evaluation of current source loading data and the assessment of chemical distribution patterns in surface and near-surface sediments suggest that sediment accumulation rates are low (relative to historical loading), natural recovery of surface sediment is not occurring to any significant degree, and ongoing sources have the potential to recontaminate surface sediment. During the industrial history of the East Branch, non-native sediment ranging from 2 to 8 ft in thickness was deposited in the study reach. The particulate (i.e., total suspended solids) load from ongoing permitted sources in the East Branch is low relative to historical loads; the maximum estimated sediment accumulation rates from permitted sources only are below 0.1 cm/year. Furthermore, these accumulating particles are expected to have elevated levels of metals and oil and grease. These findings are corroborated by the results of the

spatial trend analysis of the 0–10, 10–20, and 20–30 cm horizons in surface and near-surface sediments. Although selected chemicals (e.g., arsenic) may be decreasing to acceptable levels in surface sediments, a broad trend of natural recovery is not observed.

The stability of sediments in the GCR is governed by the magnitude and duration of conditions that can mobilize sediment. These conditions are related to the shear stress exerted by fluid flow at the sediment–water interface (i.e., related to the product of water surface slope and flow depth) or by turbulence within the flow, and to the physical properties of the sediment available for transport. Our limited understanding of the complex interplay of processes that control sediment deposition, erosion, and transport represents a unique challenge and limits our ability to assess sediment transport in the East Branch of the GCR. Available models that relate sediment resuspension (i.e., critical sheer stress) to grain size do not factor in the cohesive effects of oil and grease, a critical consideration for the oil-laden sediments in the GCR/IHC system. Oil and grease are expected to substantially increase the critical shear stress for sediments, limiting the potential for sediment erosion. The distribution of bulk density and grain size in the sediment cores suggests that the bed is currently being armored, either by coarsening of the bed or the accumulation of oil and grease in the bed sediments.

Impaired Uses

Factors associated with alleged impaired uses are not always known with scientific certainty. Nevertheless, enough is known about the effects of environmental contaminants on biological organisms to link some of the alleged impaired uses with substances introduced to the environment by humans. By considering the information collected as part of the SCS, it is now possible to focus attention on how the constituents in the sediments, water, and wetland soil of the East Branch may contribute to beneficial use impairment.

The constituents most likely to be associated with impairment of beneficial uses within the study are certain metals (chromium, lead, mercury, and zinc), polychlorinated biphenyls (PCBs), PAHs, oil and grease, and nutrients (Table ES-1). With the exception of nutrients, any of the constituents have the potential to cause direct adverse effects on aquatic organisms. High concentrations of AVS within surface sediments bind with divalent metals and thereby limit their bioavailability. Other metals (notably chromium) are not so bound and are more likely to be associated with toxic effects. Mercury and PCBs are known to accumulate in fish tissue and have the potential to adversely affect higher trophic levels (e.g., fish-eating birds) and human consumers. High nutrient concentrations, likely associated with discharges from municipal STPs, may cause excessive algal growth, which results in oxygen depletion of surface water.

The results of the SCS (as discussed in Section 4) suggest that releases from the DuPont facility potentially contributed to the accumulation of several metals (notably arsenic, copper, lead, and mercury) in the sediments in the portion of the East Branch adjacent to the facility. Those accumulations of metals appear to be buried and suggestive of historical rather than ongoing releases. Because the highest concentrations of these metals are well below the biologically active layer (i.e., the uppermost 10-cm or less), they are largely segregated from the environment and therefore unlikely to be associated with ongoing adverse effects on biota. Furthermore, the low permeability of the sediment limits any potential advective transport of dissolved constituents, and the presence of elevated concentrations of AVS in surface sediments would be expected to bind with mobile forms of copper, lead, mercury, or zinc, limiting their bioavailability. On the contrary, other chemicals whose concentrations are high in surface and near-surface sediments and that are believed to be directly linked to effects in biota (e.g., PCBs, PAHs) are not thought to be associated with releases from the DuPont facility. It can be concluded that current environmental conditions within the East Branch certainly contribute to impairment of beneficial uses, but that those conditions responsible for the use impairments are not attributable to activities at the DuPont facility.

Table ES-1. Assessment of likely contributors to alleged beneficial use impairments at the Indiana Harbor Canal, Grand Calumet River, and nearshore Lake Michigan area of concern

		Substance(s) Potentially Responsible												Medium in Which Substances Are Present		
	Alleged Beneficial Use Impairment[a]	Metals	Mercury	PCBs	Chlorinated Pesticides	Dioxins and Dioxin-Like Compounds	PAHs	Oil and Grease	Nutrients	Grain Size	Other Sediment Conventional Parameters	Fecal Coliform Bacteria	Dissolved Oxygen	Surface Water	Sediments	Organisms
i	Restrictions on Fish and Wildlife Consumption		●	●	O	O								S	S	P
ii	Tainting of Fish and Wildlife Flavor							●						S	S	P
iii	Degradation of Fish and Wildlife Populations	●	●	●	O	O	●	●		O	O		O	P	P	S
iv	Fish Tumors or Other Deformities		O				●							S	S	P
v	Bird or Animal Deformities or Reproductive Problems		O	●	O	O								S	S	P
vi	Degradation of Benthos	●	O	●	O		●	●	O	O	O		O	S	P	S
vii	Restrictions on Dredging Activities	O	O	O	O	O	O	O						S	P	--
viii	Eutrophication or Undesirable Algae								●					P	S	--
ix	Restrictions on Drinking Water Consumption (or Taste and Odor Problems)	O	O	O	O	O	O	O				O		P	S	--
x	Beach Closings											O		P	--	--
xi	Degradation of Aesthetics							●	O					S	--	--
xii	Added Cost to Agriculture or Industry	O	O	O	O	O	O	O						S	P	--
xiii	Degradation of Phytoplankton and Zooplankton Communities	O	O					O	O				O	P	S	--
xiv	Loss of Fish and Wildlife Habitat							●	O	O	O		O	S	S	--

Note: PAH - polycyclic aromatic hydrocarbon
PCB - polychlorinated biphenyl
P - primary (of primary importance in impairment of the specified use)
S - secondary (of secondary importance in impairment of the specified use, or more typically, serving as a source of the substance to the primary medium)
O - potential contributor to impaired use in general
● - likely contributor to impaired use within the East Branch of the area of concern, as interpreted by Exponent based on the results of the sediment characterization study

[a] Alleged beneficial use impairments identified in the Stage 1 remedial action plan (IDEM 1991)

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Conclusions and Recommendations

DuPont has completed an SCS in accordance with the requirements of Order 5-RCRA-97-007. With the completion of this study, DuPont believes that sufficient data exist to characterize conditions in the study area. Results of the SCS are consistent with previous studies of the GCR. First, metals and organic compounds (e.g., PCBs, PAHs), as well as oil and grease, limit the biological integrity of the GCR system. AVS concentrations reduce the bioavailability of some metals through much of the study area, yet continued loading of oil and grease, lead, zinc, and other metals may continue to limit biological improvements in surface sediments. Constituents that could be attributed to DuPont operations are buried by sediments, reducing or eliminating exposure of organisms in the biologically active zone. In addition, direct exposure of humans to these constituents is highly unlikely. The impaired uses of the GCR may be attributed to some constituents in the sediments, yet DuPont's contribution to these constituents is minimal, given the buried nature of potential historical release.

There are ongoing discussions between DuPont and others with the Natural Resource Trustees, where a final resolution to addressing sediments in the GCR is likely to result. In addition, the pending actions of USX to remediate and dredge sediments in the upper 5 miles of the East Branch of the GCR will significantly alter the system. DuPont recommends that any further studies or discussions of the GCR, should they be warranted, occur under the ongoing RCRA facility investigation. Given the high ecological value associated with onsite habitats, DuPont plans to work closely with the Nature Conservancy to manage these areas.

1. Introduction

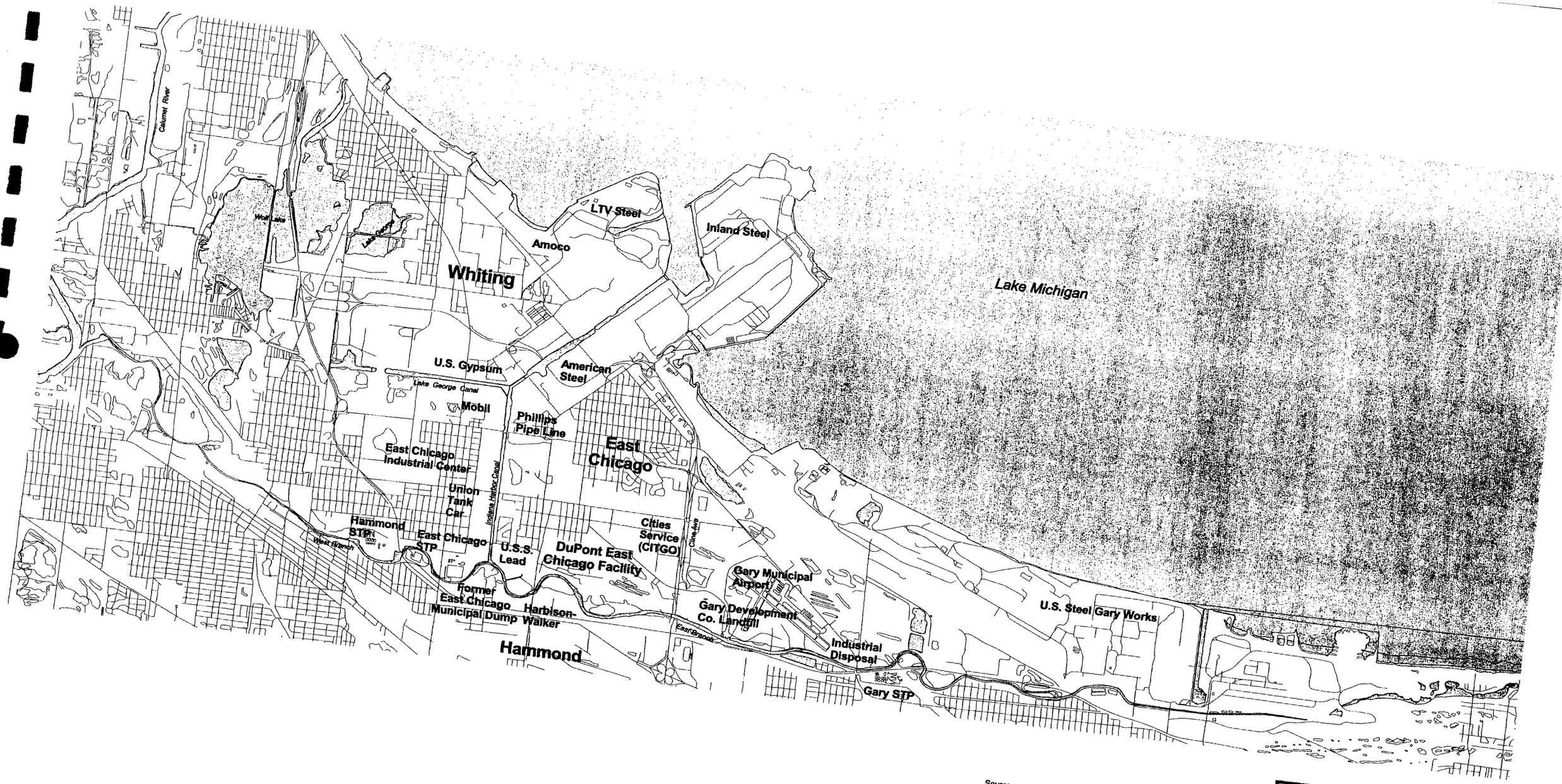
The E.I. du Pont de Nemours and Company (DuPont) entered into an agreement with the U.S. Environmental Protection Agency (EPA) pursuant to a Resource Conservation and Recovery Act (RCRA) Administrative Order on Consent (Order) (U.S. EPA 1997), dated June 25, 1997, to conduct a sediment characterization study (SCS) within a portion of the East Branch (the study area) of the Grand Calumet River (GCR) adjacent to DuPont's East Chicago facility. The revised work plan for the SCS (Exponent 1998) was submitted to EPA in April 1998 and approved by EPA on August 19, 1998. This document is the SCS report.

Together, the Indiana Harbor Canal (IHC), GCR, and nearshore Lake Michigan (Figure 1-1) represent 1 of 43 "areas of concern" (AOCs) designated by the International Joint Commission (IJC). The IJC was established by the United States and Canada as a result of the Boundary Waters Treaty of 1909, which set forth the rights and obligations of both countries regarding common boundary waters. In 1972, the first Great Lakes Water Quality Agreement was signed, which established objectives and criteria for the restoration and enhancement of water quality in the Great Lakes system to protect the Great Lakes. Since 1973, the IJC Water Quality Board has designated AOCs in the Great Lakes that have failed to meet the objectives of the Water Quality Agreement. Designation of an AOC is based on the identification of one or more beneficial uses such as drinking, swimming, fishing, and navigation that are considered to be impaired as a result of environmental changes caused by human activities.

In its Stage 1 remedial action plan for the IHC, GCR, and nearshore Lake Michigan AOC, the Indiana Department of Environmental Management (IDEM) (IDEM 1991) identified 14 beneficial uses that were either confirmed or considered likely to be impaired (Table 1-1). The beneficial uses may have been impaired as a result of contamination of surface water, sediments, or organisms; alterations to the physical

habitat; or a combination of these factors. Sediment contamination is considered to be a major cause of use impairments at 42 of the 43 Great Lakes AOCs (U.S. EPA 1994a). Eleven of the 14 beneficial uses alleged to have been impaired in the IHC, GCR, and nearshore Lake Michigan AOC are potentially attributable to sediment contamination (IJC 1997). Although tainting of fish and wildlife flavor and restrictions on drinking water consumption are more likely associated with chemical contaminants in surface water, sediments may indirectly contribute chemicals to the surface water. Beach closures, which are normally associated with high concentrations of fecal coliform bacteria originating from municipal sewage treatment plants (STPs) and/or combined sewer overflows (CSOs), are unlikely to be associated, directly or indirectly, with sediment contamination.

Sediments of the IHC, GCR, and nearshore Lake Michigan AOC are known to be contaminated with a wide variety of organic and inorganic chemicals. However, not all chemicals with elevated concentrations in sediments resulting from human activities contribute to use impairments, and, in fact, some use impairments may be associated with only a small number of chemicals. For example, fish are known to accumulate in their tissues certain organic chemicals such as polychlorinated biphenyls (PCBs), chlorinated pesticides, and polychlorinated dibenzo-*p*-dioxins that may pose a risk to humans ingesting the fish. In areas where these chemicals are present at high concentrations, fish may accumulate high tissue concentrations of the chemicals, resulting in restrictions on fish consumption to protect public health. Other organic compounds (e.g., polycyclic aromatic hydrocarbon [PAH] compounds) are readily metabolized by fish and do not accumulate in their tissues (Malins 1977; Varanasi and Gmur 1981; Malins et al. 1985a,b; Krahn et al. 1986; Collier and Varanasi 1991). Similarly, with the exception of mercury, fish can generally regulate the concentrations of metals in their tissues, so metals other than mercury are not associated with restrictions on fish consumption. In the IHC, GCR, and nearshore Lake Michigan AOC, restrictions on fish consumption have been associated only with PCBs and mercury (IDH 1997).



Sources:
Indiana Department of Environmental Management
U.S. Geological Survey

0 1000 2000 Meters

Figure 1-1.
LOCATION OF THE INDIANA HARBOR CANAL, GRAND CALUMET RIVER, AND NEARSHORE LAKE MICHIGAN AREA OF CONCERN.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/18/99
Prepared by: D. Gadsden

/calumet/projects/SCS_899.apr

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Table 1-1. Existing conditions identified as being responsible for the alleged use impairments at the Indiana Harbor Canal, Grand Calumet River, and nearshore Lake Michigan area of concern

	Alleged Use Impairment	Existing Conditions[a]
i	Restrictions on Fish and Wildlife Consumption	Advisory against eating any fish from the Grand Calumet River or the Indiana Harbor Canal. No known restrictions on wildlife consumption.
ii	Tainting of Fish and Wildlife Flavor	Tainting of fish is said to have occurred. No evidence of tainting of wildlife.
iii	Degradation of Fish and Wildlife Populations	Pollution-tolerant species of fish and benthic invertebrates are dominant. Stable, self-reproducing populations of native fish species are largely absent.
iv	Fish Tumors or Other Deformities	Carp from the Grand Calumet River and the Indiana Harbor Canal have eroded fins, swollen eyes, swollen abdomens, deformed lower jaws, and bloody fins.
v	Bird or Animal Deformities or Reproductive Problems	Limited bird and animal deformities in Grand Calumet River System and Lake George. Reproductive impairment in birds inhabiting or feeding in the area.
vi	Degradation of Benthos	Pollution-tolerant benthic species are dominant. Sediments have been shown to be toxic to, or avoided by, other organisms.
vii	Restrictions on Dredging Activities	Concern regarding sediment contamination has precluded navigational dredging in recent years.
viii	Eutrophication or Undesirable Algae	Nutrient loadings to the Grand Calumet River promote excessive phytoplankton production. Phytoplankton species typical of eutrophic environments are dominant. Water clarity and dissolved oxygen problems exist.
ix	Restrictions on Drinking Water Consumption (or Taste and Odor Problems)	Water quality of the Grand Calumet River and the Indiana Harbor Canal clearly would not support its use as a public water supply. Local area is provided with drinking water from Lake Michigan, so this is not a significant issue.
x	Beach Closings	Swimming is not recommended in the Grand Calumet River and the Indiana Harbor Canal because of poor water quality. Beaches along Lake Michigan have been closed because of coliform bacteria, but the source of the bacteria is not certain.
xi	Degradation of Aesthetics	Oil and grease apparent on the water surface, river banks, and emergent vegetation. Debris litters the river banks and benthic habitats.
xii	Added Cost to Agriculture or Industry	Concern regarding sediment contamination has precluded navigational dredging in recent years. Shipping capacity has been reduced by 15 percent, resulting in increased shipping costs.
xiii	Degradation of Phytoplankton and Zooplankton Communities	Phytoplankton counts are very low in nearshore Lake Michigan waters off Indiana Harbor.
xiv	Loss of Fish and Wildlife Habitat	Loss of appropriate physical habitat characteristics and structure diminishes the usability of the habitat by native fish species. Lack of suitable food organisms limits the ability of fish to survive in the Grand Calumet River and Indiana Harbor Canal.

[a] Summarized from the Stage I remedial action plan (RAP) (IDEM 1991) and the draft Stage II RAP (IDEM 1996).

Factors associated with the alleged impaired uses are not always known with scientific certainty. Nevertheless, enough is known about the effects of environmental contaminants on biological organisms to link some of the alleged impaired uses with substances introduced to the environment by humans. Table 3-2 in the SCS work plan (Exponent 1998) (reproduced herein as Table 1-2) summarized what was known at that time about associations between the alleged impaired uses and substances in the environment, and it identified the environmental media thought to be of primary or secondary importance in each use impairment. Environmental media may be of secondary importance not only if they serve as a direct but less important reason for the use impairment, but also if they serve as a source of the substance to the primary medium. For example, restrictions on dredging activities are primarily a function of the bulk sediment concentrations of chemicals that limit disposal options. Surface water may be a source of those chemicals to the sediments, but surface water concentrations of those chemicals are usually not a direct cause of restrictions on dredging. Similarly, restrictions on fish consumption are a function of chemical concentrations in fish tissues. Surface water or sediments may be the source of those chemicals to the fish, but concentrations of those chemicals in those media are not a direct cause of the restrictions on fish consumption.

As described in the SCS work plan (Exponent 1998), the information in Table 1-2 was used as an organizing principle for the SCS of the study area, representing the reach of the East Branch from Cline Avenue downstream to the confluence with the IHC. The collection of information in the course of the SCS, either through field sampling and laboratory analyses or through the synthesis of data from various other sources, was designed to improve our understanding of how contaminants in that portion of the AOC have contributed to, or are still contributing to, the alleged impaired uses. In addition, the SCS was intended to contribute to a better understanding of how various remedial alternatives might address improvement of the alleged impaired uses. This should allow the regional stakeholders to begin to evaluate the potential benefits of various remedial alternatives in meeting the goal of environmental improvement for the entire IHC, GCR, and nearshore Lake Michigan AOC.

TABLE 1-2. Substances potentially responsible for alleged use impairments

	Alleged Use Impairment	Substance(s) Potentially Responsible												Substance(s) Present in:		
		Metals	Mercury	PCBs	Chlorinated Pesticides	Dioxins and Dioxin-Like Compounds	PAHs	Oil and Grease	Nutrients	Grain Size	Other Sediment Conventional Parameters	Fecal Coliform Bacteria	Dissolved Oxygen	Surface Water	Sediments	Organisms
i	Restrictions on Fish and Wildlife Consumption		X[a,b,c]	X[a,b,c]	X[a,b]	X[a,b]								S	S	P
ii	Tainting of Fish and Wildlife Flavor							X[d,e,f]						S	S	P
iii	Degradation of Fish and Wildlife Populations	X[g]	X[g,h]	X[g,i]	X[b,g,j,k]	X[g,j]	X[g,l]	X[b,g]		X[m]	X[b,g]		X[b,n]	P	P	S
iv	Fish Tumors or Other Deformities		X[h]				X[f,o,p,q]							S	S	P
v	Bird or Animal Deformities or Reproductive Problems		X[h,r]	X[j,s]	X[k,t]	X[j]								S	S	P
vi	Degradation of Benthos	X[u]	X[u]	X[i,u]	X[k]		X[l]	X[f,u]	X[c,v]	X[w,x]	X[y]		X[z]	S	P	S
vii	Restrictions on Dredging Activities	X[aa,ab]	X[aa,ab]	X[aa,ab]	X[aa,ab]	X[aa,ab]	X[aa,ab]	X[aa,ab]						S	P	--
viii	Eutrophication or Undesirable Algae								X[b,ac]					P	S	--
ix	Restrictions on Drinking Water Consumption (or Taste and Odor Problems)	X[b,ad]	X[b,ad]	X[b,ad]	X[b,ad]	X[b,ad]	X[b,ad]	X[b,ad]				X[b,ad]		P	S	--
x	Beach Closings											X[b,c]		P	--	--
xi	Degradation of Aesthetics							X	X[b,ae]					S	--	--
xii	Added Cost to Agriculture or Industry	X[aa,ab,ae]	X[aa,ab,ae]	X[aa,ab,ae]	X[aa,ab,ae]	X[aa,ab,ae]	X[aa,ab,ae]	X[aa,ab,ae]						S	P	--
xiii	Degradation of Phytoplankton and Zooplankton Communities	X[af,ag]	X[h]					X[ah]	X[f,ai]				X[aj]	P	S	--
xiv	Loss of Fish and Wildlife Habitat							X[ah,ak]	X[ac]	X[b,ac]	X[g,y]		X[v]	S	S	--
Data to be acquired in SCS field sampling and laboratory analyses		SW, Sed	SW, Sed	Sed	Sed		Sed	SW, Sed	SW, Sed	Sed	Sed	SW	SW			

Note: PAH - polycyclic aromatic hydrocarbon
PCB - polychlorinated biphenyl
P - primary (of primary importance in impairment of the specified use)
S - secondary (of secondary importance in impairment of the specified use, or more typically, serving as a source of the substance to the primary medium)

TABLE 1-2. (cont.)

SW - surface water
Sed - sediment
SCS - sediment characterization study

[a] U.S. EPA (1996)
[b] U.S. EPA (1994b)
[c] U.S. EPA and Environment Canada (1995)
[d] Persson (1984)
[e] Davis (1995)
[f] U.S. EPA (1994a)
[g] U.S. EPA (1986b)
[h] U.S. EPA (1984b)
[i] Mayer et al. (1977)
[j] Giesy et al. (1994)
[k] U.S. EPA (1980a)
[l] U.S. EPA (1990)
[m] Glassner-Shwayder (1992)
[n] U.S. EPA (1986a)
[o] Myers et al. (1990)
[p] Malins et al. (1987)
[q] Van Veld et al. (1990)
[r] ATSDR (1994)
[s] U.S. EPA (1980b)
[t] Giesy (1994)
[u] Weis et al. (1992)
[v] Chesapeake Bay Program (1995)
[w] Hynes (1970)
[x] Busch and Sly (1992)
[y] U.S. EPA (1984a)
[z] Boesch (1985)
[aa] 40 CFR 230.10
[ab] 43 Fed. Reg. 4109
[ac] Kemp et al. (1983)
[ad] U.S. EPA (1993)
[ae] U.S. EPA (1994c)
[af] Havens (1994)
[ag] Hall et al. (1995)
[ah] Laws (1993)
[ai] Kimor (1992)
[aj] Nebeker et al. (1992)
[ak] API (1985)

DuPont's objectives for the SCS are as follows:

- To meet the intent of the Order by investigating the presence of constituents that may be related to the DuPont facility in sediments of the study area and specific wetlands
- To develop a conceptual understanding of physical and chemical processes that affect constituent distributions in the study area
- To collect information on beneficial uses that are alleged to have been impaired in the study area, as well as information that will contribute to an understanding of the causes of those impaired uses
- To collect information on past and present constituent loading to the East Branch that will contribute to an understanding of how those constituents have contributed to the impaired uses.

Ultimately, any restoration alternative selected should maximize the improvement in impaired uses, minimize the potential for recontamination of surface water and sediments, and minimize adverse effects on existing wetlands and associated resources. The conditions and processes of greatest interest in the SCS were organized into three general categories: source loading, chemical conditions and processes, and sediment transport.

In the following sections, the data collected during the SCS field investigation and information from regional studies and the literature are assembled and interpreted. In Section 2, background on the study area is provided, with emphasis on the physical setting, DuPont's historical and ongoing practices, and other industries or sources that could affect sediment and water quality in the study area. Sections 3, 4, and 5 address source loading, chemical conditions and processes, and sediment transport, respectively, in the East Branch in general and the study area in particular. Section 6 synthesizes the

information developed in Sections 3, 4, and 5 and assesses how the constituents in the sediment, surface water, and wetland soil of the East Branch may contribute to beneficial use impairment. Section 7 provides references cited in this report. In addition, point source loading data are provided in Appendix A, analytical results from the field investigation are provided in Appendix B, and sediment core logs and photo composites of the cores are provided in Appendix C.

2. Background

The following sections present a description of the physical setting, a brief history of industrial development in the local area, an overview of the manufacturing history and waste management practices of the DuPont facility, a description of sources of chemical contaminants to the river, an overview of the results of previous studies, and an overview of the SCS.

2.1 Physical Setting

The DuPont facility is located at 5215 Kennedy Avenue in East Chicago, Lake County, Indiana (Figure 1-1). The facility occupies approximately 430 acres on the north bank of the East Branch of the GCR, between Cline Avenue and Kennedy Avenue (Figure 2-1). The DuPont East Chicago facility is one of hundreds of industrial facilities located on the 10-mile-wide Calumet lakeplain bordering Lake Michigan in northwestern Indiana and northeastern Illinois. The surrounding area represents one of the most heavily industrialized areas in the United States. Major industries include steel mills, manufacturing plants, heavy manufacturing associated with the steel industry, petroleum-related land uses, packaging, and chemical processing plants. Numerous petroleum storage facilities and railroad tracks are found in the area surrounding the facility. The surrounding land use consists primarily of industrial and commercial lands with interspersed residential areas.

The low-relief Calumet lakeplain consists of a series of sandy dune ridges associated with Lake Michigan shoreline positions overlying the low-permeability clayey till, giving rise to the regionally unique dune and swale topography (Corps 1997). The dunes get younger and lower to the north. Soil profiles are thin except in marshes.

The drainage network on the Calumet lakeplain, of which the GCR is a part, is concentrated in the swale areas. Rainfall on the dune ridges recharges groundwater, which then flows along the stratigraphic contact between the dunes and till and discharges in the swales. River channels are low gradient and originally alternated between shallow marshy reaches and relatively narrow, deep reaches. Native vegetation consisted of more xeric species (oak and pine savannas) on the dunes and more hydric species (i.e., obligate and facultative wetland species, including white cedar) in the swales.

Within the Grand Calumet basin, the drainage network has been severely disrupted since the late nineteenth century to provide for navigation, wastewater discharge, and site drainage (Corps 1997). The flow of the GCR was originally from west to east, discharging to Lake Michigan near the present location of Marquette Park. Early in the twentieth century, the IHC was dredged, creating a new outlet to Lake Michigan and bisecting the existing channel into an East Branch and a West Branch (Figure 1-1). The former mouth of the river became permanently closed by sand dunes, and the flow was reversed in the East Branch, with discharge to the lake through the IHC (Corps 1997). In addition, much of the original topography has been obliterated as areas have been graded for transportation, industrial, and other urban uses. Dunes were graded into the swales to both flatten sites and provide drainage above the till. Other low-lying areas were filled with slag from the steel mills in the region.

Although termed a river, the East Branch of the GCR is primarily a conveyance for industrial and municipal wastewater discharges. The average daily discharge from the East Branch for the 1995 and 1996 water years was 455 cubic feet per second (cfs) at the Industrial Highway gauging station upstream from the DuPont facility (USGS 1997; IDEM 1992). The total volume of wastewater discharged to the East Branch is constantly changing as a result of alterations in industrial and municipal wastewater treatment, but has been characterized as representing in excess of 90 percent of the present flow in the East Branch. Upstream from the DuPont facility, the flow in the East Branch is primarily wastewater from the U.S. Steel–Gary Works (USX), with a

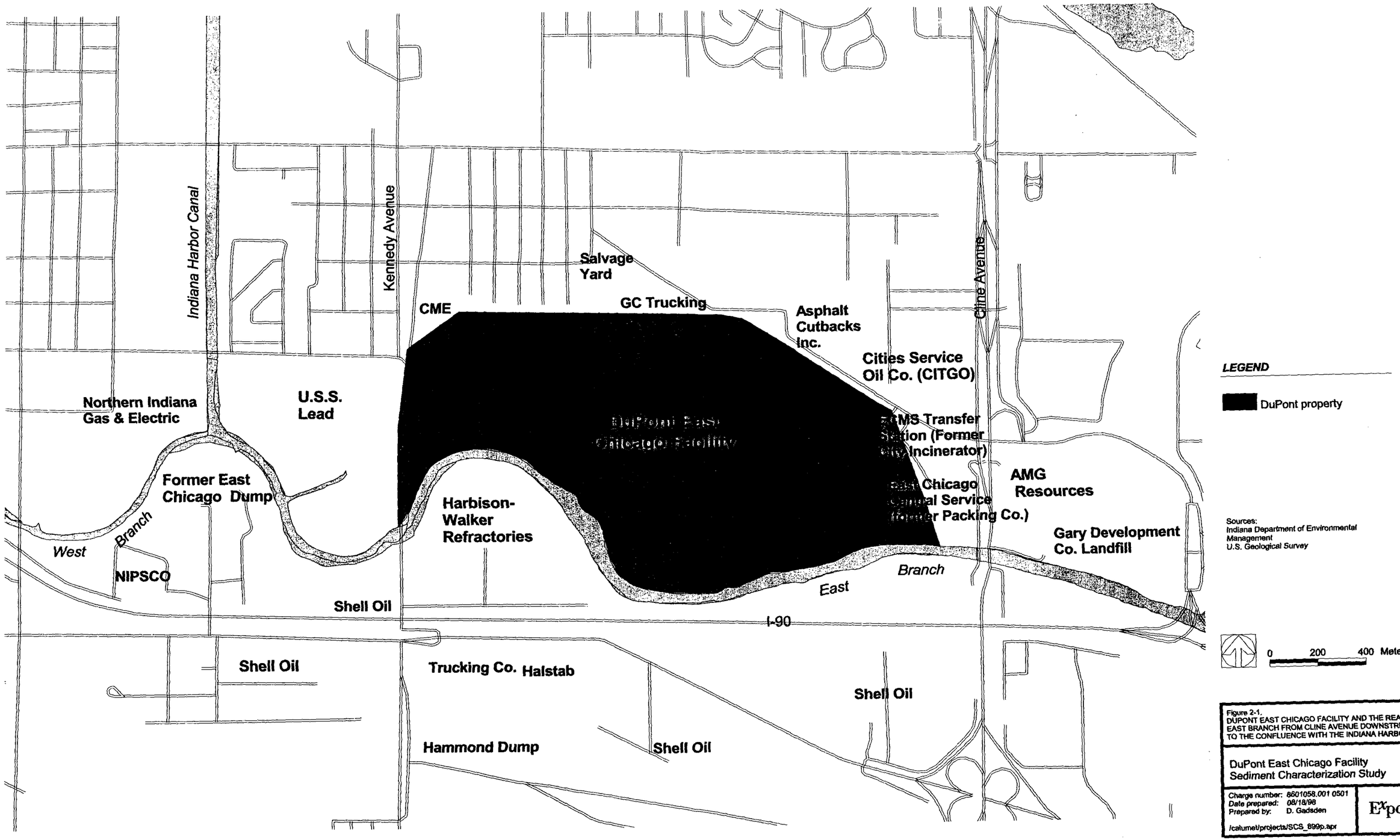

Figure 2-1.
DUPONT EAST CHICAGO FACILITY AND THE REACH OF THE EAST BRANCH FROM CLINE AVENUE DOWNSTREAM TO THE CONFLUENCE WITH THE INDIANA HARBOR CANAL.

DuPont East Chicago Facility
Sediment Characterization Study

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Prepared by: D. Gadsden
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secondary contribution of treated effluent from the Gary Sanitary District sewage treatment plant (Gary STP). All other permitted discharges to the East Branch (including DuPont) together represent less than 1 percent of the total wastewater discharged to that system. The East Branch also receives intermittent discharges from storm drains and CSOs during significant rainfall events. However, the fact that industrial wastewater discharges represent such a large fraction of the total flow in the East Branch explains the observation that total flow is relatively constant, even during rainfall events.

Additional details on the physical setting of the DuPont facility are provided in the *Current Conditions Report* (CCR) (CH2M HILL 1997).

2.2 History of Industrial Development in the Local Area

A comprehensive summary of historical industrial activities in the local area is provided by Ryder (1997). Industrial development of the area began in the late nineteenth century. Intensive development of the steel industry along the upstream reach of the East Branch began with the construction of USX in 1906. The city of Gary, which prior to the 1930s discharged domestic sewage and industrial waste to Lake Michigan, constructed its first STP on the south bank of the East Branch upstream from Clark Avenue in 1940.

Notable industrial developments and land uses along the East Branch downstream from Cline Avenue included the following:

- Grasselli Chemical Company (Grasselli) (predecessor of the DuPont facility, see following section for additional details).
- Cudahy Packing Company, constructed in 1909 on the north bank just west of Cline Avenue, and present through at least 1956. Subsequently replaced by the Purex Corporation through at least 1989

and now the site of the East Chicago Central Services (street department).

- U.S.S. Lead Refining Company, constructed in 1905 on the north bank of the East Branch west of Kennedy Avenue, and operated from 1914 to 1985 as a secondary lead smelter, obtaining lead from old automobile batteries and industrial lead scrap. The facility ceased operations in mid- to late-1985.

- Shell Petroleum–Roxana Refinery, constructed in 1917 on south bank of the East Branch between Indianapolis Boulevard and Cline Avenue. Tanks immediately west of Cline Avenue are post-1959. Also includes tanks on south bank west of Kennedy Avenue.

- Harbison-Walker Refractories, constructed in 1951–1959 on the south bank of the East Branch opposite the DuPont facility. Manufacturer of ceramic/brick linings for furnaces for the steel industry.

- Property along the south edge of the river between Cline and Harbison-Walker (known as the Siedner Dune and Swale Nature Preserve and the Beamsterboer property). Identified as the site of illegal dumping (Corps 1997).

The U.S.S. Lead facility was the subject of an EPA site assessment in 1985 (Weston-Sper 1986). At that time, it was noted that there had been numerous violations of the facility's National Pollutant Discharge Elimination System (NPDES) permit from 1975 through 1984, including exceeding effluent standards for lead discharges to the East Branch and not meeting requirements concerning permit verification, facility operation and maintenance, and sampling procedures. Weston-Sper (1986) also reported that in 1980 the flue dust collector at the facility often malfunctioned, allowing releases of dust into the air, that the facility had problems in achieving full and effective neutralization of its sulfuric acid waste, and that excessive amounts of lead, fluoride, and arsenic were migrating offsite into the East Branch. Soil samples collected from the vicinity of the

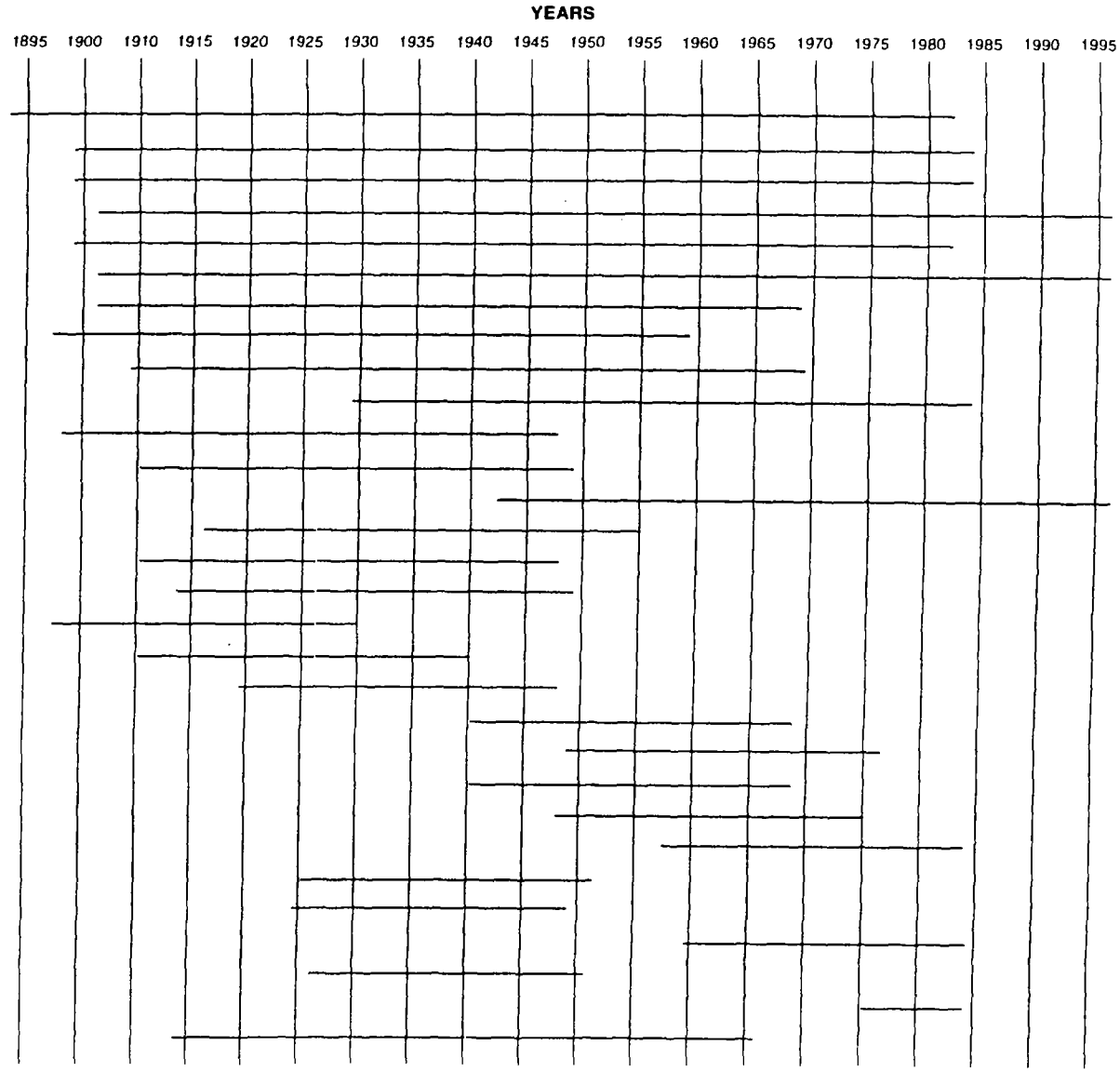
U.S.S. Lead facility and high volume air samples collected in early 1985 suggested that high levels of lead in airborne particulates were being transported to the east (toward the DuPont facility on the opposite side of Kennedy Avenue).

2.3 Manufacturing History and Waste Management Practices of the DuPont Facility

The DuPont facility was originally the site of Grasselli, which began operations in 1893. Grasselli produced inorganic chemicals, primarily acids and bases. DuPont acquired Grasselli in the 1930s. The facility grew between 1893 and 1945, and by 1930, it covered nearly 160 acres. Facility operations were always limited to the western portion of the property; the eastern portion of the property was never developed. During World War II, the facility employed nearly 2,000 workers in manufacturing 21 product lines. Operations declined after the war, and the workforce was reduced to approximately 700 between 1950 and 1970. Over its lifetime, the facility has produced more than 100 products, including reagent-grade chemicals (hydrochloric acid, sulfuric acid, sulfamic acid, nitric acid, and ammonium hydroxide), trichlorofluoromethane (TCFM, or Freon®) products, and agricultural chemicals. Figure 2-2 outlines the production history for chemical products that were manufactured at the facility for 25 or more years. By 1990, operations at the facility had been considerably reduced, with a workforce of only about 52 people manufacturing two products, sodium silicate and colloidal silica. It is likely that any significant discharges from the facility occurred prior to 1970.

Historically, DuPont managed wastes at the facility according to general industry practices at the time. DuPont began modifying its waste management practices in the 1970s as environmental regulations were enacted and in response to regulatory changes and improved knowledge regarding the relationship between practices and potential effects on the environment. Records of early operations and practices at the facility are nonexistent. Some information is available on operations since the 1980s, and most of the available information on waste management practices was summarized in the Phase I

Products	Begin Operation	Discontinued Operation	Duration Years
Sulfuric Acid Products	1893	1984	91
Nitric Acid Reagent	1899	1984	85
Sulfuric Acid Reagent	1899	1984	85
Sodium Silicate Products	1902	*	95+
Hydrochloric Acid Reagent	1899	1982	83
Acetic Acid Reagent	1902	1982	80
Zinc Chloride Products	1902	1969	67
Hydrochloric Acid and Soil Cake Products	1897	1959	62
Ammonium Chloride Products	1909	1969	60
Duclean Inhibited Acid Products	1929	1984	55
Glauber's Salt	1898	1948	50
Lead Arsenate Products	1910	1949	39
Colloidal Silica Products	1947	*	50+
Sodium Thiosulfate	1916	1955	39
Lime Sulfur Solution	1910	1948	38
Arsenic Acid	1914	1949	35
Mixed Acid	1897	1930	33
Bordeaux Mixture® Insecticide	1910	1940	30
Calcium Arsenate	1919	1948	29
Chromated Zinc Chloride Products	1940	1969	29
Trichlorofluoromethane-Kinetics Operation	1948	1977	29
Zinc Ammonium Chloride Products	1940	1969	29
Aluminum Chloride Products	1947	1975	28
Ammonium Hydroxide Reagent - New Facilities	1958	1984	26
Phosphoric Acid	1925	1951	26
Litharge®	1924	1949	25
Sulfamic Acid	1959	1984	25
Disodium Phosphate Products	1926	1951	25
Fluorosulfonic Acid	1975	1988	13
Zinc Ore Roasters	1913	1967	54



* Products still being produced

Source: Phase I Groundwater Assessment Report (CH2M HILL, 1990) and New DuPont Information

Figure 2-2.
GENERAL PRODUCTION HISTORY FOR PRODUCTS IN PRODUCTION LONGER THAN 25 YEARS.

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Groundwater Assessment (CH2M HILL 1990). Accurate estimates of historical wastes generated and total quantities disposed or discharged could not be obtained from review of readily available information. Most of the chemical manufacturing processes at the facility utilized or produced inorganic chemicals. Chemical constituents commonly associated with those processes are listed in Table 2-1. Approximate estimates of waste quantities generated are described in Volume 2 of the CCR (CH2M HILL 1997).

Prior to the early 1970s, process wastewater from the DuPont facility was discharged to the East Branch through a number of outfalls (numbered E-1 through E-9 in Figure 2-3). Detailed information does not exist to identify the nature of the wastewater discharged from Outfalls E-1 through E-9 over their entire history. The following information was summarized from a characterization of the discharges from these nine outfalls as of 1971:

- Outfall E-1 consisted of a small canal that conveyed wastes to the East Branch from the sulfamic acid area, the reagents area, the area where TCFM or Freon® products were manufactured, and the sulfuric acid area. Between 1948 and 1977, blowdown from a cooling tower associated with Freon® manufacturing was also discharged to the canal. Chemicals potentially associated with these waste streams included waste acids, neutralized acids, antimony pentachloride, boron, arsenic, chromium, lead, and sodium hydroxide. In 1977, the end of the canal was closed off, resulting in the formation of a surface water impoundment or lagoon. The outfall or lagoon also collected runoff from the hydrochloric acid neutralizing pit. Sulfur was also found on the banks of the canal and may have been present in the lagoon. The lagoon was backfilled during the winter of 1986–1987.
- Outfall E-2 discharged wastes from the sulfuric acid area to another small canal which, in turn, discharged to the East Branch.

Table 2-1. Constituents associated with historical or current manufacturing processes at the DuPont East Chicago facility

Major Inorganics (including some common metals)	
Aluminum	Nitrogen
Calcium	Phosphate
Carbonates	Silica
Chloride	Sodium
Fluoride	Sulfate
Iron	Sulfur
Trace Metals	
Antimony[a]	Copper
Arsenic	Lead
Barium	Nickel[a]
Boron[a]	Selenium[a]
Cadmium[a]	Vanadium[a]
Chromium	
Trace Inorganics	
Cyanide	
Organics	
Freon	Other Agricultural Chemicals
Carbon tetrachloride	Amines
Toluene	Ketones
Hexane	Phenols
Hexazinone	Urea

Note: Chemicals associated with facility operations are not listed here (e.g., lubricants, cleaning liquids, soaps).

[a] Trace element present at low concentration in product or waste stream (not a primary component of product produced at facility). Other trace inorganics may be present in ores or raw materials.

Figure 2-3.
CURRENT AND HISTORICAL DUPONT OUTFALLS

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LEGEND

DuPont outfalls

0 50 100 Meters

- Outfall E-3 discharged cooling water from the boiler house, which provided power generation for the facility, to the same small canal as did Outfall E-2.
- Outfall E-4 discharged wastes from the calcium sulfate area.
- Outfalls E-5 and E-6 discharged wastes from the agricultural chemical products area and the chlorides area. Wastes from the latter area may have included aluminum and ammonium chlorides, zinc, iron, barium, chromated zinc chloride, and zinc ammonium chloride.
- Outfalls E-7, E-8, and E-9 discharged wastes from the areas where sodium silicate and colloidal silica were manufactured.

In the early 1970s, DuPont applied for an NPDES permit for its wastewater discharges and subsequently consolidated those discharges into three outfalls (numbered 001, 002, and 003 in Figure 2-3). Storm sewers were separated from process sewers, and the process sewers were combined to provide wastewater treatment before discharge. The NPDES permit was first issued in 1974. Outfall 001 was for noncontact cooling water discharge from the Freon® and acid manufacturing areas near the east end of the plant, and Outfalls 002 and 003 were for process water. Use of Outfall 001 was discontinued in 1984. Outfall 002 conveyed treated wastewaters from the Freon®, sulfuric acid, sulfamic acid, and agricultural chemical manufacturing areas. These waste streams were treated by neutralization, settling, and filtration. Calcium fluoride was produced as a precipitate. Outfall 002 was shut down in April 1989 when the associated manufacturing operations were discontinued. Outfall 003 served the chloride and silicate products manufacturing areas. The treatment system upstream of Outfall 003 consisted of flocculation, thickening, and filtration before discharge. A vacuum filter was provided for sludge dewatering. Wastewaters from the system were blended with treated wastewater from the Ludox process. They received final pH adjustment and filtration before discharge. Treatment of the Ludox wastewaters consisted of neutralization and filtration.

Outfall 003 is still used today, but all other outfalls were abandoned when they were no longer needed. The current discharge rate for Outfall 003 is 420,000 gallons per day.

Figure 2-3 also shows the location of a water intake line that was previously used to pump noncontact cooling water from the East Branch (about 5,000 gpm). This water was also used in the past for fire protection. The water intake line was abandoned in 1984.

Most storm sewers and process sewers were combined before 1973. In mid-1974, stormwater was separated from process water for discharge to two storm sewers, one serving the office, the other the chloride production area and the warehouse areas. Each storm sewer discharged to an infiltration ditch dug in the cinder-filled area north of the plant. Site stormwater is now routed to the wastewater treatment system for treatment prior to discharge through Outfall 003 (Figure 2-3). Outfall 004 (Figure 2-3), which was installed and permitted in 1992, is not used during normal operations. If the volume of stormwater collected exceeds the capacity of the wastewater system during significant rainfall events, the excess stormwater is discharged through Outfall 004.

The facility implemented an emergency spill control program in 1985. The manual describing emergency procedures was initially written in 1985 and revised in 1990. If a liquid spills on paved areas in the active manufacturing area and flows toward Outfall 004, facility personnel are to follow procedures to prevent discharge of spilled fluids to the East Branch.

Additional details on DuPont facility operations are provided in the CCR (CH2M HILL 1997).

2.4 Sources of Chemical Contaminants

Sources of chemical contaminants to the GCR are (in order of likely importance) industrial and municipal outfalls, CSOs and storm water runoff, sediments, groundwater, and atmospheric deposition. Each type of source is discussed below.

2.4.1 Industrial and Municipal Outfalls

Beginning with development of the area approximately 150 years ago, many of the hundreds of industries located in the area of the GCR system historically discharged untreated waste and/or wastewater to the river (Ryder 1997). These industries include steel mills, oil refineries, manufacturing plants, metal foundries, chemical companies, and in previous years, animal processing facilities. In addition, prior to the 1920s, all municipal sewage discharges to the river were untreated. In more recent years, the amount of untreated industrial and municipal waste discharges has been reduced, so that the current discharges to the river represent only a fraction of historical discharge levels.

There are a total of between 45 and 49 NPDES-permitted industrial and municipal outfalls on the GCR system (IDEM 1996). Of these, 29 are located on the East Branch (Figure 2-4). On a volume basis, the largest permitted discharges to the East Branch are USX and the Gary STP, with smaller volumes of wastewater being discharged by DuPont, CITGO Petroleum, AMG Resources, and Harbison-Walker Refractories (Figure 2-4). U.S.S. Lead has also discharged to the East Branch (Crawford and Wangsness 1987), although EPA's permit compliance system (PCS) database does not contain any loading data for U.S.S. Lead.

By far, the major sources of industrial wastewater discharged to the East Branch are the outfalls associated with USX. This facility produces iron and steel products, coke, and coal-related chemicals. By the terms of their NPDES permit, approximately 320–350 million gallons per day (mgd) of treated process water and noncontact cooling

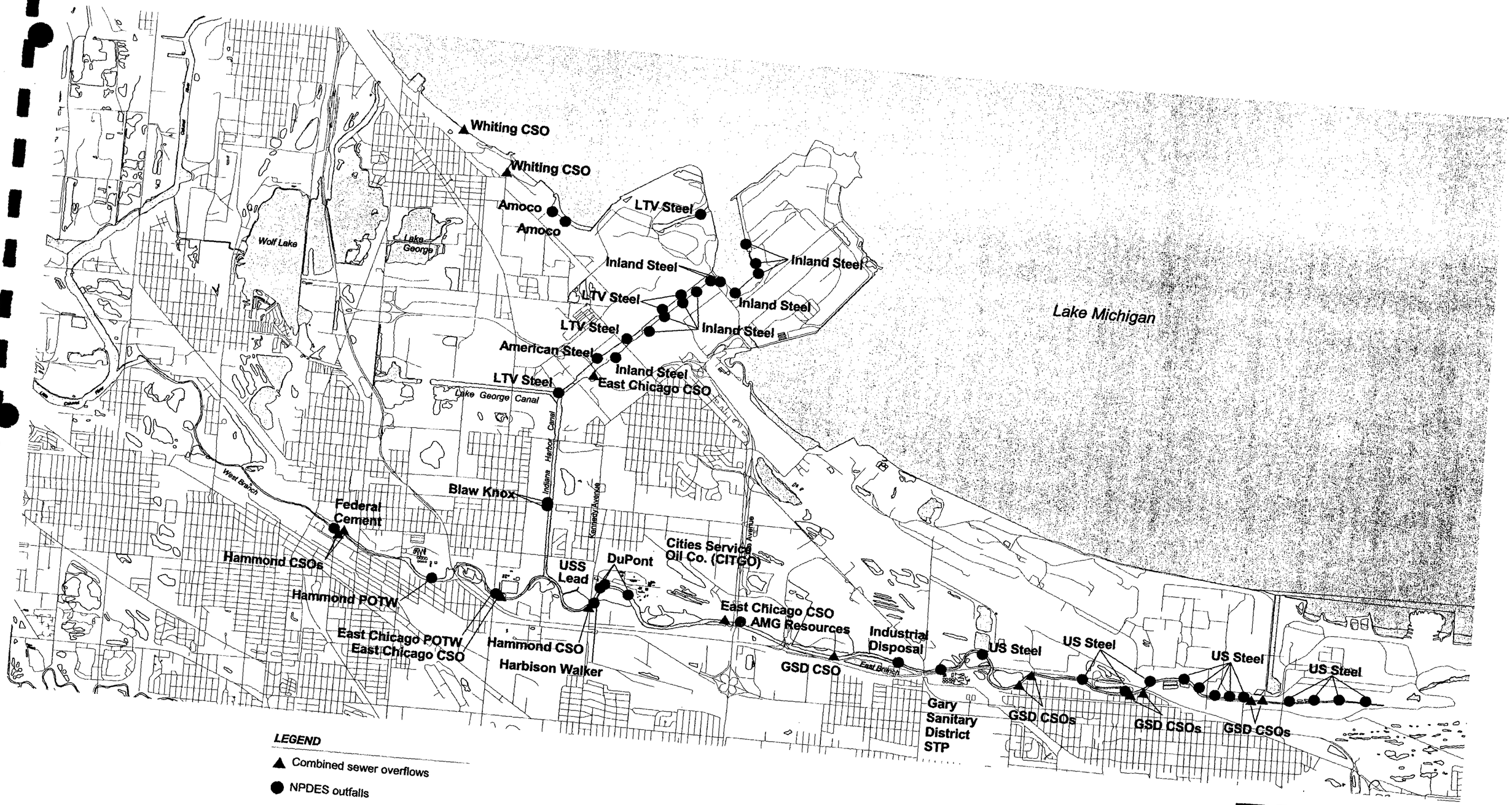
water were discharged daily in 1997. The Gary STP discharges approximately 46–60 mgd from its outfall located at river mile 8.8 (Figure 2-4). Collectively, the other nine permitted outfalls downstream of USX and the Gary STP on the East Branch discharge an average of less than 1 mgd.

In October 1984, the U.S. Geological Survey (USGS) measured discharge flows and collected water samples from 23 discharges to the GCR system during base flow conditions (USGS 1987). Twenty-one of these discharges were located on the East Branch. Surface water samples were also collected from 12 stations in the river system itself. Sampling occurred at 2- to 6-hour intervals during a 24-hour period. The data indicate that in 1984, USX and the Gary STP were the source of more than 90 percent of the discharge of suspended and dissolved solids, chloride, fluoride, biochemical oxygen demand (BOD), phenol, cyanide, ammonia, nitrate, nitrite, phosphorus, chromium, copper, iron, mercury, and nickel and more than 50 percent of the discharge of sulfate, lead, and zinc. DuPont outfalls accounted for approximately 50 percent of the organic nitrogen discharged to the river, while together the Gary STP and USX outfalls discharged a similar amount.

Loading for industrial and municipal outfalls is evaluated in greater detail in Section 3.

2.4.2 Combined Sewer Overflows and Storm Water Runoff

Prior to the 1920s, all municipal sewage discharged to the river was untreated (Ryder 1997). Although many municipal STPs have been constructed since then, an estimated 11 billion gallons per year of untreated raw wastewater still is discharged to the GCR system through approximately 14 CSOs during storm events (IDEM 1991). In addition to CSOs, storm water runoff contributes an unquantified volume of discharge to the river during rainfall events, primarily through numerous drain pipes, ditches, and weirs located along the river. The exact number of these outfalls has not been determined, but at least 23 have been identified (IDEM 1993).



LEGEND

▲ Combined sewer overflows

● NPDES outfalls

Sources:
Indiana Department of Environmental Management
U.S. Geological Survey

0 1000 2000 Meters

Figure 2-4.
INDUSTRIAL/MUNICIPAL OUTFALLS AND COMBINED SEWER OVERFLOWS.

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Loading from CSOs is described in greater detail in Section 3.

2.4.3 Sediments

Sediments can be an ongoing source of constituents of interest (COIs) via resuspension of surface sediments or advective/diffusive transport of dissolved constituents associated with buried sediments. Resuspended sediments can exchange COIs with surface water through the processes of sorption and desorption (i.e., partitioning).

The potential for advective transport was assessed by measuring the hydraulic conductivity of sediment cores and is discussed in Section 3. Partitioning, which cannot be fully assessed with the existing data, is briefly discussed in Section 4. The potential for sediment resuspension is discussed in Section 5. Previous studies of sediments in the study area are summarized in Section 2.5.

2.4.4 Groundwater

The area around the GCR is underlain by the Calumet Sand aquifer, which consists of a surficial, lacustrine sand layer 20–50 ft thick (CH2M HILL 1991a). This aquifer is, in turn, underlain by an aquaclude of lacustrine clays and glacial till, which limits downward vertical transport of groundwater to the fractured limestone bedrock beneath. A high water table exists between Lake Michigan and the GCR. The shallow groundwater (i.e., the Calumet Sand aquifer) north of the divide flows to Lake Michigan, while groundwater south of the divide discharges to the river. The hydraulic conductivity of groundwater in the Calumet Sand had been estimated to range from 8 to 135 ft/day. Recharge to the aquifer, an estimated 4–23 in./year, is almost exclusively from rainfall (USGS 1993). Discharge of groundwater to the river is estimated to be approximately 36 cfs, accounting for less than 10 percent of the total flow of the river during base flow

periods. This discharge reaches the river both directly and through leakage into the large network of sanitary sewers in the area. Because the groundwater elevations in the Calumet Sand aquifer are always higher than in the river, groundwater is always discharging to the river and the river does not provide recharge to the shallow aquifer (CH2M HILL 1991a).

Chemical loading to the river system as a result of shallow groundwater discharge has been estimated by USGS (1993). The results of this analysis indicated that, with the exception of ammonia and cyanide, the potential chemical input to the river via groundwater is small (from less than 1 percent to 5 percent, depending on the chemical) compared to the loading associated with industrial and municipal discharges.

A more detailed evaluation of groundwater loading has been deferred until the RCRA facility investigation (RFI) for DuPont's East Chicago facility has been completed.

2.4.5 Atmospheric Deposition

Atmospheric deposition may play a minor part in the chemical loading to the GCR. There have been no investigations of the potential loading to the river from atmospheric deposition. IDEM (1991) indicates that atmospheric deposition may contribute from 46–99 percent of the lead, 7–90 percent of the PCBs, 22–97 percent of the DDTs, and 72–96 percent of the benzo[a]pyrene loading to the Great Lakes; however, because of the small surface area of the river and the large amounts of loading from industrial and municipal discharges, CSOs, and, to a lesser extent, groundwater, the impact of atmospheric deposition on the river is expected to be inconsequential.

2.5 Overview of Previous Studies

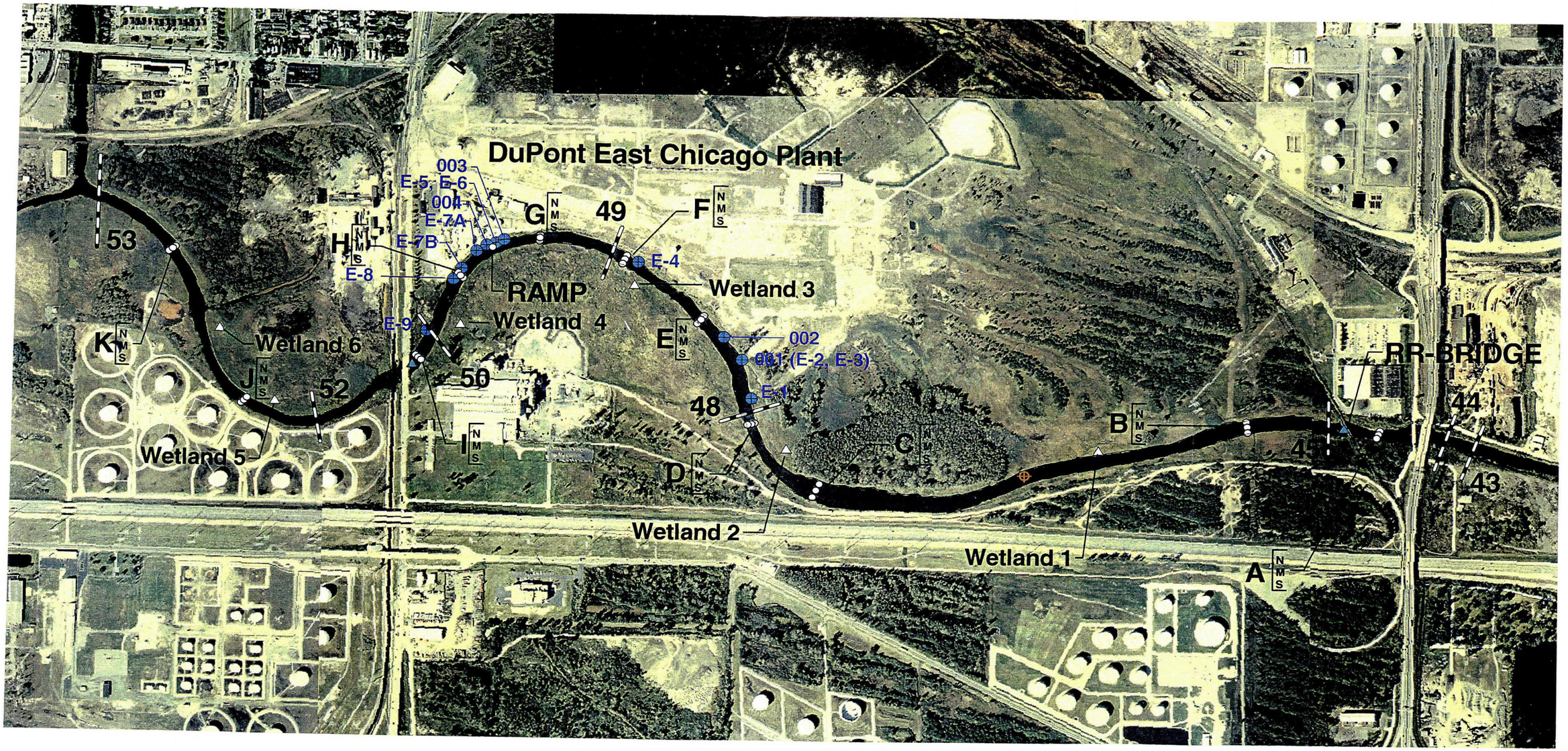
Surface water and sediments of the GCR are known to have high concentrations of bacteria, nutrients, metals, oil and grease, and various organic compounds (e.g., PCBs, PAHs, phenols) that may be associated with adverse biological effects and beneficial use impairments. As interest in the environment of the GCR has grown in recent decades, sediments have increasingly been the focus of a number of investigations. The need to maintain a navigational channel in the IHC has necessitated sampling and analysis of sediments there to evaluate dredge spoil disposal options. Although the upstream portion of the canal and all of the GCR are not navigational channels, those areas have come under increasing scrutiny as the potential need for sediment remediation in those areas is being evaluated.

It is known that for the entire GCR and IHC system, a large number of sediment investigations have been conducted. The Corps (1997) retrieved available sediment chemical data from EPA's Fully Integrated Environmental Location Decision Support sediment quality database, which includes analytical results for nearly 6,000 sediment samples collected from the Federal Channel, IHC, and East and West branches of the GCR. However, the summary tables produced (Tables 3 and 4 in Corps 1997) only reported the overall range of concentrations of various chemicals and the numbers of samples falling within relatively broad concentration ranges. There was no indication of the source of the data, the sampling locations, or the depth or type of sediment samples represented. Nevertheless, the tabled data provide convincing evidence that at least some sediments within the system have high concentrations of chemicals likely associated with historical and/or ongoing waste discharges. The concentrations reported for a number of chemicals were sufficiently high that they would likely cause adverse biological effects. One difficulty with extrapolating such data to an interpretation of present impaired beneficial uses is that sediments with the highest chemical concentrations may be deeply buried because they were a product of historical discharges. As a result of source control measures in the last several decades, more recent surface sediments may have

substantially lower chemical concentrations and may or may not have the same potential for adverse biological effects.

There have been a number of previous studies of sediments within the reach of the East Branch of the GCR extending from Cline Avenue downstream to the confluence with the IHC. In most of the previous studies that included sampling within that reach, the number of stations was small, the available information on sampling procedures was limited, and the list of analytes was highly variable. Four early studies sponsored by EPA included limited sampling in 1978, 1980, and 1982 (Townsend 1978; Kizlauskas 1980; U.S. EPA 1981; Clark et al. 1986). Hydroqual (1984) conducted a study in 1983. Because all of those early studies were conducted more than 15 years ago, prior to known improvements in the level of wastewater treatment and reductions in wastewater discharges, they are no longer considered to be representative of current sediment conditions in the East Branch. Two other more recent sediment investigations have included sampling and analysis of sediments within this reach and their results are summarized briefly below.

As part of a large-scale SCS sponsored by U.S. Steel, Floyd Browne (1993) collected deep sediment cores in 1991 at several locations along each of six cross-channel transects in the reach of the East Branch downstream from Cline Avenue (Figure 2-5). The cores generally extended to a depth believed to be representative of native (i.e., pre-industrial) sediments, but they were sectioned only into relatively broad horizons (typically 5 ft), and each horizon from a single core was composited with other similar horizon samples from the other cores along an individual transect. Because the analytical results are for sediment samples composited over such broad intervals, they are not necessarily indicative of sediments near the surface (i.e., within the biologically active zone of approximately the uppermost 10 cm). Surface sediments would be expected to have lower concentrations of most chemicals, reflecting source control measures in recent years. Indeed, even at the gross scale of the sediment intervals analyzed by Floyd Browne (1993), the surface horizon (typically 0–5 ft) often exhibited lower chemical concentrations than deeper horizons (greater than 5 ft below the sediment surface),



LEGEND

- Stilling wells
- Wetlands stations
- Sediment stations
- Surface water station
- DuPont historical outfalls
- Floyd Browne sediment transects

0 100 200 300 Meters

Figure 2-5.
SEDIMENT AND SURFACE WATER STATIONS, HISTORICAL DUPONT OUTFALLS, AND CURRENT INDUSTRIAL FACILITIES

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Sediment Characterization Study

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suggesting that historical conditions were much worse than those in the more recent past. Because of the proximity of a number of the Floyd Browne (1993) transects with the transects sampled as part of the SCS, the results of Floyd Browne (1993) will be compared and contrasted with the results of the SCS in Section 4.

Hoke et al. (1993) collected surface sediment samples in 1988 and 1989 from stations just downstream of Cline Avenue, just downstream of Kennedy Avenue, and at the confluence with the IHC. The samples were collected with a ponar grab sampler, with an estimated penetration depth of 15–45 cm. Bulk sediment and pore water samples were analyzed for semivolatile organic compounds, volatile organic compounds, pesticides, PCBs, oil and grease, acid-volatile sulfide (AVS), and total organic carbon. In addition, laboratory toxicity tests were conducted using the sediment pore water. For three reasons, the samples collected by Hoke et al. (1993) are of limited use in making comparisons with the results of the SCS. First, the samples were collected more than 10 years ago and may not be representative of present conditions. Second, these samples were collected from a broader depth horizon (15–45 cm) than would be indicative of the biologically active zone (uppermost 10 cm or less) that was to be the focus of the SCS. Third, only two of the three stations were located within the reach where sampling was conducted as part of the SCS, and the interpretation of general sediment conditions from only two points is severely limited. It is of note, however, that the maximum concentrations of many of the chemicals detected by Hoke et al. (1993) were well below the maximum concentrations reported in earlier studies, suggesting that more recently deposited near-surface and surface sediments may well be considerably less contaminated than older, deeper sediments in the East Branch.

Surface water quality has been monitored over a number of years in the GCR and IHC. IDEM has routinely analyzed surface water samples collected from seven stations in the GCR and IHC for metals and conventional analytes and less frequently for organic compounds (IDEM 1992). The only station routinely sampled by IDEM that is within the study area of the SCS is at Kennedy Avenue. Historically, the waters of the GCR system have contained elevated concentrations of iron, lead, copper, mercury, oil and

grease, PCBs, ammonia, phosphorus, chloride, fluoride, sulfate, fecal coliform bacteria, and total dissolved solids (TDS). The concentrations of these substances in the river, as of 1990, were reported by IDEM (1991) to be decreasing, although iron, mercury, lead, copper, cyanide, fecal coliform bacteria, ammonia, and TDS concentrations were still above Indiana water quality standards, and dissolved oxygen concentrations remained low. In a 1988 analysis of surface water samples for organic compounds, 35 of 145 target compounds were detected in at least one sample, but only 1,2-dichloroethane was detected at concentrations above Indiana water quality standards (IDEM 1991).

In October 1984, USGS conducted surface water sampling in the GCR system during base flow conditions (USGS 1987). Although the results of that investigation are now somewhat dated and not likely to be indicative of more recent water quality conditions, the results are still of general interest, especially as they relate to comparisons between historical conditions in the East and West Branches. Samples were collected from five stations on the East Branch, six stations on the West Branch, and one station on the IHC. Effluent samples were also collected from a total of 23 industrial and municipal discharges along the river. Sampling occurred at 2- to 6-hour intervals during a 24-hour period. Average dissolved oxygen concentrations were higher, and concentrations of TDS, total suspended solids (TSS), BOD, ammonia, nitrite, nitrate, and phosphorus were substantially lower in the East Branch than in the West Branch. In the East Branch, phosphorus and total phenols were the only analytes that exceeded state water quality standards. In the West Branch, standards were exceeded for ammonia, chloride, cyanide, TDS, fluoride, total phosphorus, mercury, and total phenols, and dissolved oxygen was below the minimum standard. These results suggest that water quality has historically been much more impaired in the West Branch than in the East Branch.

2.6 Study Overview

The SCS was designed to provide information on the distribution of COIs in streambed sediments, surface water, and wetland soils/sediments within the 100-year floodplain of

the study area. In addition, the investigation was designed to evaluate and document source loadings within the study area, and surface water hydrology/sediment transport processes specific to the study area.

During preparation of the work plan (Exponent 1998), preliminary COIs were selected based on the following criteria:

- Primary Criteria
  - Chemicals listed in the Order
  - Chemicals that have the potential to cause impaired uses within the GCR system
- Secondary Criteria
  - Chemicals potentially associated with either existing or historical industrial and municipal wastewater discharges to the GCR
  - Chemicals present in sediment samples previously collected from the GCR
  - Chemicals used in the manufacturing processes at the DuPont East Chicago facility, as well as the characteristics of these chemicals (i.e., mobility, toxicity, and persistence in the environment). The Phase I groundwater assessment (CH2M HILL 1990) and Table 2-1 include the most complete list of chemicals potentially used at the DuPont East Chicago facility.

Several chemicals listed in Table 2-1 were not included as preliminary COIs because their characteristics were such that they would not be expected to cause an impaired use

or it was determined that an analytical methodology was not available to detect them in the sediment matrix.

The list of preliminary COIs for sediments and surface water, and the rationale for the designation of each as COIs, is presented in Table 2-2.

Sample locations in the East Branch were selected based on review of topographic maps of the study area, the locations of historical and existing outfalls on the DuPont property, stream flow data from the USGS gauges on the GCR and neighboring Little Calumet River, Figure G-5 in Appendix G of Corps (1997) showing current and historical locations of industrial and municipal activities in the area, and information from prior investigations of streambed sediments throughout the East Branch. Sediment sampling transects were distributed throughout the study reach, concentrating on the former manufacturing area at the DuPont facility and providing a lesser degree of characterization upstream and downstream of these outfall locations (Figure 2-5).

Transects upstream of the former manufacturing area were designed to characterize inputs to both the river and associated wetlands from upstream sources, and to differentiate those inputs from those associated with the DuPont facility. Within the portion of the study reach where the former manufacturing area was located, the transects were spaced at regular intervals (Figure 2-5). Farther downstream, between Kennedy Avenue and the IHC, one transect (J) was located to characterize sediment conditions downstream of the DuPont facility, the Harbison-Walker discharge, and a major CSO, and one transect (K) was located to characterize sediment conditions downstream of the former U.S.S. Lead outfall.

Within each transect, sediment sample locations and depths were established both by the need to adequately characterize the spatial distribution of COIs and by an understanding of the control on sediment deposition exerted by channel pattern. Sediments were collected near each bank and in the center of the channel, generally in a symmetrical pattern (with respect to sampling depth) about the channel centerline. Channel cross

Table 2-2. Preliminary constituents of interest at the Indiana Harbor Canal, Grand Calumet River, and nearshore Lake Michigan area of concern

Constituent of Interest	Rationale
Sediments	
Metals (Ag, As, Cd, Cr, Cu, Hg, Mg, Mo, No, Pb, Sb, V, Zn)	Elevated concentrations of various metals have been detected in historical surface water, groundwater, and sediment sampling; selected metals (Ag, Mg, Mo, Ni, V) are indicators of steel mill waste; the RCRA Corrective Action Order identified As, Cd, Cr, Cu, Hg, Ni, Pb, Sb, and Zn as having 1) been discharged to the river via the DuPont facility's industrial outfalls, 2) been found in groundwater monitoring wells at the DuPont facility at concentrations above MCLs, and/or 3) been found at elevated concentrations in sediment
AVS-SEM (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn)	Indicators of biological availability of metals in sediments. If the molar concentration of AVS exceeds the molar concentration of the total SEM, these metals are likely to be tightly bound in insoluble metal sulfide compounds, and therefore unavailable for release into sediment pore water or surface water.
BTEX	Indicator of petroleum compounds
PAHs and phenols	Elevated concentrations found in historical sediment sampling
Organochlorine pesticides/PCBs	Elevated concentrations of PCBs and several organochlorine pesticides found in historical sediment sampling
2,4-D	Used briefly (for about 1 year) in the 1950s at the DuPont facility in the formulation of another chemical product.
Oil and grease	Elevated concentrations found in historical surface water and sediment sampling; indicator of petroleum and general industrial discharges
Phenolics	Elevated concentrations found in historical surface water and sediment sampling
Soluble fluoride	Elevated concentrations found in historical surface water and outfall sampling, indicator of steel mill waste
Total cyanide	Elevated concentrations found in historical industrial outfall sampling
Soluble sulfate	Elevated concentrations found in historical surface water and sediment sampling
Total sulfide	Indicator of oxygen-depleted sediments
Ammonia-nitrogen	Elevated concentration of ammonia found in historical sediment sampling
Total Kjeldahl nitrogen	Elevated concentration of ammonia found in historical sediment sampling
Total phosphorus	Indicator of phosphorus availability
pH	Important for determination of metals and organic compound transport and fate
Total organic carbon	Important for determination of organic compound transport and fate
Grain size	Potential biological effects in sediment

Table 2-2. (cont.)

Constituent of Interest	Rationale
Surface Water	
Total and dissolved metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Zn)	Metals cited in RCRA Corrective Action Order as having 1) been discharged to the river via the DuPont facility's industrial outfalls, 2) been found in groundwater monitoring wells at the DuPont facility at concentrations above MCLs, and/or 3) been found at elevated concentrations in water samples from the onsite wetlands
Fecal coliform bacteria	Indicator of sewage discharges from Gary STP and/or CSOs
BOD	Indicator of sewage discharges from Gary STP and/or CSOs
COD	Indicator of discharges from certain industrial facilities
Oil and grease	Indicator of discharges from petroleum and general industrial facilities
Phenolics	Elevated concentrations found in historical surface water and sediment sampling
Ammonia-nitrogen	Listed in RCRA Corrective Action Order as being elevated in onsite groundwater monitoring wells
Nitrate+nitrite-nitrogen	Listed in RCRA Corrective Action Order as being elevated in onsite groundwater monitoring wells
Total Kjeldahl nitrogen	Increased in concentration between Cline Ave. and Kennedy Ave. in low flow surface water sampling; listed in RCRA Corrective Action Order as being elevated in onsite groundwater monitoring wells
Orthophosphate	Indicator of phosphorus solubility/availability
Total phosphorus	Exceeded water quality standards in low flow sampling; listed in RCRA Corrective Action Order as being elevated in onsite groundwater monitoring wells and allegedly loading to river
Total suspended solids	Found at elevated concentrations in water sampling from industrial/municipal outfalls, CSOs, and storm water outfalls
Hardness	Input parameter for determining exceedance of water quality standards for some metals
pH	Important for determination of metals and organic compound transport and fate
Dissolved oxygen	Low dissolved oxygen concentrations found in historical surface water sampling; indicator of sewage discharges

Note:
AVS - acid-volatile sulifde
BOD - biochemical oxygen demand
BTEX - benzene, toluene, ethylbenzene, and xylenes
COD - chemical oxygen demand
CSO - combined sewer overflow
MCL - maximum contaminant level
PAH - polycyclic aromatic hydrocarbon
PCB - polychlorinated biphenyl
RCRA - Resource Conservation and Recovery Act
SEM - simultaneously extracted metals
STP - sewage treatment plant

sections measured in previous studies of the GCR suggested that sediment deposition patterns in the GCR are likely typical of rivers, with a mix of straight reaches and meander bends. In straight reaches, where downstream flow velocity is highest in the center of the channel, cross sections are symmetric about the centerline and sediments are likely to be preferentially deposited along both channel margins. In meander bends, where the highest flow velocity is at the outside of the bend, sediments are likely to be preferentially deposited on the inside of the bend and scoured on the outside of the bend. Sediment sampling patterns on Transects C and K reflect this asymmetry in the expected pattern of sediment deposition. On these transects, both surface and near-surface sediment samples were collected on the inside of the meander bend, but only surface sediment samples were collected on the outside of the bend.

Further rationale for the location of each of the 11 transects is provided in the work plan (Exponent 1998).

Modifications of the East Branch to accommodate large historical volumes of industrial discharges and the subsequent substantial reductions in the volume of those discharges have likely limited the potential for overbank flooding in the study area. Nevertheless, there is a potential for historical flooding to have resulted in the deposition of sediments in wetland areas adjacent to the river. Therefore, a limited amount of sampling of surface sediments in wetlands in the study area was conducted in areas within the 100-year floodplain (FEMA 1979, 1980). Wetlands on land owned by DuPont were evaluated at two stations, one between Transects B and C (Wetland 1) and one between Transects C and D (Figure 2-5). Wetlands at the Harbison-Walker facility were evaluated at two stations (Wetland 3 and Wetland 4), and wetlands at the U.S.S. Lead facility were evaluated at two stations (Wetland 5 and Wetland 6) (Figure 2-5).

The surface water sampling strategy was predicated upon an understanding of the East Branch developed from reviewing Corps (1997) and current stream flow data for the East Branch at the Industrial Highway gauging station (USGS 1997). Most of the flow in the East Branch comes from industrial and municipal discharges and is therefore dominated

by base flow conditions that fluctuate in response to residential use in Gary and cooling water use at the USX. However, the East Branch is weakly responsive to rainfall events, and CSO discharges occur only during rainfall events. Therefore, surface water sampling was conducted at a single station between Transects B and C (Figure 2-5) during two base flow events and during two rainfall events. Hydraulic measurements designed to gather reach-specific data were conducted to refine the sediment transport model currently being developed by the Corps (1997).

3. Chemical Mass Loading to the East Branch of the Grand Calumet River

An evaluation of chemical loading to the East Branch of the GCR was conducted to provide a better understanding of the processes controlling chemical distributions in the surface water and surface sediment. Ongoing loading of chemicals is of particular interest because sources of problem chemicals must be adequately controlled if sediment remediation is to occur. In the absence of adequate source controls, accumulating particles will recontaminate surface sediment continuing the impairment of beneficial uses. Consequently, source control is a necessary requirement that precedes any sediment remedial action (U.S. EPA 1990).

In the following sections, chemical loadings from point sources in the East Branch are characterized. The chemicals identified as COIs (Exponent 1998) are the focus of the loading assessment. This evaluation is primarily based on data from the PCS database, which only includes data from 1989 to the present. Loading data are not available for earlier times, when industrial activity was in full force and industrial loading was largely unregulated. For these earlier time periods, loading must be inferred from the sediment record, where much of the discharged load may have accumulated. Historical loading as reflected in the sediment record is discussed in Section 4.

The potential for in-place sediment to serve as a source of chemicals to the East Branch is also discussed. An evaluation of groundwater loading is deferred until the RFI is completed.

3.1 Industrial Point Sources and Municipal Sewage Treatment Plants

Waters have been discharged to the GCR system under NPDES permits by 10 industrial facilities and 3 municipal STPs (Figure 2-4). Six of these facilities discharge to the East

Branch of the GCR: USX, the Gary STP, CITGO Petroleum Corp., DuPont, AMG Resources, and Harbison-Walker Refractories. CSOs from the cities of Hammond and East Chicago also discharge to the East Branch. On a volume basis, the largest discharges to the East Branch come from USX and the Gary STP, with much smaller volumes of water discharged by DuPont, CITGO Petroleum, AMG Resources, and Harbison-Walker Refractories.

NPDES monitoring is conducted by the discharging industries for each permitted outfall, and average concentrations or loads are provided to EPA as required by each industry's permit. Effluent limitations are only established for chemical or conventional parameters that are considered to be significant for a particular facility. The data for monitored parameters are added to the PCS database, which is available through the EPA web site (www.epa.gov). These data were used to calculate total loads over the permit periods, to examine trends in loading rates and to establish current loading rates. Discharge data were available in most cases only until January 1998 and were extrapolated to estimate annual loads for 1998. These estimated loads for 1998 were included in the total load calculation, but the current loading rates were based on the data set for 1997, the most recent year for which complete data were available. Available information from the summaries of annual and total loads by month for permitted industries that discharge to the GCR/IHC system is provided in Appendix A.

The NPDES data set for discharges to the GCR system contained several limitations and idiosyncrasies, notably the absence of data for many of the COIs from many of the industries. No data were available for discharges of organic compounds, including PCBs, pesticides, PAHs, and benzene, toluene, ethylbenzene, and xylenes (BTEX); thus, loading rates for these compounds could not be established. The substances most commonly monitored were TSS and oil and grease. Monitoring for metals was not usually required or completed. On the East Branch, metals were monitored only by the Gary STP (arsenic, total and hexavalent chromium, copper, lead, mercury, and zinc) and by USX (total chromium, lead, and zinc). Despite these limitations, the data provide a useful indication of chemical loads to the East Branch and associated sources.

NPDES discharge data were not available for every industry that discharged into the GCR/IHC system, including two important industries that historically discharged into the East Branch: U.S.S. Lead and Industrial Disposal. U.S.S. Lead operated a large facility on property adjacent and west of DuPont. U.S.S. Lead ceased operation in 1985 and has been in the process of closing the facility for the last several years. Its discharge permit expired in February 1995 (IDEM 1996). Industrial Disposal is located upstream of DuPont and constitutes a potential source of COIs to sediment near the DuPont facility. A summary of substances that were monitored by each East permittee, not all of which are industries, is provided in Table 3-1. Data were not available for permittees that are not included in this list, and loading contributions by these permittees could not be included in the calculations for annual and total loads.

Records in the PCS database were entered as concentrations in the effluent (e.g., mg/L), loading rates (e.g., lb/day), or both. When both types of information were provided, preference was given to data presented as loading rates. Loading rates were available only from 1989 to January 1998, and the time span was smaller in some cases. Data were available for fewer than 12 months of a year in some instances, and in these cases, the annual load was adjusted upward based on the number of months for which data were available.

When an analyte was not detected, half the detection limit was used to calculate loads. The presence of detection limits necessarily creates some degree of inaccuracy in the calculation of loading rates and total loads. A concentration of zero may be assumed when a substance is not detected, but this assumption results in a loading rate that is too low when the substance is indeed present, as is likely when the analyte is detected during a portion of the monitoring events. If the detection limit is used as the analyte concentration, the loading rate will almost certainly be too high. The assumption that the analyte is present at half the detection limit constitutes a compromise between these extremes. However, maximum loads were also calculated using the full detection limit

Table 3-1. Available information from the PCS database for East Branch industries

NPDES Number	Facility	Parameter	Years
IN0050563	AMG Resources Corporation	Flow	1989 – 1997
IN0050563	AMG Resources Corporation	Oil/Grease	1989 – 1997
IN0050563	AMG Resources Corporation	TDS	1989 – 1997
IN0050563	AMG Resources Corporation	TSS	1989 – 1997
IN0000159	CITGO Petroleum Corp.	Flow	1989 – 1995
IN0000159	CITGO Petroleum Corp.	Oil/Grease	1989 – 1995
IN0000159	CITGO Petroleum Corp.	Lead	1989 – 1995
IN0000329	E.I. DuPont de Nemours	Flow	1989 – 1998
IN0000329	E.I. DuPont de Nemours	TDS	1989 – 1998
IN0000329	E.I. DuPont de Nemours	TSS	1989 – 1998
IN0022977	Gary STP	Arsenic	1988 – 1998
IN0022977	Gary STP	Chromium	1988 – 1998
IN0022977	Gary STP	Chromium(VI)	1994 – 1998
IN0022977	Gary STP	Copper	1988 – 1998
IN0022977	Gary STP	Flow	1988 – 1998
IN0022977	Gary STP	Mercury	1988 – 1998
IN0022977	Gary STP	Oil/Grease	1988 – 1998
IN0022977	Gary STP	Lead	1988 – 1998
IN0022977	Gary STP	TDS	1988 – 1998
IN0022977	Gary STP	TSS	1988 – 1998
IN0022977	Gary STP	Zinc	1987 – 1994
IN0000248	Harbison-Walker Refractories	Flow	1993 – 1998
IN0000248	Harbison-Walker Refractories	Oil/Grease	1993 – 1998
IN0000281	U.S. Steel – Gary Works, USX C	Chromium	1994 – 1997
IN0000281	U.S. Steel – Gary Works, USX C	Flow	1989 – 1999
IN0000281	U.S. Steel – Gary Works, USX C	Oil/Grease	1989 – 1997
IN0000281	U.S. Steel – Gary Works, USX C	Lead	1989 – 1997
IN0000281	U.S. Steel – Gary Works, USX C	TSS	1989 – 1997
IN0000281	U.S. Steel – Gary Works, USX C	Zinc	1983 – 1996

Note: NPDES - National Pollutant Discharge Elimination System
PCS - permit compliance system
STP - sewage treatment plant
TDS - total dissolved solids
TSS - total suspended solids

when a COI was undetected in most of the monitoring samples. The instances where this procedure was used are clearly described in the text.

Current loading rates, represented by loading data for 1997, are provided in Table 3-2. Summaries of total loads and annual loading rates for measured substances discharged to the East Branch are provided in Appendix A (Tables A-1 and A-2) and discussed in the following sections. In the following discussion, loading values are generally expressed to a maximum of three significant figures.

3.1.1 Flow

By far the largest sources of discharge to the East Branch are the 13 outfalls associated with USX. This facility produces iron and steel products, coke, and coal-related chemicals. According to NPDES monitoring data, approximately 520 mgd of treated process water and noncontact cooling water was discharged daily in 1989, the first year for which NPDES data were available. The annual average flow rate for USX has decreased somewhat since that time to an average rate of 377 mgd in 1997 (Figure 3-1).

Overall, the discharge rate for the Gary STP is approximately 10 percent of USX's rate. The discharge rate for the Gary STP has fluctuated from 40 mgd (in 1992) to 55 mgd (in 1993) without a clear increasing or decreasing trend. Approximately 45 mgd was discharged in 1989 and 42 mgd in 1997. The combined flow of the four minor industrial dischargers to the East Branch has generally remained close to 1 mgd. Discharges from DuPont remained fairly constant from 1989 to 1996, averaging 0.41 mgd over this time period, but increased to 0.73 mgd in 1997. Annual average discharge rates to the East Branch are provided in Appendix A (Table A-3).

Table 3-2. Estimated current loading rates to the East Branch

Material	Year	AMG Resources Corp.	CITGO Petroleum Corp.	E.I. DuPont de Nemours	Gary STP	Harbison-Walker Refractories	U.S. Steel – Gary Works, USX C	Total
TSS (kg)	1997	4,840		54,000	106,000		118,000	283,000
Oil/Grease (kg)	1997	698			243,000	346	137,000	381,000
Arsenic (kg)	1997				158			158
Chromium (kg)	1997				265		352	617
Chromium(VI) (kg)	1997				457			457
Copper (kg)	1997				1,130			1,130
Mercury (kg)	1997				8			8
Lead (kg)	1997				653		546	1,200
Zinc (kg)	1996						169	169

Note: STP - sewage treatment plant
TSS - total suspended solids

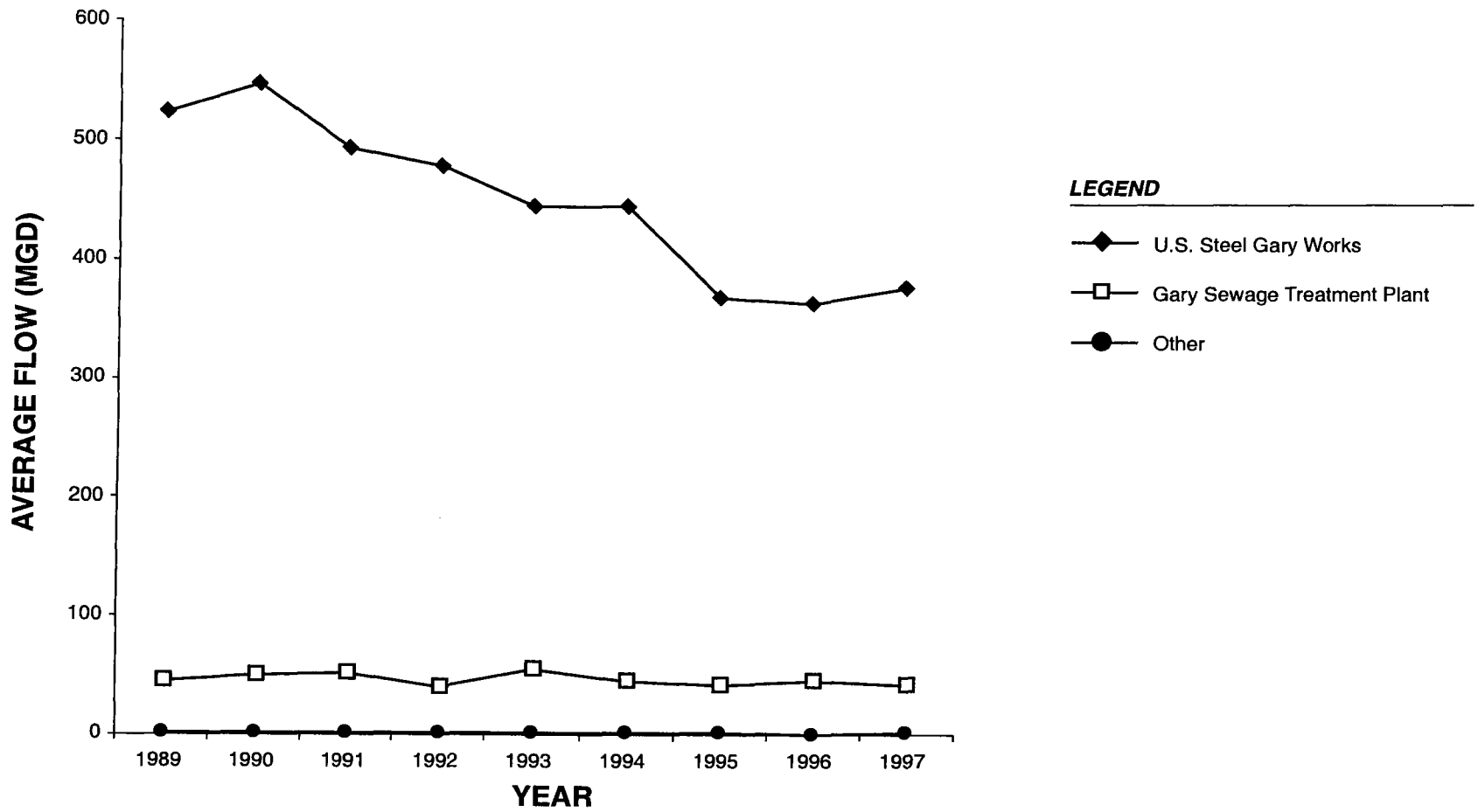

Figure 3-1.
DISCHARGES UNDER NPDES PERMIT.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

3.1.2 Oil and Grease

Oil and grease has been discharged to the East Branch by AMG Resources, CITGO Petroleum, the Gary STP, Harbison-Walker Refractories, and USX. The total load of oil and grease discharged to the East Branch under NPDES permits from 1989 through 1998 was approximately 18,000,000 kg (Table A-1 in Appendix A). The annual loading rates for oil and grease have decreased overall for the main dischargers, the Gary STP and USX, over the course of their permit periods (Figure 3-2). In 1997, the total oil and grease load to the East Branch was approximately 381,000 kg. The largest contributions came from Gary STP and USX, at 243,000 and 137,000 kg, respectively.

The oil and grease load from USX is somewhat uncertain because oil and grease was reported as undetected for more than half of the records for USX. It is possible that the calculated oil and grease output is actually too low because oil and grease was usually detected for a portion of the monitoring periods at each outfall and may well have been present at levels above half the detection limit when it was reported as undetected. Calculations using the full detection limit rather than half the detection limit yield a maximum total load of approximately 13,700,000 kg of oil and grease discharged by USX from 1989 through 1997. Oil and grease levels were always measurable for the Gary STP.

3.1.3 Total Suspended Solids

Permitted discharges of TSS have been released to the East Branch by AMG Resources, DuPont, the Gary STP, and USX. The total permitted load discharged to the East Branch from 1989 through 1998 was approximately 8,900,000 kg (Table A-1 in Appendix A). The annual loading rates for TSS have decreased substantially from 1989 and 1990 to 1998 for the two largest dischargers, the Gary STP and USX (Figure 3-3). In 1997, the TSS load to the East Branch was 283,000 kg, with the largest loads still discharged by USX and the Gary STP, at 118,000 (42 percent) and 106,000 kg (37 percent),

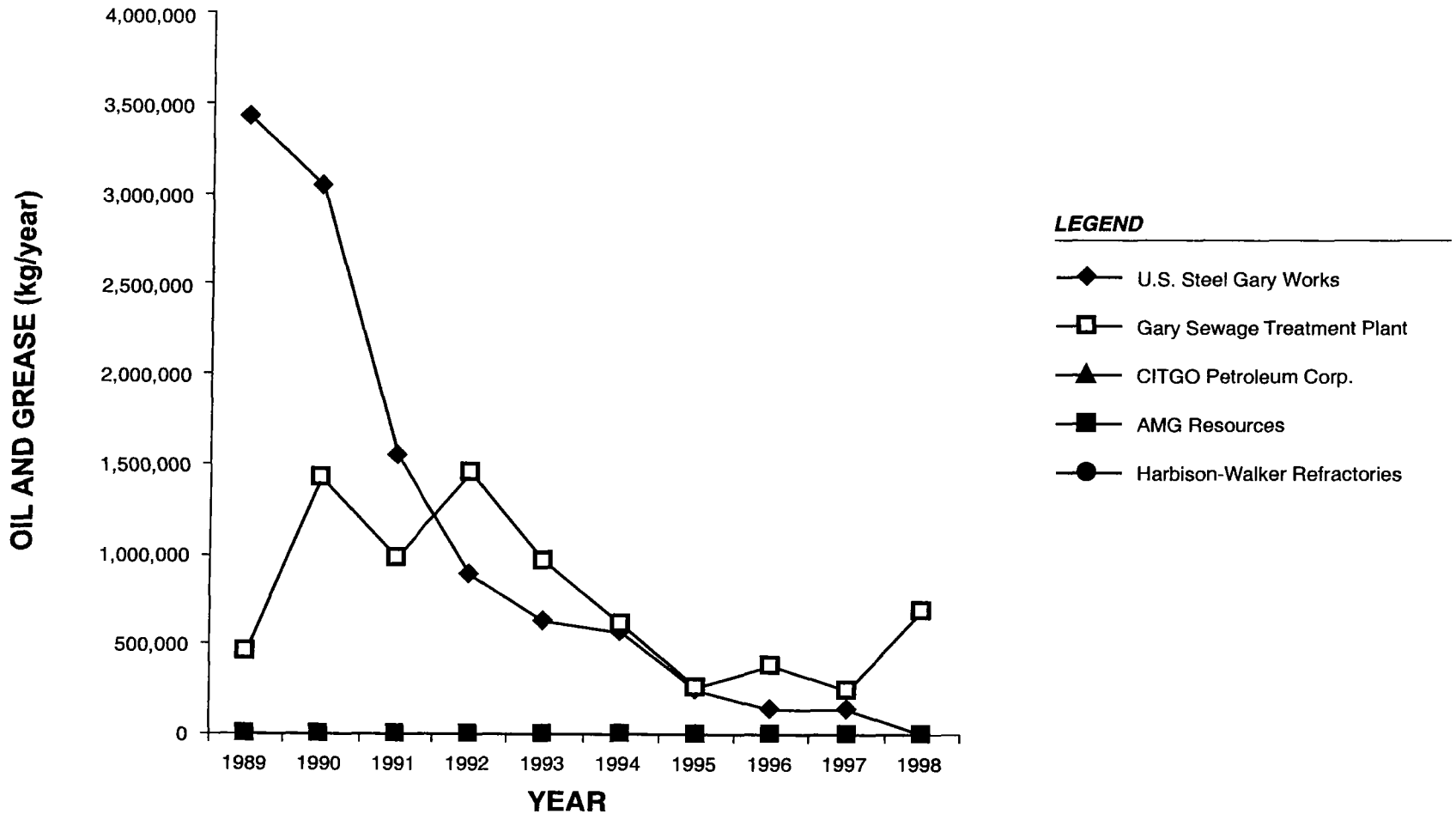

Figure 3-2.
OIL AND GREASE LOADING TO THE EAST BRANCH BETWEEN 1989 AND 1998.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

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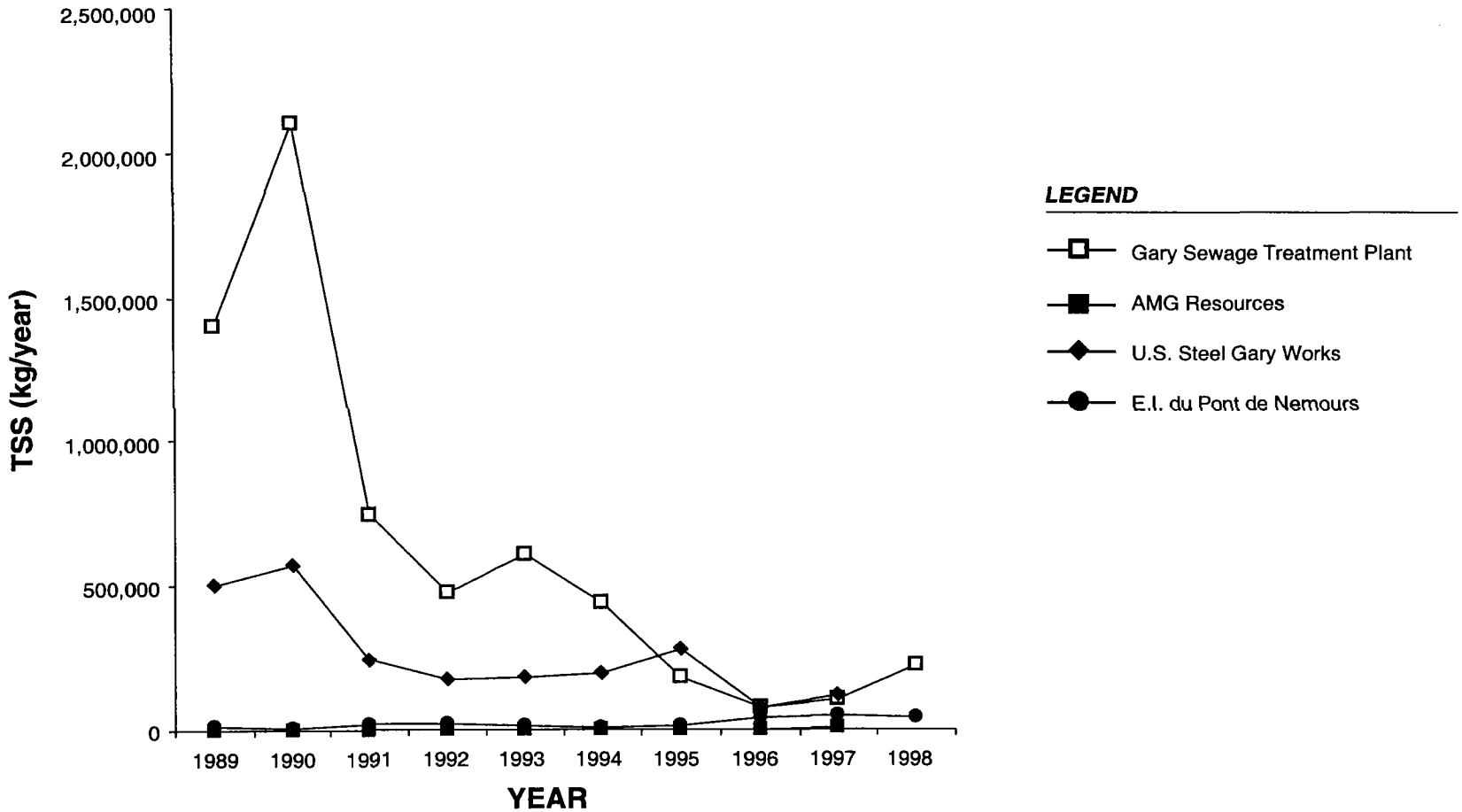

Figure 3-3.
TOTAL SUSPENDED SOLIDS LOADING TO THE EAST BRANCH BETWEEN 1989 AND 1998.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 09/16/99
Prepared by: Betty Dowd

Exponent

respectively. DuPont experienced a step increase in the annual load of TSS, from 12,900 kg in 1995 to 43,000 kg in 1996. The loads remained at the higher level in 1997 (46,200 kg) and 1998 (39,600 kg), resulting in a relative contribution of approximately 17 percent of the total load of TSS to the East Branch for 1997.

3.1.4 Arsenic

Only the Gary STP monitored arsenic releases to the East Branch. Data were reported from 1994 through January 1998, and 67 percent of the reported readings were below the detection limit. When arsenic was detected, it was generally present at concentrations at or slightly above the detection limit. It is therefore possible that arsenic was present at concentrations only slightly below the detection limit when it was not detected. The maximum total reported release of arsenic from 1994 to 1998, calculated using the full value of the detection limit, was probably close to 1,800 kg. The annual loading rate, calculated using the full value of the detection limit, has decreased sharply, from 775 kg in 1994 to 208 kg in 1997. Use of half the detection limit for load calculations results in a total load of approximately 1,300 kg from 1994 to 1998 and an annual load of 158 kg in 1997.

3.1.5 Total and Hexavalent Chromium

Chromium is monitored in the discharges to the East Branch from the Gary STP and USX. The total chromium load discharged by these sources from 1989 through 1998 was approximately 9,000 kg. Data for USX were available only from November 1994 through 1997, and only for one outfall (34A). Chromium was detected in the discharge from that outfall at concentrations close to the detection limit in November 1994 and from February through July 1995. Assuming release levels at half the detection limit, a total of approximately 1,800 kg of chromium was released by USX from 1994 through 1997. More than 75 percent of the measurements made for the Gary STP resulted in

detected levels of chromium. The annual chromium loading rates have decreased for the Gary STP, from 2,027 kg in 1989 to 265 kg in 1997.

The Gary STP is the only facility that holds a permit to discharge hexavalent chromium. Hexavalent chromium was detected for only 15 of the 40 monitoring events, always at or only slightly above the detection limit. Based on this limited information and assuming concentrations at half the detection limit when hexavalent chromium was not detected, approximately 2,500 kg of hexavalent chromium was released from the Gary STP during the period from 1995 through 1998. The total annual release declined from 823 kg in 1994 to 457 kg in 1997. The calculated annual loading rates for hexavalent chromium are consistently higher than the total chromium loads for the Gary STP. This is an artifact that results from higher detection limits for hexavalent chromium than for total chromium and indicates that the hexavalent chromium load is likely to be lower than estimated.

3.1.6 Copper

The only permitted source of copper to the East Branch is the Gary STP, which released approximately 20,000 kg from 1989 through 1998. The annual copper loading rates have decreased overall during the course of the permit period, from a maximum of 4,750 kg in 1990 to 1,130 kg in 1997. These loading rates are likely to be relatively accurate within the given time frames because copper was undetected for only 6 of the 104 measurements used to calculate the load.

3.1.7 Mercury

The Gary STP holds the only permit to discharge mercury to the East Branch. A total of approximately 150 kg was released by the Gary STP from 1989 through 1998. The annual mercury loading rates (based on half the detection limit) have fluctuated over the

course of the permit period but have decreased overall from a maximum of 30 kg in 1990 to a release of 8 kg in 1997. Mercury was not detected in approximately 30 percent of the samples and was usually detected at concentrations close to the detection limit. In 1997, mercury was detected in only two of the monthly samples. Maximum loads, based on calculations using detection limits at their full value, would be a total of 164 kg for the period 1989 through 1998 and 11 kg for 1997.

3.1.8 Lead

Lead is monitored in the discharges from the Gary STP and USX. The lead load discharged by the Gary STP from 1989 through 1998 was approximately 8,600 kg. Lead was detected in more than 80 percent of the monitoring samples collected for this facility. The annual loading rate for lead has decreased for the Gary STP over the course of the permit period from the maximum of 2,830 kg in 1990 to 653 kg in 1997. Lead was undetected in more than 90 percent of the discharge samples for USX, and the concentrations were generally close to the detection limit when lead was measured. The lead load (using half the detection limit) from USX was approximately 2,900 kg for the period 1989 through 1998 and 546 kg in 1997. Assuming lead concentrations at the detection limit, a maximum of 5,200 kg could have been released from USX from 1989 through 1997, with a maximum annual release of 1,100 kg in 1997.

3.1.9 Zinc

The NPDES data set for zinc is quite patchy. Zinc was monitored at various times from 1983 through 1996 by the Gary STP and USX. Total discharges for the Gary STP were 14,600 kg for the year 1994. No other monitoring data were available for this facility. Zinc was not detected in approximately two-thirds of the monitoring samples for USX. Using detection limits at their full value, the maximum load from USX would be

13,000 kg for the years 1983 and 1994 through 1996. No data for zinc discharges were available for 1997. The USX load for 1996 was 169 kg.

3.2 Combined Sewer Overflows and Storm Drains

An estimated 11 billion gallons per year of raw wastewater is discharged into the GCR System through approximately 14 CSOs (IDEM 1991). Nine of these CSOs are located on the East Branch (Figure 2-4). Eight of the outfalls, from either the Gary or East Chicago sanitation districts, are located upstream of the DuPont plant, while the single CSO associated with the Hammond Sanitary District is located just downstream of the DuPont plant at Kennedy Avenue. It is estimated that 57 percent of the volume discharged from CSOs occurs from discharge points east of Cline Avenue. In addition to CSOs, storm water runoff contributes an unquantified volume of discharge to the river during rainfall events, primarily through numerous drain pipes, ditches, and weirs located along the river. The exact number of these outfalls has not been determined, but at least 23 have been identified (IDEM 1993).

IDEM collected 41 water samples from 9 CSOs and 14 storm water outfalls on the river during 7 rainfall events in June, July, and August of 1993 (IDEM 1993). The majority of the stations were located on the East Branch. The samples were analyzed for metals, oil and grease, total phenols, nutrients, and conventional parameters; the samples were also tested for acute toxicity to *Ceriodaphnia dubia* (a cladoceran) and *Pimephales promelas* (fathead minnow). Results of the toxicity testing for East Branch samples are presented in Table 3-3, and analytical results are summarized in Table 3-4. Although many measured parameters are elevated at various stations during each of the seven monitoring events, there is no consistent pattern in chemical elevations and toxic response, suggesting that the measured parameters in Table 3-4 may not be responsible for the acute toxicity of the five samples in Table 3-3.

Table 3-3. Summary of toxicity results for combined sewer overflow and storm water outfall sampling at the Grand Calumet River, summer 1993

Site ID	Sample Site Location	Discharge Type	Number of Samples	Number of Toxic Samples	Number of Slightly Toxic Samples
G	145th St. pump station	CSO	2	0	0
H	Gary Airport ditch	SWO	2	1	0
J	Gary Airport runway sewer	SWO	1	0	0
K	Gary Airport Toll Road	SWO	3	0	0
L	Toll Road at Airport	SWO	2	0	0
M	Gary S.D. Rhode Island St.	CSO	2	2	0
O	Gary S.D. Polk St. CSO	CSO	2	0	1
P	Gary S.D. Pierce St. CSO	CSO	1	0	0
Q	Gary S.D. Bridge St. CSO	CSO	1	0	0
R	Gary S.D. Chase St. CSO	CSO	2	1	1
S	Gary S.D. Colfax St. CSO	CSO	2	1	0
T	East of Broadway near USX	SWO	2	0	0
U	West of Broadway near USX	SWO	2	0	1
V	Gary Airport at I-90	SWO	2	0	0
W	Exit 13 I-90	SWO	2	0	0
X	USX	SWO	1	0	0
AA	I-90 at Cline Avenue	SWO	2	0	1
CC	Cline Avenue access road	SWO	2	0	1

Source: IDEM (1993)

Note: CSO - combined sewer overflow
SWO - storm water outfall

Table 3-4. Analytical results for combined sewer overflow and storm water outfall sampling at the Grand Calumet River, summer 1993

Site ID	Location	Date	Alkalinity (mg/L $CaCO_3$)	Aluminum (mg/L)	Arsenic (mg/L)	Cadmium (mg/L)	Calcium (mg/L)	Carbonaceous Biochemical Oxygen Demand (mg/L)	Chemical Oxygen Demand (mg/L)
G	145th St. pump station CSO	08/19/93	130	0.187	<0.005	<0.005	42.2	4.34	17.4
		08/23/93	300	0.129	<0.005	<0.005	120	17.1	<15.0
H	Gary Airport ditch	06/24/93	290	0.0372	0.0053	<0.005	95.1	<5.60	29.8
		07/25/93	265	0.0272	<0.005	<0.005	95.2	<2.0	45.3
J	Gary Airport runway sewer	06/24/93	300	0.0212	0.0076	<0.005	88.5	<5.60	26.7
K	Gary Airport Toll Road	06/24/93	370	0.0457	<0.005	<0.005	121	<5.60	20.5
		07/25/93	330	0.0329	<0.005	<0.005	113	<2.0	26.7
		08/19/93	305	0.033	0.0058	<0.005	98.7	<2.00	23.6
L	Toll Road at Airport	07/13/93	201	0.0243	<0.005	<0.005	25.5	<2.00	51.4
		08/06/93	270	0.127	<0.005	<0.005	12.2	<2.00	60.7
M	Gary S.D. Rhode Island St.	06/24/93	230	0.153	<0.005	<0.005	57.1	20	70
		07/25/93	160	0.281	<0.005	<0.005	46	84.4	175
O	Gary S.D. Polk St. CSO	07/25/93	55	1.12	<0.005	<0.005	19.9	41.4	144
		08/06/93	50	0.619	<0.005	<0.005	11.2	14.9	94.7
P	Gary S.D. Pierce St. CSO	07/25/93	60	0.552	<0.005	<0.005	18.3	20.4	119
Q	Gary S.D. Bridge St. CSO	08/06/93	110	0.11	<0.005	<0.005	31.9	<2.00	<15.0
R	Gary S.D. Chase St. CSO	07/18/93	205	0.179	<0.005	<0.005	43.3	47.1	150
		07/25/93	80	0.355	<0.005	<0.005	20.1	21.4	79.3
S	Gary S.D. Colfax St. CSO	08/19/93	118	0.777	<0.005	<0.005	29.1	26.7	91.6
		07/25/93	80	1.84	0.0066	<0.005	42.8	20.4	256
T	East of Broadway near USX	07/18/93	25	0.167	<0.005	<0.005	13.5	4.8	32.9
		07/25/93	25	1.69	<0.005	<0.005	22.1	6.87	73.1
U	West of Broadway near USX	07/13/93	46	0.124	<0.005	<0.005	22.4	14.7	104
		07/18/93	40	0.183	<0.005	<0.005	10.4	6.02	36
V	Gary Airport at I-90	07/13/93	177	0.0439	<0.005	<0.005	56.8	<2.00	26.7
		07/18/93	165	0.0433	<0.005	<0.005	56.7	<2.00	29.8
W	Exit 13 I-90	07/13/93	41	0.123	<0.005	<0.005	24	12.4	150
		07/18/93	45	0.0663	<0.005	<0.005	14.9	6.04	63.8
X	USX	08/23/93	60	6.09	0.0099	0.006	42.8	12.6	1,167
AA	I-90 at Cline Avenue	08/06/93	100	0.138	<0.005	<0.005	38.9	<2.00	<15.0
		08/19/93	115	0.453	<0.005	<0.005	31.3	21.9	66.9
CC	Cline Avenue access road	08/06/93	120	0.161	<0.005	<0.005	37.9	<2.00	<15.0
		08/19/93	115	0.0148	<0.005	<0.005	39.4	2.92	<15.0

Table 3-4. (cont.)

Site ID	Location	Date	Chloride (mg/L)	Chromium (mg/L)	Copper (mg/L)	Total Cyanide (mg/L)	Oil and Grease (mg/L)	Hardness (mg/L $CaCO_3$)	Lead (mg/L)
G	145th St. pump station CSO	08/19/93	49.48	<0.010	<0.010	<0.010	<2.00	149	0.0059
		08/23/93	56.98	<0.010	<0.010	<0.010	<2.00	382	<0.005
H	Gary Airport ditch	06/24/93	160	<0.010	<0.010	<0.010	<2.00	314.9	<0.100
		07/25/93	202	<0.010	<0.010	<0.010	<2.00 J	321.7	<0.005
J	Gary Airport runway sewer	06/24/93	75	<0.010	<0.010	<0.010	<2.00	291.4	<0.005
K	Gary Airport Toll Road	06/24/93	20	<0.010	<0.010	<0.010	<2.00	394	<0.100
		07/25/93	13	0.011	<0.010	<0.010	<2.00 J	362.5	<0.005
		08/19/93	11.5	<0.010	<0.010	0.011	<2.00	308.3	<0.005
L	Toll Road at Airport	07/13/93	530	<0.010	<0.010	<0.010	<2.00	195.9	<0.005
		08/06/93	77.5	<0.010	<0.010	<0.010	<2.00	231.8	<0.005
M	Gary S.D. Rhode Island St.	06/24/93	111	<0.010	<0.014	<0.010	<2.00	202.7	<0.100
		07/25/93	89	<0.010	<0.010	<0.010	2.758 J	162.2	0.0088
O	Gary S.D. Polk St. CSO	07/25/93	15	<0.010	0.012	<0.010	9.136 J	70.6	0.0539
		08/06/93	8.5	<0.010	0.013	<0.010	4.66	37.9	0.0216
P	Gary S.D. Pierce St. CSO	07/25/93	27	<0.010	<0.010	<0.010	3.898 J	63.4	0.0172
Q	Gary S.D. Bridge St. CSO	08/06/93	18.5	<0.010	0.012	<0.010	<2.00	120.8	<0.005
R	Gary S.D. Chase St. CSO	07/17/93	93	<0.010	0.011	<0.010	6.437 J	162.9	<0.005
		07/25/93	31	<0.010	<0.010	<0.010	2.471 J	71.8	0.0269
S	Gary S.D. Colfax St. CSO	08/19/93	3.5	<0.010	0.016	<0.010	3.29	101.7	0.0086
		07/25/93	23	<0.010	<0.010	<0.010	8.194 J	151.3	0.0844
T	East of Broadway near USX	07/18/93	38	<0.010	<0.010	<0.010	<2.00 J	40.1	0.0064
		07/25/93	12	0.014	0.016	<0.010	2.557 J	70.4	0.0649
U	West of Broadway near USX	07/13/93	44	<0.010	0.014	<0.010	3.55	65.2	0.0062
		07/18/93	8	<0.010	<0.010	<0.010	4.146 J	32.2	0.0065
V	Gary Airport at I-90	07/13/93	320	<0.010	<0.010	<0.010	<2.00	191.7	<0.005
		07/18/93	287	<0.010	<0.010	<0.010	<2.00 J	192.6	<0.005
W	Exit 13 I-90	07/13/93	11	<0.010	0.023	0.01	<2.00	75.1	0.0062
		07/18/93	7	<0.010	0.013	<0.010	<2.00 J	48.9	<0.005
X	USX	08/23/93	30	0.03	0.215	0.082	2.84	133.3	0.319
AA	I-90 at Cline Avenue	08/06/93	48.7	<0.010	<0.010	<0.010	<2.00	141.2	<0.005
		08/19/93	32.5	<0.010	0.012	<0.010	2.36	108.3	0.0086
CC	Cline Avenue access road	08/06/93	47.5	<0.010	<0.010	<0.010	<2.00	137.9	<0.005
		08/19/83	40.49	<0.010	<0.010	<0.010	<2.00	142	<0.005

Table 3-4. (cont.)

Site ID	Location	Date	Magnesium (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Nitrate-Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrogen-Ammonia (mg/L)	Total Kjeldahl Nitrogen (mg/L)	pH (pH units)
G	145th St. pump station CSO	08/19/93	10.6	<0.0005	<0.20	1	<0.20	0.39	1.09	7.69
		08/23/93	20	<0.0005	<0.20	1.34	<0.20	0.2	0.69	7.76
H	Gary Airport ditch	06/24/93	18.8	<0.0005	<0.020	0.47	<0.20	7.8	9.21	7.82
		07/25/93	20.4	<0.0005	<0.20	0.83	<0.20	6.41	8.21	7.63
J	Gary Airport runway sewer	06/24/93	17.1	<0.0005	<0.020	0.52	<0.20	0.55	0.87	7.84
K	Gary Airport Toll Road	06/24/93	22.3	<0.0005	<0.020	<0.20	<0.20	0.21	0.36	7.71
		07/25/93	19.5	<0.0005	<0.20	<0.20	<0.20	0.29	<0.50	7.55
		08/19/93	15	<0.0005	<0.20	<0.20	<0.20	0.9	1.23	7.41
L	Toll Road at Airport	07/13/93	32.1	<0.0005	0.067	0.43	<0.20	0.36	2.54	7.34
		08/06/93	48.9	<0.0005	0.105	<0.20	<0.20	<0.20	1.88	7.83
M	Gary S.D. Rhode Island St.	06/24/93	14.6	<0.0005	<0.020	<0.20	<0.20	4.64	8.75	7.47
		07/25/93	11.5	<0.0005	<0.20	<0.20	<0.20	3.28	8.81	7.01
O	Gary S.D. Polk St. CSO	07/25/93	5.07	<0.0005	<0.020	0.3	<0.20	0.3	4.26	7.05
		08/06/93	2.41	<0.0005	<0.20	0.87	<0.20	0.68	2.66	7.28
P	Gary S.D. Pierce St. CSO	07/25/93	4.3	<0.0005	<0.020	1.01	<0.20	1.94	5.26	7.14
Q	Gary S.D. Bridge St. CSO	08/06/93	10	<0.0005	<0.20	0.41	<0.20	0.5	<0.50	7.98
R	Gary S.D. Chase St. CSO	07/17/93	13.3	<0.0005	<0.20	<0.20	<0.20	10.3	16.7	7.19
		07/25/93	5.25	<0.0005	<0.20	0.5	<0.20	3.15	5.78	7.25
S	Gary S.D. Colfax St. CSO	08/19/93	7.04	<0.0005	<0.20	<0.20	0.24	3.05	5.82	7.21
		07/25/93	10.8	<0.0005	<0.20	0.54	<0.20	1.75	8.36	7.61
T	East of Broadway near USX	07/18/93	1.56	<0.0005	<0.20	0.83	<0.20	<0.20	<0.50	7.86
		07/25/93	3.7	<0.0005	<0.20	0.6	<0.20	<0.20	<0.50	8.57
U	West of Broadway near USX	07/13/93	2.25	<0.0005	<0.020	1.62	<0.20	0.31	1.22	7.16
		07/18/93	1.51	<0.0005	<0.20	0.6	<0.20	<0.20	<0.50	7.49
V	Gary Airport at I-90	07/13/93	12.1	<0.0005	<0.020	0.74	<0.20	<0.20	0.9	7.96
		07/18/93	12.4	<0.0005	<0.20	1.22	<0.20	<0.20	0.93	7.63
W	Exit 13 I-90	07/13/93	3.69	<0.0005	<0.020	2.21	<0.20	0.49	2.29	7.11
		07/18/93	2.85	<0.0005	<0.20	1.43	<0.20	<0.20	0.52	7.48
X	USX	08/23/93	6.42	0.0033	<0.20	0.61	<0.20	0.3	7.16	7.23
AA	I-90 at Cline Avenue	08/06/93	10.7	<0.0005	<0.20	1.25	<0.20	0.46	0.66	7.82
		08/19/93	7.33	<0.0005	<0.20	1.19	<0.20	2.4	4.14	7.74
CC	Cline Avenue access road	08/06/93	10.5	<0.0005	<0.20	1.18	<0.20	0.32	<0.50	7.76
		08/19/83	10.6	<0.0005	<0.20	1.87	<0.20	0.33	0.81	7.58

Table 3-4. (cont.)

Site ID	Location	Recoverable Phenolics (mg/L)	Total Phosphorus (mg/L)	Selenium (mg/L)	Sulfate (mg/L)	Total Organic Carbon (mg/L)	Total Suspended Solids (mg/L)	Zinc (mg/L)
G	145th St. pump station CSO	LE	<0.20	<0.005	43.7	5.27	21	0.129
		<0.02	<0.20	<0.005	186	10.04	12	0.143
H	Gary Airport ditch	0.065	<0.20	<0.005	120	19.52	<10.0	<0.020
		<0.02	<0.20	<0.005	86.2 *J*	19.64	<10.0	0.067
J	Gary Airport runway sewer	<0.02	<0.20	<0.005	76	20.08	11	0.078
K	Gary Airport Toll Road	<0.02	<0.20	<0.005	197	60.11	<10.0	0.04
		<0.02	<0.20	<0.005	135	23.71	<10.0	0.061
		<0.02	<0.20	<0.005	111	30.42	27	0.126
L	Toll Road at Airport	<0.03	<0.20	<0.005	193	24.35	<10.0	0.201
		<0.02	<0.20	<0.005	362	32.32	37	0.049
M	Gary S.D. Rhode Island St.	<0.02	0.88	<0.005	47.9	50.16	13	0.068
		0.034	1.07	<0.005	47.8	60.85	40	0.144
O	Gary S.D. Polk St. CSO	0.097	0.9	<0.005	12.6	19.73	140	0.232
		0.0517	0.83	<0.005	13	15.99	38	0.148
P	Gary S.D. Pierce St. CSO	0.07	0.66	<0.005	19.6	29.2	20	0.131
Q	Gary S.D. Bridge St. CSO	<0.02	<0.20	<0.005	24.6	8.502	<0.10	0.06
R	Gary S.D. Chase St. CSO	1.106	1.88	<0.005	23.2	50.68	22	0.136
		0.076	0.65	<0.005	17	24.77	14	0.096
S	Gary S.D. Colfax St. CSO	0.061	0.62	<0.005	31.2	28.96	69	0.187
		0.142	1.33	0.0057	19.3	18.92	232	0.266
T	East of Broadway near USX	0.07	<0.20	<0.005	19.2	10.43	<10.0	0.119
		0.043	<0.20	<0.005	19.6	10.98	36	0.329
U	West of Broadway near USX	0.0568	<0.20	<0.005	50.6	30.43	<10.0	0.387
		0.034	<0.20	<0.005	9.7	10.27	<10.0	0.104
V	Gary Airport at I-90	0.0378	<0.20	<0.005	41.8	12.72	<10.0	0.438
		0.02	<0.20	<0.005	39.7	17.84	<10.0	0.082
W	Exit 13 I-90	0.0568	<0.20	<0.005	32.1	44.32	<10.0	0.36
		0.052	<0.20	<0.005	16.5	22.72	<10.0	0.07
X	USX	0.0427	1.41	<0.005	63.8	15.25	864	0.884
AA	I-90 at Cline Avenue	<0.02	<0.20	<0.005	32.6	9.177	<0.10	0.065
		<0.02	0.34	<0.005	30.3	18.36	58	0.141
CC	Cline Avenue access road	<0.02	<0.20	<0.005	34.1	11.54	<0.10	0.062
		<0.02	<0.20	<0.005	34.1	9.62	11	0.196

Source: IDEM (1993)

Note: CSO - combined sewer overflow
J - estimated

3.3 DuPont Sources

Loading of COIs from DuPont's permitted outfalls is described above. None of the COIs identified for the SCS are associated with current DuPont activities or are included in DuPont's existing NPDES permit. In this section, the permitted releases from DuPont are briefly described.

DuPont has discharged treated effluent under its NPDES permit since 1974. DuPont applied for a renewal of this permit in 1989, but no action was taken by EPA. DuPont once again applied for a renewal of this permit in 1998, and negotiations with EPA on the terms of the renewed permit are continuing. Currently, the existing NPDES permit limits discharges of sulfate, ammonia, BOD, chemical oxygen demand (COD), TSS, TDS, and chlorides. Based on a review of monitoring data for the DuPont facility, EPA has concluded that BOD, chlorides, and ammonia do not exhibit a reasonable potential to exceed water quality standards and has therefore proposed removal of these parameters from the permit. On the contrary, EPA has determined that aluminum, copper, mercury, zinc, and total residual chlorine (all of which were not subject to discharge limits in the existing permit) exhibit the reasonable potential to exceed water quality standards and has therefore proposed limits on their discharge and intends to require that these parameters be monitored for a minimum 2-year period. At the end of that period, DuPont may request a review of these parameters and, if they are found not to have a reasonable potential to exceed water quality standards, they may be removed from the permit.

NPDES monitoring data for the years 1989 through 1997 were obtained from the PCS database that is maintained by EPA for the NPDES program. DuPont (Hwang 1999, pers. comm.) supplied NPDES monitoring data for 1997 and 1998. Monitoring data were not available for discharges that occurred prior to 1989.

Annual loading rates for sulfate, chloride, TSS, and TDS follow a similar pattern (Table 3-5). The annual loads for these parameters increased from 1989 to 1991, decreased from then until 1994, and increased once more to a 1997 maximum. Loading

Table 3-5. Annual discharges by DuPont from 1989 through 1998

Year	Chloride (kg)	COD (kg)	Ammonia-Nitrogen (kg)	Sulfate (kg)	TDS (kg)	TSS (kg)	BOD (kg)
PCS Data							
1989	10,700	3,700	15	2,530,000	3,390,000	10,600	1,020
1990	23,700	3,200	75	2,980,000	4,590,000	9,740	900
1991	29,500	5,250	128	4,030,000	6,690,000	19,000	1,100
1992	9,610	4,200	130	4,300,000	6,070,000	18,200	1,300
1993	7,050	5,510	138	3,310,000	5,150,000	12,400	1,230
1994	5,730	6,460	208	2,910,000	5,580,000	6,880	1,260
1995	8,300	4,510	158	4,010,000	5,890,000	12,900	1,210
1996	17,300	10,000	206	3,890,000	5,790,000	43,000	1,760
Data provided by DuPont							
1997	20,500	10,600	431	5,020,000	7,200,000	46,200	1,020
1998	16,600	6,940	103	4,820,000	6,840,000	39,600	947
Total DuPont load from 1989 through 1998							
	143,000	62,000	1,690	37,300,000	56,800,000	226,000	12,100

Note: Detection limits are included at half their value.

When data are not reported for all months of a year for a particular discharge, the amount is adjusted upward based on the number of months for which discharges are actually reported.
Differences between the values calculated from the PCS and by DuPont are the result of extra measurements in the DuPont data set and differences in the way months were weighted to calculate average monthly loads.

BOD - biochemical oxygen demand
COD - chemical oxygen demand
PCS - permit compliance system
TDS - total dissoved solids
TSS - total suspended solids

rates for ammonia and COD were more variable. The maximum loads for these parameters occurred in 1997. The annual BOD releases have remained fairly constant at approximately 900–1,300 kg per year, with a small spike in 1996 to 1,760 kg. The load for all of the NPDES-permitted parameters decreased from 1997 to 1998. In a February 1999 briefing memo on the draft renewed permit, EPA indicated that there had been no violations of the permit limits during the 2-year period from September 1996 to September 1998.

3.4 Buried Sediments

Sediments can be a source of COIs if the sediments are actively eroded or if the advective flux of groundwater drives dissolved constituents into the overlying water. The potential for sediment erosion is discussed in Section 5. In this section, the potential for groundwater migration through the sediments is briefly discussed.

Hydraulic conductivity was measured on two undisturbed sediment horizons collected at Station G-N. This location was considered to be representative of non-native sediments in the study area. A sediment core was collected using the same methods used for the deep cores and sectioned at two horizons, from the 0.83–1.5 ft depth interval and the 3–4 ft depth intervals. Core sections were transported undisturbed to the laboratory and tested for hydraulic conductivity by ASTM Method D 5084. Laboratory results indicated hydraulic conductivity ranging from 2.2×10^{-6} to 4.7×10^{-7} cm/s. These results are consistent with silt or glacial till (Freeze and Cherry 1979) and indicate that sediments would act as an effective barrier to advective groundwater transport. The presence of high concentrations of oily material in the upper 2 ft of sediments (described in Section 4) is expected to limit both advective and diffusive flux of COIs from pore water to overlying water.

Two other conditions also suggest that sediments are unlikely to be a source of dissolved constituents to the overlying water. First, high levels of AVS are observed, which will

effectively immobilize divalent metals in surface sediments throughout much of the study area (see Section 4.1.2). Second, metal concentrations in water samples from the East Branch are relatively low, suggesting that any loading from sediments or from point sources is not adversely affecting water quality (Section 4.3).

3.5 Summary of Chemical Mass Loading to the East Branch

Based on the available loading data for NPDES-permitted facilities, ongoing loading of copper, chromium, lead, mercury, zinc, and oil and grease have the potential to adversely affect sediment quality downstream of their sources. The primary sources of these chemicals are USX and the Gary STP. The potential effect of permitted loads on sediment quality was evaluated by conducting a simple "worst case" analysis of the data. It was assumed that all or most of the metals load is bound to the corresponding particle load from a given facility. This evaluation is expected to overestimate particulate metal concentrations. Despite their high particle affinity, it is unlikely that 100 percent of the metals are actually bound to particles, although in some cases the percentage may be quite high. The assignment of half the detection limit to undetected values is also expected to introduce uncertainty into these estimates. The resulting particulate (or "sediment") concentrations (to two significant figures) are as follows:

	Chemical	Gary STP (kg/year)	USX (kg/year)	Observed Ranges 0–10 cm Horizons
Annual Load (1997) Total	TSS	106,000	118,000	
	Oil and Grease	243,000	137,000	
	Chromium	265	352	
	Copper	1,130	--	
	Lead	653	546[a]	
	Mercury	8	--	
	Zinc	14,600[b]	169[c]	
		mg/kg	mg/kg	mg/kg
Concentration Total[d]	Chromium	2,500	2,900	42–2,040
	Copper	11,000		16–624
	Lead	6,200	4,600	94–4,300
	Mercury	75	--	0.11–15.5
	Zinc	140,000	1,400	292–10,600

[a] For USX, concentrations in 80 percent of the lead analyses were undetected.

[b] For the year 1994.

[c] For the year 1996.

[d] Excluding oil and grease.

If oil and grease are assumed to accumulate with the TSS from the respective facilities, sediment oil and grease concentration of 70 percent is predicted for Gary STP and a concentration of 54 percent is predicted for USX (compared to observed concentrations in the upper 10 cm ranging from 0.51 to 14.7 percent).

The East Branch has experienced dramatic decreases in TSS and oil and grease loading since 1989 (Figures 3-2 and 3-3). However, if the loads from USX and Gary STP are deposited in the sediments without sufficient dilution by relatively clean sources of particulate material, sediment quality problems in the East Branch will persist. Existing sediment quality data (shown above) suggests that this may be the case for chromium, lead, zinc, and oil and grease (of the COIs associated with permitted sources).

4. Chemical Conditions, Processes, and Potential Effects

An evaluation of chemical conditions in the surface water and sediment of the East Branch of the Grand Calumet was conducted to provide a better understanding of the processes affecting chemical distributions, bioavailability, persistence, and potential biological effects. Sediments are the primary focus of this investigation and are potentially associated with the majority of the impaired uses in the GCR/IHC system. Surface water conditions have a much faster response time to environmental variables and can be considered a "snapshot" of conditions. Sediments, on the other hand, represent the integrated record of decades of releases. Sediments and surface water interact; suspended particulates carried in surface water can deposit on sediments and resuspended sediments can affect the quality of surface water.

The vertical distribution of chemicals in sediments can be used to reconstruct their release history (i.e., in general, older releases are buried, newer releases are surficial). Potential adverse human health and ecological effects are associated only with exposure to surface sediments; in the absence of erosion (or other intrusive activities), exposure to deeper sediments does not occur. The horizontal distribution of chemicals can be related to source location and release history if the environment in the vicinity of the source is depositional. The bioavailability of chemicals can strongly influence their toxicity; AVS can entirely eliminate the toxicity of some metals when present in sufficient quantity. The persistence (or resistance to degradation) of chemicals also influences environmental conditions. For example, BTEX constituents are much less persistent than PAH constituents and would generally affect environmental conditions for a much shorter period of time.

In the following sections, chemical conditions in sediment, wetlands, and surface water of the East Branch are characterized, and the sources and processes contributing to these

distributions are discussed. A preliminary assessment of potential effects is also provided.

4.1 Sediment

Three types of sediment samples were collected on 11 transects, as described in the work plan (Exponent 1998) and summarized in Section 2.6:

- **16 Surface Sediment Samples**—Surface samples represented the upper 10 cm of sediment (the biologically active zone).
- **11 Short Cores (36 samples)**—Short cores represented three depth horizons; 0–10 cm, 10–20 cm, and 20–30 cm.
- **11 Deep Cores (38 samples)**—Deep cores were collected as deep as the vibracorer would penetrate (i.e., refusal), which varied from location to location. Three horizons were sampled from each deep core. At some locations, native sediments were not reached.

Transects A, B, C, and D are positioned upstream of historical DuPont outfalls. Transects E, F, G, and H are adjacent to DuPont's historical outfalls. Transects I, J, and K are adjacent and downstream of the U.S.S. Lead facility. The rationale for positioning the transects is described in greater detail in the work plan (Exponent 1998).

Three distinct sediment layers (or horizons) were noted during collection of the deep cores. The uppermost layer of each core consisted of oily sediments with a mild to strong petroleum odor. The middle layer consisted of other non-native material, and the bottom layer (in most cases) consisted of native sediment. Figure 4-1 illustrates the changes in the relative thickness of these oily and non-native layers throughout the length of the study area. The most notable feature of the distribution of sediment types is the depth of oily material at Transect C. The longest core (15 ft) was collected at this location, and it

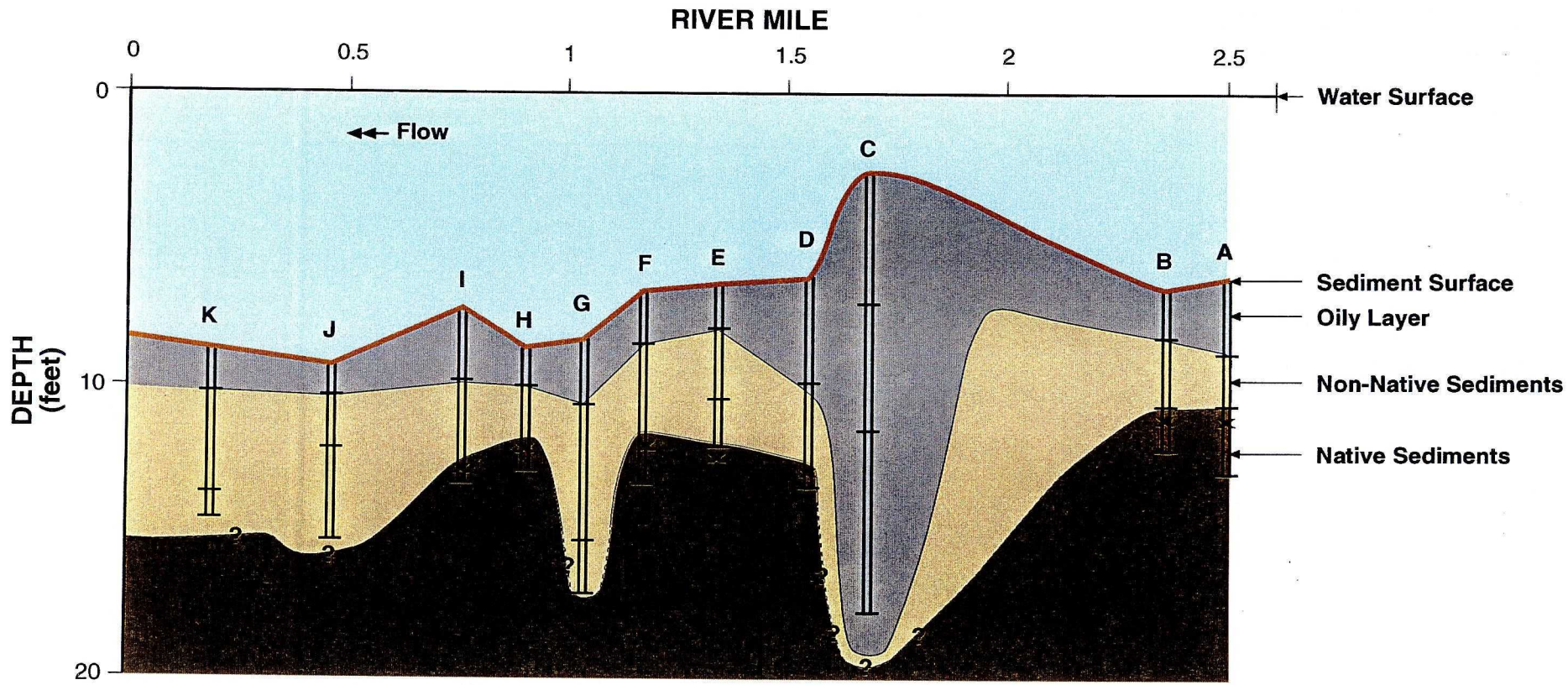

Figure 4-1.
CROSS SECTION OF SEDIMENT CORE SAMPLES.

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failed to penetrate through the oily layer. In contrast, the oily layer was only a couple of feet thick at other locations. The odor of the deep sediment core from Transect C was also distinctly different from the other cores.

In addition to the gross layered features of the cores, much finer layering in color and textures was observed. Photo composites of each of the cores and detailed core logs are provided in Appendix C.

The results of sediment chemical analyses are discussed in the following sections in relation to the overall chemical distributions, bioavailability, bioaccumulation potential, and potential for natural recovery. Appendix B contains tables of all individual chemical results.

4.1.1 Chemical Distributions in Sediment

The distribution of chemicals in sediment is interpreted in the context of historical and current sources and the inferred chronology of releases. Sediment quality in the study areas is assumed to be influenced by historical and ongoing upstream sources (e.g., USX and the Gary STP) and potential sources adjacent to the study areas (currently Harbison-Walker, DuPont, the Shell Oil storage facilities, U.S.S. Lead, and various CSOs and storm drains. Results are also compared to the results from the investigation of Floyd Browne (1993), in which cores from throughout the East Branch, from the IHC, and from a portion of the West Branch were collected and analyzed. Major facilities, outfalls, and sampling locations within the SCS study area are shown in Figure 2-5.

The following groups of sediment chemicals are discussed separately:

- Metals
- BTEX

- PAHs and phenols
- Pesticides and PCBs
- Oil and grease
- Grain size and total organic carbon.

The method used to represent the 3-dimensional distributions is necessarily a simplification of the data. For the surface sediments, color-coded polygons were used to represent chemical concentrations of each station where the 0–10 cm horizon was characterized. The axial cross section of the river was prepared by hand-contouring concentration isolines. Three data points represent each core, and each data point represents a composite of the horizon portrayed. These contours are intended to delineate major features in the concentration distributions and cannot be considered accurate portrayals of smaller features (e.g., the fine-scale layering observed in the photo composites in Appendix C). As discussed in Section 2.6, not all analytes were measured in all samples.

4.1.1.1 Metals

The distribution of arsenic (Figure 4-2) is characterized by a distinctive subsurface maximum centered on Transects E and F and by uniformly low concentrations in surface sediments (i.e., the upper 10 cm), with the exception of Station F-N, located adjacent to DuPont (Figure 2-5). The presence of a subsurface maximum at Transects E and F is consistent with the investigation conducted by Floyd Browne (1993), which identified a subsurface maximum at Transect 49, located between Transects E and F (Figure 2-5). Two additional areas of elevated subsurface arsenic concentrations are noted at Transects I/J and at Transect B. Most short cores (described in Section 4.1.4) have higher arsenic concentrations in subsurface samples than in surface samples. The subsurface arsenic maximum at Transects E and F appears to be quite limited in spatial extent and well isolated; concentrations in the 1.5- to 2-ft horizons overlying the subsurface

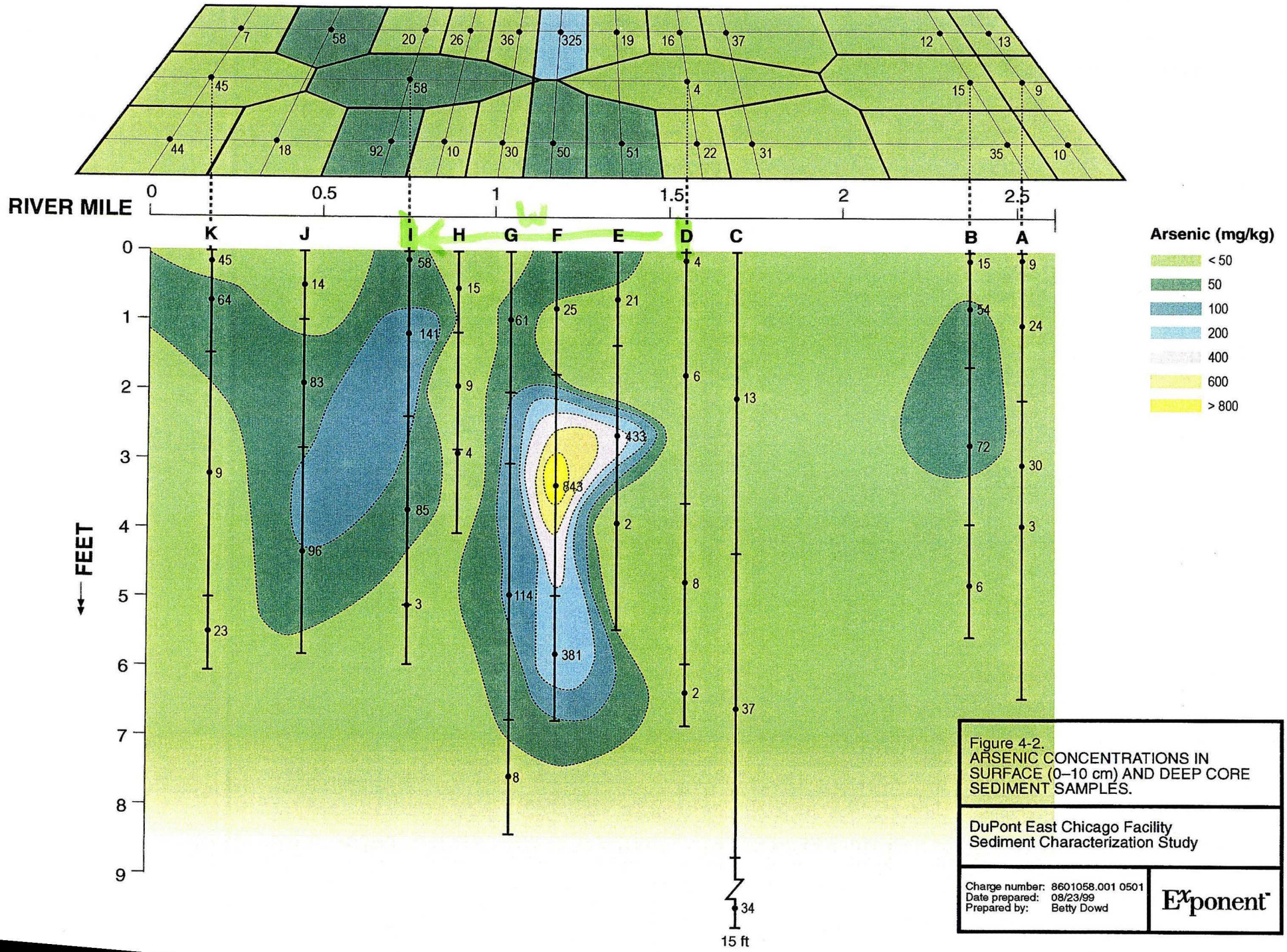

Figure 4-2.
ARSENIC CONCENTRATIONS IN SURFACE (0–10 cm) AND DEEP CORE SEDIMENT SAMPLES.

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maximum range from 21 mg/kg (at Transect F) to 25 mg/kg (at Transect E). Ambient arsenic concentrations measured by Floyd Browne (1993) throughout the GCR and IHC ranged from 10 to 70 mg/kg. The buried arsenic may be attributable to historical releases from DuPont; however, the physical isolation of the deposit substantially reduces or eliminates the potential for exposure to human or ecological receptors.

Antimony was detected in only about half of the sediment samples analyzed (Table B1-3 in Appendix B). The highest concentrations, approximately 60–70 mg/kg, were found in the two uppermost horizons of the short core at Station I-S (i.e., the south end of Transect I).

Cadmium concentrations in surface sediment were commonly less than 1 mg/kg, but higher concentrations were found on Transects E, F, and I; the highest concentration in surface sediment was found at Station I-S (33 mg/kg). Cadmium concentrations do not appear to vary systematically with depth. The highest subsurface concentration was approximately 50 mg/kg at the 10–20 cm horizon at Station I-S. The variable concentrations of cadmium throughout the study area are within the range of cadmium concentrations observed by Floyd Browne (1993) for the larger GCR/IHC system.

The distribution of chromium (Figure 4-3) is dominated by the dramatically high concentrations measured throughout the deep core at Transect C to the maximum depth of penetration (15 ft). Comparably high concentrations of chromium are observed in surface sediment at the north and south ends of this transect, with variably high concentrations observed in surface sediment throughout the study area. The horizontal distribution of these elevated chromium concentrations at depth appears to be limited, because they are not found downstream at Transect D or upstream at Transect B. For locations other than Transect C, chromium concentrations decrease systematically with depth. The chromium concentrations observed at Transect C are comparable to the chromium concentrations observed by Floyd Browne (1993) at Transects 3 through 8, adjacent to USX, although variably high concentrations were reported by Floyd Browne throughout the larger system. The Floyd Browne transects that would have been

collected in the vicinity of Transect C (Transects 46 and 47) were deleted from the study (Floyd Browne 1993). The property on the south bank of the river adjacent to this transect was known for illegal dumping (Corps 1997).

As was the case for arsenic, the distribution of copper (Figure 4-4) is characterized by a distinctive subsurface maximum centered on Transects E and F. The presence of a subsurface copper maximum at Transects E and F is consistent with the results of the investigation conducted by Floyd Browne (1993), which identified a subsurface maximum at Transect 49, located between Transects E and F (Figure 2-5). As was the case for arsenic, the subsurface copper maximum at Transects E and F appears to be quite limited in spatial extent and relatively isolated; concentrations in the 1.5- to 2-ft horizons overlying the subsurface maximum range from 111 mg/kg (at Transect F) to 146 mg/kg (at Transect E). The surface stations on the south end of Transects E and F also have relatively elevated copper concentrations, at 417 and 496 mg/kg, respectively. There seems to be some elevation of the copper concentrations associated with the very high chromium concentrations at Transect C as well as subsurface elevations at Transects I, J, and K. Ambient copper concentrations measured by Floyd Browne throughout the GCR/IHC system typically ranged from 50 to 200 mg/kg. The subsurface copper maximum at Transects E and F may be attributable to historical releases from DuPont.

As was the case for copper and arsenic, the distribution of lead (Figure 4-5) is characterized by a distinctive subsurface maximum centered on Transects E and F. The presence of a subsurface maximum at Transects E and F is consistent with the investigation conducted by Floyd Browne (1993), which identified a subsurface maximum at Transect 49, located between Transects E and F (Figure 2-5). As was the case for arsenic and copper, the subsurface lead maximum at Transects E and F appears to be limited in spatial extent. In addition, subsurface elevations in lead concentrations are broadly observed at Transects I and J, which are located adjacent to U.S.S. Lead. The spatial separation between the subsurface maximum at Transects E/F/(G) and the subsurface maximum at Transects I/J is confirmed by the data from Transect H (this study) and from Transect 50 (Floyd Browne 1993), both of which had low lead

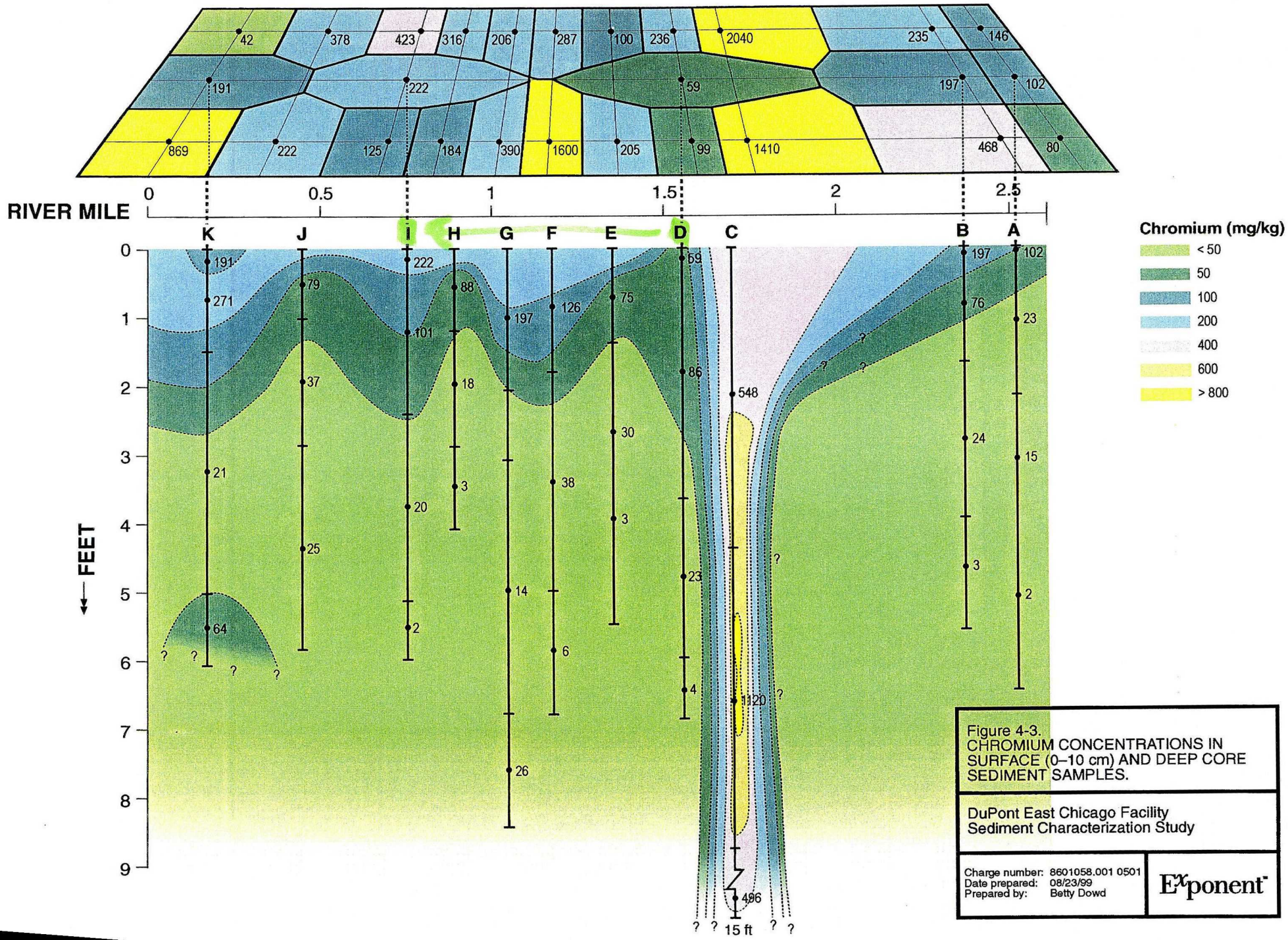

Figure 4-3.
CHROMIUM CONCENTRATIONS IN SURFACE (0–10 cm) AND DEEP CORE SEDIMENT SAMPLES.

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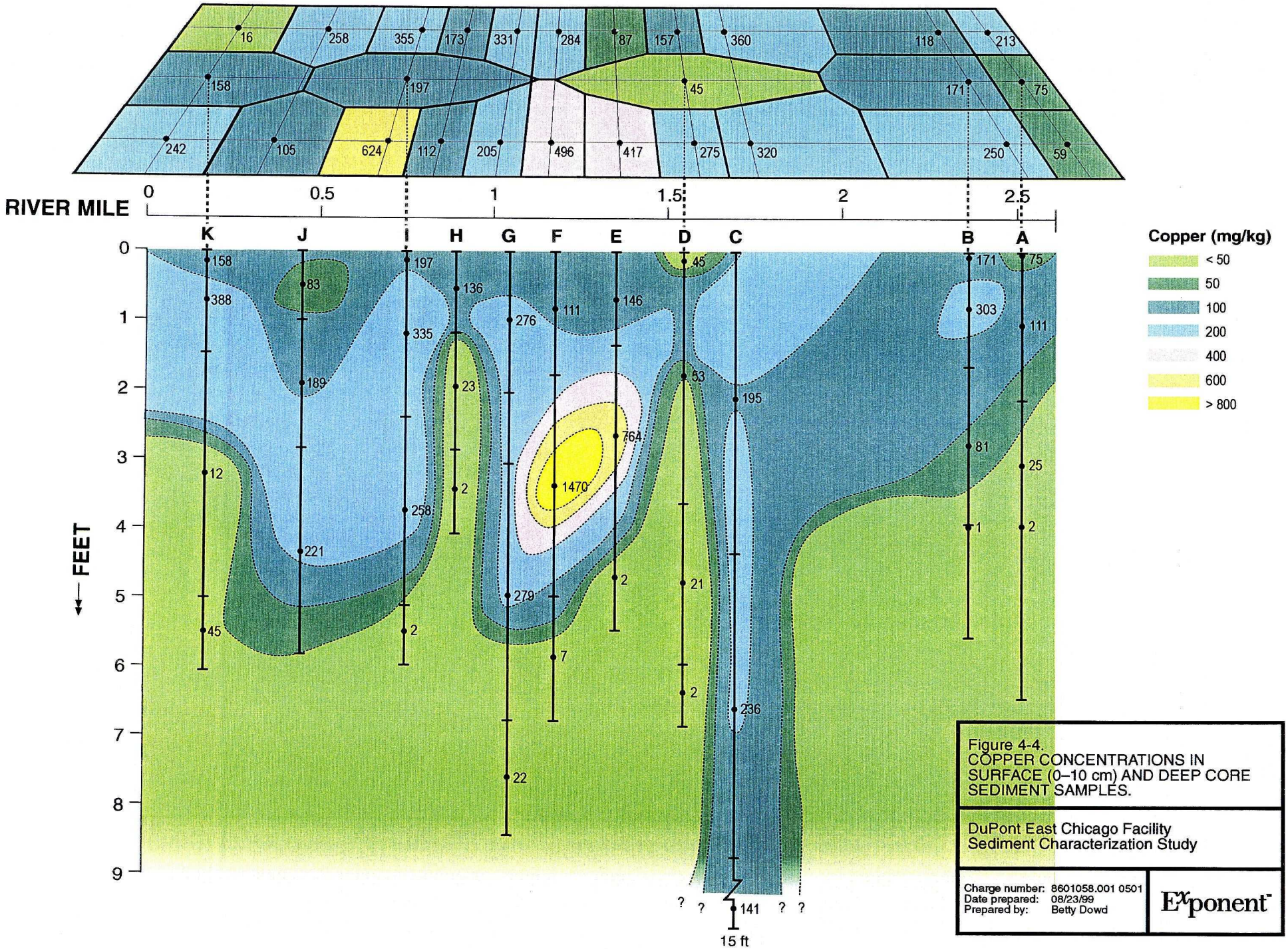

Figure 4-4.
COPPER CONCENTRATIONS IN SURFACE (0–10 cm) AND DEEP CORE SEDIMENT SAMPLES.

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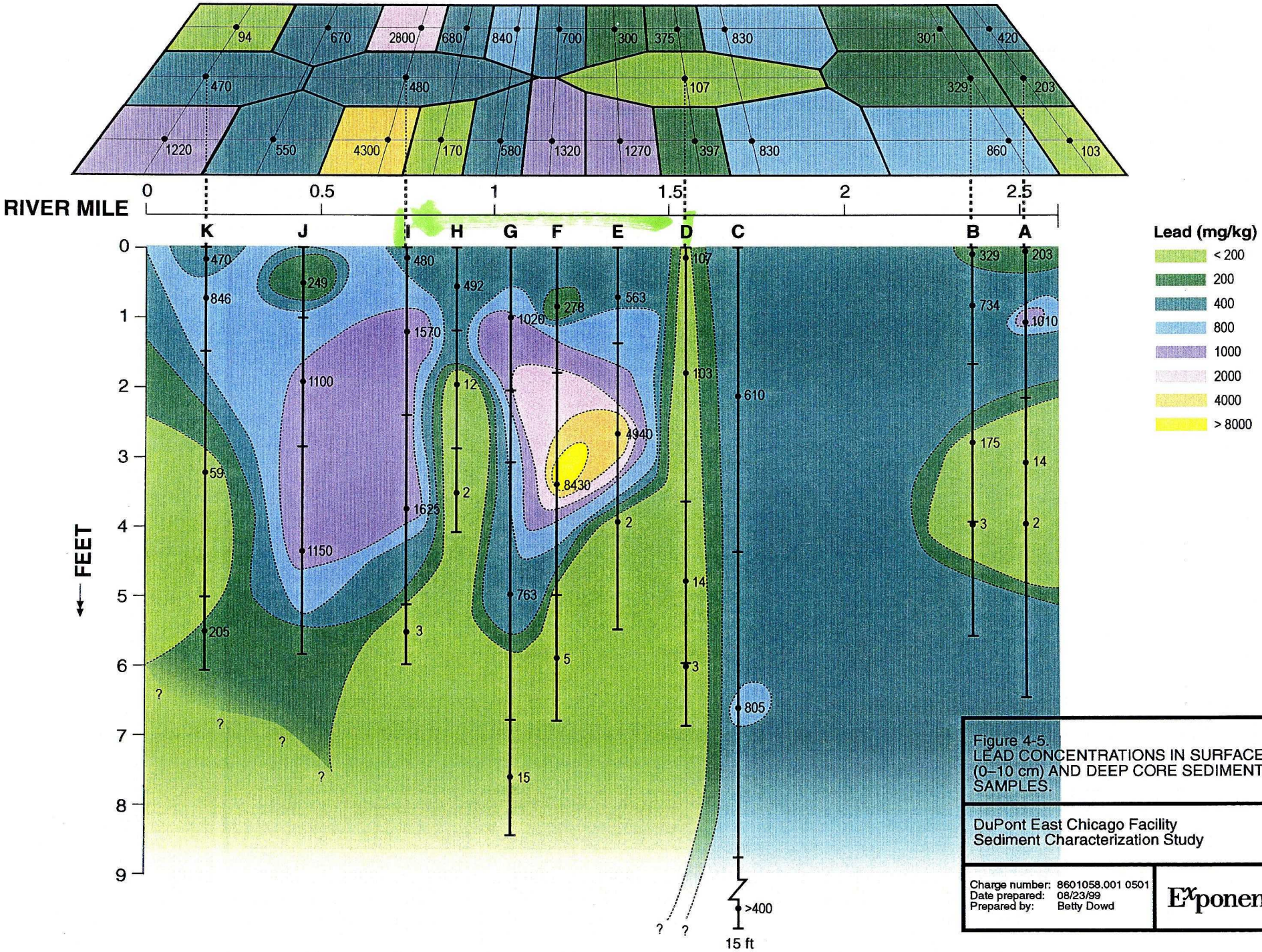

Figure 4-5.
LEAD CONCENTRATIONS IN SURFACE (0–10 cm) AND DEEP CORE SEDIMENT SAMPLES.

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concentrations. As was the case for copper, elevated surface concentrations of lead are observed at the south ends of Transects E and F (1,270 and 1,320 mg/kg, respectively). The highest surface concentrations of lead were observed at the north and south ends of Transect I (2,800 and 4,300, respectively), in the vicinity of the drainage ditch bordering U.S.S. Lead and Kennedy Avenue (and paralleling the railroad). Lead concentrations throughout the remainder of the study area are similar to the system-wide concentrations observed by Floyd Browne, which typically ranged from 200 to 1,800 mg/kg. Elevated lead concentrations at the localized, subsurface location at Transects E and F may be associated with historical releases from DuPont; however, the physical isolation of the deposit substantially reduces or eliminates the potential for exposure to human or ecological receptors. The elevated concentrations in surface and near-surface locations throughout the remainder of the study appear to be associated with upstream sources and the historically active lead smelter (U.S.S. Lead) just downstream of the DuPont facility.

Mercury distributions (Figure 4-6) are similar to lead, sharing the subsurface maximum at Transects E and F (adjacent to DuPont) and at Transects I and J (adjacent to U.S.S. Lead). As was the case for lead, two of the highest mercury concentrations in surface sediment were observed at the north and south ends of Transect I (9.1 and 15.5 mg/kg, respectively). An isolated mercury maximum was also observed at the north end of Transect A (10 mg/kg). Mercury concentrations throughout the remainder of the study area are comparable to the system-wide concentrations observed by Floyd Browne, which typically ranged from 0.5 to 6 mg/kg.

Molybdenum concentrations do not show a clear spatial trend throughout the river. The highest concentrations are found in the deep core at Transect C. Molybdenum is one of the chemicals considered to be an indicator of steel mill waste (Exponent 1998). There is a clear trend of decreasing concentrations with depth: concentrations are higher in surface horizons of short and deep cores than in deeper horizons. Overall, the distribution of molybdenum resembles that of chromium.

Nickel concentrations do not show either a clear spatial trend or a trend with depth. A number of relatively high concentrations are found at Transects B and C, extending throughout the entire length of the deep core at Transect C. Like molybdenum, nickel is one of the chemicals considered to be an indicator of steel mill waste (Exponent 1998). Elevated concentrations are also found in surface or near-surface sediment samples at a number of transects (Table B1-3 in Appendix B). The extremely high nickel concentration observed by Floyd Browne at the deep horizon of Transect 49 (approximately 2,700 mg/kg) was not observed in this study; in fact, nickel concentrations never exceeded 50 mg/kg in the deep cores at Transects E and F.

Concentrations of zinc are typically higher than any of the other metals throughout the study area, and concentrations are generally higher in the surface than the subsurface (Figure 4-7). With the exception of the subsurface maximum at Transects E/F, high zinc concentrations are generally observed in the upper 2 ft of sediment, with the highest concentrations observed in the surface and near surface (i.e., upper 30 cm), suggesting a recent source. Concentrations of zinc in the study areas are within the range observed by Floyd Browne (1993) for the larger system (i.e., typically ranging from 500 to 10,000 mg/kg). Zinc concentrations throughout the study area are attributable to the historical and ongoing source of zinc from regional sources.

4.1.1.2 Organic Chemicals

Surface sediment and short core samples at Transects A, B, D, and I were analyzed for BTEX to identify the distribution of non-persistent petroleum compounds. Although toluene was generally undetected at Transect A, the highest concentrations of total BTEX are found in the 10–20 and 20–30 cm horizons at Station A-M, where benzene, ethylbenzene, and toluene are present at levels ranging from 0.34 to 1.3 mg/kg, 1 to 2 orders of magnitude higher than elsewhere. Xylene was also elevated in the 0–10 cm horizon at Station B-S and in the 20–30 cm horizon. BTEX compounds were analyzed in the current study because of the elevated levels found in the study area during the Floyd

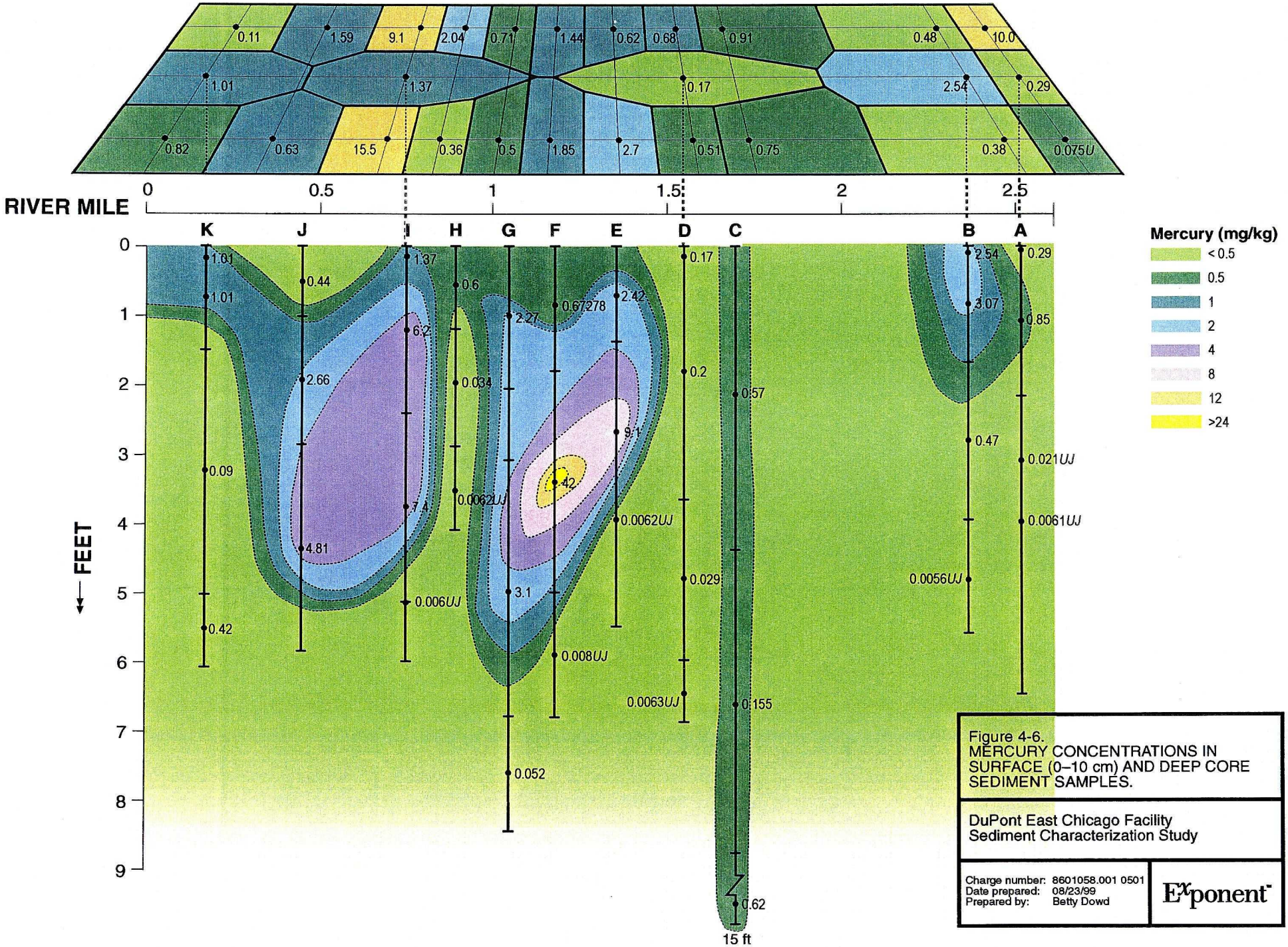

Figure 4-6.
MERCURY CONCENTRATIONS IN SURFACE (0–10 cm) AND DEEP CORE SEDIMENT SAMPLES.

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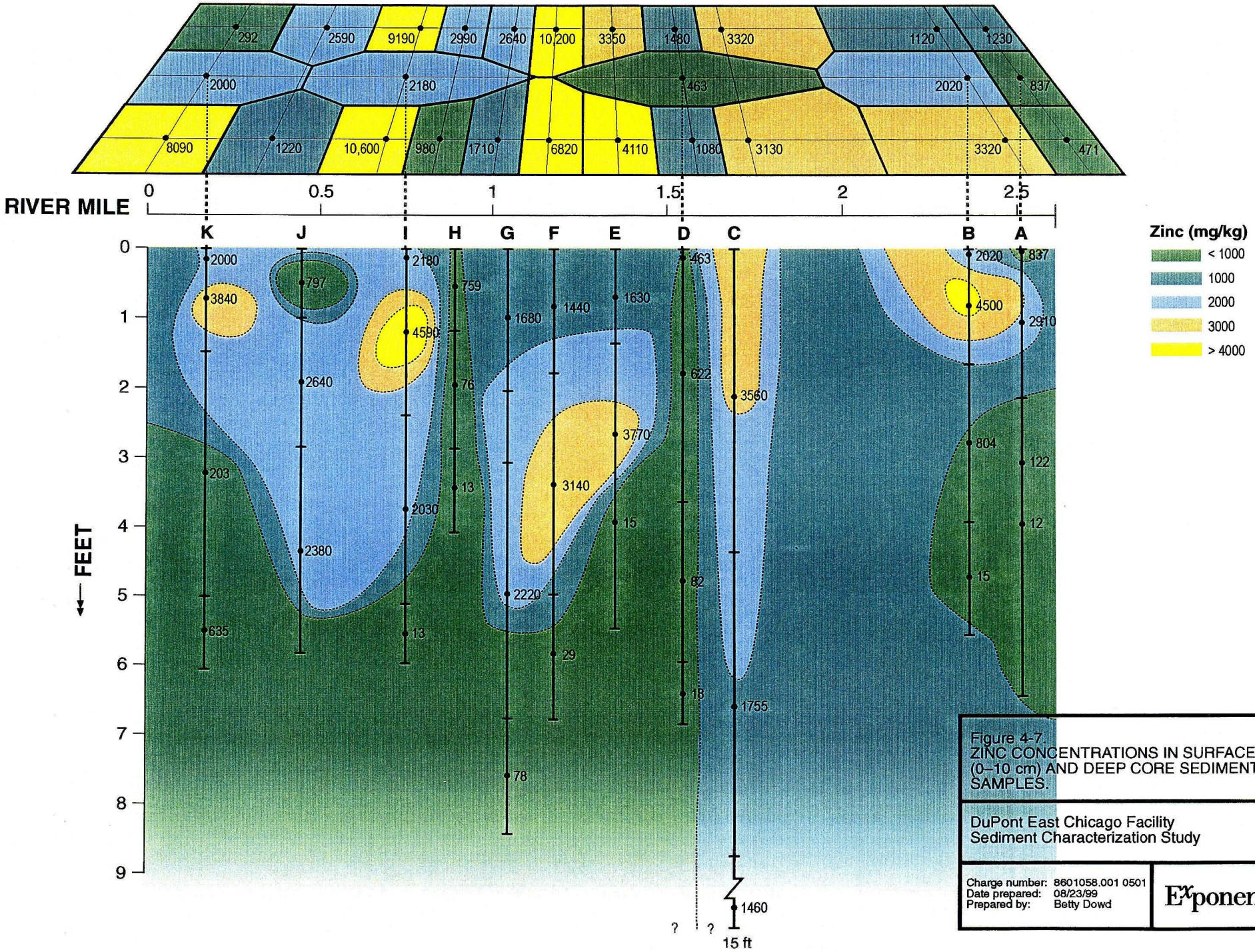

Figure 4-7.
ZINC CONCENTRATIONS IN SURFACE (0–10 cm) AND DEEP CORE SEDIMENT SAMPLES.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

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Browne investigation. The highest BTEX concentrations observed in the study area by Floyd Browne were in the surface horizon at Transect 45, which was located approximately midway between Transects A and B (Figure 2-5). Concentrations ranged from 6 mg/kg (benzene, ethylbenzene, toluene) to 12 mg/kg (xylene). These elevated concentrations may be associated with surface runoff from Cline Avenue.

Like chromium, oil and grease distributions (Figure 4-8) are dominated by the very elevated concentrations observed throughout the deep core at Transect C. With the exception of Transect C, high oil and grease concentrations were generally observed in the upper 2 ft of sediment, with the highest concentrations observed in the surface and near-surface (i.e., upper 30 cm, or 1 ft). This pattern is similar to that seen for chromium, zinc, and lead, suggesting a recent or ongoing source. Surface concentrations of oil and grease were highest along the south shore at Transects B, C, E, and F. Surface and near-surface concentrations of oil and grease at Transect K, just downstream of the U.S.S. Lead canal and the Shell Oil petroleum storage facility, were also very high. With a few exceptions, concentrations of oil and grease in the study areas were within the range observed by Floyd Browne (1993) for the larger system (i.e., typically ranging from 10,000 to 80,000 mg/kg). The highest oil and grease concentration observed by Floyd Browne in the study area (approximately 140,000 mg/kg) was at Transect 45, located between Transects A and B. This concentration is similar to the oil and grease concentration in the surface sample (0–10 cm) collected at the south end of Transect B in the current study (137,000 mg/kg). Oil and grease concentrations throughout the study area are likely attributable to the historical and ongoing release of oil and grease from USX and the Gary STP, historical and ongoing releases from CSOs and storm drains, and potential releases from oil storage facilities. The concentrations of chromium and oil and grease at Transect C are similar to the concentrations of those chemicals observed adjacent to USX (Transects 3 through 8) in the Floyd Browne investigation.

PAHs were analyzed in surface sediment, short core, and deep core samples from Transects A, B, D, G, and I. Concentrations of total PAH varied widely, but like oil and grease, were generally higher in surface sediment and in the upper core horizons than in

subsurface sediment. The highest total PAH concentration (24,000 mg/kg) was observed in the 20–30 cm horizon of a short core at Station A-M.

Phenols were analyzed in surface sediment, short core, and deep core samples from Transects A, B, D, G, and I, but were undetected in all samples (Table B1-4 in Appendix B).

Organochlorine pesticides and PCBs were analyzed in selected surface sediment, short core, and deep core samples from Transects A, B, D, G, and I. Most pesticides were detected infrequently, and at concentrations near the detection limit (Table B1-7 Appendix B). These concentrations do not appear to follow any systematic pattern. One exception is the detection of several pesticides in samples from Transect A. The short core at Station A-M contained detectable concentrations of beta-hexachlorocyclohexane, delta-hexachlorocyclohexane, endosulfan sulfate, DDT, endrin aldehyde, and dieldrin. Surface sediment at Station A-N contained detectable concentrations of beta-hexachlorocyclohexane, alpha-endosulfan, endosulfan sulfate, and endrin aldehyde. Among these chemicals, the concentrations of beta-hexachlorocyclohexane, endosulfan sulfate, and endrin aldehyde were the highest relative to detection limits. None of these pesticides were historically produced by DuPont at the East Chicago facility.

Two other isolated instances of relatively high pesticide concentrations were observed: endrin aldehyde in surface sediment at Station B-S and gamma-chlordane in the upper horizon of the deep core at Station I-M.

PCBs were analyzed and quantified as Aroclors® in selected surface sediment, short core, and deep core samples from Transects A, B, D, G, and I. Aroclor® 1248 was the only PCB mixture detected (detection limits ranged from approximately 0.1 mg/kg to 2.3 mg/kg). Aroclor® 1248 was detected in surface sediment (0–10 cm) at Stations A-M, A-N, B-N, B-S, D-N, and I-M and also at 10–20 cm at Station I-M. The highest concentration, 69 mg/kg, was found at Station B-S.

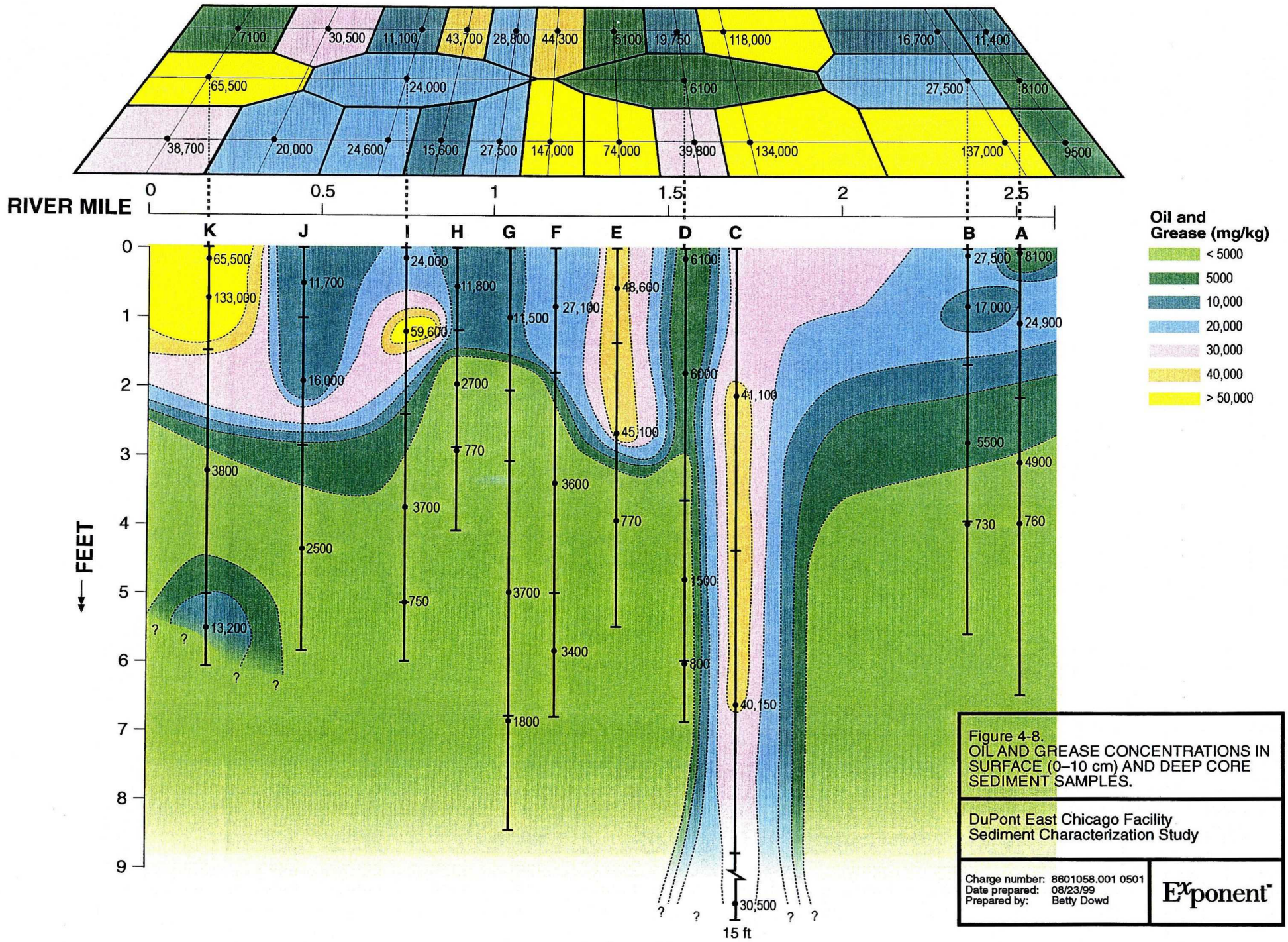

Figure 4-8.
OIL AND GREASE CONCENTRATIONS IN SURFACE (0–10 cm) AND DEEP CORE SEDIMENT SAMPLES.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

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4.1.2 Bioavailability and Potential to Cause Adverse Effects

The potential effects of sediment chemicals on ecological receptors in the East Branch were evaluated in two ways:

- Comparison of metal, PAH, and PCB concentrations to no-effect concentrations (NEC) calculated by Ingersoll et al. (1996) for the *Hyalella azteca* bioassay using nationwide data.
- Computation of the difference between simultaneously extracted metals (SEM) and AVS concentrations in surface sediment (i.e., as an estimate of the concentration of total divalent metals that is potentially bioavailable)

Metal concentrations in surface sediments are compared to NEC values in Table 4-1. NEC values are screening levels and do not indicate causation or predict effects (Ingersoll et al. 1996). The following discussion is limited to the 27 surface sediment samples (0–10 cm) that were collected throughout the study area. The upper 10 cm is the sediment horizon to which aquatic organisms would be exposed.

Several metals had a very limited number of NEC value exceedances. Arsenic exceeded the NEC at only 1 of the 27 surface sediment stations (Station F-N). Cadmium exceeded the NEC value at 4 of 27 stations (Stations E-S, F-N, F-S, and I-S). Copper exceeded the NEC value at only 1 surface station (Station I-S).

Chromium, lead, nickel, and zinc exceeded the NEC values at more than half of the 27 stations evaluated. Exceedances were as follows:

Table 4-1. Exceedances of NEC values by metals in surface sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility[a]

	Upper depth (cm)	Lower depth (cm)	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
NEC			100	8	95	580	130	43	1,300
Station									
A-M	0	10	8.50	0.0720 *UR*	102	75.4	203	33.3	837 *J*
A-N[b]	0	10	12.7	0.575 *J*	147	222	395	57.9 *J*	1,245 *J*
A-S	0	10	9.90	0.140 *UR*	79.8	58.6	103	34.6	471 *J*
B-M	0	10	15.4	0.0940 *UR*	197	171	329	66.1	2,020
B-N	0	10	12.1	0.420 *UR*	235	118	301	107	1,120 *J*
B-S	0	10	35.0	0.580 *UR*	468	250	860	129	3,320 *J*
C-N	0	10	37.0	0.770 *UR*	2,040	360	830	147	3,320 *J*
C-S	0	10	31.0	0.570 *UR*	1,410	320	830	151	3,130 *J*
D-M	0	103	5.80	0.0660 *UR*	86.0	52.9 *J*	103	24.1	622
D-N	0	10	16.4	0.10 *UR*	240	157 *J*	380	66 *J*	1,480
D-S	0	10	22.0	2.72 *J*	99.2	275 *J*	397	39.1 *J*	1,080
E-N	0	10	18.6	7.56 *J*	99.7	87.3 *J*	300	37.8 *J*	3,350
E-S	0	10	51.0	23.7 *J*	205	417 *J*	1,270	48.0 *J*	4,110
F-N	0	10	325	9.03	287	284 *J*	700	79.4 *J*	10,200
F-S	0	10	50.0	11.7 *J*	1,600	496 *J*	1,320	188 *J*	6,820
G-N	0	10	36.0	0.380 *J*	206	331 *J*	840	46.8 *J*	2,640
G-S[b]	0	10	36.5	0.710 *UR*	405	211 *J*	580	99.2 *J*	1,765
H-N	0	10	26.0	3.54 *J*	316	173 *J*	680	57.5 *J*	2,990
H-S	0	10	10.4	0.0670 *UR*	184	112 *J*	170	58.0 *J*	980
I-M	0	10	58.0	2.20 *UR*	222	197	480	74.0	2,180
I-N	0	10	19.7	3.60 *UR*	423	355	2,800	81.0	9,190
I-S	0	10	92.0	33.2 *J*	125	624	4,300	30.1 *J*	10,600
J-N	0	10	58.0	0.130 *UR*	378	258	670	117	2,590
J-S	0	10	17.5	0.0830 *UR*	222	105	550	47.5	1,220
K-M	0	10	45.0	0.0910 *UR*	191	158	470	62.7	2,000
K-N[b]	0	10	6.60 *J*	0.0720 *URJ*	42.9	16.7	81.5	8.75	308
K-S	0	10	44.0	2.80 *UR*	869	242	1,220	93.0	8,090

Note: All concentrations in dry weight.

NEC values are from Ingersoll et al. (1996).

J - estimated
NEC - no-effect concentration
R - rejected
U - undetected at detection limit shown

[a] Exceedances of NEC values are boxed

[b] Average of field duplicates

Transect	Chromium	Lead	Nickel	Zinc
A	2/3	2/3	1/3	0/3
B	3/3	3/3	3/3	2/3
C	2/2	2/2	2/2	2/2
D	2/3	2/3	1/3	1/3
E	2/2	2/2	1/2	2/2
F	2/2	2/2	2/2	2/2
G	2/2	2/2	2/2	2/2
H	2/2	2/2	2/2	1/2
I	3/3	3/3	2/3	3/3
J	2/2	2/2	2/2	1/2
K	2/3	2/3	2/3	2/3
Total	24/27	24/27	20/27	18/27

Chromium and lead exceeded the NEC values at the same surface stations, and nickel and zinc exceeded the NEC values at subsets of these stations.

NEC values for PAHs were exceeded at nearly all stations in the East Branch where PAH was analyzed, including all surface horizons (Table 4-2).

PCBs were analyzed in only 27 samples, 8 of which represented the upper 0–10 cm of sediment. NEC values for PCBs were exceeded in six of the eight surface horizons analyzed (i.e., A-M, A-N, B-N, B-S, D-N, and I-M), and at one near-surface station (the 10–20 cm horizon at Station I-M). PCB detection limits for many samples were also above the NEC value.

SEM and AVS were analyzed in surface sediment on Transects A, B, D, and I. Excess SEM was found only at Stations D-N, I-N, and I-S (Table 4-3). The highest value of excess SEM was found at Station I-N. In all cases of excess SEM, zinc was the greatest contributor to total SEM, constituting 79 to 88 percent of the total. For stations with negative values for SEM-AVS, the divalent metals are not considered bioavailable because there is sufficient sulfide to bind with all of the divalent metals to form relatively insoluble metal sulfides.

Table 4-2. Exceedances of NEC values by PAH compounds in surface sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility[a]

	Upper depth (cm)	Lower depth (cm)	Naphthalene (μg/kg)	Fluorene (μg/kg)	Phenanthrene (μg/kg)	Anthracene (μg/kg)	Pyrene (μg/kg)	Fluoranthene (μg/kg)	Chrysene (μg/kg)
NEC			**1,400**	**3,000**	**20,000**	**2,000**	**9,000**	**10,000**	**3,000**
Station									
A-M	0	10	1,200 *J*	4,900	26,000	11,000	35,000	46,000	25,000
A-N[b]	0	10	1,900 *J*	4,050	31,000	6,750	36,000	35,500	30,500
A-S	0	10	820 *J*	2,200 *J*	19,000	2,300 *J*	20,000	9,400	18,000
B-N	0	10	1,400 *J*	2,400 *J*	8,800	2,800	18,000	19,000	12,000
B-S	0	10	5,700 *J*	30,000	100,000	20,000	87,000	84,000	54,000
D-N	0	10	6,600 *J*	5,700	15,000 *J*	6,100	28,000 *J*	31,000 *J*	25,000 *J*
D-S	0	10	1,500 *J*	16,000	250,000	22,000	230,000	82,000	210,000
I-M	0	10	2,200 *J*	2,800 *J*	8,900	3,200	18,000	15,000	18,000
I-N	0	10	2,700 *J*	4,500 *J*	14,000	5,200	34,000 *J*	26,000	26,000
I-S	0	10	1,000 *J*	950 *J*	2,200 *J*	1,600 *J*	23,000	9,900	12,000

Table 4-2. (cont.)

	Upper depth (cm)	Lower depth (cm)	Benzo[a]-pyrene (µg/kg)	Benz[a]-anthracene (µg/kg)	Indeno[1,2,3-cd]pyrene (µg/kg)	Benzo[ghi]-perylene (µg/kg)	Dibenz[a,h]-anthracene (µg/kg)
NEC			**1,000**	**3,000**	**770**	**1,200**	**870**
Station							
A-M	0	10	24,000	24,000	15,000	12,000	3,700
A-N[b]	0	10	22,000	23,000	14,500	12,500	3,800
A-S	0	10	4,800	8,200	3,000 *J*	4,000 *J*	1,300 *J*
B-N	0	10	9,300	9,600	6,700	6,200	1,600 *J*
B-S	0	10	30,000	37,000	19,000 *J*	17,000 *J*	5,400 *J*
D-N	0	10	23,000 *J*	19,000 *J*	19,000 *J*	18,000 *J*	4,700
D-S	0	10	43,000	90,000	23,000	33,000	13,000
I-M	0	10	11,000	10,000	4,700	4,700	1,400 *J*
I-N	0	10	18,000 *J*	17,000	8,700 *J*	8,200 *J*	2,700 *J*
I-S	0	10	5,500 *J*	8,300	1,900 *J*	1,700 *J*	430 *UJ*

Note: All concentrations in dry weight.

NEC values from Ingersoll et al. (1996) national NEC, *Hyalella azteca* 28-day bioassay.

J - estimated
NEC - no-effect concentration
PAH - polycyclic aromatic hydrocarbon
U - undetected at detection limit shown

[a] Exceedances of NEC values are boxed.

[b] Average of field duplicates.

Table 4-3. SEM–AVS in surface sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Upper depth (cm)	Lower depth (cm)	Total SEM (μmol/g dry)	AVS (μmol/g dry)	SEM–AVS (μmol/g dry)
A-M	0	10	10.2	16.1	–5.9
A-N	0	10	22.8	38.6	–15.8
A-N (dup.)	0	10	11.5	28.5	–17.0
A-S	0	10	22.2	26.6	–4.4
B-N	0	10	10.6	14.9	–2.16
B-S	0	10	21.9	112	–90.1
D-N	0	10	25.0	10.7	14.3
D-S	0	10	16.8	42.6	–25.8
I-M	0	10	23.4	42.9	–19.5
I-N	0	10	111.5	66.7	44.8
I-S	0	10	164.7	160	4.7

Note: AVS - acid-volatile sulfide

SEM - simultaneously extracted metals

SEM-AVS results suggest that copper, cadmium, nickel, lead, inorganic mercury, and zinc are bound to the AVS fraction at many locations. Surface sediment concentrations of chromium, lead, nickel, and zinc exceeded the NEC values throughout most of the study area. Results suggest that chromium, followed by lead and zinc, poses the greatest potential risk to aquatic organisms because it is not bound up by sulfides.

4.1.3 Potential to Bioaccumulate

The primary COIs with regard to bioaccumulation in fish within the East Branch are PCBs and mercury, both of which are known to be elevated in fish collected in this area (Table 4-4). The concentrations of PCBs in fish from the area are sufficiently high to warrant fish consumption advisories; the concentrations of mercury, although elevated, would not warrant the same level of advisories in the absence of PCBs. The primary route of uptake of these chemicals by fish in the East Branch is not known, but it can be assumed to be via diet. The extent to which fish prey take up PCBs and mercury from sediments is also not known. It can be assumed that inorganic mercury in the sediments is largely not bioavailable because of the presence of high concentrations of sulfides in the sediments, which result in the formation of relatively insoluble metal sulfides. The uptake of mercury by fish is likely due to the presence of methylmercury concentrations, which have not been investigated in this system. Fish prey may become contaminated with PCBs both from the sediments and from the water column, but the relative magnitudes of these two potential sources are difficult to estimate. The presence of PCBs in surface sediments suggests an ongoing or recent source of PCBs. If the source of PCBs is ongoing, it can be assumed that the potential for bioaccumulation of PCBs would remain even in the absence of PCBs currently present in the sediments.

Table 4-4. Total PCBs and mercury in carp fillets collected in the Grand Calumet River/Indiana Harbor Canal system

Sample Location/ Number	Date of Collection	Mean Size (cm)	Mean Weight (g)	Percent Lipid	n	PCBs (mg/kg ww)	Mercury (µg/kg ww)	Lipid Normalized Concentration PCBs (mg/kg)
Bridge St.								
41201188	9/21/94	50.7	1,887	5.37	2	6.8	20 *U*	127
41201189	9/21/94	35.1	993	5.99	1	6.6	50	110
61200735	8/27/96	49.4	1,731	9.77	1	20 [a]	56.3	205
61200736	8/27/96	36.4	739	6.25	2	13 [a]	36.3	208
61200737	8/27/96	36.4	739	5.87	2	12 [a]	14.8	204
Cline Ave.								
41201191	9/21/94	37.2	762	1.64	2	0.8	30	49
41201192	9/21/94	46.1	1,703	5.09	2	8.4	20	165
41201194	9/21/94	78.5	7,037	11.98	1	27	130	225
61200742	8/27/96	62.2	3,093	5.7	1	7.2 [a]	267	126
61200743	8/27/96	42.4	1,320	7.79	2	13 [a]	37	167
61200744	8/27/96	29.9	408	4.7	1	6.7 [a]	24	143
Dickey Rd.								
30301041	9/30/92	80.0	8,427	11.88	1	8.6	90	72
30301043	9/30/92	37.7	874	6.23	5	4.5	10	72
30301044	9/30/92	54.2	2,263	8.34	4	4.6	30	55
30301045	9/30/92	26.3	275	4.52	5	2.6	10	58
40900692	8/25/94	32.8	624	2.7	1	3	40 *U*	111
40900693	8/25/94	53.7	2,100	3.46	1	4.9	50	142
40900694	8/25/94	49.5	2,724	20.86	1	23	60	110
61200758	8/28/96	39.8	993	6.89	1	7.1	5.6	103
61200759	8/28/96	28.4	378	4.31	2	2.7	6 *U*	63
61200760	8/28/96	28.4	378	4.09	2	2.6	5.5 *U*	64
61200761	8/28/96	36.4	648	4.04	1	3.5	5.8 *U*	87
90602983	11/1/88	61.5	3,440	6.08	3	1.5	84	25
90602985	11/1/88	74.0	6,691	21.68	1	2.2	124	10
90602984[b]	11/1/88	61.5	3,440	6.4	3	1.7	84	27
Indianapolis Blvd.								
41201196	9/28/94	48.4	2,072	8.22	3	11	20	134
41201197	9/28/94	41.4	1,052	5.03	3	5.7	20	113
41201198	9/28/94	55.1	2,696	16.51	1	19	40	115
61200763	8/28/96	28.3	350	2.98	3	2.7	5.5 *U*	91
61200764	8/28/96	36.0	748	6.89	1	3.3	7	48
61200765	8/28/96	19.6	150	4.98	1	4.1	7.5	82
Kennedy Ave.								
41201200	9/28/94	41.3	1,078	4.75	3	7.9	30	166
41201201	9/28/94	29.9	474	6.64	4	6.5	20	98
41201202	9/28/94	62.7	3,632	8.81	2	16	130	182
61200749	8/29/96	24.7	250	2.62	2	2.4 [a]	34.5	92
61200750	8/29/96	39.1	875	5.36	3	9.2 [a]	28.1	172
61200754	8/29/96	44.5	1,334	4.26	2	8.8 [a]	43.5	207
South of Dickey Rd.								
11202139	8/15/90	58.8	2,819	6.26	3	5.5	139	88
11202140	8/15/90	58.8	2,819	6.42	3	4.5	121	70
11202141	8/15/90	43.8	1,320	3.42	2	2.5	14	73

Note: PCB - polychlorinated biphenyl
U - undetected at detection limit shown
ww - wet weight

[a] Quantitated from a dilution.

[b] Duplicate of 90602983.

4.1.4 Potential for Natural Recovery

The potential for natural recovery was assessed by:

- Evaluating chemical gradients in the three strata sampled within each of the 0–30 cm shallow cores
- Reviewing the hydraulic modeling performed by the U.S. Army Corps of Engineers (Corps) and the sediment transport evaluation conducted by USGS (Corps 1997)
- Estimating the potential impact of point source particulate loading on the East Branch and comparing the chemical composition of particulates from point sources to existing sediment concentrations (discussed in Section 3)
- Conducting a general assessment of the potential for erosion and deposition of sediments in the East Branch (discussed in Section 5).

Recent changes in the chemical composition of freshly deposited sediments were assessed by evaluating chemical gradients in near-surface (0–30 cm) sediments. If conditions are improving, surface concentrations of COIs (i.e., in the 0–10 cm horizon) should be lower than subsurface concentrations (i.e., in the 10–20 and 20–30 cm horizons). Under steadily improving conditions, concentration gradients should follow the pattern:

1. $C_{0\text{–}10\ cm} < C_{10\text{–}20\ cm} < C_{20\text{–}30\ cm}$

Under steadily worsening conditions, concentration gradients should follow the reverse pattern:

2. $C_{0\text{–}10\ cm} > C_{10\text{–}20\ cm} > C_{20\text{–}30\ cm}$

For deposition environments, these concentration gradients are a balance between two processes: the rate of accumulation of contaminated particles, and the rate of accumulation of clean particles. As discussed in Section 3, concentrations of several COIs are predicted to be elevated in the particulate loads from the two major permitted facilities on the East Branch, USX and the Gary STP. The rate of supply and deposition of clean material is unknown, but is critical to the natural recovery of surface sediments. If the supply of clean material is sufficient to dilute the permitted loads of TSS and COIs, a surface minimum in COIs (Pattern 1, above) will be observed. Pattern 2, worsening conditions, can occur when there is recent source loading, or when the load of clean material has diminished faster than the load of contaminated material. In erosional environments, a surface maximum can occur if a formerly buried layer is newly exposed.

Depth profiles at the 11 stations where short cores were collected show variable vertical trends in COIs (Figure 4-9). Arsenic concentrations nearly always have a pronounced surface minimum, indicating recovery (i.e., historical releases that have been buried by clean material). Chromium concentrations generally show slight decreases at the stations with the highest concentrations (i.e., K-S, G-S, and C-N), whereas at other stations a slight surface maximum is generally observed. Lead trends are variable, with pronounced surface minima at Stations A-M and I-M, a pronounced maximum at Station I-S, and unchanging concentrations or slight surface maxima at the remaining stations. Zinc concentrations are similarly variable, with a pronounced surface minimum at Stations G-N and I-M, and relatively constant or depth-variable trends at the remaining stations. Oil and grease was also variable, with several stations showing surface minima (A-M, E-N, G-S, I-M), several showing surface maxima (C-N, E-S, G-N, I-S), and the remainder unchanging.

The results of this spatial trend analysis support the conclusion of the loading analysis. While selected chemicals (e.g., arsenic) may be recovering to acceptable levels in surface sediments, a broad trend of natural recovery is not occurring. The absence of natural recovery is attributed to ongoing loading of chromium, lead, zinc, and oil and grease, and the insufficient supply of clean material.

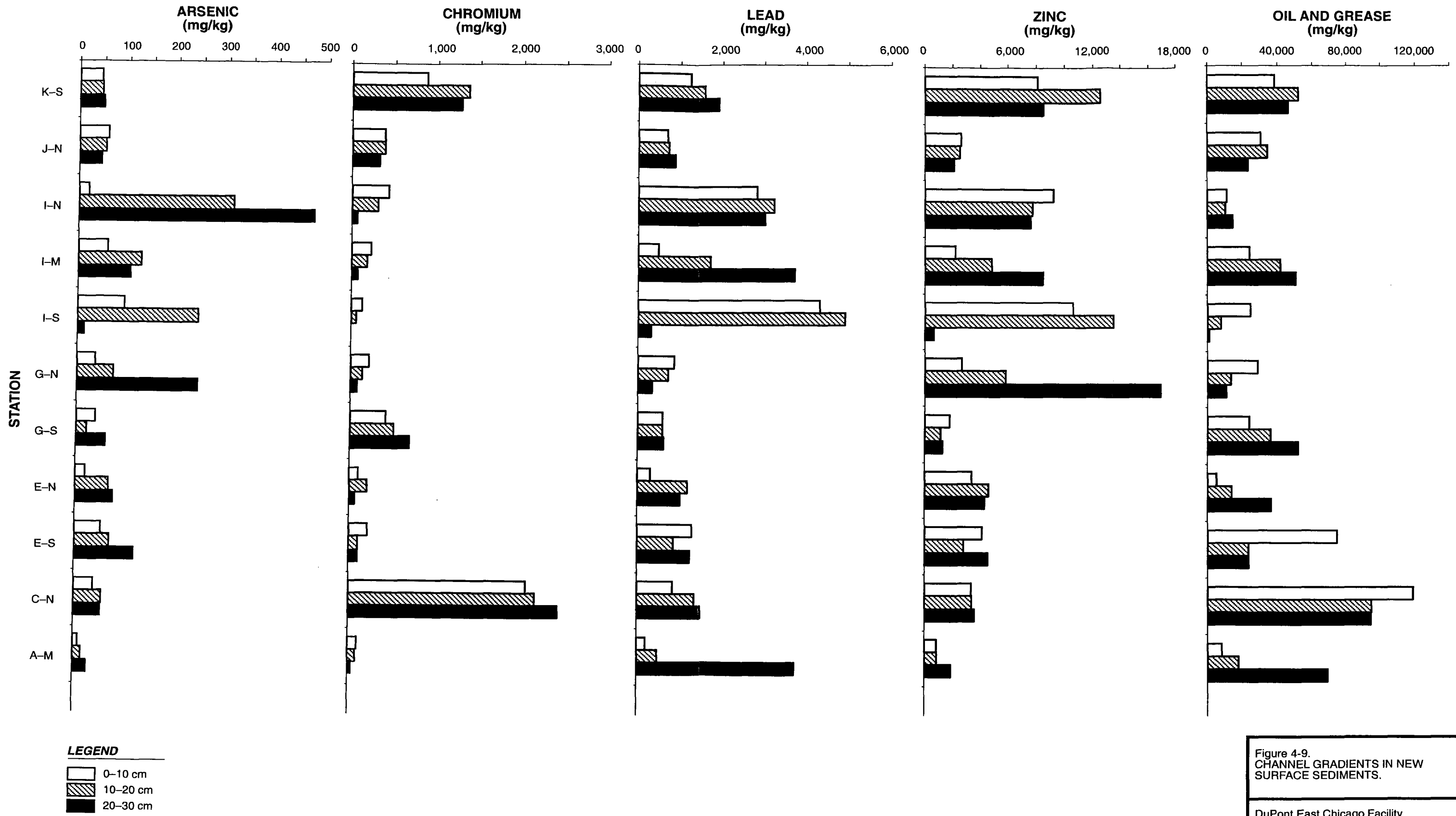

Figure 4-9.
CHANNEL GRADIENTS IN NEW SURFACE SEDIMENTS.

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4.2 Wetlands

The study area contains the largest contiguous riparian wetlands in the GCR basin, with approximately 200 acres considered to be wetland (Figure 4-10). Most of the wetlands in the reach are classified in the National Wetlands Inventory (NWI) as emergent marshes, although there are areas of deciduous forested wetland—particularly adjacent to the East Branch on the DuPont property—and deciduous shrub-scrub wetland on the south bank of the East Branch. In addition, there are several small seasonally flooded unvegetated and vegetated ponds on both sides of the river between Cline and Kennedy avenues. Most of these wetland and natural areas in the reach are on DuPont property, which includes the largest remaining remnant of dune and swale habitat in the GCR basin (170 acres, including dune uplands). The extent of wetlands, types of hydric soils, and general habitat quality, flora, and fauna of the natural areas on this property have been described in detail by CH2M HILL (1991b, 1996) and Corps (1997). Similarly detailed information regarding the remaining wetlands in the study area is very limited. Only the NWI is comprehensive for the reach.

A field evaluation of wetland flora (and, to the extent possible, fauna) was performed in September 1998 prior to sampling of wetland soils to supplement existing information about wetlands in the study reach. The objectives of this task were to document the extent to which there is direct interaction between sensitive habitats (natural area remnants and wetlands) and the East Branch, to describe the extent of those wetlands (and associated natural areas) present within the DuPont reach not already evaluated, and to describe the habitat types and species present in these areas. The three wetland/natural area complexes evaluated during the field survey were as follows:

- The DuPont dune and swale natural area, located on the north bank of the East Branch between Cline Avenue and the DuPont manufacturing facility

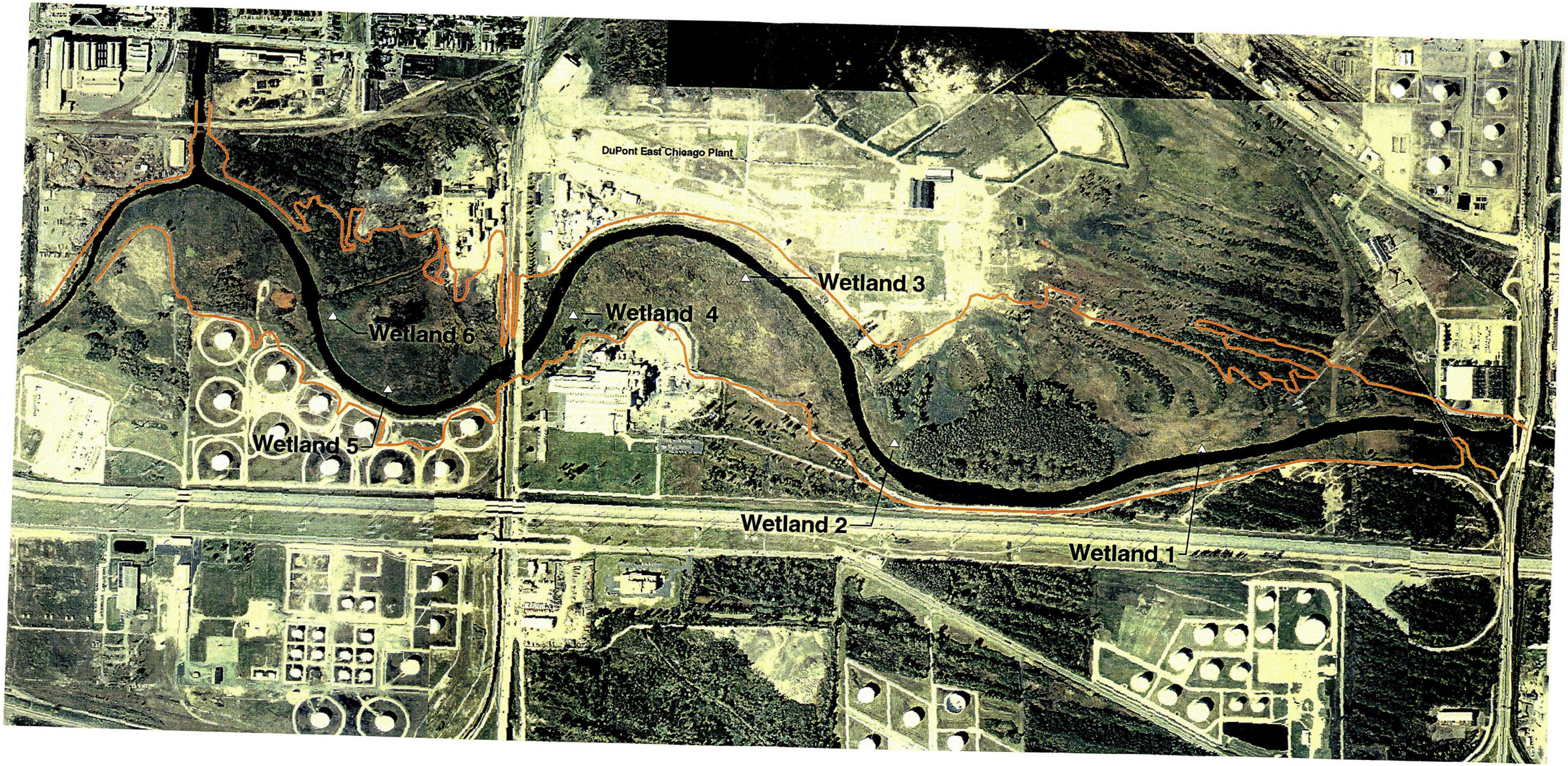
- Wetlands on the Harbison-Walker property south of the East Branch opposite the DuPont property, bounded by Cline Avenue, Kennedy Avenue, and a railroad and I-90
- The U.S.S. Lead wetlands and natural area, between Kennedy Avenue and the IHC on the north bank of the East Branch.

Evaluation of the two wetlands off of the DuPont property was hampered by lack of access. Therefore, the investigation focused on those attributes visible from the river or from vantage points on the DuPont property. Until onsite mapping is possible, the NWI as modified by current aerial photography (shown in Figure 4-10) will have to be considered the best source of information on the extent of wetlands in the study reach.

4.2.1 Hydrology and Soils

Between half and a quarter of the wetlands in the reach are truly riparian—that is, directly connected to the river system. Using flood insurance studies (FEMA 1979, 1980), a rough estimate of the areas historically inundated by moderate (i.e., 10–50 year) floods were determined. Most of the wetland areas on the south side of the East Branch and on the U.S.S. Lead property are within the pre-1985 100-year floodplain, as are at least one-third of the wetlands on the DuPont property (Figure 4-10). A base flow reduction of 870 cfs associated with operational modifications at USX after 1985 resulted in substantially reduced inundation frequency.

However, at least some of the wetlands on the channel margins are likely to be inundated during moderate flood events. A review of aerial photographs from 1951 to the present, compiled in U.S. EPA (1991), showed the history of the floodplain in the study reach. With only slight deviations, the channel bank of the East Branch has remained in its current position since 1958 (Figure 4-11). Between 1951 and 1958, two significant changes occurred. First, the meander bend upstream of DuPont Outfall 001 was pushed northward approximately 100 ft to accommodate construction of the Indiana Toll Road in



LEGEND

△ Wetlands stations

100-year floodplain

0 100 200 300 Meters

Figure 4-10.
WETLANDS SAMPLING STATIONS WITH 100-YEAR FLOODPLAIN

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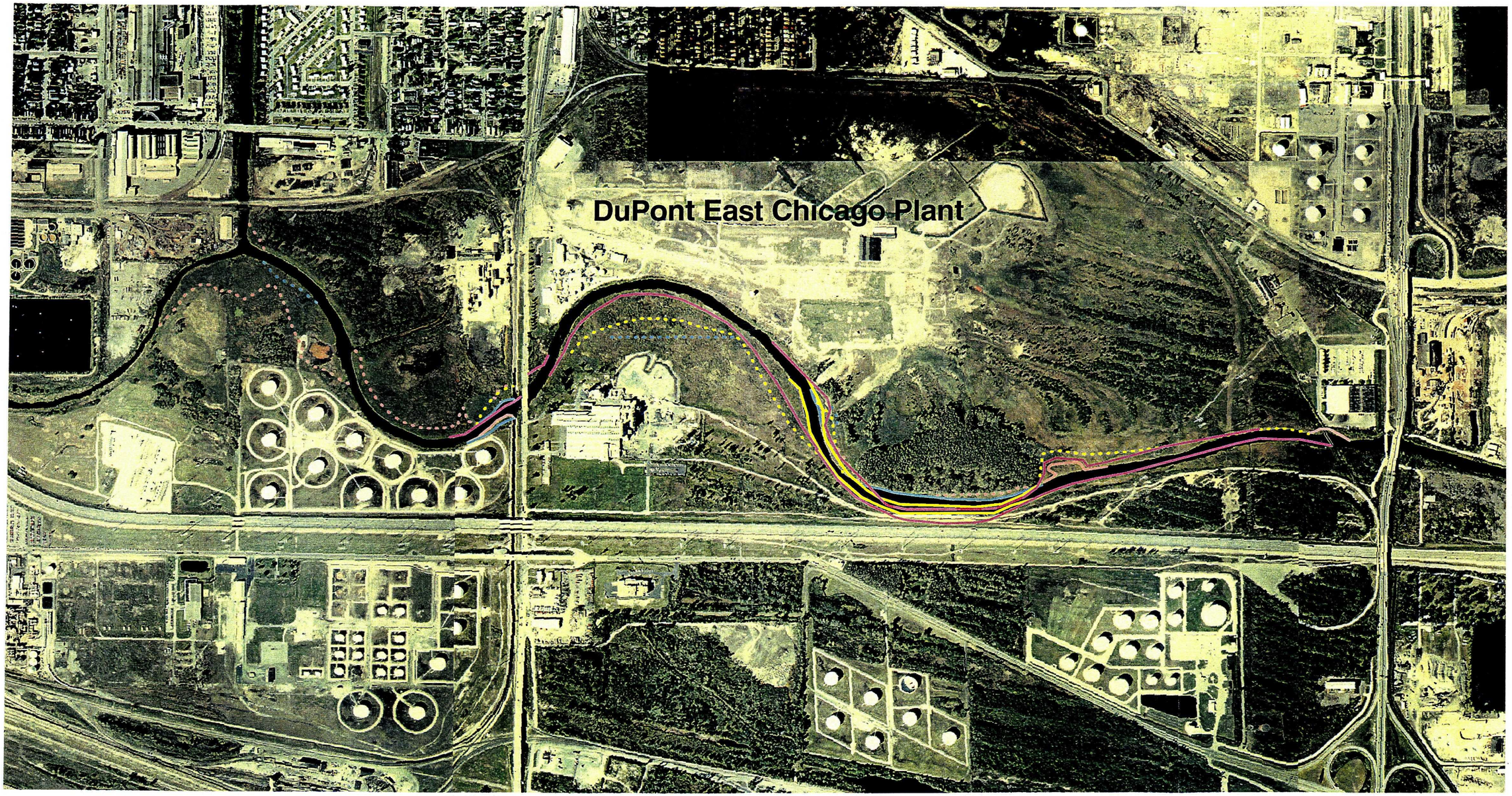

LEGEND

- 12/9/51 bank location
- 9/12/58 bank location
- 9/12/58 limits of deposition
- 7/15/65 bank location
- 7/15/65 limits of deposition
- 4/19/80 bank location
- 4/19/80 limits of deposition

0 300 600 Meters

Figure 4-11.
DEVIATIONS IN CHANNEL BANK LOCATIONS (1951 - PRESENT), AND INFERRED MARGINS OF SEDIMENT DEPOSITION

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1954 (Labus 1999; U.S. EPA 1991). Second, the channel has narrowed in the upstream one-third of the study reach, and along the Harbison-Walker property. This narrowing appeared to occur naturally and was likely mediated by encroachment on the channel from aggressive exotic vegetation.

Mud lines observed during the field reconnaissance suggest that inundation depth had exceeded the conditions present in mid-September 1998 by approximately 1.5 ft within the last year, and that they regularly exceeded those conditions by approximately 0.6 ft. Areas of standing water as a result of the high water table still occur on the DuPont, Harbison-Walker, and U.S.S. Lead properties (this study; Labus 1999; CH2M HILL 1996). On the DuPont property, these areas and adjacent areas have hydric (i.e., frequently saturated) soils (Labus 1999; CH2M HILL 1996). A survey of soil depth located near Station Wetland-1 (Figure 4-10) on the DuPont property found that more than 400 ft back from the bank of the East Branch, a surface organic soil layer was at least 2 ft thick, and exceeded 6 ft in thickness adjacent to the bank. This rapid buildup of organic matter is the mechanism by which aggressive exotic or weedy vegetation (principally *Phragmites* and *Typha*) effectively narrows the channel if not disturbed by flood flows.

As further evidence of the degree of hydraulic connection between the East Branch and adjacent wetlands, areas of recent deposition could be seen on the aerial photographs in U.S. EPA (1991). These areas are shown on Figure 4-11 and represent a minimum distance away from the bank that sediments from the river were deposited into the wetlands. On the north bank, the only significant area of deposition is in the vicinity of Station Wetland-1, immediately upstream of the cottonwood grove (described below). Here, fresh sediments were seen on the 1958 photograph extending approximately 300 ft back from the current streambank position (which is equivalent to approximately 100 ft back from the bank position in that photograph). On the Harbison-Walker property, fresh (unvegetated) sediments could be seen on the 1965 photograph extending approximately 500 ft back from the edge of the water at the apex of the meander bend, defining a point bar deposit. The geometry of the boundary between the vegetation and unvegetated

sediments (east-west and straight) suggests that this deposit resulted from either a substantial flood or from human clearing of the vegetation. On the U.S.S. Lead property, fresh sediments could be seen on the 1958 and 1980 photographs extending approximately 100–200 ft back from the edge of the water.

4.2.2 Flora

Most of what is known about flora of the wetlands in the study reach was obtained from existing surveys, again because of no access to offsite wetland properties. This section summarizes that literature, which, for the DuPont property, is quite complete, and adds observations made during the field investigation and by Labus (1999).

On the DuPont property, four globally rare plant communities can be found: sedge meadow, wet-mesic sand prairie, dry-mesic sand prairie, and sand savanna. The first two of these are emergent marsh wetland communities. The floristic quality of the DuPont dune and swale natural area is quite remarkable: 261 different plant species have been found on the site, of which 226 are native, 5 are rare (white water indigo, paper birch, golden sedge, Kalm's St. Johns wort, and lake shore rush), 1 is threatened (stiff aster), and 2 (Bebb's sedge and common water horehound) are endangered. The ridges are dominated by black oak with an herbaceous understory dominated by little bluestem (CH2M HILL 1996). Species common in the swale areas include stiff aster, meadow sedge, blue joint grass, tall coreopsis, marsh blazing star, great bulrush, and pussy willow. These and other species observed in swales in September and October 1998 are described in Labus (1999).

However, wetland areas near the East Branch (and deeper parts of the swales) have poorer floristic quality and are dominated by the invasive cattails (*Typha* spp.), common reed, and purple loosestrife (*Phragmites australis* and *Lythrum salicaria,* respectively; Stations Wetland-1 and Wetland-2 in Table 4-5; Labus 1999). Fires on the DuPont property are generally suppressed, affecting the plant communities on the site, although a

Table 4-5. Vegetation observed at wetland soils sites adjacent to the East Branch of the Grand Calumet River, September 1998[a]

Station	Location	Species Observed
Wetland-1	North bank, upstream of cottonwood grove and downstream of powerline right-of-way	*Typha* spp. *Phragmites australis* *Lythrum salicaria* *Cephalanthus occidentalis* *Pilea pumila* *Polygonum lapathifolium* *Solanum dulcamara*
Wetland-2	North bank, approximately 500 ft upstream from former chrome outfall and at downstream margin of cottonwood grove	*Typha* spp. *Phragmites australis* *Lythrum salicaria* *Pilea pumila* *Solanum dulcamara*
Wetland-3	South bank, slightly upstream of Transect F	*Typha* spp. *Lythrum salicaria* *Cypress strigosus* *Impatiens capensis* *Pilea pumila* *Polygonum lapathifolium* *Solanum dulcamara*
Wetland-4	South bank, near the downstream extent of wetlands on Harbison-Walker property and downstream of nearly all industrial activities associated with DuPont, approximately 350 ft upstream of Transect I.	*Typha* spp. *Lythrum salicaria*
Wetland-5	North bank, in approximate middle of U.S.S. Lead wetlands, approximately 300 ft upstream of Transect J and opposite the oil storage facility on the south bank	*Typha* spp. *Lythrum salicaria* *Impatiens capensis*
Wetland-6	North bank, approximately 150 ft upstream from U.S.S. Lead outfall, approximately 650 ft upstream of Transect K, and downstream of the oil storage facility	*Typha* spp. *Lythrum salicaria* *Cephalanthus occidentalis* *Pilea pumila* *Solanum dulcamara*

[a] Labus (1999).

fire did occur in April 1996. There is a 25-acre stand of cottonwood trees (with little floristic value, although potentially good bird or mammal habitat) at the apex of the meander bend upstream of the industrial use area. It is growing on fill, as this area was marsh on the earliest available air photos (U.S. EPA 1991). The ground cover in this forested area is dominated by common reed (Labus 1999; CH2M HILL 1996).

The entire south-side wetland complex, which includes the Harbison-Walker property, including 80 acres of remnant dune and swale, is described as being degraded by exotic species (Corps 1997). This survey found that the Harbison-Walker property is dominated by cattails, with substantial areas of common reed and purple loosestrife (Stations Wetland-3 and Wetland-4 in Table 4-5). These species are all apparently exotic to the area, and purple loosestrife is considered a noxious weed (Labus 1999). The mean coefficient of conservatism (a measure of the niche specificity of each plant species) on the Beamsterboer property near Cline Avenue is similar to that on the DuPont property, indicating that a native flora is still present. However the overall index of floristic quality (derived from the absolute number of conservative plant species) is about 60 percent of the index value for the DuPont property.

No quantitative information is available for the U.S.S. Lead property. The U.S.S. Lead property consists of a large cattail marsh, patches of *Phragmites*, and, near the IHC, small dune and swale remnants. These remnants are less than 20 acres in area and are in the late stage of succession (i.e., overgrown) because of the absence of periodic fires. Lack of access prevented a more complete vegetation survey of this site, but the vegetation observed at Stations Wetland-5 and Wetland-6 is provided in Table 4-5.

4.2.3 Fauna

The diversity of bird, herpetofauna, and mammal species reflects the complex plant community structure in these natural areas. The DuPont property was extensively sampled as part of a regional airport study (Mierzwa et al. 1991). During this study, nine

species of amphibians and reptiles were observed on the site, including Blanding's turtle, a federal "species-at-risk." Mammals trapped during this study included short-tailed shrews, gray squirrels, an Indiana-endangered Franklin's ground squirrel, white-footed mice, prairie deermice, and a meadow vole. Combining this with other studies, 86 bird species have been observed on the property, including the endangered American bittern, least bittern, black-crowned night heron, black tern, and golden-winged warbler; the threatened marsh wren; and the Virginia rail, a species-of-special-concern. The Harbison-Walker property/Calumet tern site contains nesting habitat of regionally rare or endangered birds, including the great egret, black tern, and black-crowned night heron.

Almost no fauna were observed during the field reconnaissance, except for great blue heron and mallards at the upstream end of the study reach. A pair of hawks is thought to be nesting in the cottonwoods.

4.2.4 Chemical Distributions in Wetland Soils

Wetland soils samples were collected from the surface (i.e., 0–33 cm deep) at the six wetland stations described above and shown on Figure 4-10. These stations were sited several tens of feet inland from the water's edge to characterize the distribution of COIs within the wetlands, but are primarily characteristic of the wetland margins that are potentially currently subjected to stream flows from the East Branch. Wetland soils were analyzed for metals (with selected samples analyzed for AVS and SEM), BTEX (in the two upstream samples only), phenols, 2,4-D, nutrients, oil and grease, pH, and grain size. Results for metals and oil and grease are provided in Figure 4-12, and all data associated with analyses of the wetland soils are presented in Appendix B. In addition, Labus (1999) sampled a transect 147 m (482 ft) inland from the edge of the water near Station Wetland-1 to describe the distribution of oil and grease in the subsurface at that location.

Wetland soils are dominated by silt- and clay-sized particles, with at least two-thirds of the grains in all samples less than 64 μm (the sand-silt break) and more than 90 percent of

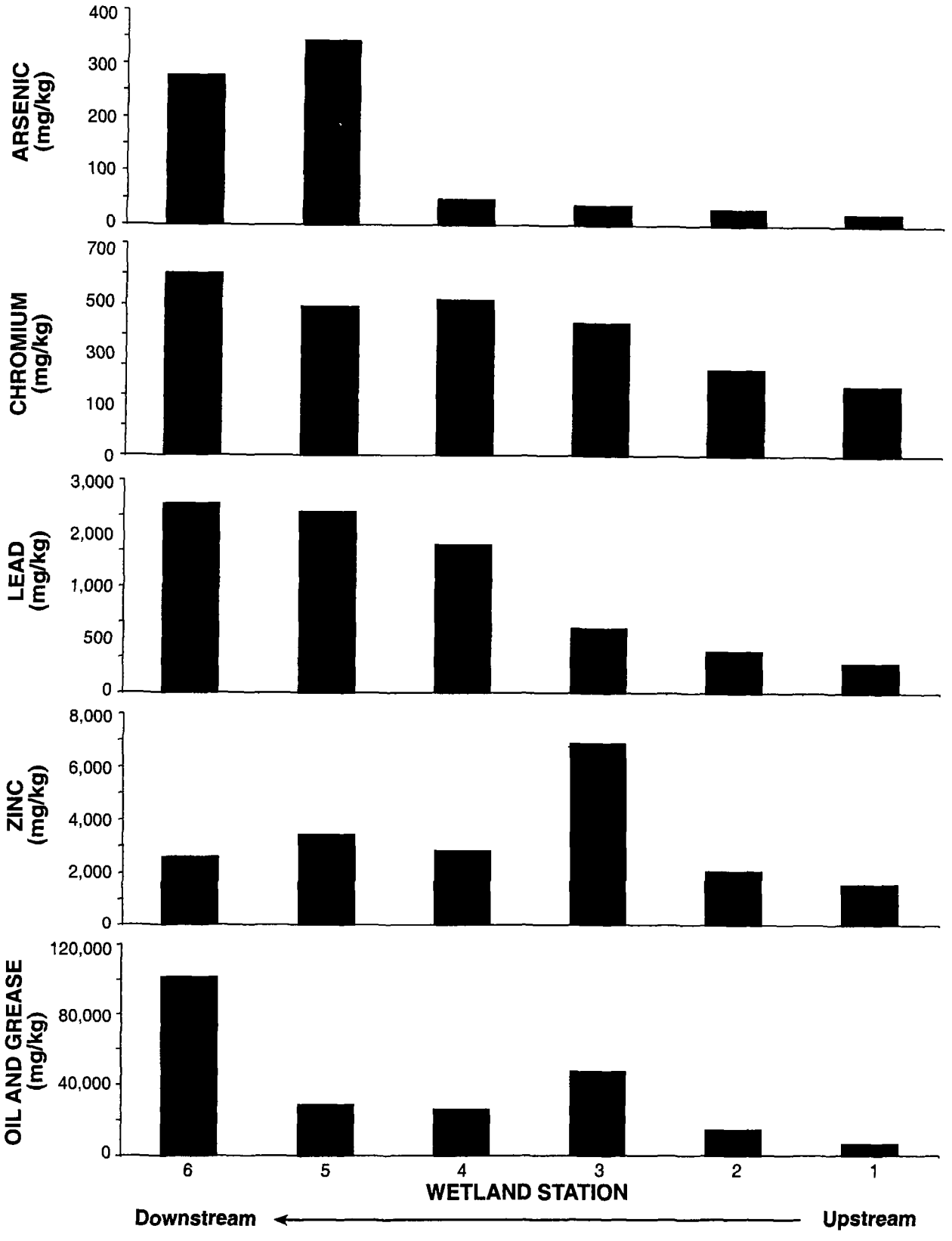

Figure 4-12.
WETLAND CHEMISTRY (station locations shown on Figure 2-5).

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all particles less than 1 mm (1,000 μm) in diameter, and are remarkably uniform between stations (Appendix B). These soils are indicative of the grain sizes transported in suspension by the East Branch (see Section 5 for a more thorough discussion of riverine transport processes) and are deposited by stream flows made quiescent by the dense vegetation. Organic carbon content ranges from 4.9 to 8.1 percent, which is approximately double that found in the channel sediments and is indicative of the buildup of vegetative litter.

Concentrations of metals in wetland soils do not display consistent spatial trends. With the exception of the most upstream sample always being substantially less metals-enriched than downstream samples, there is no consistent location at which these metals concentrations increase markedly, nor do the locations of these concentration increases correlate with the distribution of metals in the sediments described in Section 4.1.1.

In addition to the results of the chemical analyses, Table 4-6 presents a comparison of the metals concentrations in these soils with Ingersoll et al.'s (1996) NEC criteria (with the recognition that the NEC criteria were developed for aquatic systems, and these soils represent mixed aquatic and terrestrial systems). Concentrations of chromium, lead, nickel, and zinc exceed these criteria consistently throughout the study reach, while arsenic exceeds the criteria at the downstream two stations and cadmium exceeds the criteria at Station Wetland-5.

Wetland soils from Stations Wetland-1, -2, and -5 were analyzed for AVS and SEM. Zinc was the dominant divalent metal present, with lead as a secondary contributor. AVS was undetected in all of these samples, suggesting that the metals would likely be bioavailable (i.e., they would not be bound up as metal sulfides, as in the sediments from the East Branch).

Wetland soils at Stations Wetland-1 and -2 were analyzed for BTEX, and all samples were analyzed for 2,4-D. These compounds were undetected in all cases. Phenols ranged in concentration from 1.0 to 18.1 mg/kg, with concentrations in samples from

Table 4-6. Chemical composition of wetland soils adjacent to the East Branch of the Grand Calumet River

Analyte	Units	Wetland-1	Wetland-2	Wetland-3	Wetland-4	Wetland-5	Wetland-6
Antimony	mg/kg	1 *U*	3.9 [a]	15.9	25.9	67.7	51
Arsenic	mg/kg	20.6 [a]	29.0 [a]	35.2	46.4	343	276
Cadmium	mg/kg	0.17 [a]	0.31 *U*	0.28 *J*	1.07	9.82	3.54
Chromium	mg/kg	234 [a]	286 [a]	439	513	493	601
Copper	mg/kg	175 [a]	208 [a]	278	327	377	415
Cyanide	mg/kg	2.2 [a]	2.0 [a]	8.7	0.30 *U*	3.2	6.9
Fluoride	mg/kg	10.1 [a]	20.1	14	17.5	15.2	5.0 [a]
Lead	mg/kg	403 [a]	579 [a]	906	2,080	2,540	2,660
Magnesium	mg/kg	5,105 [a]	5,385 [a]	7,730	7,840	4,360	3,690
Mercury	mg/kg	0.65 [a]	0.606 [a]	0.99	1.38	1.86	1.6
Molybdenum	mg/kg	11.1 [a]	20.15 [a]	21.3	27.6	25.1	37.3
Nickel	mg/kg	52.6 [a]	64.9 [a]	85.5	90.1	92.4	73.4
Silver	mg/kg	3.21 [a]	3.05 [a]	5.3	7.44	5.67	7.89
Vanadium	mg/kg	36.8 [a]	54.1 [a]	67.2	78	78.5	78.9
Zinc	mg/kg	1,540 [a]	2,055 [a]	6,860	2,800	3,410	2,570
Benzene	µg/kg	6 *U*	9 *U*				
Ethylbenzene	µg/kg	6 *U*	9 *U*				
Toluene	µg/kg	6 *U*	9 *U*				
Xylene	µg/kg	6 *U*	9 *U*				
2,4-D	µg/kg	120 *U*	200 *U*	350 *U*	280 *U*	270 *U*	300 *U*
Phenols	mg/kg	1.0 [a]	2.1 [a]	13.1	2.5 *J*	1.0 [a]	18.1
Oil and grease	mg/kg	6,150 [a]	14,000	47,000	25,600	28,400	101,000
pH	s.u.	6.85	6.2	6.77	6.6	6.28	6.51
Ammonia-nitrogen	mg/kg	1,570	1,880 [a]	830	1,110	1,240	710
Nitrogen (Kjeldahl)	mg/kg	8,200 [a]	20,500 [a]	14,000	12,500	10,600	7,300
Phosphorus	mg/kg	4,400 [a]	3,200 [a]	5,100	3,200	4,400	3,200
Sulfate	mg/kg	1,020 [a]	7,670	23,200	11,900	4,400	2,835 [a]
Sulfide - Tl	mg/kg	21 *U*	33 *U*	1,700	667	55 *J*	608

Note: Blank space indicates no analysis performed
Boxed values indicate exceedance of Ingersoll et al. (1996) NEC criteria
J - estimated
NEC - no-effect concentration
U - undetected at detection limit shown

[a] Average of duplicate analyses

Stations Wetland-3 and -6 approximately an order of magnitude greater than those at the other stations. Notably, concentrations of phenols were higher in wetland samples than in the sediment samples from the East Branch. Oil and grease ranged from <1 to >10 percent, a range comparable to that found in the surface sediments from the East Branch. Oil was found to extend back 270 ft from the river in the transect sampled by Labus (1999) near Station Wetland-1.

4.3 Surface Water

Surface water samples were collected at one station located adjacent to the DuPont wetlands (Figure 2-5). Data for two low-flow events and one high-flow event were collected in September and October of 1998. A second high-flow event was sampled in July 1999 and will be included in the final draft of this report. Samples for high-flow and low-flow events were collected using an autosampler, which collected 12 subsamples over a 24-hour period, each representing a discrete time interval. For all analyses except fecal coliform bacteria, sequential subsamples were combined into four composites, each representing three sequential subsamples. Because of holding time constraints, fecal coliform bacteria samples were collected from the first of the 12 subsamples.

Target analytes for surface water included metals, conventional analytes (including nutrients), fecal coliform bacteria, and phenols. An overview of the study design is provided in Section 2.6, and details are provided in the work plan (Exponent 1998). Data for surface water samples are in Appendix B.

4.3.1 Potential to Cause Adverse Effects

The potential for adverse effects associated with metals was determined by comparing dissolved concentrations to EPA ambient water quality criteria (criterion continuous concentration) (AWQC [CCC]) (Table 4-7). Dissolved concentrations of arsenic,

Table 4-7. Dissolved metals in the East Branch of the Grand Calumet River—comparison to AWQC (CCC)

	Date	Sample ID	Antimony (µg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Total Mercury (µg/L)	Nickel (µg/L)	Zinc (µg/L)
AWQC (CCC)[a]				**150**	**2.2**	**74**	**9**	**2.5**	**0.77**	**52**	**120**
Sampling Event											
Low Flow 1	09/30/98	LF1BC1	5.30 *U*	40.0 *U*	0.630 *U*	2 *U*	4.7 *U*	6.5 *UJ*	0.04 *U*	4.7 *J*	11.5 *U*
	09/30/98	LF1BC2	5.30 *U*	40.0 *U*	0.630 *U*	1.7 *U*	4 *U*	6.5 *UJ*	0.042 *U*	3.7 *J*	12.2 *U*
	09/30/98	LF1BC3	5.30 *U*	40.0 *U*	0.630 *U*	2.5 *U*	4.7 *U*	6.5 *UJ*	0.042 *U*	3 *U*	17.4 *U*
High Flow 1	10/01/98	HF1BC1	5.30 *U*	40.0 *U*	0.630 *U*	1.7 *U*	2.2 *U*	6.5 *UJ*	0.043 *U*	11	8 *U*
	10/01/98	HF1BC2	5.30 *U*	40.0 *U*	0.630 *U*	1.7 *U*	2.7 *U*	6.5 *UJ*	0.042 *U*	6.3	11.7 *U*
	10/01/98	HF1BC3	5.30 *U*	40.0 *U*	0.630 *U*	1.7 *U*	2.6 *U*	6.5 *UJ*	0.042 *U*	3.2 *J*	8.6 *U*
	10/01/98	HF1BC4	5.30 *U*	40.0 *U*	0.630 *U*	1.7 *U*	3.1 *U*	6.5 *UJ*	0.042 *U*	3.1 *J*	6.6 *U*
Low Flow 2	10/11/98	LF2BC1	5 *U*	7 *UJ*	0.630 *U*	1.7 *U*	1.7 *UJ*	6.5 *U*	0.04 *U*	3 *U*	10.6 *U*
	10/11/98	LF2BC2	5.30 *U*	7 *UJ*	0.630 *U*	1.7 *U*	1.7 *UJ*	6.5 *U*	0.042 *U*	3 *U*	10.9 *U*
	10/11/98	LF2BC3	5.30 *U*	7 *UJ*	0.630 *U*	1.7 *U*	1.7 *UJ*	6.5 *U*	0.042 *U*	3 *U*	10.8 *U*
	10/11/98	LF2BC4	5.30 *U*	7 *UJ*	0.630 *U*	1.7 *U*	1.7 *UJ*	6.5 *U*	0.042 *U*	3 *U*	13.1 *U*

Note: AWQC (CCC) - ambient water quality criteria (criterion continuous concentration)

[a] U.S. EPA (1999)

cadmium, chromium, copper, mercury, nickel, and zinc were below AWQC (CCC), and most were undetected. Dissolved lead concentrations were undetected; however, the detection limits slightly exceeded AWQC (CCC). It is unlikely that actual concentrations of lead in surface water are at levels potentially associated with adverse effects. The observation of detected concentrations of metals is not clearly related to high or low-flow events.

Fecal coliform bacteria counts were approximately 10 times higher during the high-flow event (730 colonies/100 mL) than during low-flow events (40 to 80 colonies/100 mL), indicating that CSOs and surface runoff from rainfall have the potential to cause a short-term health hazard in the East Branch. It is unlikely that the instantaneous sample collected for fecal coliform represents the highest concentration associated with the subject rainfall event.

Suspended solids concentrations were uniformly low (at or near the detection limit of 2.6 mg/L) during the low-flow events and increased somewhat during the high-flow event, ranging from 17.6 to 36.8 mg/L in the first three of four composite samples (representing the first 18 hours of the rainfall event).

Oil and grease and phenols were the only organic substances analyzed. Phenols were undetected in all high-flow samples, but were detected in two of the four low-flow samples at concentrations very near the detection limit of 0.007 mg/L. Oil and grease was undetected in 6 of the 11 samples in which it was analyzed, and was quantified at levels at or below the method detection limit in the remaining 5 samples. Detected concentrations of oil and grease were about 4 mg/L; samples without detected oil and grease had slightly higher detection limits (about 5 mg/L).

BOD was highest in two of the four October 1998 low-flow samples, which had values of 222 and 465 mg/L. Another October 1998 low-flow sample had a value of 20 mg/L, and all other samples had BOD values of 10 mg/L or less.

4.3.2 Trophic State

Trophic state was assessed by the method of Carlson (1977), using the total phosphorus concentration in surface water to calculate the trophic state index (TSI). Total phosphorus concentrations measured during the high-flow event in October 1998 corresponded to TSI values of 60–73, representative of eutrophic conditions. The abundance of phosphorus, which is usually the limiting plant nutrient in freshwater systems, suggests that excessive plant growth may occur, which could, in turn, deplete dissolved oxygen and be detrimental to animal life. The TSI value during October 1998 low-flow sampling was 67, indicating that there is little or no difference between high- and low-flow conditions. Total phosphorus was not detected during low-flow sampling in September 1998, so a TSI value cannot be calculated.

These results indicate that water quality in the East Branch may be adversely affected by nutrient loading from the Gary STP, CSOs, and storm drains.

Dissolved oxygen in the East Branch was monitored from late July through October 1999. Low dissolved oxygen concentrations can result from high nutrient concentrations and high primary productivity and can adversely affect aquatic life. Low oxygen conditions are most likely to occur in late summer and early fall, when productivity and respiration rates are high. Dissolved oxygen was measured at the Cline Avenue and Kennedy Avenue bridges two ways: 1) manually, by lowering a probe through the water column and taking measurements at various depths, and 2) automatically, by installing probes on the footings of the two bridges at a position a couple of feet above the sediment surface.

Dissolved oxygen concentrations are relatively constant with depth (Table 4-8), but show strong diurnal variations likely related to productivity and respiration (Figure 4-13). The lowest oxygen concentrations occur in the early morning hours prior to sunrise, and the highest levels are observed in the early afternoon, during peak productivity. During a

Table 4-8. Dissolved oxygen concentrations in the East Branch of the Grand Calumet River during July, August, and September 1999

Depth (feet)	Dissolved Oxygen (mg/L) 7/30/99 13:30 hours	8/13/99 15:30 hours	8/20/99 14:45 hours	8/24/99 12:50 hours	9/1/99 05:00 hours	9/1/99 11:00 hours	9/1/99 17:00 hours	9/1/99 23:00 hours	9/14/99 10:30 hours
Kennedy Avenue Bridge									
1	7.70	7.35	6.75	6.24	4.80	5.75	6.48	6.05	6.51
2	7.70	7.33	6.75	6.26	4.80	5.70	6.48	6.07	6.48
3	7.70	7.33	6.75	6.24	4.76	5.68	6.42	6.05	6.44
4	7.80	7.27	6.73	6.24	4.73	5.65	6.40	5.97	6.42
5	7.80	7.15	6.68	6.20	4.65	5.61	6.39	6.03	6.33
6		7.02	6.57	6.19	4.61	5.51	6.35	5.95	6.33
7			6.46						
8			6.41						

Depth (feet)	Dissolved Oxygen (mg/L) 7/30/99 10:45 hours	8/13/99 09:30 hours	8/20/99 10:45 hours	8/24/99 12:10 hours
Cline Avenue Bridge				
1	7.00	6.15	6.35	6.64
2	7.00	6.13	6.36	6.58
3	6.90	6.09	6.32	6.58
4	6.90	6.09	6.31	6.60
5	7.00	6.09	6.32	6.35
6	6.90	6.04	6.29	6.30
7	6.80	6.01	6.27	
8			6.13	

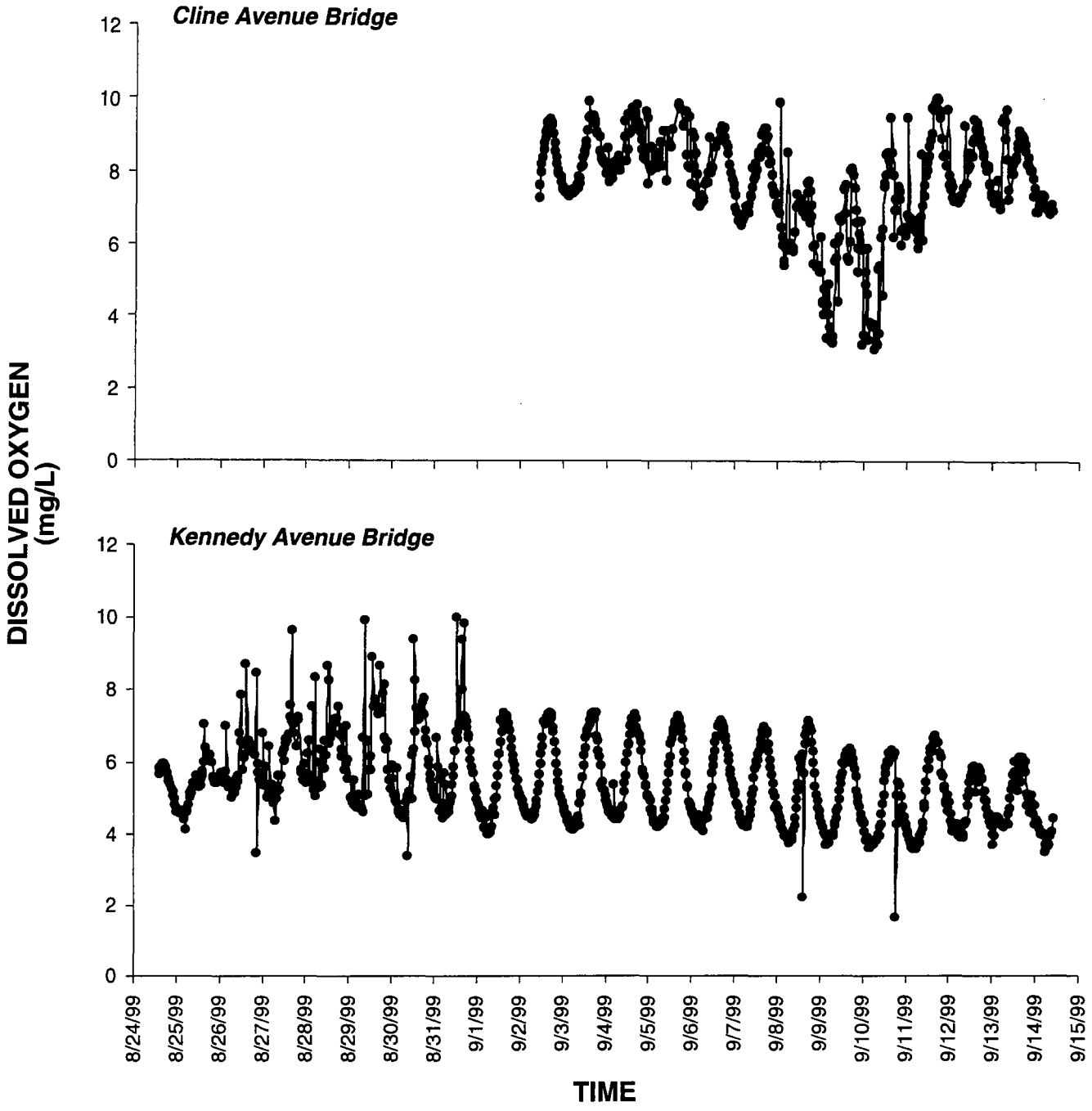

Figure 4-13.
DIURNAL VARIATIONS IN DISSOLVED OXYGEN CONCENTRATIONS AT THE CLINE AVENUE AND KENNEDY AVENUE BRIDGES.

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typical oxygen cycle, dissolved oxygen concentrations may vary by more than 3 mg/L (Figure 4-13). The data from the two continuously recording probes should be interpreted with caution because there were problems with calibration and calibration drift. The continuous record from Cline Avenue (Figure 4-13) appears to be systematically higher by approximately 1.5 mg/L than the manual measurements (Table 4-8). Despite these data limitations, results suggest that oxygen depletion may be a seasonal problem for portions of the GCR/ICH system. Dissolved oxygen concentrations approach the minimum surface water quality criteria for aquatic life, established by the state of Indiana (327 IAC 2-1.5-8). This regulation states that "concentrations of dissolved oxygen shall average at least five (5.0) mg/L per calendar day and shall not be less than four (4.0) mg/L at any time."

4.3.3 Metals Partitioning

Metals partitioning was initially included as an interpretive element to better understand the behavior of metals in surface water. Given the low and undetected values measured for most metals and for TSS, this calculation would not be meaningful. Dissolved and total concentrations of nickel, which was detected more frequently than any other metal, indicate that nearly all of the nickel is present in dissolved form. This case is likely true for other metals and is typical of conditions were TSS concentrations are very low. A greater fraction of the metals might be expected to be associated with the particulate phase under conditions of high suspended load (e.g., after a major storm event with significant runoff).

4.4 Conclusions

The following major conclusions can be drawn from the evaluation of chemical distributions in sediments:

- Non-native sediment reaching thicknesses from 2 to more than 15 ft are present in the East Branch from Cline Avenue to the junction with the IHC

- A localized, very thick deposit is present at Transect C, characterized by high levels of chromium and oil and grease that extends from the surface to the maximum depth of the core (15 ft). The extraordinary depth of contaminated sediment at this location suggests that the underlying native material may have been excavated prior to the deposition of waste containing high concentrations of chromium and oil and grease. Because Transect C is within the river reach that was relocated during construction of Interstate 90, it is possible that such an excavation may have occurred during channel relocation.

  Because elevated concentrations of chromium extend to the surface of the deep core at Transect C, instead of being buried as they are for the deposits adjacent to DuPont, it seems likely that contaminated material was introduced at Transect C after other sources of metals had ceased and their deposits had begun to be buried. The steel industry is the most likely source of this material. This deposit is not associated with DuPont activities; it is well upstream of all historical outfalls, and the presence of oil and grease is not consistent with DuPont industrial processes or associated wastes.

- A localized, subsurface deposit potentially attributable to historical releases from DuPont is present at Transects E and F. This sediment deposit contains elevated concentrations of arsenic, copper, mercury, lead and zinc. This sediment deposit likely represents wastes that were discharged primarily between the early 1900s and 1950, when several product lines associated with metal-bearing wastes were terminated or volumes were reduced. Nearly all product lines associated with potential metal wastes terminated prior to 1974, when outfalls were

consolidated and regulation of wastes under an NPDES permit began. Aerial deposition of emissions from U.S.S. Lead that were deposited on the DuPont facility (see Section 2.2) may have contributed to these sediment deposits. This deposit is isolated from surface sediments, and this physical isolation substantially reduces or eliminates the potential for exposure to humans or ecological receptors.

- A localized, subsurface deposit is present at Transects I and J. This deposit has characteristically high levels of lead and mercury and is likely attributable to historical releases from U.S.S. Lead, which was active from 1914 to 1985.

- Elevated concentrations of oil and grease, chromium, lead, and zinc are found in the surface and near-surface sediments, suggesting a recent or ongoing source. The loading analysis in Section 3 suggests that these substances may originate from the Gary STP and USX, located upstream of the study area.

- SEM-AVS results suggest that copper, cadmium, nickel, lead, and zinc are bound to the AVS fraction at many locations. Surface sediment concentrations of chromium, lead, nickel, and zinc exceed NEC values throughout most of the study area. Results suggest that of the metals, chromium poses the greatest potential risk to aquatic organisms, followed by lead and zinc.

- The extremely elevated concentrations of oil and grease pose a risk to benthic infauna on the basis of physical disturbance alone. Constituents of oil and grease (i.e., PAH) exceed NEC values at all locations tested.

- PCB concentrations in the sediments may serve as a source of the PCBs found in fish tissues, but the fact that there appear to be ongoing sources of PCBs to the East Branch (as evidenced by high surface

concentrations) suggests that fish advisories might still be in effect even in the absence of PCBs in the sediments.

- Mercury in the sediments is less likely to be a significant source of the mercury accumulating in fish tissues because much of the total mercury in the sediments is likely bound up in relatively insoluble metal sulfides. It is more likely that bioaccumulation of mercury in fish is related to methylmercury in the water column, although data on methylmercury have not yet been collected.

For the wetlands, the following conclusions can be drawn from literature review, evaluation of field conditions and aerial photographs, and concentrations of COIs in the wetland soils:

- The DuPont wetlands and natural area tract represent a unique resource in the region on the basis of floristic integrity and wildlife usage. However, on the margins of the East Branch, this tract has become dominated by aggressive, generally exotic vegetation (i.e., cattails, common reed, and purple loosestrife) that must be actively controlled to maintain the biotic integrity of the tract.
- Both the Harbison-Walker and U.S.S. Lead wetland parcels are dominated by these same aggressive, generally exotic plant species. Therefore, while these wetlands likely support a high degree of water quality improvement function (i.e., removal of nutrients and particulates by filtering water flow) their value as wildlife habitat is substantially more limited.
- The distribution of contaminated sediments in soil samples and the extent of unvegetated channel banks visible on the aerial photographs demonstrates the extent of historical (i.e., pre-1985) connection between the channel and the wetlands. This connection, associated

with higher than present base flows, extended locally 300 ft inward from the current river bank on the DuPont tract, covered much of the Harbison-Walker wetland parcel, and extended approximately 100–200 ft inward from the current river bank on the U.S.S. Lead parcel. Contaminated wetland soils are gradually being buried by a buildup of plant debris as the channel narrows to adjust to the current lower base flow regime.

Surface water results indicate that dissolved metals are below AWQC (CCC), suggesting that the high concentrations of metals in sediments do not adversely affect water quality (at least under the observed flow conditions). The East Branch receives sufficient nutrient load to be eutrophic, at least during a portion of the year. The abundance of phosphorus, which is usually the limiting plant nutrient in freshwater systems, suggests that excessive plant growth may occur, which could, in turn, deplete dissolved oxygen and be detrimental to aquatic life.

5. Sediment Transport

Sediment dynamics play a critical role in controlling current and future sediment quality in the East Branch of the GCR, both in terms of the deposition of contaminated particles (and dilution with clean material) and in terms of the potential for erosion and exposure of buried chemicals. During the industrial history of the East Branch, non-native sediment ranging from 2 to 8 ft in thickness was deposited in the study reach. The potential effects of ongoing permitted sources of particulate material on surface sediment quality are discussed in Section 3. The deposition pattern of COIs and their relationship to historical and ongoing sources are discussed in Section 4. The stability of sediments in the GCR is governed by the magnitude and duration of conditions that can mobilize sediment. These conditions are related to the shear stress exerted by fluid flow at the sediment–water interface (i.e., related to the product of water surface slope and flow depth) or by turbulence within the flow, and to the physical properties of the sediment available for transport.

In the following sections, the processes governing sediment transport are described, as well as some of the unique challenges and limitations in applying conventional methods to the assessment of sediment transport in the East Branch of the GCR. Empirical data related to sediment accumulation and particulate transport are summarized.

5.1 Hydrology

Surface water flow patterns are a key component of the evaluation of sediment transport processes. The existing hydrologic and sediment transport studies and the associated data (USGS 1999; Corps 1997) were reviewed. This review focuses on surface water flow characteristics that affect sediment transport processes.

The surface water hydrology of the East Branch of the GCR is unique. Surface water flows opposite to the direction of historical flow into Lake Michigan. This flow reversal is a result of its connection to the IHC, a dredged industrial shipping channel that bisects the GCR and connects it with Lake Michigan. The resulting watershed area for the GCR is small (approximately 22 mi^2), and the headwaters of the East Branch are located around the historical junction of the GCR with Lake Michigan.

Figure 5-1 compares recorded flow in both the East Branch of the GCR and in the Little Calumet River (USGS 1999). The flow axes of these two rivers are parallel and are located approximately 2 miles from each other. A comparison of the two rivers illustrates the effects of both watershed changes and land use in the East Branch relative to the Little Calumet River. Principally:

- Base flow in the East Branch is very high relative to the catchment area, reflecting the fact that the majority of surface water in the system represents industrial and municipal wastewater discharges.
- Flows in the East Branch are largely unaffected by storm events, reflecting the small storm flows from the small catchment area despite the dominantly industrial and urban land use (which, because of large areas with impervious surfaces, tends to favor higher relative storm flows). Storm peak flow events over the period of record (1994–1996) are no greater than the variability in industrial and municipal wastewater discharges.

These characteristics suggest that storms are unlikely to significantly affect the surface water flow and sediment transport regime. Over the 5-year period of stream flow records, average daily discharge in the East Branch at the Industrial Highway gauge has ranged from 305 to 601 cfs, with a mean of 467 cfs; the highest recorded instantaneous measurement has been 891 cfs, which represents a *de facto* 5-year flood event. The relatively short gauging record may not be representative of larger storm events. FEMA

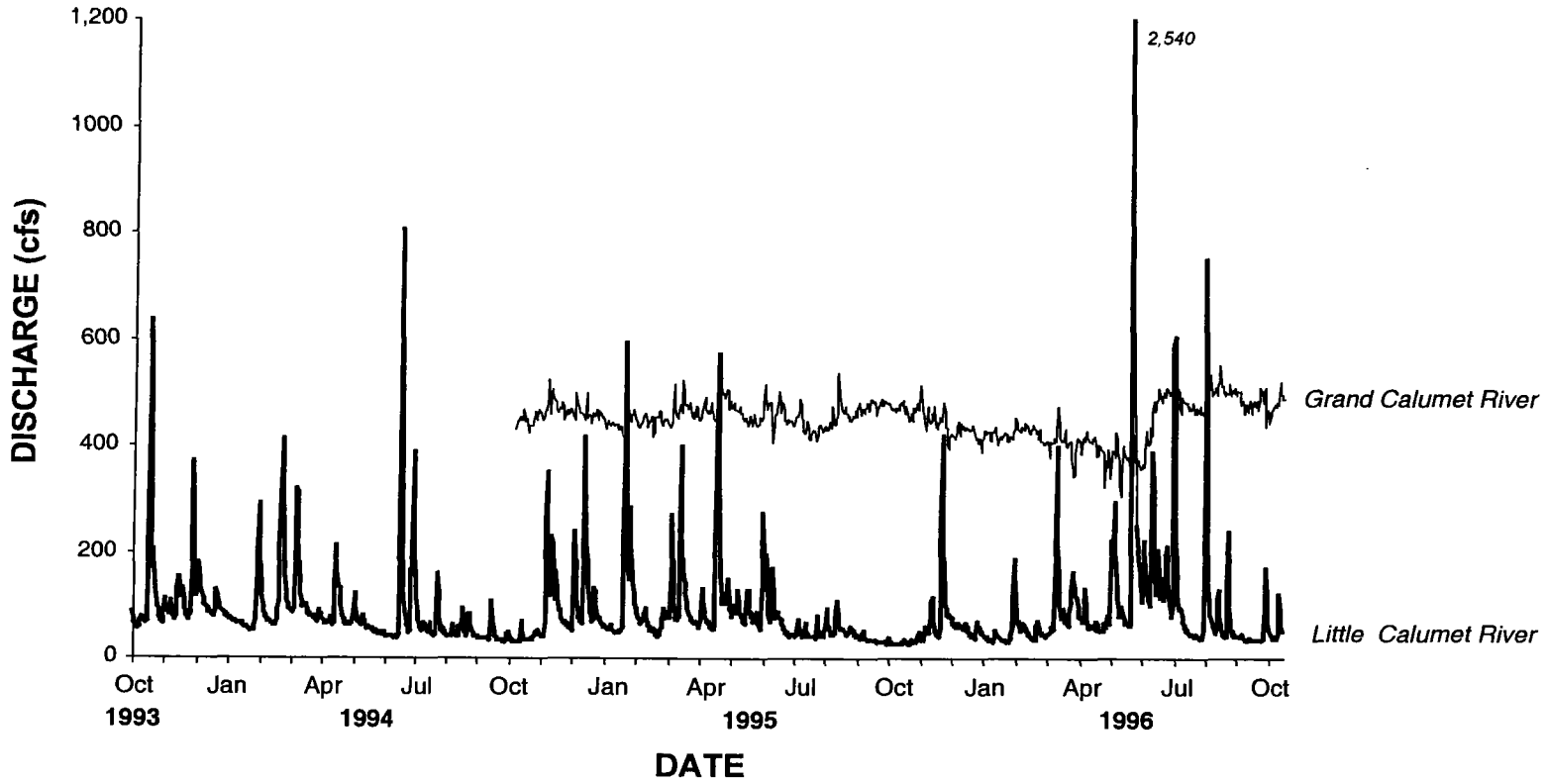

Figure 5-1.
STREAM FLOW COMPARISON OF THE GRAND CALUMET RIVER AT INDUSTRIAL HIGHWAY AND THE LITTLE CALUMET RIVER AT PORTER, INDIANA.

DuPont East Chicago Facility
Sediment Characterization Study

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(1979) estimated 10-year through 500-year flood flows in the study reach. However, after 1985, base flow in the GCR decreased by approximately 870 cfs as a result of decreased discharges from the USX plant near the headwaters of the GCR. Correcting for this change, flood flows are estimated to be 2,220 cfs for the 10-year flood, 2,720 cfs for the 50-year flood, and 2,895 cfs for the 100-year flood. More recent decreases in flow are discussed in Section 3.

In addition to the above-mentioned flow characteristics, flow in the East Branch is affected by the water surface elevation in Lake Michigan (Corps 1999; FEMA 1979). These lake levels fluctuate over both seasonal and longer time scales associated with short-term climate fluctuations. In the 81 years of record, the lake has fluctuated between a March 1964 low of 576.05 ft international Great Lakes datum (IGLD) and an October 1986 high of 582.35 ft IGLD, with a mean elevation of 579.02 ± 1.28 ft IGLD. Lake levels fluctuated between slightly above and slightly below average during the fall of 1998. High lake levels increase the stage and decrease the flow velocities well into the upper reaches of the East Branch. These fluctuations are of particular concern for the DuPont reach, which is at the downstream end of the East Branch and therefore is most susceptible to these fluctuating lake levels. High lake levels decrease water surface slope and flow velocities sufficiently to favor deposition in the DuPont reach. In contrast, low lake levels may increase water surface slope, thereby enhancing either transport of sediment through the reach or erosion of sediment from the streambed in the reach. The magnitude and spatial distribution of these effects on the sediment transport regime are crucial to understanding the present sediment characteristics in the DuPont reach.

5.2 Physical Attributes of Grand Calumet River Sediment

Sediment characteristics observed during the SCS field sampling in 1998 varied substantially by location and by depth. The geometric mean sediment grain size ranged from 16 to 975 μm and generally decreased in the downstream direction, as expected by virtue of the increasing influence of Lake Michigan (Table 5-1). Interestingly, grain size

Table 5-1. Grain size distribution by class of sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Transect		N[a]	Clay (percent)	Silt (percent)	Sand (percent)	Gravel (percent)	Geometric Mean Diameter (μm)
A	minimum	10	0.5	3.5	33.2	0.9	122
	mean		1.8	12.0	69.5	16.7	358
	maximum		8.0	38.0	92.3	46.5	844
B	minimum	7	0.5	3.0	37.7	0.1	55
	mean		2.4	26.7	60.0	10.9	250
	maximum		4.0	46.0	95.9	44.8	975
C	minimum	8	0.5	31.5	27.0	0.2	39
	mean		1.0	58.2	38.9	2.0	58
	maximum		2.0	70.5	67.6	8.9	110
D	minimum	6	0.5	3.5	19.4	0.1	24
	mean		5.8	30.4	58.6	5.3	216
	maximum		16.5	60.5	94.1	18.2	844
E	minimum	9	0.5	6.0	25.1	0.6	27
	mean		2.9	34.5	45.8	16.8	266
	maximum		9.0	65.0	92.4	55.2	844
F	minimum	6	2.0	14.5	26.7	0.9	27
	mean		3.9	39.2	52.6	4.3	63
	maximum		6.5	64.0	82.5	16.5	139
G	minimum	11	0.5	10.0	10.0	0.7	16
	mean		2.1	45.7	35.7	16.4	212
	maximum		4.0	83.5	59.9	50.6	597
H	minimum	5	0.5	8.0	18.8	0.9	27
	mean		4.8	36.4	42.2	16.6	106
	maximum		10.5	60.0	90.6	38.2	154
I	minimum	13	0.5	4.5	24.5	0.2	39
	mean		2.5	41.2	53.6	2.7	74
	maximum		9.3	74.5	94.8	10.0	150
J	minimum	7	0.5	6.5	28.2	0.2	27
	mean		3.4	32.9	59.4	4.4	82
	maximum		9.0	50.5	86.7	21.8	150
K	minimum	10	0.5	4.5	24.6	0.4	27
	mean		1.4	27.6	68.4	2.7	155
	maximum		4.0	74.5	92.9	12.5	595

[a] All sediment depth horizons and field replicates are included in this evaluation. The number of samples varies for the different transects because the study design varied. All transects contain one deep core (three samples) and varying numbers of surface samples (0–10 cm horizons), short cores (0–10, 10–20, and 20–30 cm horizons), and field replicates.

also decreased with depth. The mean clay content was less than 6 percent for all transects, mean silt content ranged from 12 to 58.2 percent, mean sand content ranged from 35.7 to 69.5 percent, and mean gravel content ranged from 2.0 to 16.8 percent (Table 5-1).

Moisture content ranged from 18 to 77 percent for transect sediment samples. Sediment bulk density is primarily a function of the water content of the sediment and varies as the water content changes as a result of sediment deposition and subsequent compaction (Jepsen et al. 1997). Bulk density, calculated on the basis of moisture content (assuming a particle density of 2.65 g/cm^3), ranged from 1.15 to 2.04 g/cm^3 (Table 5-2). By comparison, bulk density of the wetland samples (characteristic of overbank and therefore quiescent deposition) was substantially lower, ranging from 1.11 to 1.20 g/cm^3. These calculated bulk densities are likely to be somewhat high (resulting from the assumption of particle density equivalent to that of quartz), but the relative magnitude of bulk densities should be equivalent. Notably, bulk density was systematically greater at depth (as would be expected with compaction of mineral sediments) for only 3 of the 11 core samples (those at Transects B, H, and I). In the remaining cores, the intermediate interval commonly had the lowest bulk density.

5.3 Effects of Sediment Physical Characteristics on Erosion Rates

A major question in the GCR/IHC system is whether buried sediments and contaminants can be exposed and eroded during large floods and storms. To quantitatively understand and predict the transport and fate of sediments and contaminants during large floods, knowledge of the resuspension and erosion properties of sediments at high shear stresses is needed. Because contaminants are typically associated with fine-grained sediments, knowledge of the properties of these fine-grained sediments is essential (McNeil et al. 1996). Early experiments in sediment entrainment (the initiation of particle motion from the streambed) demonstrated that for noncohesive uniform sediments, fine, sand-sized particles are the most easily mobilized size fractions, with the minimum critical flow

Table 5-2. Oil and grease, moisture, and TOC content and bulk density of sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Transect		N[a]	Oil and Grease mg/kg	Oil and Grease Percent	Total Organic Carbon mg/kg	Total Organic Carbon Percent	Moisture (percent)	Bulk Density (g/cm^3)
A	minimum	10	760	0.1	3,380	0.3	21	1.17
	mean		18,846	1.9	18,118	1.8	39	1.66
	maximum		68,500	6.9	39,000	3.9	77	1.97
	std dev		19,749	2.0	11,064	1.1	18	0.25
B	minimum	7	730	0.1	2,530	0.3	18	1.15
	mean		30,490	3.0	23,090	2.3	54	1.45
	maximum		137,000	13.7	42,000	4.2	79	2.04
	std dev		47,780	4.8	14,767	1.5	22	0.31
C	minimum	8	30,500	3.1	18,800	1.9	38	1.26
	mean		80,350	8.0	27,425	2.7	55	1.40
	maximum		134,000	13.4	37,000	3.7	67	1.62
	std dev		38,611	1.9	6,249	0.6	11	0.14
D	minimum	6	800	0.1	4,500	0.5	22	1.23
	mean		12,367	1.2	16,050	1.6	44	1.60
	maximum		39,800	4.0	33,400	3.3	70	1.94
	std dev		15,116	1.5	12,456	1.2	22	0.34
E	minimum	9	770	0.1	4,100	0.4	22	1.23
	mean		30,052	3.0	18,260	1.8	48	1.52
	maximum		74,000	7.4	48,000	3.8	70	1.94
	std dev		23,389	2.3	15,582	1.6	17	0.26
F	minimum	6	1,400	0.1	6,700	0.7	35	1.17
	mean		37,800	3.8	18,200	1.8	52	1.46
	maximum		147,000	14.7	43,000	4.3	77	1.68
	std dev		56,141	5.6	14,163	1.4	19	0.23
G	minimum	11	1,800	0.2	6,300	0.6	33	1.22
	mean		18,800	1.9	17,991	1.8	55	1.41
	maximum		51,800	5.2	34,000	3.4	71	1.72
	std dev		15,860	1.6	9,171	0.9	13	0.17
H	minimum	5	770	0.1	4,000	0.4	23	1.23
	mean		14,914	1.5	16,740	1.7	48	1.54
	maximum		43,700	4.4	32,000	3.2	70	1.93
	std dev		17,234	1.7	12,685	1.3	12	0.34
I	minimum	13	750	0.1	2,100	0.2	10	1.21
	mean		20,355	2.2	17,308	1.7	56	1.41
	maximum		59,600	6.0	34,900	3.5	72	1.99
	std dev		19,923	2.0	8,655	0.9	16	0.23
J	minimum	7	2,500	0.3	5,300	0.5	26	1.26
	mean		19,900	2.0	17,657	1.8	49	1.48
	maximum		34,600	3.5	28,000	2.8	67	1.85
	std dev		11,034	1.1	8,549	0.9	13	0.21
K	minimum	10	3,600	0.4	4,400	0.4	25	1.37
	mean		36,920	3.7	14,497	1.4	38	1.65
	maximum		133,000	13.3	27,000	2.7	56	1.87
	std dev		40,836	4.1	8,668	0.9	13	0.20

[a] All sediment depth horizons and field replicates are included in this evaluation. The number of samples varies for the different transects because the study design varied. All transects contain one deep core (three samples) and varying numbers of surface samples (0–10 cm horizons), short cores (0–10, 10–20, and 20–30 cm horizons), and field replicates.

velocity associated with 0.2-mm diameter particles (Hjulström 1935). Fine-grained mineral sediments in a heterogeneous mixture, behaving noncohesively, are less susceptible to erosion than the same grain size in a homogeneous mixture (Wiberg and Smith 1997). Fine-grained sediments behaving cohesively—either due to compaction, chemical attraction between particles, or the presence of other binding materials (e.g., oil and grease)—are less susceptible to erosion than either similar-sized materials that are not cohesive or, to a lesser degree, than coarser materials (McNeil et al. 1996).

For noncohesive sediments, the threshold condition for transport is specified by a particular (critical) value of the applied stress, τ_c, that causes the grain on the bed surface to be entrained. The threshold condition for a cohesive streambed occurs when the applied stress equals the shear strength, τ_s, associated with the bed surface flocs (i.e., clusters of fine particles). In the latter case, the floc is detached from its neighbors, to which it is otherwise linked by cohesion, and is entrained. Flocs typically have substantially lower buoyant weights than noncohesive materials. In turn, after the cohesive bonds are broken, the floc is readily brought into suspension (Mehta and Lee 1993).

Because the measurements of bulk properties of sediments are standard and can be taken relatively easily, it would be useful if sediment erosion rates could be predicted from a knowledge of the sediment bulk properties. However, at present, no general quantitative theory of sediment resuspension/erosion properties is available for fine-grained or cohesive sediments, and experiments are therefore needed to determine these properties (McNeil et al. 1996). For specific locations and depths below the sediment–water interface, variations in erosion rates can usually (but not always) be qualitatively related to variations in one or more of the measured bulk properties. However, current knowledge of the dependence of erosion rates on bulk properties is insufficient to quantitatively estimate erosion rates from bulk properties.

Roberts et al. (1998) devised an experimental procedure to determine the effect of particle size and bulk density on the erosion of quartz particles. Average particle sizes

ranged from 5 to 1,350 μm, a size range similar to that of the sediments in the GCR. Bulk densities ranged from 1.65 to 1.95 g/cm^3, which is also within the range of conditions found in the study reach. For the larger particles, the sediments behaved in a noncohesive manner (i.e., they consolidated rapidly and the surface eroded particle by particle). For the smaller particles, the sediments behaved in a cohesive manner (i.e., they consolidated relatively slowly and the surface eroded in chunks). Erosion rates were a very strong decreasing function of density for the finer particles and were essentially independent of density for the larger particles. Critical stresses for erosion were strongly dependent on particle size and, for the smaller particles, were also strongly dependent on bulk density.

In addition to particle size distribution and bulk density, the sizes and numbers of gas bubbles and the amounts of oil and grease are known to have a significant effect on erosion rates. Bubble formation (or ebullition) is a common phenomenon in freshwater sediments and occurs when methane is produced by methanogenic bacteria. Most of the methane production occurs in the upper few centimeters of sediments, where bacteria are most active. The formation of bubbles and their upward movement through sediments can disrupt sediment integrity, contributing to sediment erosion. Bubble formation was not observed during the sediment investigation in September and October 1998; however, some bubble formation may be occurring in the study area. Further work is needed to determine all of the parameters on which sediment erosion depends and the quantitative dependence of erosion rates on these parameters (Mehta and Lee 1993). The Corps has begun this study for the GCR (Corps 1997), but has not yet acquired the *in situ* experimental results needed to quantify the critical shear stress needed to initiate particle motion from sediments in the study reach.

5.4 Sediment Deposition and Transport in the Study Reach

A number of empirical observations in the study area and in the larger GCR/IHC provide useful insight into sediment deposition and transport. These observations are discussed briefly in this section.

During the industrial history of the East Branch, non-native sediment ranging from 2 to 8 ft in thickness was deposited in the study reach, indicating high levels of sediment accumulation in the past. Current TSS data from point sources in the East Branch provide a rough indication of current sediment accumulation. It is likely that permitted loads are not the only sources of particulate material; however, the presence of a significant source of relatively clean particulate material is unlikely, given the chemical concentrations in surface sediment (i.e., there appears to be insufficient supply of clean sediments to dilute the load of contaminated particulate material). If it is assumed that all of the material (particulate and oil and grease) discharged by USX is deposited in the reach of the East Branch downstream of that facility to the junction with the IHC (approximately 170 acres, or 680,000 m^2), an incremental yearly deposition rate of 37 mg/cm^2-year is predicted. If it is assumed that all of the material discharged by the Gary STP is deposited in the reach of the East Branch downstream of that facility (approximately 100 acres, or 400,000 m^2), an incremental yearly deposition of 87 mg/cm^2-year is predicted. Assuming 50 percent moisture content and particle densities of 2.5 mg/cm^3, these mass accumulation rates translate to accumulation rates of less than 0.1 cm/year. In reality, these rates are likely to be overestimates of permitted particulate loads because it is unrealistic to expect that all of the materials discharged would deposit in this area. However, other sources of particulate material (e.g., storm runoff, CSOs) are not included in the estimates.

These findings are corroborated by the results of the natural recovery assessment, in which chemical gradients were evaluated in near-surface (0–30 cm) sediments at 11 locations in the study area (Section 4.1.4). When conditions are improving (i.e., surface sediments are recovering), surface concentrations of COIs (i.e., in the 0–10 cm

horizon) would be expected to be lower than shallow subsurface concentrations (i.e., in the 10–20 and 20–30 cm horizons). For deposition environments, the concentration gradient in subsurface and shallow subsurface is a balance between two processes: the rate of accumulation of contaminated particles, and the rate of accumulation of clean particles. Although selected chemicals (e.g., arsenic) may be decreasing to acceptable levels in surface sediments, a broad trend of natural recovery is not occurring. The absence of natural recovery is attributed to ongoing loading of chromium, lead, zinc, and oil and grease and the insufficient supply of clean material.

Within and between transects, the patterns of grain size distribution provide an indication of net deposition or the potential for erosion. These patterns demonstrate the importance of local bed shear stress in controlling the deposition of fines. Within transects, comparison of grain size data from the 0–10 cm samples at the north and south stations on Transects C, G, and K shows that sediment from stations on the outside of the river bend is coarser than sediment on the inside of the bend (Figure 5-2). This pattern is to be expected because flow velocities are higher on the outside of a river bend than on the inside of a river bend. This effect is most pronounced at Transect G, which has the sharpest bend, and least pronounced at Transect C. The profiles in Figure 5-2, which show the contrast between different depositional regimes, can be used to evaluate the potential depositional regime at other locations in the river. Surface sediments in Transects B and D are the coarsest (most erosional), whereas Transects I and J appear to be the most fine-grained (i.e., depositional) with Transects A and K intermediate in their depositional character.

USGS, under a support agreement with the Chicago District of the Corps, conducted suspended sediment sampling and flow monitoring in the IHC (near Dickey Road, downstream of the junction with the Lake George Canal) from May 1996 through April 1997. From these measurements, it was calculated that, on average, 23.6 tons of suspended sediment is transported per day from the GCR/IHC system downstream toward Lake Michigan (Corps 1997). This rate corresponds to an estimated annual sediment transport of about 8,700 tons per year (or about 7,900,000 kg/year). In contrast,

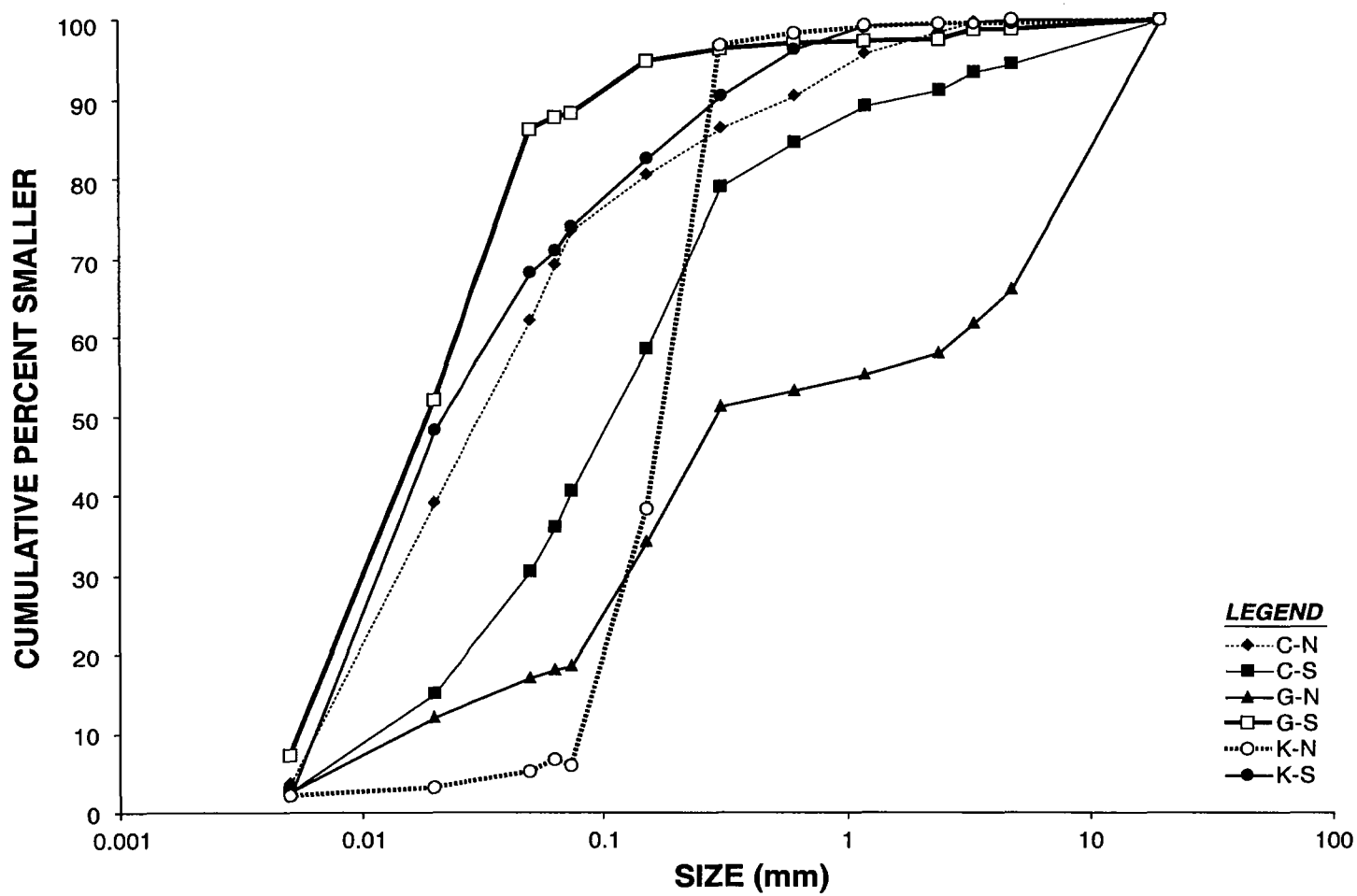

Figure 5-2.
CUMULATIVE PERCENT OF SEDIMENT LESS THAN A SPECIFIED SIZE FOR SURFACE SEDIMENT AT SELECTED TRANSECTS.

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Prepared by: Betty Dowd

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the 1997 annual loading rates estimated in Section 3.1.3 for TSS from permitted discharges within the East Branch total only 283,000 kg/year. Therefore, the TSS load associated with permitted discharges in the East Branch accounts for less than 4 percent of the TSS load from the entire GCR/IHC system upstream of Dickey Road. The vast majority of the suspended solids load from the system as a whole must come from other sources of particulate material in the East Branch, flows from the West Branch, direct point source discharges to the IHC, or resuspension of sediments in the downstream portion of this system.

5.5 Conclusions

The lack of site-specific experimental results needed to quantify entrainment of sediment from the bed significantly hampers our ability to quantify the amount of riverbed–water column interaction, scour, and deposition in the reach, although analytical data from sediment cores suggest that sediment scour has been minimal. The spatial distribution of variations in surface sediment grain size conforms to the pattern expected at river bends and indicates that different depositional conditions occur throughout the East Branch. In general, downstream locations appear to be more depositional than upstream locations.

The evaluation of current source loading data and the assessment of substance distribution patterns in surface and near-surface sediments suggest that historical sediment accumulation rates were high, current sediment accumulation rates are low, natural recovery of surface sediment is not occurring to any significant degree, and that ongoing permitted sources have the potential to recontaminate surface sediment but constitute a small portion of the particulate mass discharged to the downstream reach of the IHC.

The distribution of bulk density and grain size in the sediment cores suggests that the riverbed is currently being armored, either by coarsening of the bed or the accumulation of oil and grease in the bed sediments. As shown in Figure 5-1, the GCR does not

undergo discharge spikes, as does the Little Calumet River, so the actual impact of local high-flow conditions is difficult to estimate even qualitatively. This difficulty points to the need for a better understanding of the potential for sediment resuspension and erosion at this site, which of necessity must be achieved experimentally with these sediments.

6. Impaired Beneficial Uses

As discussed in the *Introduction*, one of the goals of the SCS was to collect information on constituent distributions and past and present source loading to the system to provide a better understanding of how those constituents have contributed to the alleged impaired beneficial uses. It was intended that by focusing attention on the alleged impaired beneficial uses, a better understanding could also be developed of how various remedial alternatives might address improvement of the beneficial uses. The SCS focused only on the downstream reach of the East Branch of the GCR, and, therefore, the results of the SCS are only generally applicable to an understanding of impaired uses throughout the entire AOC. Other investigations of the headwaters of the East Branch, the entire West Branch, the IHC, and the nearshore area of Lake Michigan may contribute to a more comprehensive understanding of impaired uses throughout the AOC. In addition, several of the impaired uses apply only to portions of the AOC. For example, restrictions on dredging activities and the consequent added costs to industry or agriculture apply only to the IHC, which is the only portion of the AOC subject to navigational dredging. Similarly, closures of swimming beaches would apply only to the nearshore area of Lake Michigan because there are no beaches on the IHC or GCR, and restrictions on drinking water consumption also would affect only the nearshore area of Lake Michigan because that it is the only portion of the AOC where surface water is used as a source of drinking water.

Table 3-2 in the SCS work plan (Exponent 1998) (reproduced herein as Table 1-2) summarized what was known at that time about associations between the alleged impaired uses and substances in the environment, and it identified the environmental media thought to be of primary or secondary importance in each use impairment. Environmental media may be of secondary importance not only if they serve as a direct but less important reason for the use impairment, but also if they serve as a source of the substance to the primary medium. The information in Table 1-2 represented a general

understanding of the effects of environmental contaminants on beneficial uses, but information specific to the AOC was not available at the time of submittal of the SCS work plan (Exponent 1998). By considering the information collected as part of the SCS, it is now possible to focus attention on how the constituents in the sediment, surface water, and wetland soil of the East Branch may contribute to beneficial use impairment. Table 6-1 expands upon Table 1-2 by identifying those constituents most likely associated with the alleged use impairments in the AOC. Where the available information now suggests that it is less likely that a specific constituent contributes to an alleged use impairment, that constituent is retained in Table 6-1 but is deemphasized. A brief discussion of the implications of the findings of the SCS for each of the alleged impaired beneficial uses is presented in the following sections.

6.1 Restrictions on Fish and Wildlife Consumption

The AOC is subject to a Group 5 fish consumption advisory (recommending no consumption of fish) based on the concentrations of PCBs detected in carp collected from the GCR. Mercury concentrations in fish are also elevated, although not to the same extent as PCBs. In the absence of PCB contamination, mercury contamination would likely result in only a Group 2 or Group 3 (restrict consumption) advisory. Neither chlorinated pesticides nor dioxins and dioxin-like compounds have been identified as chemicals of concern for fish within the AOC. As discussed in Section 4.1.3, mercury in the sediments is likely to not be bioavailable because of the presence of high concentrations of sulfide in the sediments, which result in the formation of relatively insoluble metal sulfides. The uptake of mercury by fish is likely more a factor of methylmercury concentrations in the water column, which have not been investigated in this system. Fish prey may become contaminated with PCBs both from the sediments and from the water column, but the relative magnitudes of these two potential sources are difficult to estimate. Because there appear to be ongoing sources of PCBs to the system from municipal and industrial discharges, it can be assumed that the potential for bioaccumulation of PCBs would remain even in the absence of PCBs currently present in

Table 6-1. Assessment of likely contributors to alleged beneficial use impairments at the Indiana Harbor Canal, Grand Calumet River, and nearshore Lake Michigan area of concern

		Substance(s) Potentially Responsible												Medium in Which Substances Are Present		
	Alleged Beneficial Use Impairment[a]	Metals	Mercury	PCBs	Chlorinated Pesticides	Dioxins and Dioxin-Like Compounds	PAHs	Oil and Grease	Nutrients	Grain Size	Other Sediment Conventional Parameters	Fecal Coliform Bacteria	Dissolved Oxygen	Surface Water	Sediments	Organisms
i	Restrictions on Fish and Wildlife Consumption		●	●	O	O								S	S	P
ii	Tainting of Fish and Wildlife Flavor							●						S	S	P
iii	Degradation of Fish and Wildlife Populations	●	●	●	O	O	●	●		O	O		O	P	P	S
iv	Fish Tumors or Other Deformities		O				●							S	S	P
v	Bird or Animal Deformities or Reproductive Problems		O	●	O	O								S	S	P
vi	Degradation of Benthos	●	O	●	O		●	●	O	O	O		O	S	P	S
vii	Restrictions on Dredging Activities	O	O	O	O	O	O	O						S	P	--
viii	Eutrophication or Undesirable Algae								●					P	S	--
ix	Restrictions on Drinking Water Consumption (or Taste and Odor Problems)	O	O	O	O	O	O	O				O		P	S	--
x	Beach Closings											O		P	--	--
xi	Degradation of Aesthetics							●	O					S	--	--
xii	Added Cost to Agriculture or Industry	O	O	O	O	O	O	O						S	P	--
xiii	Degradation of Phytoplankton and Zooplankton Communities	O	O					O	O				O	P	S	--
xiv	Loss of Fish and Wildlife Habitat							●	O	O	O		O	S	S	--

Note: PAH - polycyclic aromatic hydrocarbon
PCB - polychlorinated biphenyl
P - primary (of primary importance in impairment of the specified use)
S - secondary (of secondary importance in impairment of the specified use, or more typically, serving as a source of the substance to the primary medium)
O - potential contributor to impaired use in general
● - likely contributor to impaired use within the East Branch of the area of concern, as interpreted by Exponent based on the results of the sediment characterization study

[a] Alleged beneficial use impairments identified in the Stage 1 remedial action plan (IDEM 1991)

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the sediments. In addition, because all of Lake Michigan is under a fish consumption advisory attributable to PCBs, it is unlikely that sediment remediation within the East Branch would result in elimination of that advisory.

6.2 Tainting of Fish and Wildlife Flavor

Oil and grease are considered to be the constituents with the greatest potential for tainting fish or wildlife flavor. Although the only evidence of tainting of fish in the AOC is anecdotal, it would not be unreasonable to assume that such tainting could occur, given the high concentrations of oil and grease found in the sediments of the East Branch. Oil and grease concentrations found throughout the study area are considered to be attributable to both the historical and ongoing releases from USX and the Gary STP, historical and ongoing releases from CSOs and storm drains, and potential releases from oil storage facilities. Sediment remediation within the study area might reduce the potential for tainting of fish or wildlife; however, ongoing releases of oil and grease from the aforementioned sources will continue to contribute to any such problem.

6.3 Degradation of Fish and Wildlife Populations

Fish and wildlife populations within the AOC have the potential to be degraded by a broad spectrum of contaminants (Table 1-1). Nevertheless, the results of the SCS may help to focus attention on the contaminants more likely to have a major role. The SCS demonstrated that chromium, and to a lesser extent lead and zinc, are the metals most likely to be bioavailable and to have adverse effects on biota. The high sulfide concentrations in the sediments in the study area favor the formation of relatively insoluble metal sulfides, which reduces the bioavailability of divalent metals. Mercury, PCBs, PAHs, and oil and grease were all found in the sediments in concentrations sufficient to adversely affect biota. On the contrary, the relatively low concentrations of

chlorinated pesticides and dioxins within the study area suggest that they are less likely to adversely affect biota.

6.4 Fish Tumors or Other Deformities

Historically, carp from the GCR and IHC were said to have had eroded fins, swollen abdomens, deformed lower jaws, and bloody fins. It is not known whether recent data are available on the prevalence of such conditions within the AOC. In general, the chemicals most likely to be responsible for causing tumors and other deformities in fish are PAHs, and the concentrations of PAHs present in the sediments of the study area are certainly elevated. Although potentially responsible for such conditions in other aquatic systems, it is less likely that mercury would play such a role in the study area because of the high sulfide concentrations, which tend to bind up the mercury and make it relatively insoluble. In the absence of further data on the nature of such effects and identification of the causative agents, it is difficult to speculate on the potential effects of sediment remediation on this impaired use.

6.5 Bird or Animal Deformities or Reproductive Problems

Historically, there were said to have been limited bird and animal deformities and the potential for reproductive impairment in birds inhabiting or feeding within the AOC. In general, the chemicals thought to be responsible for such effects are chlorinated organic compounds such as dioxins, PCBs, and chlorinated pesticides. In some cases, mercury has also been implicated. Considering the elevated concentrations of PCBs in fish and sediments within the East Branch, it is possible that such effects could occur within this system as a result of exposure to PCBs. Because there appear to be ongoing sources of PCBs to the system from municipal and industrial discharges, it can be assumed that the potential for uptake of PCBs through the food web would remain even in the absence of PCBs currently present in the sediments. In addition, because fish throughout Lake

Michigan are known to be contaminated with PCBs, it is unlikely that sediment remediation within the East Branch would result in a substantial reduction in the exposure of higher trophic level organisms. The relatively low concentrations of dioxins and chlorinated pesticides in the study area suggest that they are less likely to be associated with such effects in this area. As indicated earlier, the mercury within the sediments tends to be bound up by the sulfide in the sediments, making it less bioavailable. However, uptake of mercury through the food web is more likely to be attributable to methylmercury, which has not been investigated within the study area.

6.6 Degradation of Benthos

The potential for adverse effects on the benthos within the study area was assessed by comparing chemical concentrations in the sediments to the NEC values of Ingersoll et al. (1996). Surface sediment concentrations of chromium, lead, nickel, and zinc exceeded the NEC values throughout most of the study area. Results suggest that chromium, followed by lead and zinc, poses the greatest potential risk to benthos because it is not bound up by sulfide. NEC values for PAHs were exceeded at all stations in the study area, including all surface horizons. NEC values for PCBs were exceeded in six of the eight surface horizons analyzed. These results suggest that all of these chemicals have the potential to adversely affect benthic organisms at the concentrations found in the sediments in the study area. Although NEC values are not available for the chlorinated pesticides, the relatively low concentrations of these compounds in the sediments of the study area suggest that they are not likely to be associated with adverse effects on benthos.

6.7 Restrictions on Dredging Activities

As indicated earlier, restrictions on dredging activities within the AOC are associated with the condition of sediments in the IHC, and not with sediments in the East Branch.

There are numerous sources surrounding the IHC that contribute contaminants to sediments at levels that would likely cause restrictions to be placed on dredging even if there were no connection of the IHC to the East and West Branches of the GCR. Although there may certainly be some transport of contaminants to the IHC from the GCR, the results of the SCS suggest that there is not a significant ongoing bed load transport of contaminated sediments, nor does there appear to be a threat of resuspension of significant volumes of contaminated sediment because there is such little variation in flow in the East Branch (i.e., the likelihood of flooding is minimal because most of the flow in the East Branch is wastewater discharges and not runoff). Hence, there appears to be little reason to believe that, even if sediments within the East Branch were remediated, there would be any change in the restrictions on dredging in the IHC.

6.8 Eutrophication or Undesirable Algae

As part of the SCS, trophic state of the East Branch was assessed by the method of Carlson (1977), using the total phosphorus concentration in surface water to calculate the TSI. Total phosphorus concentrations measured during the high-flow event indicated eutrophic conditions. The abundance of phosphorus, which is usually the limiting plant nutrient in freshwater systems, suggests that excessive plant growth may occur, which could, in turn, deplete dissolved oxygen and be detrimental to animal life. The TSI value during one of the low-flow events indicated that there was little or no difference between high- and low-flow conditions. These results indicate that water quality in the East Branch may be adversely affected by nutrient loading from the Gary STP, CSOs, and storm drains.

6.9 Restrictions on Drinking Water Consumption

As indicated earlier, restrictions on drinking water consumption affect only the nearshore area of Lake Michigan because that it is the only portion of the AOC where surface water

is used as a source of drinking water. The limited water quality sampling of the East Branch that was conducted as part of the SCS suggests that the East Branch is unlikely to contribute significantly to conditions in Lake Michigan that might affect drinking water supply systems.

6.10 Beach Closings

Beach closures within the AOC have occurred only along the Lake Michigan beaches because there are no beaches within the GCR or IHC. The beach closures are likely the result of the discharge of fecal coliform bacteria from STPs or CSOs near those beaches, and are unlikely to result from similar discharges far inland along the East Branch. The water quality sampling conducted as part of the SCS demonstrated that fecal coliform bacteria counts in the East Branch were relatively low, although an approximately 10-fold increase in the counts occurred during high-flow events, indicative of the effects of upstream CSO discharges. It is unlikely that the fecal coliform bacteria counts observed in the East Branch during high-flow events would have any effect on the coastal Lake Michigan water quality conditions.

6.11 Degradation of Aesthetics

Degradation of aesthetics is primarily associated with visual affronts to human observers. In the East Branch, such affronts might be expected to be a result of visible oil and grease on the water surface, river banks, and emergent vegetation or of debris littering the river banks and benthic habitat. Chemical contamination of the sediments, while potentially a problem for biota, is unlikely to contribute directly to degradation of aesthetics. To the extent primary contributors to the degradation of aesthetics are associated with ongoing sources (e.g., discharges from CSOs), sediment remediation alone is unlikely to result in a significant improvement.

6.12 Added Costs to Agriculture or Industry

In general, added costs to agriculture or industry may be associated either with restrictions on dredging resulting from sediment contamination or with limitations on the use of surface water for livestock watering or irrigation resulting from water quality problems. Within the heavily industrialized area surrounding the IHC, GCR, and nearshore Lake Michigan AOC, it is unlikely that there would be any use of surface water for livestock watering or irrigation. Hence, the only likely added costs to agriculture or industry within the AOC are those associated with restrictions on dredging in the IHC. As indicated in Section 6.7 above, the fact that sediment conditions in the East Branch likely have little effect on sediment conditions in the IHC suggests that, even if sediments within the East Branch were remediated, there would be no change in the restrictions on dredging in the IHC.

6.13 Degradation of Phytoplankton and Zooplankton Communities

The health of phytoplankton and zooplankton communities within the AOC is of greater interest in the nearshore area of Lake Michigan, where phytoplankton counts are said to be very low, than within the East Branch, where the food web would not be expected to be based on these communities. The eutrophic state of the East Branch would tend to favor excessive algal growth, which could have its own problems in inshore waters. The ultimate discharge of phosphorus-containing waters to Lake Michigan could actually enhance phytoplankton growth there if nutrients were otherwise limiting. The cause of low phytoplankton counts in this area of Lake Michigan must be attributable to other, as yet unknown, reasons.

6.14 Loss of Fish and Wildlife Habitat

The loss of appropriate physical habitat characteristics and structure diminishes the usability of the habitat by native fish species. Furthermore, the lack of suitable food organisms limits the ability of fish to survive within the AOC. The presence of high concentrations of substances such as oil and grease and PAHs in surface sediments of the East Branch certainly makes it a less hospitable environment for native fish species. Studies have not been conducted of the availability of food organisms in the East Branch, although it can be assumed that water and sediment quality conditions have altered the natural community. Given the fact that the vast majority of the flow of the East Branch consists of industrial and municipal wastewaters, however, it is unrealistic to expect this water body to revert to a pre-industrial condition and to support abundant native fish populations even if all of the sediments within the East Branch were remediated.

6.15 Relationship of Releases from DuPont to the Impaired Beneficial Uses

The results of the SCS (as discussed in Section 4) suggest that releases from the DuPont facility potentially contributed to the accumulation of several metals (notably arsenic, copper, lead, and mercury) in the sediments in the portion of the East Branch adjacent to the facility. Those accumulations of metals appear to be buried and suggestive of historical rather than ongoing releases. Because the highest concentrations of these metals are well below the biologically active layer (i.e., the uppermost 10 cm or less), they are largely segregated from the environment and therefore unlikely to be associated with ongoing adverse effects on biota. Furthermore, the low permeability of the sediments limits any potential advective transport of dissolved constituents, and the presence of elevated concentrations of AVS in surface sediments would be expected to bind with mobile forms of copper, lead, or mercury, limiting their bioavailability. On the contrary, other chemicals whose concentrations are high in surface and near-surface sediments and which are more likely to be directly linked to effects in biota (e.g., chromium, PCBs, PAHs, oil and grease) are not associated with releases from the DuPont

facility. It can be concluded that current environmental conditions within the East Branch certainly contribute to impairment of beneficial uses, but that those conditions responsible for the use impairments are not attributable to activities at the DuPont facility.

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Appendix A

Point Source Loading Data

Contents

Table A-1. Total loads of constituents of interest from permitted discharges to the East Branch of the Grand Calumet River (1989–1997)

Table A-2. Estimated total annual loads of constituents of interest to the East Branch of the Grand Calumet River by year

Table A-3. Average flow rates of permitted discharges into the Grand Calumet River system by year

Table A-1. Total loads of constituents of interest from permitted discharges to the East Branch of the Grand Calumet River (1989–1997)

Parameter	AMG Resources Corp.	CITGO Petroleum Corp.	E.I. du Pont de Nemours	Gary STP	Harbison-Walker Refractories	U.S. Steel – Gary Works, USX C	Total
Lead (kg)				8,597		2,873	11,470
Zinc (kg)				14,585		9,357	23,942
Oil/Grease (kg)	4,406	18,489		7,473,357	3,437	10,593,678	18,093,367
TSS (kg)	8,494		224,039	6,345,879		2,341,379	8,919,791
TDS (kg)	340,577		56,166,255	314,576,463			371,083,294
Arsenic (kg)				1,317			1,317
Chromium (kg)				7,171		1,807	8,978
Chromium(VI) (kg)				2,533			2,533
Copper (kg)				19,538			19,538
Mercury (kg)				149			149

Note: Data for 1998 were available only for January.

Permit compliance system data were retrieved by EVS (1998).

When a parameter was analyzed but not detected, half the detection limit was used to calculate loads.

When data are not reported for all months of a year for a particular discharge, the amount is adjusted upward based on the number of months for which discharges are actually reported.

Because data were not available for all time periods for all monitored constituents, the total loads should be considered minimum estimates and the actual total loads may have been substantially higher.

STP - sewage treatment plant
TDS - total dissolved solids
TSS - total suspended solids

Table A-2. Estimated total annual loads of constituents of interest to the East Branch of the Grand Calumet River by year

Material	Year	AMG Resources Corp.	CITGO Petroleum Corp.	E.I. du Pont de Nemours	Gary STP	Harbison-Walker Refractories	U.S. Steel – Gary Works, USX C	Total
Arsenic (kg)	1994				594			594
	1995				364			364
	1996				107			107
	1997				158			158
	1998				94			94
Chromium (kg)	1989				2,027			2,027
	1990				1,271			1,271
	1991				696			696
	1992				635			635
	1993				798			798
	1994				529		668	1,197
	1995				490		519	1,009
	1996				333		269	602
	1997				265		352	617
	1998				126			126
Chromium(VI) (kg)	1994				823			823
	1995				511			511
	1996				427			427
	1997				457			457
	1998				315			315
Copper (kg)	1989				2,689			2,689
	1990				4,747			4,747
	1991				3,653			3,653
	1992				2,242			2,242
	1993				2,242			2,242
	1994				1,147			1,147
	1995				415			415
	1996				1,020			1,020
	1997				1,131			1,131
	1998				252			252
Mercury (kg)	1989				12			12
	1990				30			30
	1991				22			22
	1992				14			14
	1993				22			22
	1994				7			7
	1995				13			13
	1996				15			15
	1997				8			8
	1998				6			6
Oil/Grease (kg)	1989	448	2,877		456,592		3,419,671	3,879,588
	1990	1,233	3,670		1,424,380		3,045,410	4,474,693
	1991	174	2,853		977,129		1,537,669	2,517,825
	1992	294	2,329		1,450,265		881,636	2,334,525
	1993	446	2,124		967,544	689	628,527	1,599,329
	1994	336	3,328		616,334	849	561,758	1,182,605
	1995	400	1,309		266,280	722	248,792	517,503
	1996	378			379,126	792	133,464	513,760
	1997	698			243,383	346	136,750	381,178
	1998				692,323	39		692,362
Lead (kg)	1989				1,337		1	1,338
	1990				2,831		3	2,834
	1991				1,236		26	1,262
	1992				494		2	496
	1993				402		2	404
	1994				161		619	780

Table A-2. (cont.)

Material	Year	AMG Resources Corp.	CITGO Petroleum Corp.	E.I. du Pont de Nemours	Gary STP	Harbison-Walker Refractories	U.S. Steel – Gary Works, USX C	Total
Lead (kg) (cont.)								
	1995				664		695	1,359
	1996				441		979	1,420
	1997				653		546	1,199
	1998				378			378
TDS (kg)	1989	59,821		3,394,066	25,668,432			29,122,318
	1990	43,303		4,586,388	34,502,102			39,131,793
	1991	58,100		6,693,441	36,155,293			42,906,834
	1992	45,654		6,072,667	28,312,966			34,431,288
	1993	11,432		5,145,889	34,817,619			39,974,940
	1994	12,602		5,581,139	34,712,209			40,305,951
	1995	29,115		5,888,733	25,780,388			31,698,237
	1996	11,501		5,792,258	30,791,290			36,595,050
	1997	69,049		7,185,383	31,213,920			38,468,351
	1998			6,830,989	32,622,243			39,453,232
TSS (kg)	1989	879		10,607	1,396,753		503,576	1,911,815
	1990	444		9,736	2,102,662		570,036	2,682,877
	1991	405		19,047	742,813		245,255	1,007,520
	1992	280		18,152	476,854		175,964	671,250
	1993	411		12,396	603,389		179,234	795,429
	1994	210		6,884	438,941		194,467	640,502
	1995	569		12,858	178,428		280,646	472,500
	1996	460		42,961	74,065		73,937	191,424
	1997	4,836		46,182	105,913		118,264	275,195
	1998			39,561	226,061			265,622
Zinc (kg)	1983						1,950	1,950
	1984							0
	1985							0
	1986							0
	1987							0
	1990							0
	1994				14,585		6,528	21,113
	1995						710	710
	1996						169	169

Note: Because data were not available for all time periods for all monitored constituents, the total loads should be considered minimum estimates and the actual total loads may have been substantially higher.

When a parameter was analyzed but not detected, half the detection limit was used to calculate loads.

STP - sewage treatment plant
TDS - total dissolved solids
TSS - total suspended solids

Table A-3. Average flow rates of permitted discharges into the Grand Calumet River system by year

		Flow (mgd)									
	Industry	1989	1990	1991	1992	1993	1994	1995	1996	1997	Jan-98
East	U.S. Steel – Gary Works, USX C	522.50	547.03	492.47	477.32	444.63	444.04	368.35	362.75	376.82	
East	Gary STP	45.29	50.69	52.45	39.88	54.77	44.34	41.91	45.32	42.11	44.70
East	CITGO Petroleum Corp.	0.38	0.43	0.40	0.36	0.37	0.37	0.34			
East	E.I. du Pont de Nemours	0.36	0.36	0.48	0.46	0.42	0.38	0.41	0.44	0.73	0.38
East	AMG Resources Corporation	0.10	0.12	0.047	0.059	0.062	0.051	0.070	0.065	0.12	
East	Harbison-Walker Refractories					0.20	0.21	0.21	0.22	0.21	0.18
West	Calumet Flexicore Corporation	0.007	0.009	0.008	0.007	0.009	0.007	0.008	0.007	0.007	0.010
West	East Chicago Municipal STP	14.23	17.92	15.79	12.64	16.47	13.56	13.61	13.57	13.11	15.79
West	Hammond Municipal STP	36.74	41.30	38.38	32.13	46.69	37.67	38.38	40.03	40.77	50.10
Canal	American Oil Company (AMOCO)	131.83	122.56	120.96	111.31	116.35	127.38	133.51	133.78	134.93	
Canal	American Steel Foundries	0.15	0.12	0.12	0.11	0.078	0.075	0.087	0.081	0.034	
Canal	Inland Steel Company	421.31	375.40	345.74	290.81	338.01	299.60	283.51	268.26	252.79	264.07
Canal	LTV Steel Company	175.82	198.22	223.76	197.48	196.13	200.41	175.74	201.13	189.20	228.84
Canal	Phillips Pipeline Company	0.005	11.47			0.19					

Note: Data for 1998 were available only for January.

Permit compliance system data were retrieved by EVS (1998).

When data are not reported for all months of a year for a particular discharge, the amount is adjusted upward based on the number of months for which discharges are actually reported.

mgd - million gallons per day
STP - sewage treatment plant

Appendix B

Analytical Results for Sediment, Surface or Subsurface Wetland Soil, and Surface Water Samples

Appendix B1

Analytical Results for Sediment Samples

Contents

Table B1-1. BTEX results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B1-2. Grain size and TOC results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B1-3. Metals results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B1-4. Miscellaneous results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B1-5. Oil and grease results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B1-6. PAH results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B1-7. Pesticides and PCBs results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B1-8. SEM and AVS results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B1-1. BTEX results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Benzene (µg/kg)	Toluene (µg/kg)	Ethylbenzene (µg/kg)	Xylene isomers (total) (µg/kg)
A-M	ECH-E-AM01	--	0	10	2.00 *U*	2.00 *U*	2.00 *U*	9.00 *J*
A-M	ECH-E-AM02	--	10	20	340 *J*	84.0 *U*	84.0 *U*	480
A-M	ECH-E-AM03	--	20	30	570 *J*	81.0 *UJ*	750 *J*	1,300 *J*
A-N	ECH-E-AN01	1	0	10	2.00 *U*	2.00 *U*	2.00 *U*	21.0
A-N	ECH-E-AN01	2	0	10	2.00 *U*	2.00 *U*	2.00 *J*	20.0
A-S	ECH-E-AS01	--	0	10	4.00 *U*	4.00 *U*	4.00 *U*	4.00 *U*
B-N	ECH-E-BN01	--	0	10	2.00 *U*	2.00 *U*	2.00 *J*	18.0
B-S	ECH-E-BS01	--	0	10	9.00 *J*	7.00 *J*	13.0 *J*	100 *J*
D-N	ECH-E-DN01	--	0	10	97.0 *J*	17.0 *J*	14.0 *J*	25.0 *J*
D-S	ECH-E-DS01	--	0	10	5.00 *U*	5.00 *U*	5.00 *U*	23.0 *J*
I-M	ECH-E-IM01	--	0	10	5.00 *J*	4.00 *J*	2.00 *U*	11.0 *J*
I-M	ECH-E-IM02	1	10	20	7.00 *J*	6.00 *J*	6.00 *J*	18.0
I-M	ECH-E-IM02	2	10	20	6.00 *J*	6.00 *J*	3.00 *U*	11.0 *J*
I-M	ECH-E-IM03	--	20	30	6.00 *J*	5.00 *U*	5.00 *U*	6.00 *J*
I-N	ECH-E-IN01	--	0	10	15.0 *J*	4.00 *UJ*	14.0 *J*	66.0 *J*
I-N	ECH-E-IN02	--	10	20	7.00 *J*	9.00 *J*	8.00 *J*	54.0
I-N	ECH-E-IN03	--	20	30	21.0 *J*	18.0 *J*	17.0 *J*	150 *J*
I-S	ECH-E-IS01	--	0	10	7.00 *J*	6.00 *J*	4.00 *U*	4.00 *J*
I-S	ECH-E-IS02	--	10	20	6.00 *U*	6.00 *U*	6.00 *U*	6.00 *U*
I-S	ECH-E-IS03	--	20	30	1.00 *U*	1.00 *U*	1.00 *U*	1.00 *U*

Note: All results reported in dry weight.

BTEX - benzene, toluene, ethylbenzene, and xylenes
J - estimated
U - undetected at detection limit shown

Table B1-2. Grain size and TOC results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 0.001 mm (percent wet)	Particles smaller than 0.002 mm (percent wet)	Particles smaller than 0.005 mm (percent wet)	Particles smaller than 0.020 mm (percent wet)	Particles smaller than 0.050 mm (percent wet)
A-M	ACORE01SD	1	0	69	1.50	1.50	2.00	6.50	8.00
A-M	ACORE01SD	2	0	69	1.50	1.50	2.50	7.00	8.00
A-M	ACORE02SD	--	69	122	0.500 *U*	0.500 *U*	2.00	8.50	12.0
A-M	ACORE03SD	--	122	200	1.00	1.50	2.00	5.50	5.50
A-M	ECH-E-AM01	--	0	10	0.500 *U*	0.500 *U*	1.50	3.50	5.50
A-M	ECH-E-AM02	--	10	20	0.500 *U*	0.500 *U*	0.500 *U*	2.00	3.00
A-M	ECH-E-AM03	--	20	30	0.500 *U*	0.500 *U*	0.500 *U*	2.00	3.00
A-N	ECH-E-AN01	1	0	10	1.50	1.50	3.00	8.50	15.0
A-N	ECH-E-AN01	2	0	10	1.50	2.00	3.00	9.50	16.5
A-S	ECH-E-AS01	--	0	10	4.00	8.00	16.0	35.0	43.0
B-M	BCORE01SD	--	0	55	0.500 *U*	2.00	4.00	26.0	46.5
B-M	BCORE02SD	1	55	120	2.50	4.00	7.50	19.5	29.5
B-M	BCORE02SD	2	55	120	2.00	3.50	7.00	15.0	26.5
B-M	BCORE03SD	--	120	173	0.500 *U*	0.500 *U*	1.00	2.00	3.00
B-M	ECH-E-BM01	--	0	10	0.500 *U*	2.00	3.00	9.00	15.5
B-N	ECH-E-BN01	--	0	10	0.500 *U*	1.00	2.00	8.00	14.0
B-S	ECH-E-BS01	--	0	10	4.00	4.00	4.50	15.0	34.0
C-CORE	CCORE01SD	--	0	135	0.500 *U*	0.500 *U*	2.00	17.0	24.0
C-CORE	CCORE02SD	--	135	269	0.500 *U*	0.500 *U*	5.50	43.0	62.0
C-CORE	CCORE03SD	--	269	460	0.500 *U*	0.500 *U*	7.00	38.5	50.0
C-N	ECH-E-CN01	--	0	10	0.500 *U*	1.00	3.50	39.0	62.0
C-N	ECH-E-CN02	--	10	20	0.500 *U*	1.50	8.00	50.0	68.0
C-N	ECH-E-CN03	1	20	30	0.500 *U*	1.50	6.00	46.0	66.5
C-N	ECH-E-CN03	2	20	30	0.500 *U*	2.00	6.50	49.0	70.5
C-S	ECH-E-CS01	--	0	10	0.500 *U*	0.500 *U*	2.50	15.0	30.5
D-M	DCORE01SD	--	0	103	0.500 *U*	0.500 *U*	1.50	3.50	4.50
D-M	DCORE02SD	--	103	180	8.50	16.5	28.0	56.5	69.5
D-M	DCORE03SD	--	180	208	0.500 *U*	2.00	4.00	8.50	11.0
D-M	ECH-E-DM01	--	0	10	0.500 *U*	0.500 *U*	1.00	3.00	3.50
D-N	ECH-E-DN01	--	0	10	2.50	4.00	7.00	17.5	39.0
D-S	ECH-E-DS01	--	0	10	6.00	11.0	19.0	55.0	70.5
E-CORE	ECORE01SD	--	0	45	1.00	1.00	1.00	3.50	5.00
E-CORE	ECORE02SD	--	45	118	2.00	7.00	17.5	52.0	69.5
E-CORE	ECORE03SD	--	118	165	0.500 *U*	0.500 *U*	2.50	5.50	6.00

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 0.001 mm (percent wet)	Particles smaller than 0.002 mm (percent wet)	Particles smaller than 0.005 mm (percent wet)	Particles smaller than 0.020 mm (percent wet)	Particles smaller than 0.050 mm (percent wet)
E-N	ECH-E-EN01	--	0	10	0.500 *U*	0.500 *U*	1.00	3.00	6.00
E-N	ECH-E-EN02	--	10	20	0.500 *U*	1.00	2.00	10.0	20.0
E-N	ECH-E-EN03	--	20	30	3.50	9.00	21.5	40.0	54.0
E-S	ECH-E-ES01	--	0	10	0.500 *U*	0.500 *U*	6.00	37.0	54.0
E-S	ECH-E-ES02	--	10	20	1.00	5.00	15.0	32.0	48.5
E-S	ECH-E-ES03	--	20	30	1.00	1.50	3.00	23.0	39.0
F-CORE	FCORE01SD	--	0	55	2.00	2.00	3.00	7.00	12.5
F-CORE	FCORE02SD	--	55	150	2.00	6.50	11.0	33.5	56.5
F-CORE	FCORE03SD	1	150	205	1.50	4.50	10.5	20.5	25.0
F-CORE	FCORE03SD	2	150	205	2.00	4.50	9.50	22.0	26.5
F-N	ECH-E-FN01	--	0	10	0.500 *U*	2.00	5.50	21.0	43.5
F-S	ECH-E-FS01	--	0	10	3.50	4.00	7.00	32.0	59.5
G-M	GCORE01SD	--	0	64	0.500 *U*	1.50	3.00	5.50	29.0
G-M	GCORE02SD	--	94	208	2.00	4.00	6.00	17.5	41.0
G-M	GCORE03SD	1	208	259	0.500 *U*	3.00	3.50	12.5	33.0
G-M	GCORE03SD	2	208	259	0.500 *U*	2.00	5.00	9.50	22.5
G-N	ECH-E-GN01	--	0	10	0.500 *U*	0.500 *U*	2.50	12.0	17.0
G-N	ECH-E-GN02	--	10	20	0.500 *U*	0.500 *U*	2.00	8.00	11.0
G-N	ECH-E-GN03	--	20	30	2.00	2.00	2.50	8.50	11.5
G-S	ECH-E-GS01	1	0	10	2.50	4.00	7.00	52.0	86.0
G-S	ECH-E-GS01	2	0	10	0.500 *U*	2.50	6.00	47.0	83.0
G-S	ECH-E-GS02	--	10	20	0.500 *U*	0.500 *U*	4.00	53.0	76.0
G-S	ECH-E-GS03	--	20	30	0.500 *U*	3.00	11.0	61.0	79.0
H-CORE	HCORE01SD	--	0	36	6.00	10.5	18.5	37.0	47.5
H-CORE	HCORE02SD	--	36	89	2.00	7.50	15.0	27.0	37.0
H-CORE	HCORE03SD	--	89	124	0.500 *U*	0.500 *U*	1.50	6.00	8.00
H-N	ECH-E-HN01	--	0	10	1.50	1.50	2.50	23.0	37.5
H-S	ECH-E-HS01	--	0	10	2.50	4.00	9.00	24.0	49.0
I-M	ICORE01SD	--	0	74	0.500 *U*	3.00	9.50	26.0	42.5
I-M	ICORE02SD	--	74	155	4.7	9.2	16	35	48
I-M	ICORE03SD	--	155	183	1.00	2.50	3.00	3.00	5.50
I-M	ECH-E-IM01	--	0	10	0.500 *U*	2.00	5.50	15.5	29.0
I-M	ECH-E-IM02	1	10	20	0.500 *U*	2.00	5.50	24.0	35.0
I-M	ECH-E-IM02	2	10	20	0.500 *U*	0.500 *U*	4.00	21.0	33.0

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 0.001 mm (percent wet)	Particles smaller than 0.002 mm (percent wet)	Particles smaller than 0.005 mm (percent wet)	Particles smaller than 0.020 mm (percent wet)	Particles smaller than 0.050 mm (percent wet)
I-M	ECH-E-IM03	--	20	30	0.500 *U*	0.500 *U*	4.00	38.0	54.5
I-N	ECH-E-IN01	--	0	10	0.500 *U*	0.500 *U*	1.50	52.0	72.5
I-N	ECH-E-IN02	--	10	20	2.00	4.50	10.0	49.0	60.0
I-N	ECH-E-IN03	--	20	30	0.500 *U*	2.00	11.0	34.0	45.0
I-S	ECH-E-IS01	--	0	10	0.500 *U*	0.500 *U*	8.50	23.0	38.5
I-S	ECH-E-IS02	--	10	20	0.500 *U*	5.00	16.0	42.5	57.0
I-S	ECH-E-IS03	--	20	30	0.500 *U*	0.500 *U*	2.00	4.50	4.50
J-CORE	JCORE01SD	--	0	30	0.500 *U*	0.500 *U*	1.50	6.00	6.00
J-CORE	JCORE02SD	--	30	86	3.00	4.00	6.00	16.5	23.0
J-CORE	JCORE03SD	--	86	178	4.00	9.00	16.0	35.0	46.0
J-N	ECH-E-JN01	--	0	10	1.00	3.00	5.00	12.5	39.0
J-N	ECH-E-JN02	--	10	20	0.500 *U*	2.00	6.00	16.5	37.5
J-N	ECH-E-JN03	--	20	30	2.00	3.50	6.00	28.5	51.5
J-S	ECH-E-JS01	--	0	10	1.00	1.50	3.50	11.0	19.5
K-M	ECH-E-KM01	--	0	10	2.50	2.50	2.50	2.50	13.0
K-M	KCORE01SD	--	0	46	1.50	2.00	3.00	3.00	4.00
K-M	KCORE02SD	1	46	152	0.500 *U*	0.500 *U*	2.00	4.00	6.00
K-M	KCORE02SD	2	46	152	0.500 *U*	0.500 *U*	1.00	4.00	5.00
K-M	KCORE03SD	--	152	183	3.00	4.00	6.00	14.0	17.0
K-N	ECH-E-KN01	1	0	10	0.500 *U*	0.500 *U*	1.00	2.50	6.50
K-N	ECH-E-KN01	2	0	10	2.00	2.00	2.00	3.00	5.00
K-S	ECH-E-KS01	--	0	10	0.500 *U*	0.500 *U*	2.00	48.0	68.0
K-S	ECH-E-KS02	--	10	20	0.500 *U*	0.500 *U*	2.00	50.0	72.0
K-S	ECH-E-KS03	--	20	30	0.500 *U*	0.500 *U*	1.00	35.0	65.0

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 0.064 mm (percent wet)	Particles smaller than 0.075 mm (percent wet)	Particles smaller than 0.150 mm (sieve #100) (percent wet)	Particles smaller than 0.3 mm (percent wet)	Particles smaller than 0.6 mm (percent wet)
A-M	ACORE01SD	1	0	69	8.50	9.10	23.5	70.2	78.7
A-M	ACORE01SD	2	0	69	9.00	10.0	23.2	73.5	82.3
A-M	ACORE02SD	--	69	122	14.0	16.1	17.7	20.4	24.7
A-M	ACORE03SD	--	122	200	5.50	5.40	24.7	93.1	97.1
A-M	ECH-E-AM01	--	0	10	6.50	8.10	39.6	90.3	93.8
A-M	ECH-E-AM02	--	10	20	4.00	4.50	14.9	50.4	59.7
A-M	ECH-E-AM03	--	20	30	4.00	3.80	8.70	30.1	40.3
A-N	ECH-E-AN01	1	0	10	19.0	21.7	57.6	95.3	97.6
A-N	ECH-E-AN01	2	0	10	21.0	23.5	72.0	97.0	98.4
A-S	ECH-E-AS01	--	0	10	46.0	46.0	60.5	69.9	72.3
B-M	BCORE01SD	--	0	55	48.0	49.4	61.2	76.2	82.9
B-M	BCORE02SD	1	55	120	37.5	42.4	46.4	51.0	58.2
B-M	BCORE02SD	2	55	120	33.5	38.0	40.7	43.7	48.8
B-M	BCORE03SD	--	120	173	3.50	3.80	27.9	85.8	94.3
B-M	ECH-E-BM01	--	0	10	17.5	19.3	36.4	50.4	52.6
B-N	ECH-E-BN01	--	0	10	23.0	29.4	57.0	95.4	98.5
B-S	ECH-E-BS01	--	0	10	41.0	46.3	59.9	85.9	92.6
C-CORE	CCORE01SD	--	0	135	32.0	37.4	61.1	93.7	97.4
C-CORE	CCORE02SD	--	135	269	70.0	74.8	82.5	86.7	90.6
C-CORE	CCORE03SD	--	269	460	51.0	52.4	75.1	92.7	94.5
C-N	ECH-E-CN01	--	0	10	69.0	73.3	80.5	86.4	90.5
C-N	ECH-E-CN02	--	10	20	72.0	76.9	79.2	81.7	85.7
C-N	ECH-E-CN03	1	20	30	71.0	75.1	79.2	82.4	86.5
C-N	ECH-E-CN03	2	20	30	72.5	74.6	78.9	81.5	85.6
C-S	ECH-E-CS01	--	0	10	36.0	40.5	58.4	78.9	84.6
D-M	DCORE01SD	--	0	103	5.50	5.60	34.7	95.7	98.6
D-M	DCORE02SD	--	103	180	70.0	70.2	75.0	78.6	81.4
D-M	DCORE03SD	--	180	208	12.0	12.3	67.3	99.5	99.7
D-M	ECH-E-DM01	--	0	10	4.00	3.90	14.4	80.1	81.2
D-N	ECH-E-DN01	--	0	10	54.0	64.1	88.1	94.8	97.0
D-S	ECH-E-DS01	--	0	10	71.5	72.6	82.2	90.7	94.6
E-CORE	ECORE01SD	--	0	45	7.00	8.10	15.3	38.8	45.6
E-CORE	ECORE02SD	--	45	118	72.0	74.9	83.4	87.9	91.3
E-CORE	ECORE03SD	--	118	165	7.00	7.40	33.0	97.4	98.8

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 0.064 mm (percent wet)	Particles smaller than 0.075 mm (percent wet)	Particles smaller than 0.150 mm (sieve #100) (percent wet)	Particles smaller than 0.3 mm (percent wet)	Particles smaller than 0.6 mm (percent wet)
E-N	ECH-E-EN01	--	0	10	7.00	7.20	16.0	30.1	34.4
E-N	ECH-E-EN02	--	10	20	24.0	26.1	43.5	53.0	55.1
E-N	ECH-E-EN03	--	20	30	61.0	65.2	66.4	69.5	76.2
E-S	ECH-E-ES01	--	0	10	59.0	62.6	71.2	79.7	90.0
E-S	ECH-E-ES02	--	10	20	56.5	61.5	64.8	70.9	80.1
E-S	ECH-E-ES03	--	20	30	43.0	44.3	73.0	92.4	94.2
F-CORE	FCORE01SD	--	0	55	16.5	19.0	48.1	95.7	98.0
F-CORE	FCORE02SD	--	55	150	70.0	80.7	84.5	88.2	91.3
F-CORE	FCORE03SD	1	150	205	25.0	25.3	52.4	91.2	94.4
F-CORE	FCORE03SD	2	150	205	26.0	25.7	51.6	91.8	95.1
F-N	ECH-E-FN01	--	0	10	53.0	59.3	67.4	76.1	79.2
F-S	ECH-E-FS01	--	0	10	68.0	73.8	85.3	92.0	96.6
G-M	GCORE01SD	--	0	64	36.0	40.7	53.7	79.2	83.5
G-M	GCORE02SD	--	94	208	48.5	52.8	60.2	67.4	74.4
G-M	GCORE03SD	1	208	259	38.5	41.9	46.1	52.2	60.7
G-M	GCORE03SD	2	208	259	30.0	34.3	38.5	45.6	55.8
G-N	ECH-E-GN01	--	0	10	18.0	18.5	34.2	51.2	53.2
G-N	ECH-E-GN02	--	10	20	12.0	13.0	21.2	41.2	43.7
G-N	ECH-E-GN03	--	20	30	12.0	12.4	23.9	35.4	38.9
G-S	ECH-E-GS01	1	0	10	87.5	88.2	94.6	96.2	96.9
G-S	ECH-E-GS01	2	0	10	86.0	87.6	93.8	95.5	96.6
G-S	ECH-E-GS02	--	10	20	77.5	77.9	78.9	81.0	86.1
G-S	ECH-E-GS03	--	20	30	80.5	81.2	82.4	84.0	87.2
H-CORE	HCORE01SD	--	0	36	49.5	50.8	55.8	66.9	73.7
H-CORE	HCORE02SD	--	36	89	43.0	48.2	49.4	50.8	52.8
H-CORE	HCORE03SD	--	89	124	8.50	8.40	34.8	97.2	98.3
H-N	ECH-E-HN01	--	0	10	41.0	43.8	50.2	58.0	62.7
H-S	ECH-E-HS01	--	0	10	64.0	73.2	90.3	94.6	96.6
I-M	ICORE01SD	--	0	74	45.0	46.5	67.5	90.6	94.2
I-M	ICORE02SD	--	74	155	52	54	63	70	74
I-M	ICORE03SD	--	155	183	6.00	7.60	51.9	92.3	95.4
I-M	ECH-E-IM01	--	0	10	34.0	39.4	78.6	95.5	97.4
I-M	ECH-E-IM02	1	10	20	39.5	42.7	74.9	93.4	96.2
I-M	ECH-E-IM02	2	10	20	39.0	42.4	78.2	93.7	96.1

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 0.064 mm (percent wet)	Particles smaller than 0.075 mm (percent wet)	Particles smaller than 0.150 mm (sieve #100) (percent wet)	Particles smaller than 0.3 mm (percent wet)	Particles smaller than 0.6 mm (percent wet)
I-M	ECH-E-IM03	--	20	30	61.0	64.6	71.7	78.0	83.9
I-N	ECH-E-IN01	--	0	10	75.0	75.8	80.0	83.1	87.2
I-N	ECH-E-IN02	--	10	20	62.0	63.9	66.8	71.3	78.2
I-N	ECH-E-IN03	--	20	30	48.0	49.1	53.8	63.2	72.5
I-S	ECH-E-IS01	--	0	10	42.5	46.0	60.2	80.5	85.9
I-S	ECH-E-IS02	--	10	20	59.5	60.9	69.0	77.9	83.4
I-S	ECH-E-IS03	--	20	30	5.00	4.80	30.8	98.3	99.2
J-CORE	JCORE01SD	--	0	30	7.00	7.30	32.4	87.5	90.5
J-CORE	JCORE02SD	--	30	86	23.5	24.3	52.4	98.3	99.1
J-CORE	JCORE03SD	--	86	178	50.0	51.8	57.4	61.1	64.1
J-N	ECH-E-JN01	--	0	10	47.5	52.6	82.5	94.9	97.2
J-N	ECH-E-JN02	--	10	20	49.0	57.0	86.3	95.9	97.9
J-N	ECH-E-JN03	--	20	30	54.0	58.4	87.4	96.7	98.4
J-S	ECH-E-JS01	--	0	10	23.0	25.2	45.0	91.8	96.8
K-M	ECH-E-KM01	--	0	10	20.0	25.2	57.5	80.0	87.3
K-M	KCORE01SD	--	0	46	7.50	10.3	11.7	39.3	67.0
K-M	KCORE02SD	1	46	152	6.00	5.80	46.8	95.0	96.7
K-M	KCORE02SD	2	46	152	6.00	5.80	44.9	95.8	97.5
K-M	KCORE03SD	--	152	183	17.5	18.0	53.1	93.5	95.8
K-N	ECH-E-KN01	1	0	10	7.00	6.10	38.0	95.9	97.5
K-N	ECH-E-KN01	2	0	10	6.50	5.70	38.2	96.8	98.3
K-S	ECH-E-KS01	--	0	10	71.0	73.8	82.5	90.4	96.3
K-S	ECH-E-KS02	--	10	20	75.0	77.3	83.6	87.9	90.9
K-S	ECH-E-KS03	--	20	30	73.0	78.1	81.2	83.8	87.8

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 1.18 mm (percent wet)	Particles smaller than 2.36 mm (percent wet)	Particles smaller than 3.35 mm (percent wet)	Particles smaller than 4.75 mm (sieve #4) (percent wet)	Particles smaller than 19.0 mm (percent wet)
A-M	ACORE01SD	1	0	69	83.0	84.4	88.0	91.3	98.3
A-M	ACORE01SD	2	0	69	85.4	87.0	90.4	92.3	100
A-M	ACORE02SD	--	69	122	34.9	63.1	83.4	95.2	100
A-M	ACORE03SD	--	122	200	97.5	97.8	99.4	99.4	100
A-M	ECH-E-AM01	--	0	10	94.8	95.2	95.7	95.9	100
A-M	ECH-E-AM02	--	10	20	66.1	74.6	79.3	84.8	99.2
A-M	ECH-E-AM03	--	20	30	48.6	53.5	64.6	77.2	100
A-N	ECH-E-AN01	1	0	10	98.3	98.8	98.9	99.0	100
A-N	ECH-E-AN01	2	0	10	98.9	99.1	99.4	99.4	100
A-S	ECH-E-AS01	--	0	10	75.4	79.2	91.3	98.7	100
B-M	BCORE01SD	--	0	55	92.4	99.9	99.9	100	100
B-M	BCORE02SD	1	55	120	74.8	92.3	98.2	100	100
B-M	BCORE02SD	2	55	120	59.0	80.2	92.7	100	100
B-M	BCORE03SD	--	120	173	98.1	99.4	99.7	99.7	100
B-M	ECH-E-BM01	--	0	10	54.1	55.2	56.4	56.8	100
B-N	ECH-E-BN01	--	0	10	99.3	99.6	99.8	99.8	100
B-S	ECH-E-BS01	--	0	10	96.6	97.3	98.9	99.2	100
C-CORE	CCORE01SD	--	0	135	99.0	99.6	99.9	100	100
C-CORE	CCORE02SD	--	135	269	97.0	99.0	100	100	100
C-CORE	CCORE03SD	--	269	460	97.3	98.5	99.1	99.6	100
C-N	ECH-E-CN01	--	0	10	95.6	98.6	99.8	99.9	100
C-N	ECH-E-CN02	--	10	20	93.1	99.0	99.9	100	100
C-N	ECH-E-CN03	1	20	30	93.4	98.8	100	100	100
C-N	ECH-E-CN03	2	20	30	93.7	99.8	100	100	100
C-S	ECH-E-CS01	--	0	10	89.1	91.1	93.3	94.4	100
D-M	DCORE01SD	--	0	103	99.4	99.6	99.7	99.8	100
D-M	DCORE02SD	--	103	180	85.5	89.4	99.8	100	100
D-M	DCORE03SD	--	180	208	99.8	99.9	99.9	99.9	100
D-M	ECH-E-DM01	--	0	10	81.6	81.8	81.9	82.0	100
D-N	ECH-E-DN01	--	0	10	98.3	99.5	99.8	99.9	100
D-S	ECH-E-DS01	--	0	10	96.9	98.3	99.8	100	100
E-CORE	ECORE01SD	--	0	45	52.0	58.6	65.3	71.1	98.5
E-CORE	ECORE02SD	--	45	118	95.5	97.1	97.4	97.8	100
E-CORE	ECORE03SD	--	118	165	99.2	99.4	99.5	99.6	100

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 1.18 mm (percent wet)	Particles smaller than 2.36 mm (percent wet)	Particles smaller than 3.35 mm (percent wet)	Particles smaller than 4.75 mm (sieve #4) (percent wet)	Particles smaller than 19.0 mm (percent wet)
E-N	ECH-E-EN01	--	0	10	38.1	44.8	51.8	59.4	98.6
E-N	ECH-E-EN02	--	10	20	56.9	59.2	63.2	68.5	92.8
E-N	ECH-E-EN03	--	20	30	86.9	97.6	99.9	99.9	100
E-S	ECH-E-ES01	--	0	10	97.7	99.1	99.7	99.8	100
E-S	ECH-E-ES02	--	10	20	91.2	97.8	99.9	100	100
E-S	ECH-E-ES03	--	20	30	95.0	95.5	96.0	96.2	100
F-CORE	FCORE01SD	--	0	55	98.8	99.0	99.3	99.5	100
F-CORE	FCORE02SD	--	55	150	94.8	96.7	99.7	99.8	100
F-CORE	FCORE03SD	1	150	205	96.4	97.8	98.4	98.7	100
F-CORE	FCORE03SD	2	150	205	97.0	98.2	98.7	99.4	100
F-N	ECH-E-FN01	--	0	10	81.3	83.5	86.7	90.4	100
F-S	ECH-E-FS01	--	0	10	98.4	99.1	99.5	99.7	100
G-M	GCORE01SD	--	0	64	88.5	93.8	95.9	97.7	100
G-M	GCORE02SD	--	94	208	86.2	98.8	99.9	100	100
G-M	GCORE03SD	1	208	259	72.9	85.4	98.7	99.4	100
G-M	GCORE03SD	2	208	259	71.0	89.9	98.5	100	100
G-N	ECH-E-GN01	--	0	10	55.1	58.0	61.8	66.2	100
G-N	ECH-E-GN02	--	10	20	46.0	49.4	53.4	59.2	95.7
G-N	ECH-E-GN03	--	20	30	43.9	50.1	55.6	61.9	89.1
G-S	ECH-E-GS01	1	0	10	97.3	97.5	98.7	98.8	100
G-S	ECH-E-GS01	2	0	10	97.8	98.1	99.0	99.0	100
G-S	ECH-E-GS02	--	10	20	94.4	99.1	100	100	100
G-S	ECH-E-GS03	--	20	30	93.9	99.3	100	100	100
H-CORE	HCORE01SD	--	0	36	81.2	88.5	97.4	99.3	100
H-CORE	HCORE02SD	--	36	89	56.8	61.8	81.6	92.9	100
H-CORE	HCORE03SD	--	89	124	98.8	99.1	99.4	99.7	100
H-N	ECH-E-HN01	--	0	10	66.1	69.6	75.7	82.4	100
H-S	ECH-E-HS01	--	0	10	97.4	98.1	98.4	98.6	100
I-M	ICORE01SD	--	0	74	96.3	96.9	98.3	98.7	100
I-M	ICORE02SD	--	74	155	81	90	97	100	100
I-M	ICORE03SD	--	155	183	96.9	97.9	98.2	98.5	100
I-M	ECH-E-IM01	--	0	10	98.3	99.0	99.3	99.5	100
I-M	ECH-E-IM02	1	10	20	96.9	97.2	97.7	98.1	100
I-M	ECH-E-IM02	2	10	20	97.2	97.5	98.7	99.4	100

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 1.18 mm (percent wet)	Particles smaller than 2.36 mm (percent wet)	Particles smaller than 3.35 mm (percent wet)	Particles smaller than 4.75 mm (sieve #4) (percent wet)	Particles smaller than 19.0 mm (percent wet)
I-M	ECH-E-IM03	--	20	30	92.6	98.2	98.9	99.0	100
I-N	ECH-E-IN01	--	0	10	95.4	99.5	100	100	100
I-N	ECH-E-IN02	--	10	20	90.3	99.7	100	100	100
I-N	ECH-E-IN03	--	20	30	85.8	99.2	100	100	100
I-S	ECH-E-IS01	--	0	10	93.2	98.2	99.4	99.8	100
I-S	ECH-E-IS02	--	10	20	88.9	91.4	96.9	99.3	100
I-S	ECH-E-IS03	--	20	30	99.5	99.8	99.9	100	100
J-CORE	JCORE01SD	--	0	30	92.4	93.7	94.7	96.0	100
J-CORE	JCORE02SD	--	30	86	99.5	99.7	99.9	100	100
J-CORE	JCORE03SD	--	86	178	70.4	78.2	91.8	97.5	100
J-N	ECH-E-JN01	--	0	10	98.3	99.0	99.5	99.6	100
J-N	ECH-E-JN02	--	10	20	99.0	99.5	99.8	99.9	100
J-N	ECH-E-JN03	--	20	30	99.3	99.8	100	100	100
J-S	ECH-E-JS01	--	0	10	99.1	99.6	99.7	99.8	100
K-M	ECH-E-KM01	--	0	10	91.5	93.8	95.9	97.1	100
K-M	KCORE01SD	--	0	46	79.8	87.5	95.1	96.8	100
K-M	KCORE02SD	1	46	152	97.9	98.8	99.1	99.4	100
K-M	KCORE02SD	2	46	152	98.4	98.8	99.2	99.4	100
K-M	KCORE03SD	--	152	183	97.4	98.6	99.2	99.6	100
K-N	ECH-E-KN01	1	0	10	98.2	98.7	98.9	99.0	100
K-N	ECH-E-KN01	2	0	10	99.0	99.4	99.5	99.6	100
K-S	ECH-E-KS01	--	0	10	99.2	99.5	99.8	99.9	100
K-S	ECH-E-KS02	--	10	20	95.5	99.6	99.9	100	100
K-S	ECH-E-KS03	--	20	30	95.3	98.3	99.6	99.9	100

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 37.5 mm (percent wet)	Particles smaller than 75 mm (percent wet)	Total organic carbon (mg/kg dry)
A-M	ACORE01SD	1	0	69	100	100	11,100 *J*
A-M	ACORE01SD	2	0	69	100	100	9,300 *J*
A-M	ACORE02SD	--	69	122	100	100	39,000 *J*
A-M	ACORE03SD	--	122	200	100	100	3,380
A-M	ECH-E-AM01	--	0	10	100	100	10,300 *J*
A-M	ECH-E-AM02	--	10	20	100	100	12,200 *J*
A-M	ECH-E-AM03	--	20	30	100	100	32,000 *J*
A-N	ECH-E-AN01	1	0	10	100	100	22,400 *J*
A-N	ECH-E-AN01	2	0	10	100	100	20,300 *J*
A-S	ECH-E-AS01	--	0	10	100	100	21,200 *J*
B-M	BCORE01SD	--	0	55	100	100	30,000 *J*
B-M	BCORE02SD	1	55	120	100	100	42,000 *J*
B-M	BCORE02SD	2	55	120	100	100	35,000 *J*
B-M	BCORE03SD	--	120	173	100	100	2,530 *J*
B-M	ECH-E-BM01	--	0	10	100	100	10,400 *J*
B-N	ECH-E-BN01	--	0	10	100	100	11,700 *J*
B-S	ECH-E-BS01	--	0	10	100	100	30,000 *J*
C-CORE	CCORE01SD	--	0	135	100	100	18,800 *J*
C-CORE	CCORE02SD	--	135	269	100	100	26,700 *J*
C-CORE	CCORE03SD	--	269	460	100	100	20,800 *J*
C-N	ECH-E-CN01	--	0	10	100	100	34,000 *J*
C-N	ECH-E-CN02	--	10	20	100	100	37,000 *J*
C-N	ECH-E-CN03	1	20	30	100	100	30,000 *J*
C-N	ECH-E-CN03	2	20	30	100	100	28,200 *J*
C-S	ECH-E-CS01	--	0	10	100	100	23,900 *J*
D-M	DCORE01SD	--	0	103	100	100	4,500 *J*
D-M	DCORE02SD	--	103	180	100	100	25,600 *J*
D-M	DCORE03SD	--	180	208	100	100	4,900 *J*
D-M	ECH-E-DM01	--	0	10	100	100	6,300 *J*
D-N	ECH-E-DN01	--	0	10	100	100	21,600
D-S	ECH-E-DS01	--	0	10	100	100	33,400
E-CORE	ECORE01SD	--	0	45	100	100	23,400
E-CORE	ECORE02SD	--	45	118	100	100	48,000
E-CORE	ECORE03SD	--	118	165	100	100	4,100

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 37.5 mm (percent wet)	Particles smaller than 75 mm (percent wet)	Total organic carbon (mg/kg dry)
E-N	ECH-E-EN01	--	0	10	100	100	4,500
E-N	ECH-E-EN02	--	10	20	100	100	5,840 *J*
E-N	ECH-E-EN03	--	20	30	100	100	36,100
E-S	ECH-E-ES01	--	0	10	100	100	22,500
E-S	ECH-E-ES02	--	10	20	100	100	12,500 *J*
E-S	ECH-E-ES03	--	20	30	100	100	7,400
F-CORE	FCORE01SD	--	0	55	100	100	10,100
F-CORE	FCORE02SD	--	55	150	100	100	27,000 *J*
F-CORE	FCORE03SD	1	150	205	100	100	6,700 *J*
F-CORE	FCORE03SD	2	150	205	100	100	8,500
F-N	ECH-E-FN01	--	0	10	100	100	13,900 *J*
F-S	ECH-E-FS01	--	0	10	100	100	43,000 *J*
G-M	GCORE01SD	--	0	64	100	100	11,900 *J*
G-M	GCORE02SD	--	94	208	100	100	31,000 *J*
G-M	GCORE03SD	1	208	259	100	100	25,000 *J*
G-M	GCORE03SD	2	208	259	100	100	34,000 *J*
G-N	ECH-E-GN01	--	0	10	100	100	10,800
G-N	ECH-E-GN02	--	10	20	100	100	7,300
G-N	ECH-E-GN03	--	20	30	100	100	6,300 *J*
G-S	ECH-E-GS01	1	0	10	100	100	16,400
G-S	ECH-E-GS01	2	0	10	100	100	17,500
G-S	ECH-E-GS02	--	10	20	100	100	22,200
G-S	ECH-E-GS03	--	20	30	100	100	15,500 *J*
H-CORE	HCORE01SD	--	0	36	100	100	28,100
H-CORE	HCORE02SD	--	36	89	100	100	32,000
H-CORE	HCORE03SD	--	89	124	100	100	4,000
H-N	ECH-E-HN01	--	0	10	100	100	13,200
H-S	ECH-E-HS01	--	0	10	100	100	6,400
I-M	ICORE01SD	--	0	74	100	100	25,000 *J*
I-M	ICORE02SD	--	74	155	100	100	18,000 *J*
I-M	ICORE03SD	--	155	183	100	100	6,300
I-M	ECH-E-IM01	--	0	10	100	100	13,100 *J*
I-M	ECH-E-IM02	1	10	20	100	100	19,400
I-M	ECH-E-IM02	2	10	20	100	100	11,300

Table B1-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 37.5 mm (percent wet)	Particles smaller than 75 mm (percent wet)	Total organic carbon (mg/kg dry)
I-M	ECH-E-IM03	--	20	30	100	100	20,400
I-N	ECH-E-IN01	--	0	10	100	100	34,900 *J*
I-N	ECH-E-IN02	--	10	20	100	100	25,000 *U*
I-N	ECH-E-IN03	--	20	30	100	100	22,000 *U*
I-S	ECH-E-IS01	--	0	10	100	100	12,500 *J*
I-S	ECH-E-IS02	--	10	20	100	100	15,000 *J*
I-S	ECH-E-IS03	--	20	30	100	100	2,100
J-CORE	JCORE01SD	--	0	30	100	100	5,300 *J*
J-CORE	JCORE02SD	--	30	86	100	100	11,400
J-CORE	JCORE03SD	--	86	178	100	100	28,000 *J*
J-N	ECH-E-JN01	--	0	10	100	100	25,000 *J*
J-N	ECH-E-JN02	--	10	20	100	100	23,600
J-N	ECH-E-JN03	--	20	30	100	100	19,500
J-S	ECH-E-JS01	--	0	10	100	100	10,800 *J*
K-M	ECH-E-KM01	--	0	10	100	100	26,600 *J*
K-M	KCORE01SD	--	0	46	100	100	17,900 *J*
K-M	KCORE02SD	1	46	152	100	100	6,600 *J*
K-M	KCORE02SD	2	46	152	100	100	6,370 *J*
K-M	KCORE03SD	--	152	183	100	100	15,500 *J*
K-N	ECH-E-KN01	1	0	10	100	100	4,400 *J*
K-N	ECH-E-KN01	2	0	10	100	100	4,600
K-S	ECH-E-KS01	--	0	10	100	100	27,000
K-S	ECH-E-KS02	--	10	20	100	100	16,000 *J*
K-S	ECH-E-KS03	--	20	30	100	100	20,000 *J*

Note: *J* - estimated
U - undetected at detection limit shown

Table B1-3. Metals results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Antimony (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)
A-M	ACORE01SD	1	0	69	15.2 *J*	23.8	1.61 *J*	23.1	111	1,010
A-M	ACORE01SD	2	0	69	18.4 *J*	19.3	1.91 *J*	16.5	148	670
A-M	ACORE02SD	--	69	122	1.80 *UJ*	29.9	0.210 *UR*	15.3	25.1	13.5
A-M	ACORE03SD	--	122	200	0.530 *U*	3.40 *U*	0.0640 *UJ*	2.05	2.04	2.10
A-M	ECH-E-AM01	--	0	10	2.30 *U*	8.50	0.0720 *UR*	102	75.4	203
A-M	ECH-E-AM02	--	10	20	1.80 *U*	15.7	0.0680 *UJ*	82.9	115	480
A-M	ECH-E-AM03	--	20	30	11.8	25.0	2.62 *J*	32.3	454	3,700
A-N	ECH-E-AN01	1	0	10	3.30 *U*	12.8	0.710 *J*	146	213	420
A-N	ECH-E-AN01	2	0	10	2.60 *U*	12.6	0.440 *J*	148	231	370
A-S	ECH-E-AS01	--	0	10	1.10 *U*	9.90	0.140 *UR*	79.8	58.6	103
B-M	BCORE01SD	--	0	55	26.0 *J*	54.0 *J*	18.3 *J*	76.0	303 *J*	734
B-M	BCORE02SD	1	55	120	4.30 *J*	71.9	1.47 *J*	24.1	81.0 *J*	175
B-M	BCORE02SD	2	55	120	2.90 *J*	73.7	0.340 *J*	20.2	69.8 *J*	151
B-M	BCORE03SD	--	120	173	0.560 *J*	5.50	0.0620 *UR*	3.08	1.31 *U*	3.30 *U*
B-M	ECH-E-BM01	--	0	10	1.50 *U*	15.4	0.0940 *UR*	197	171	329
B-N	ECH-E-BN01	--	0	10	10.3 *U*	12.1	0.420 *UR*	235	118	301
B-S	ECH-E-BS01	--	0	10	27.0 *U*	35.0	0.580 *UR*	468	250	860
C-CORE	CCORE01SD	--	0	135	6.80 *U*	13.2 *J*	0.830 *UR*	548	195 *J*	610
C-CORE	CCORE02SD	--	135	269	8.0 *U*	37 *J*	0.97 *UR*	1,120	240 *J*	810
C-CORE	CCORE03SD	--	269	460	7.10 *J*	34.3	0.0870 *UR*	496	141 *J*	481
C-N	ECH-E-CN01	--	0	10	24.0 *U*	37.0	0.770 *UR*	2,040	360	830
C-N	ECH-E-CN02	--	10	20	25.0 *U*	54.0 *R*	0.730 *UR*	2,150	323	1,330
C-N	ECH-E-CN03	1	20	30	20.0 *U*	53.0	0.660 *UR*	2,410	379	1,480
C-N	ECH-E-CN03	2	20	30	24.0 *U*	41.0	0.670 *UR*	2,470	385	1,510
C-S	ECH-E-CS01	--	0	10	14.0 *U*	31.0	0.570 *UR*	1,410	320	830
D-M	DCORE01SD	--	0	103	1.60 *J*	5.80	0.0660 *UR*	86.0	52.9 *J*	103
D-M	DCORE02SD	--	103	180	1.40 *J*	7.60	0.120 *UR*	22.9	20.9 *J*	14.2
D-M	DCORE03SD	--	180	208	0.550 *U*	2.30 *J*	0.0670 *UR*	4.47	2.39 *J*	3.20 *U*
D-M	ECH-E-DM01	--	0	10	2.60	4.40	0.330 *J*	58.5	44.6 *J*	107
D-N	ECH-E-DN01	--	0	10	7.6	16.4	0.10 *UR*	240	157 *J*	380
D-S	ECH-E-DS01	--	0	10	6.20	22.0	2.72 *J*	99.2	275 *J*	397
E-CORE	ECORE01SD	--	0	45	11.4 *J*	21.0	15.0 *J*	74.9	146	563
E-CORE	ECORE02SD	--	45	118	10.9 *J*	433	21.3 *J*	30.2	764	4,940
E-CORE	ECORE03SD	--	118	165	0.540 *U*	1.50 *U*	0.0650 *UJ*	2.59	2.20	2.20
E-N	ECH-E-EN01	--	0	10	5.40	18.6	7.56 *J*	99.7	87.3 *J*	300

Table B1-3. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Antimony (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)
E-N	ECH-E-EN02	--	10	20	42.0	65.0	49.9	201	154 *J*	1,160
E-N	ECH-E-EN03	--	20	30	41.0	74.0	42.0 *J*	65.0 *J*	356 *J*	1,000
E-S	ECH-E-ES01	--	0	10	37.0	51.0	23.7 *J*	205	417 *J*	1,270
E-S	ECH-E-ES02	--	10	20	33.0	68.0	29.0 *J*	97.0	343 *J*	850
E-S	ECH-E-ES03	--	20	30	38.0	117	9.80	98.9	210 *J*	1,220
F-CORE	FCORE01SD	--	0	55	4.10 *J*	25.0	0.950 *J*	126	111	278
F-CORE	FCORE02SD	--	55	150	15.2 *J*	843	21.5 *J*	38.2	1,470	8,430
F-CORE	FCORE03SD	1	150	205	0.700 *U*	381	0.0850 *UR*	6.22	6.89	4.90
F-CORE	FCORE03SD	2	150	205	0.710 *UJ*	361	0.0860 *UJ*	5.65	6.29	4.60
F-N	ECH-E-FN01	--	0	10	13.4 *J*	325	9.03	287	284 *J*	700
F-S	ECH-E-FS01	--	0	10	34.0 *J*	50.0	11.7 *J*	1,600	496 *J*	1,320
G-M	GCORE01SD	--	0	64	10.2 *J*	61.0	0.110 *UR*	197	276 *J*	1,020
G-M	GCORE02SD	--	94	208	7.80 *J*	114	4.35 *J*	13.6	279 *J*	763
G-M	GCORE03SD	1	208	259	1.70 *J*	8.10 *J*	0.150 *UR*	25.6	22.2 *J*	15.0
G-M	GCORE03SD	2	208	259	1.30 *U*	8.50 *J*	0.160 *UR*	20.7	23.7 *J*	15.9
G-N	ECH-E-GN01	--	0	10	13.8 *J*	36.0	0.380 *J*	206	331 *J*	840
G-N	ECH-E-GN02	--	10	20	7.8 *J*	72	2.9	127	190 *J*	710
G-N	ECH-E-GN03	--	20	30	23.1 *J*	240	12.5	74.5	412 *J*	330
G-S	ECH-E-GS01	1	0	10	16.0 *J*	30.0	0.700 *U*	390	205 *J*	580
G-S	ECH-E-GS01	2	0	10	10.9 *J*	43.0	0.720 *UR*	419	217 *J*	580
G-S	ECH-E-GS02	--	10	20	16.0 *J*	21.0	0.650 *UR*	496	152 *J*	580
G-S	ECH-E-GS03	--	20	30	24.0 *J*	57.0	0.660 *UR*	683	181 *J*	610
H-CORE	HCORE01SD	--	0	36	1.20 *UJ*	14.8 *J*	0.150 *J*	88.0	136	492
H-CORE	HCORE02SD	--	36	89	1.40 *U*	8.50 *U*	0.170 *UR*	17.7	23.2	12.3
H-CORE	HCORE03SD	--	89	124	0.540 *U*	3.80 *U*	0.0650 *UJ*	2.56	2.28	2.40
H-N	ECH-E-HN01	--	0	10	11.0 *J*	26.0	3.54 *J*	316	173 *J*	680
H-S	ECH-E-HS01	--	0	10	6.00 *J*	10.4	0.0670 *UR*	184	112 *J*	170
I-M	ICORE01SD	--	0	74	18.6 *J*	141	19.7 *J*	101	335	1,570
I-M	ICORE02SD	--	74	155	6.4 *J*	85	13.3 *J*	19.8	260	1,630
I-M	ICORE03SD	--	155	183	0.520 *U*	2.50 *U*	0.0630 *UJ*	2.42	2.11	2.60
I-M	ECH-E-IM01	--	0	10	18.0 *U*	58.0	2.20 *UR*	222	197	480
I-M	ECH-E-IM02	1	10	20	23.0 *U*	127	2.80 *UR*	181	368	1,740
I-M	ECH-E-IM02	2	10	20	23.0 *U*	123	2.80 *UR*	178	350	1,670
I-M	ECH-E-IM03	--	20	30	34.0 *U*	104	22.7 *J*	70.0	529	3,700
I-N	ECH-E-IN01	--	0	10	40.0 *U*	19.7	3.60 *UR*	423	355	2,800

Table B1-3. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Antimony (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)
I-N	ECH-E-IN02	--	10	20	28.0 *U*	310	3.40 *UR*	299	357	3,200
I-N	ECH-E-IN03	--	20	30	46.0 *U*	470	21.0 *J*	60.0	546	2,990
I-S	ECH-E-IS01	--	0	10	58.2	92.0	33.2 *J*	125	624	4,300
I-S	ECH-E-IS02	--	10	20	69.2	240	50.6 *J*	53.6	1,030	4,900
I-S	ECH-E-IS03	--	20	30	4.90	12.9	3.83 *J*	3.46	43.2	310
J-CORE	JCORE01SD	--	0	30	1.27 *J*	14.1	1.96 *J*	78.6	82.7	249
J-CORE	JCORE02SD	--	30	86	43.2 *J*	82.9	16.3 *J*	37.2	189	1,100
J-CORE	JCORE03SD	--	86	178	2.10 *J*	96.1	11.6 *J*	24.9	221	1,150
J-N	ECH-E-JN01	--	0	10	7.40	58.0	0.130 *UR*	378	258	670
J-N	ECH-E-JN02	--	10	20	23.0 *U*	53.0	2.80 *UR*	378	255	700
J-N	ECH-E-JN03	--	20	30	5.6 *U*	44	0.49 *UR*	310	170	870
J-S	ECH-E-JS01	--	0	10	39.0	17.5	0.0830 *UR*	222	105	550
K-M	ECH-E-KM01	--	0	10	9.00	45.0	0.0910 *UR*	191	158	470
K-M	KCORE01SD	--	0	46	12.4 *J*	63.7	7.17 *J*	271	388 *J*	846
K-M	KCORE02SD	1	46	152	2.60 *J*	8.70	0.600 *J*	21.0 *J*	12.2 *J*	58.5 *J*
K-M	KCORE02SD	2	46	152	13.4 *J*	13.0	7.02 *J*	61.1 *J*	150 *J*	313 *J*
K-M	KCORE03SD	--	152	183	4.30 *J*	23.4	2.14 *J*	64.1	45.4 *J*	205
K-N	ECH-E-KN01	1	0	10	1.70 *U*	7.00 *J*	0.0750 *J*	42.0	16.2	94.0
K-N	ECH-E-KN01	2	0	10	1.36 *U*	6.20	0.0690 *UR*	43.7	17.2	69.0
K-S	ECH-E-KS01	--	0	10	23.0 *U*	44.0	2.80 *UR*	869	242	1,220
K-S	ECH-E-KS02	--	10	20	26.0 *U*	45.0	2.60 *UR*	1,360	321	1,560
K-S	ECH-E-KS03	--	20	30	41.0 *U*	48.0	2.90 *UR*	1,270	266	1,890
SD009	SD009	--	0	0	7.3	96	34.1	20.7	108	1,300

Table B1-3. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Magnesium (mg/kg)	Total mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Silver (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
A-M	ACORE01SD	1	0	69	7,860	0.720	4.76	7.07	0.900 *U*	5.80 *J*	2,910
A-M	ACORE01SD	2	0	69	6,560	0.970	4.27	7.05	0.780 *U*	4.78 *J*	2,530
A-M	ACORE02SD	--	69	122	8,380	0.0210 *UJ*	3.20 *U*	24.3	0.390 *U*	18.8 *J*	122
A-M	ACORE03SD	--	122	200	3,330	0.00610 *UJ*	0.550 *U*	3.28	0.110 *U*	2.52	12.1
A-M	ECH-E-AM01	--	0	10	9,320	0.290	4.29	33.3	1.30	8.54	837 *J*
A-M	ECH-E-AM02	--	10	20	18,000	0.800	4.99	46.1	1.09	8.81	850 *J*
A-M	ECH-E-AM03	--	20	30	11,100	1.30	4.76	23.5 *J*	1.44	14.7	1,850 *J*
A-N	ECH-E-AN01	1	0	10	14,700	18.0 *J*	11.8	53.6 *J*	2.99	17.1	1,230 *J*
A-N	ECH-E-AN01	2	0	10	13,900	1.99 *J*	11.0	62.2	3.53	19.7	1,260 *J*
A-S	ECH-E-AS01	--	0	10	11,100	0.0750 *U*	3.90 *U*	34.6	0.520 *J*	23.7	471 *J*
B-M	BCORE01SD	--	0	55	5,700	3.07 *J*	9.50 *U*	33.0 *U*	8.40 *U*	27.4	4,500
B-M	BCORE02SD	1	55	120	8,790	0.520 *J*	1.00 *U*	26.8	0.390 *U*	31.0	804
B-M	BCORE02SD	2	55	120	8,090	0.424 *J*	1.40 *U*	26.5	0.390 *U*	24.5	709
B-M	BCORE03SD	--	120	173	4,090	0.00560 *UJ*	0.280 *U*	3.91	0.100 *U*	4.02	14.9
B-M	ECH-E-BM01	--	0	10	7,270	2.54	10.8	66.1	2.06	21.5	2,020
B-N	ECH-E-BN01	--	0	10	7,170	0.480	12.8	107	1.81	26.8	1,120 *J*
B-S	ECH-E-BS01	--	0	10	8,360	0.380	21.7	129	2.59	48.0	3,320 *J*
C-CORE	CCORE01SD	--	0	135	5,210	0.570 *J*	15.5 *U*	128	5.40 *U*	16.2	3,560
C-CORE	CCORE02SD	--	135	269	5,200	0.75 *J*	13 *U*	142	4.6	34	1,800
C-CORE	CCORE03SD	--	269	460	6,450	0.620 *J*	7.15	57.0	1.80	46.8	1,460
C-N	ECH-E-CN01	--	0	10	6,570	0.910	27.4	147	4.86	77.7	3,320 *J*
C-N	ECH-E-CN02	--	10	20	6,310	1.52	23.7	136	4.94	63.4	3,370 *J*
C-N	ECH-E-CN03	1	20	30	5,430	1.26	24.7	170	5.08	61.0	3,550 *J*
C-N	ECH-E-CN03	2	20	30	5,500	1.00	24.8	173	5.21	65.8	3,560 *J*
C-S	ECH-E-CS01	--	0	10	5,780	0.750	19.8	151	3.27	38.2	3,130 *J*
D-M	DCORE01SD	--	0	103	3,860	0.200 *J*	2.21 *U*	24.1	0.790 *U*	5.46	622
D-M	DCORE02SD	--	103	180	16,500	0.0290 *J*	0.220 *U*	27.1	0.210 *U*	26.9	81.7
D-M	DCORE03SD	--	180	208	5,110	0.00630 *UJ*	0.290 *U*	4.98	0.110 *U*	5.45	17.8
D-M	ECH-E-DM01	--	0	10	2,540	0.170 *J*	1.96 *U*	16.1 *J*	0.870	6.03 *J*	463
D-N	ECH-E-DN01	--	0	10	7,200	0.68 *J*	13.7	66 *J*	2.2	40 *J*	1,480
D-S	ECH-E-DS01	--	0	10	8,770	0.510 *J*	7.10 *U*	39.1 *J*	1.16	26.7 *J*	1,080
E-CORE	ECORE01SD	--	0	45	2,200	2.42	4.66	50.0	1.94	25.7	1,630
E-CORE	ECORE02SD	--	45	118	5,390	9.10	2.00 *U*	14.3	1.64 *U*	13.7 *J*	3,770
E-CORE	ECORE03SD	--	118	165	4,130	0.00620 *UJ*	0.320 *U*	5.26	0.110 *U*	3.21	14.9
E-N	ECH-E-EN01	--	0	10	1,950	0.620 *J*	5.40 *U*	37.8 *J*	1.07	16.2 *J*	3,350

Table B1-3. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Magnesium (mg/kg)	Total mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Silver (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
E-N	ECH-E-EN02	--	10	20	2,040	2.33 *J*	7.57	108 *J*	1.78	41.6 *J*	4,580
E-N	ECH-E-EN03	--	20	30	4,960	2.91 *J*	5.80 *U*	14.0 *J*	3.45	61.8 *J*	4,270
E-S	ECH-E-ES01	--	0	10	5,180	2.70 *J*	11.7	48.0 *J*	3.54	54.8 *J*	4,110
E-S	ECH-E-ES02	--	10	20	5,980	2.16 *J*	6.70	20.0 *J*	2.73	73.2 *J*	2,760
E-S	ECH-E-ES03	--	20	30	2,090	3.73 *J*	6.95	121 *J*	1.95	40.7 *J*	4,490
F-CORE	FCORE01SD	--	0	55	5,510	0.670	5.11	30.5	1.18 *U*	9.88	1,440
F-CORE	FCORE02SD	--	55	150	10,100	42.0	3.20 *U*	27.8	3.05 *U*	32.3	3,140
F-CORE	FCORE03SD	1	150	205	7,120	0.00800 *UJ*	1.09 *U*	9.20	0.140 *U*	6.87	29.2
F-CORE	FCORE03SD	2	150	205	6,370	0.00810 *UJ*	0.820 *U*	8.40	0.230 *U*	6.26	26.2
F-N	ECH-E-FN01	--	0	10	3,350 *J*	1.44 *J*	12.9 *J*	79.4 *J*	2.19 *J*	72.1	10,200
F-S	ECH-E-FS01	--	0	10	14,800 *J*	1.85 *J*	34.4 *J*	188 *J*	7.62 *J*	84.3	6,820
G-M	GCORE01SD	--	0	64	9,480	2.27 *J*	9.90 *J*	52.6	2.37	47.7	1,680
G-M	GCORE02SD	--	94	208	18,800	3.10 *J*	0.990 *U*	18.0	0.290 *U*	15.7	2,220
G-M	GCORE03SD	1	208	259	16,200	0.0550 *J*	1.90 *U*	25.5	0.250 *U*	32.4	77.7
G-M	GCORE03SD	2	208	259	16,000	0.0490 *J*	1.90 *U*	26.1	0.260 *U*	24.8	76.8
G-N	ECH-E-GN01	--	0	10	6,740 *J*	0.710 *J*	31.0 *J*	46.8 *J*	3.13 *J*	38.2	2,640
G-N	ECH-E-GN02	--	10	20	6,600 *J*	0.79 *J*	33 *J*	51 *J*	3.0 *J*	20	5,800
G-N	ECH-E-GN03	--	20	30	2,780 *J*	4.30 *J*	6.19 *J*	140 *J*	2.38 *J*	38.2	16,900
G-S	ECH-E-GS01	1	0	10	7,020 *J*	0.420 *J*	17.0 *J*	94.4 *J*	2.98 *J*	74.4	1,710
G-S	ECH-E-GS01	2	0	10	7,230 *J*	0.580 *J*	16.9 *J*	104 *J*	3.53 *J*	87.2	1,820
G-S	ECH-E-GS02	--	10	20	3,380 *J*	0.450 *J*	10.3 *J*	97.5 *J*	3.61 *J*	76.6	1,090
G-S	ECH-E-GS03	--	20	30	3,320 *J*	0.480 *J*	13.3 *J*	98.1 *J*	4.82 *J*	89.1	1,240
H-CORE	HCORE01SD	--	0	36	7,800	0.600	5.20	34.5	0.980 *U*	19.5	759
H-CORE	HCORE02SD	--	36	89	12,800	0.0340 *J*	2.70 *U*	26.9	0.430 *U*	20.7	76.0
H-CORE	HCORE03SD	--	89	124	4,530	0.00620 *UJ*	0.740 *U*	3.80	0.110 *U*	3.32	12.5
H-N	ECH-E-HN01	--	0	10	6,310 *J*	2.04 *J*	25.9 *J*	57.5 *J*	3.18 *J*	34.2	2,990
H-S	ECH-E-HS01	--	0	10	4,850 *J*	0.360 *J*	10.4 *J*	58.0 *J*	1.35 *J*	42.9	980
I-M	ICORE01SD	--	0	74	4,540	6.20	4.20	23.1	2.42	14.3	4,590
I-M	ICORE02SD	--	74	155	5,100	7.4	0.50 *U*	14.9	0.20 *U*	11.3	2,030
I-M	ICORE03SD	--	155	183	8,500	0.00600 *UJ*	0.490 *U*	3.63	0.110 *U*	3.32	13.1
I-M	ECH-E-IM01	--	0	10	6,740	1.37 *J*	11.2	74.0	4.40 *U*	17.2 *J*	2,180
I-M	ECH-E-IM02	1	10	20	7,590	4.90 *J*	12.9	72.0 *J*	4.70 *U*	17.0 *J*	4,750
I-M	ECH-E-IM02	2	10	20	7,050	5.80 *J*	11.9	80.0 *J*	4.70 *U*	19.0 *J*	4,780
I-M	ECH-E-IM03	--	20	30	6,470	11.0 *J*	6.30 *U*	28.0 *J*	6.80 *U*	36.0 *J*	8,490
I-N	ECH-E-IN01	--	0	10	3,220	9.10 *J*	18.9	81.0	20.0 *U*	54.0	9,190

Table B1-3. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Magnesium (mg/kg)	Total mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Silver (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
I-N	ECH-E-IN02	--	10	20	4,410	6.10 *J*	16.0	59.0	14.0 *U*	63.0 *J*	7,720
I-N	ECH-E-IN03	--	20	30	5,590	6.30 *J*	6.40 *U*	23.0 *J*	6.10 *U*	56.0	7,610
I-S	ECH-E-IS01	--	0	10	5,730	15.5 *J*	4.60 *U*	30.1 *J*	4.45	45.2	10,600
I-S	ECH-E-IS02	--	10	20	8,520	15.6 *J*	2.40 *U*	18.9 *J*	4.74	45.3	13,500
I-S	ECH-E-IS03	--	20	30	694	1.05 *J*	0.310 *U*	2.47 *J*	0.120 *U*	2.75	636
J-CORE	JCORE01SD	--	0	30	2,600	0.440	2.87	17.5	0.590 *U*	8.37	797
J-CORE	JCORE02SD	--	30	86	2,500	2.66	2.75	19.2	1.79	9.64	2,640
J-CORE	JCORE03SD	--	86	178	7,640	4.81	0.760 *U*	22.8	0.450 *U*	18.1	2,380
J-N	ECH-E-JN01	--	0	10	11,000	1.59 *J*	20.2	117	2.07	94.1	2,590
J-N	ECH-E-JN02	--	10	20	9,310	1.38 *J*	22.1	117	5.40 *U*	41.0	2,490
J-N	ECH-E-JN03	--	20	30	4,800	0.99 *J*	13.6	85	1.0 *U*	22 *J*	2,100
J-S	ECH-E-JS01	--	0	10	3,980	0.630 *J*	10.1	47.5	2.57	23.0	1,220
K-M	ECH-E-KM01	--	0	10	5,200	1.01 *J*	8.23	62.7	1.27	24.3	2,000
K-M	KCORE01SD	--	0	46	3,300	1.01 *J*	12.2	96.2	2.17	22.4	3,840
K-M	KCORE02SD	1	46	152	4,820	0.107 *J*	0.640 *U*	8.44 *J*	0.110 *U*	5.63	203 *J*
K-M	KCORE02SD	2	46	152	4,220	0.0727 *J*	2.33 *U*	14.7 *J*	0.480 *U*	8.24	425 *J*
K-M	KCORE03SD	--	152	183	5,550	0.420 *J*	1.87 *U*	17.8	0.370 *U*	11.4	635
K-N	ECH-E-KN01	1	0	10	2,750	0.0898 *J*	1.39	9.30	0.180 *U*	4.68	292
K-N	ECH-E-KN01	2	0	10	2,820	0.140 *J*	1.22	8.19	0.120 *U*	4.13	323
K-S	ECH-E-KS01	--	0	10	5,910	0.820 *J*	18.2	93.0	5.00 *U*	48.0	8,090
K-S	ECH-E-KS02	--	10	20	5,490	1.35 *J*	21.8	129	13.0 *U*	62.0	12,500
K-S	ECH-E-KS03	--	20	30	4,140	0.920 *J*	23.3	123	9.70 *U*	47.0	8,520
SD009	SD009	--	0	0	7,120	6.2	1.27 *U*	15	4.16	44.9	450 *J*

Note: All results reported in dry weight.

J - estimated
R - rejected
U - undetected at detection limit shown

Table B1-4. Miscellaneous results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Percent moisture (percent wet)	Total Residue (percent wet)	pH (pH wet)	Fluoride (mg/kg dry)	Sulfate (mg/kg dry)	Sulfide Titration (mg/kg dry)	Acid-volatile sulfide (μmol/g dry)
A-M	ACORE01SD	1	0	69	31.5	68.5	7.70	1.70	495 *J*	1,760	96 *J*
A-M	ACORE01SD	2	0	69	29.9	70.1	7.59	2.50	540 *J*	1,920	89 *J*
A-M	ACORE02SD	--	69	122	76.7	23.3	7.16	6.80	6,600 *J*	808	82 *J*
A-M	ACORE03SD	--	122	200	21	79.3	7.26	1.00 *J*	570 *J*	6.90 *U*	2.0 *J*
A-M	ECH-E-AM01	--	0	10	28.9	71.1	7.36	11.0 *UJ*	1,130 *J*	638 *J*	16.1
A-M	ECH-E-AM02	--	10	20	26.2	73.8	7.49	1.90 *J*	3,300 *J*	1,000 *J*	37.8 *J*
A-M	ECH-E-AM03	--	20	30	30.5	69.5	7.77	7.10 *J*	3,200 *J*	6,750 *J*	56.7 *J*
A-N	ECH-E-AN01	1	0	10	40.9	59.1	7.35	2.3 *J*	612 *J*	1,650 *J*	38.6
A-N	ECH-E-AN01	2	0	10	37.6	62.4	7.34	3.40 *J*	919 *J*	1,690 *J*	28.5 *J*
A-S	ECH-E-AS01	--	0	10	63.1	36.9	7.50	3.70 *J*	2,160 *J*	180 *J*	26.6 *J*
B-M	BCORE01SD	--	0	55	63.5	36.5	7.58	5.30 *J*	2,070 *J*	4,100 *J*	203 *J*
B-M	BCORE02SD	1	55	120	78.7	21.3	7.32	10.8 *J*	4,340 *J*	688 *J*	46.6 *J*
B-M	BCORE02SD	2	55	120	78.6	21.4	7.27	11.0 *J*	5,980 *J*	317 *J*	36.6
B-M	BCORE03SD	--	120	173	18.2	81.8	7.79	1.50 *J*	326 *J*	6.70 *UJ*	1.40 *J*
B-M	ECH-E-BM01	--	0	10	45.5	54.5	7.09	2.90 *J*	561 *J*	530 *J*	20.2 *J*
B-N	ECH-E-BN01	--	0	10	40.4	59.6	7.08	8.70 *J*	386 *J*	380 *J*	14.9 *J*
B-S	ECH-E-BS01	--	0	10	56.0	44.0	7.10	4.20 *J*	830 *J*	1,590 *J*	112 *J*
C-CORE	CCORE01SD	--	0	135	38.4	61.6	7.68	10.5 *J*	1,660 *J*	993 *J*	25.5
C-CORE	CCORE02SD	--	135	269	49	51.9	7.85	11.6 *J*	1,040 *J*	850 *J*	16.2
C-CORE	CCORE03SD	--	269	460	42.8	57.2	7.57	4.8 *J*	820 *J*	827 *J*	26.3
C-N	ECH-E-CN01	--	0	10	66.7	33.3	7.33	5.90 *J*	24,200 *J*	4,140 *J*	75.8 *J*
C-N	ECH-E-CN02	--	10	20	65.6	34.4	7.43	8.60 *J*	2,360 *J*	1,420 *J*	36.9 *J*
C-N	ECH-E-CN03	1	20	30	62.3	37.7	7.53	7.60 *J*	7,500 *J*	1,610 *J*	30.3 *J*
C-N	ECH-E-CN03	2	20	30	62.2	37.8	7.48	6.90 *J*	3,300 *J*	1,300 *J*	46.1 *J*
C-S	ECH-E-CS01	--	0	10	55.2	44.8	8.09	6.80 *J*	3,830 *J*	5,010 *J*	98 *J*
D-M	DCORE01SD	--	0	103	23.2	76.8	7.70	2.00 *J*	650 *J*	82.0 *J*	1.25 *J*
D-M	DCORE02SD	--	103	180	59.6	40.4	7.37	2.00 *UJ*	137 *J*	85 *J*	8.80
D-M	DCORE03SD	--	180	208	25.0	75.0	7.55	1.10 *UJ*	485 *J*	10.3 *J*	0.750 *J*
D-M	ECH-E-DM01	--	0	10	22.2	77.8	7.32	1.80 *J*	410 *J*	106 *J*	4.30
D-N	ECH-E-DN01	--	0	10	61.8	38.2	7.00	8.00 *J*	600 *J*	290 *J*	10.7 *J*
D-S	ECH-E-DS01	--	0	10	70.4	29.6	7.06	7.60 *J*	5,070 *J*	420 *J*	42.6 *J*
E-CORE	ECORE01SD	--	0	45	22.3	77.7	8.49	1.90	1,280 *J*	1,870	119 *J*
E-CORE	ECORE02SD	--	45	118	69.6	30.4	7.38	8.4	3,500 *J*	6,430	106 *J*
E-CORE	ECORE03SD	--	118	165	22	77.9	7.66	4.90	580 *J*	7.00 *U*	0.26 *UJ*

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Table B1-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Percent moisture (percent wet)	Total Residue (percent wet)	pH (pH wet)	Fluoride (mg/kg dry)	Sulfate (mg/kg dry)	Sulfide Titration (mg/kg dry)	Acid-volatile sulfide (μmol/g dry)
E-N	ECH-E-EN01	--	0	10	54.4	45.6	7.30	5.90 *J*	980 *J*	328 *J*	6.60
E-N	ECH-E-EN02	--	10	20	38.9	61.1	7.32	17.2 *J*	2,130 *J*	400 *J*	70.3
E-N	ECH-E-EN03	--	20	30	64.1	35.9	7.46	6.00 *J*	1,220 *J*	2,370 *J*	172
E-S	ECH-E-ES01	--	0	10	56.7	43.3	7.2	5.40 *J*	1,610 *J*	2,970 *J*	61.9
E-S	ECH-E-ES02	--	10	20	56.1	43.9	7.54	5.80 *J*	2,690 *J*	3,110 *J*	121
E-S	ECH-E-ES03	--	20	30	46.6	53.4	8.32	34.0 *J*	2,920 *J*	2,900 *J*	32.8
F-CORE	FCORE01SD	--	0	55	35.1	64.9	7.60	2.60	1,530 *J*	1,450	27 *J*
F-CORE	FCORE02SD	--	55	150	76.3	23.7	7.44	9.50	920 *J*	1,860	340 *J*
F-CORE	FCORE03SD	1	150	205	40.1	59.9	7.40	4.70	1,590 *J*	266	27 *J*
F-CORE	FCORE03SD	2	150	205	40.5	59.5	7.39	4.70	1,080 *J*	314	13 *J*
F-N	ECH-E-FN01	--	0	10	43.3	56.7	7.25	11.4 *J*	2,100 *J*	4,160 *J*	176
F-S	ECH-E-FS01	--	0	10	76.9	23.1	7.56	9.4 *J*	3,450 *J*	8,610 *J*	352
G-M	GCORE01SD	--	0	64	53.7	46.3	7.06	86.0 *UJ*	10,600 *J*	2,970 *J*	36.6 *J*
G-M	GCORE02SD	--	94	208	71.1	28.9	6.9	140 *UJ*	17,600 *J*	1,700 *J*	263 *J*
G-M	GCORE03SD	1	208	259	66.0	34.0	6.51	120 *UJ*	5,700 *J*	1,690 *J*	129 *J*
G-M	GCORE03SD	2	208	259	67.9	32.1	6.55	120 *UJ*	6,000 *J*	1,840 *J*	131 *J*
G-N	ECH-E-GN01	--	0	10	48.0	52.0	7.9	8.60 *J*	6,090 *J*	2,040 *J*	89.7
G-N	ECH-E-GN02	--	10	20	33	67.3	7.47	6.0 *J*	1,180 *J*	3,910 *J*	70
G-N	ECH-E-GN03	--	20	30	36.8	63.2	7.32	13.6 *J*	2,090 *J*	6,800 *J*	354
G-N	G-N-1	--	25.3	45.73							
G-N	G-N-2	--	91.5	122							
G-S	ECH-E-GS01	1	0	10	63.5	36.5	7.31	4.90 *J*	126 *J*	160 *J*	8.20
G-S	ECH-E-GS01	2	0	10	64.5	35.5	7.56	5.20 *J*	266 *J*	170 *J*	7.00
G-S	ECH-E-GS02	--	10	20	60.6	39.4	8.42	13.3 *J*	46.0 *J*	110 *J*	5.30
G-S	ECH-E-GS03	--	20	30	61.4	38.6	8.60	20 *J*	10.1 *J*	110 *J*	9.80
H-CORE	HCORE01SD	--	0	36	63.9	36.1	8.07	6.50	3,070 *J*	350	39 *J*
H-CORE	HCORE02SD	--	36	89	70.4	29.6	8.87	8.70	440 *J*	760	57 *J*
H-CORE	HCORE03SD	--	89	124	22.5	77.5	10.4	1.30	11.3 *J*	110	3.1 *J*
H-N	ECH-E-HN01	--	0	10	56.6	43.4	7.71	6.40 *J*	429 *J*	2,800 *J*	194
H-S	ECH-E-HS01	--	0	10	24.1	75.9	7.09	9.40 *J*	396 *J*	165 *J*	7.40
I-M	ICORE01SD	--	0	74	55.9	44.1	7.27	4.70	1,660 *J*	2,010	74.3 *J*
I-M	ICORE02SD	--	74	155	70.5	29.5	7.13	4.4	1,480 *J*	734	41 *J*
I-M	ICORE03SD	--	155	183	20.0	80.0	7.86	1.50	297 *J*	19.0 *J*	0.250 *UJ*
I-M	ECH-E-IM01	--	0	10	42.3	57.7	7.13	2.80	591 *J*	875 *J*	42.9 *J*

Table B1-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Percent moisture (percent wet)	Total Residue (percent wet)	pH (pH wet)	Fluoride (mg/kg dry)	Sulfate (mg/kg dry)	Sulfide Titration (mg/kg dry)	Acid-volatile sulfide (μmol/g dry)
I-M	ECH-E-IM02	1	10	20	56.5	43.5	7.21	4.50 *J*	1,380 *J*	2,480 *J*	106 *J*
I-M	ECH-E-IM02	2	10	20	55.5	44.5	7.18	2.60	1,210 *J*	2,670 *J*	136 *J*
I-M	ECH-E-IM03	--	20	30	69.4	30.6	7.31	3.80	1,730 *J*	5,430 *J*	293 *J*
I-N	ECH-E-IN01	--	0	10	65.0	35.0	6.91	3.30	760 *J*	2,480 *J*	66.7 *J*
I-N	ECH-E-IN02	--	10	20	62.9	37.1	7.15	3.0	420 *J*	1,810 *J*	78.7 *J*
I-N	ECH-E-IN03	--	20	30	65.4	34.6	7.28	3.80	1,180 *J*	3,190 *J*	71.1 *J*
I-S	ECH-E-IS01	--	0	10	61.4	38.6	7.55	2.90	1,610 *J*	4,100 *J*	160 *J*
I-S	ECH-E-IS02	--	10	20	72.1	27.9	7.73	5.60	2,310 *J*	4,890 *J*	204 *J*
I-S	ECH-E-IS03	--	20	30	30.5	69.5	7.11	1.90	685 *J*	282 *J*	16.1 *J*
J-CORE	JCORE01SD	--	0	30	26.3	73.7	7.60	2.60	1,150 *J*	387	13 *J*
J-CORE	JCORE02SD	--	30	86	41.1	58.9	7.26	4.10	683 *J*	792	33 *J*
J-CORE	JCORE03SD	--	86	178	67	32.7	7.20	3.30	2,090 *J*	230	15 *J*
J-N	ECH-E-JN01	--	0	10	62.6	37.4	7.06	9.00 *J*	2,080 *J*	970	29.5 *J*
J-N	ECH-E-JN02	--	10	20	56.2	43.8	7.16	8.30 *J*	1,030 *J*	1,370	54.4 *J*
J-N	ECH-E-JN03	--	20	30	51	49.5	7.25	5.5 *J*	70 *J*	890	18 *J*
J-S	ECH-E-JS01	--	0	10	38.6	61.4	7.2	7.20 *J*	960 *J*	215	20.3 *J*
K-M	ECH-E-KM01	--	0	10	44.7	55.3	7.56	5.70 *J*	371 *J*	1,520	34.9 *J*
K-M	KCORE01SD	--	0	46	27.4	72.6	7.61	3.5 *J*	1,500 *J*	2,160 *J*	79.1 *J*
K-M	KCORE02SD	1	46	152	25.1	74.9	8.00	1.70 *J*	1,340 *J*	73.0 *J*	1.40 *J*
K-M	KCORE02SD	2	46	152	28.2	71.8	8.0	2.30 *J*	1,350 *J*	33.0 *J*	0.790 *J*
K-M	KCORE03SD	--	152	183	37.7	62.3	7.47	7.10 *J*	7,600 *J*	631 *J*	20.8 *J*
K-N	ECH-E-KN01	1	0	10	28.5	71.5	8.14	2.40 *J*	603 *J*	194	8.80 *J*
K-N	ECH-E-KN01	2	0	10	27.8	72.2	7.86	1.30 *J*	581 *J*	229	13.5 *J*
K-S	ECH-E-KS01	--	0	10	54.9	45.1	7.23	8.90 *J*	660 *J*	1,310	39.1 *J*
K-S	ECH-E-KS02	--	10	20	52.7	47.3	7.26	12.8 *J*	45.0 *J*	1,680	47.3 *J*
K-S	ECH-E-KS03	--	20	30	56.4	43.6	7.39	11.4 *J*	30.0 *J*	1,090	14.1 *J*
SD009	SD009	--	0	0	2.39						

Table B1-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Total Phosphorus (mg/kg dry)	Ammonia-nitrogen (MOD) (mg/kg dry)	Total Kjeldahl nitrogen (mg/kg dry)	Cyanide (mg/kg dry)	Di-*n*-butyl phthalate (µg/kg dry)	Phenol (µg/kg dry)
A-M	ACORE01SD	1	0	69	640	180 *J*	1,310	8.87 *J*		
A-M	ACORE01SD	2	0	69	490	172 *J*	710	10.3 *J*		
A-M	ACORE02SD	--	69	122	1,000	1,300	12,300	0.420 *UR*		
A-M	ACORE03SD	--	122	200	90.0	90.0 *J*	350 *J*	0.120 *UR*		
A-M	ECH-E-AM01	--	0	10	910	47.0 *J*	540 *J*	0.98 *J*		470 *U*
A-M	ECH-E-AM02	--	10	20	620	123 *J*	1,100	0.170 *J*		900 *U*
A-M	ECH-E-AM03	--	20	30	480	130 *U*	2,260 *J*	1.71 *J*		4,800 *U*
A-N	ECH-E-AN01	1	0	10	1,900	51.0	1,490	1.19 *J*		560 *U*
A-N	ECH-E-AN01	2	0	10	1,800	60.0	1,420	1.80 *J*		530 *U*
A-S	ECH-E-AS01	--	0	10	650	360	5,300 *J*	0.260 *UR*		900 *U*
B-M	BCORE01SD	--	0	55	1,900	220 *J*	1,900 *J*	5.12		910 *U*
B-M	BCORE02SD	1	55	120	1,200	1,270	16,600 *J*	0.470 *U*		310 *U*
B-M	BCORE02SD	2	55	120	1,100	1,330	13,100 *J*	0.470 *U*		
B-M	BCORE03SD	--	120	173	80.0	150 *U*	370 *J*	0.12 *U*		81.0 *U*
B-M	ECH-E-BM01	--	0	10	2,100	230 *J*	3,380 *J*	3.10 *J*		
B-N	ECH-E-BN01	--	0	10	2,000	72.0	990	1.61 *J*		560 *U*
B-S	ECH-E-BS01	--	0	10	2,200	194	3,400 *J*	1.96 *J*		3,800 *U*
C-CORE	CCORE01SD	--	0	135	2,600	540	1,170 *J*	0.160 *U*		
C-CORE	CCORE02SD	--	135	269	2,200	720	2,090 *J*	0.190 *U*		
C-CORE	CCORE03SD	--	269	460	860	340 *J*	2,900 *J*	3.08		
C-N	ECH-E-CN01	--	0	10	4,300	170	1,900	2.46 *J*		
C-N	ECH-E-CN02	--	10	20	3,800	310	2,200	0.590 *J*		
C-N	ECH-E-CN03	1	20	30	4,000 *J*	280	1,700	0.470 *J*		
C-N	ECH-E-CN03	2	20	30	7,700 *J*	350	1,900	0.460 *J*		
C-S	ECH-E-CS01	--	0	10	1,900	60.0 *J*	1,670	3.69 *J*		
D-M	DCORE01SD	--	0	103	470	81.0 *U*	360 *J*	0.130 *U*		
D-M	DCORE02SD	--	103	180	1,100	670	5,100 *J*	0.250 *U*		
D-M	DCORE03SD	--	180	208	140	170 *U*	590 *J*	0.130 *U*		
D-M	ECH-E-DM01	--	0	10	370	110 *U*	290 *U*	0.130 *UJ*		
D-N	ECH-E-DN01	--	0	10	1,900	470	1,290	0.90 *J*		870 *U*
D-S	ECH-E-DS01	--	0	10	820	670	3,300	1.50 *J*		1,100 *U*
E-CORE	ECORE01SD	--	0	45	1,100	120 *U*	950	1.17 *J*		
E-CORE	ECORE02SD	--	45	118	1,600	670 *J*	5,800	10.9 *J*		
E-CORE	ECORE03SD	--	118	165	100	120 *U*	370 *J*	0.130 *UR*		

Table B1-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Total Phosphorus (mg/kg dry)	Ammonia-nitrogen (MOD) (mg/kg dry)	Total Kjeldahl nitrogen (mg/kg dry)	Cyanide (mg/kg dry)	Di-*n*-butyl phthalate (µg/kg dry)	Phenol (µg/kg dry)
E-N	ECH-E-EN01	--	0	10	220	67.0 *U*	320 *U*	0.640 *J*		
E-N	ECH-E-EN02	--	10	20	1,500	230 *U*	240 *U*	2.98 *J*		
E-N	ECH-E-EN03	--	20	30	1,700	270	470 *U*	5.74 *J*		
E-S	ECH-E-ES01	--	0	10	2,300	81.0 *J*	380 *U*	3.30 *J*		
E-S	ECH-E-ES02	--	10	20	1,700	136	320 *U*	2.84 *J*		
E-S	ECH-E-ES03	--	20	30	1,400	19.9 *J*	280 *U*	1.68 *J*		
F-CORE	FCORE01SD	--	0	55	1,200	132 *J*	730 *J*	0.150 *UR*		
F-CORE	FCORE02SD	--	55	150	1,600	1,200	9,500	0.420 *UR*		
F-CORE	FCORE03SD	1	150	205	240	230 *J*	1,830	0.16 *UR*		
F-CORE	FCORE03SD	2	150	205	240	214 *J*	1,880	0.170 *UR*		
F-N	ECH-E-FN01	--	0	10	2,200	34.0 *J*	930 *J*	1.65 *J*		
F-S	ECH-E-FS01	--	0	10	7,200	390 *J*	1,220 *J*	4.90 *J*		
G-M	GCORE01SD	--	0	64	1,000	2,200	4,000 *J*	0.620 *J*		720 *U*
G-M	GCORE02SD	--	94	208	2,300	930 *J*	21,600 *J*	0.340 *U*		230 *U*
G-M	GCORE03SD	1	208	259	1,500	13,500	19,200 *J*	0.290 *U*		200 *U*
G-M	GCORE03SD	2	208	259	1,400	14,300	19,300 *J*	0.310 *U*		210 *U*
G-N	ECH-E-GN01	--	0	10	1,300	137 *J*	1,230 *J*	1.00 *J*		
G-N	ECH-E-GN02	--	10	20	600	40 *U*	850 *J*	4.7 *J*		
G-N	ECH-E-GN03	--	20	30	670	21.0 *U*	1,170 *J*	15.9 *J*		
G-N	G-N-1	--	25.3	45.73						
G-N	G-N-2	--	91.5	122						
G-S	ECH-E-GS01	1	0	10	1,900	71.0 *J*	500 *U*	2.32 *J*		
G-S	ECH-E-GS01	2	0	10	1,900	200	2,100 *J*	3.16 *J*		
G-S	ECH-E-GS02	--	10	20	1,400	242 *J*	590 *U*	5.94 *J*		
G-S	ECH-E-GS03	--	20	30	1,500	350	400 *U*	2.28 *J*		
H-CORE	HCORE01SD	--	0	36	1,400	720	6,700	0.270 *UR*		
H-CORE	HCORE02SD	--	36	89	1,100	1,240	8,700	0.340 *UR*		
H-CORE	HCORE03SD	--	89	124	100	72.0 *J*	280 *J*	0.130 *UR*		
H-N	ECH-E-HN01	--	0	10	2,100	261 *J*	2,200 *J*	1.78 *J*		
H-S	ECH-E-HS01	--	0	10	1,300	148	640 *J*	0.380 *J*		
I-M	ICORE01SD	--	0	74	1,500	210	390 *J*	3.07 *J*		760 *U*
I-M	ICORE02SD	--	74	155	720	1,230 *J*	5,300	0.29 *UR*		230 *U*
I-M	ICORE03SD	--	155	183	130	160 *U*	240 *J*	0.120 *UR*		83.0 *U*
I-M	ECH-E-IM01	--	0	10	2,200	216 *J*	1,870	1.38 *J*		580 *U*

Table B1-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Total Phosphorus (mg/kg dry)	Ammonia-nitrogen (MOD) (mg/kg dry)	Total Kjeldahl nitrogen (mg/kg dry)	Cyanide (mg/kg dry)	Di-*n*-butyl phthalate (µg/kg dry)	Phenol (µg/kg dry)
I-M	ECH-E-IM02	1	10	20	2,300	171 *J*	2,300	2.76 *J*		770 *U*
I-M	ECH-E-IM02	2	10	20	2,100	540	2,300	2.55 *J*		750 *U*
I-M	ECH-E-IM03	--	20	30	2,300	270 *J*	2,600	5.90 *J*	1,100 *U*	1,100 *U*
I-N	ECH-E-IN01	--	0	10	3,400	290 *J*	2,300	3.03 *J*		950 *U*
I-N	ECH-E-IN02	--	10	20	2,700	260 *J*	2,000	2.55 *J*		450 *U*
I-N	ECH-E-IN03	--	20	30	2,400	300	2,200	6.52 *J*		1,900 *U*
I-S	ECH-E-IS01	--	0	10	1,300	200 *J*	1,800	5.37 *J*		860 *U*
I-S	ECH-E-IS02	--	10	20	1,500	360	4,400	9.40 *J*		1,200 *U*
I-S	ECH-E-IS03	--	20	30	80.0	190 *U*	460 *J*	1.08 *J*		480 *U*
J-CORE	JCORE01SD	--	0	30	420	180 *U*	340 *J*	0.130 *UR*		
J-CORE	JCORE02SD	--	30	86	650	210 *J*	720 *J*	3.57 *J*		
J-CORE	JCORE03SD	--	86	178	1,800	1,700	8,600	0.300 *UR*		
J-N	ECH-E-JN01	--	0	10	3,600 *J*	170	4,500 *J*	1.59 *J*		
J-N	ECH-E-JN02	--	10	20	2,900 *J*	330	2,400 *J*	1.62 *J*		
J-N	ECH-E-JN03	--	20	30	2,000 *J*	510	2,140 *J*	1.5 *J*		
J-S	ECH-E-JS01	--	0	10	2,100 *J*	88.0 *J*	1,120 *J*	0.160 *UJ*		
K-M	ECH-E-KM01	--	0	10	2,300 *J*	71.0 *J*	2,450 *J*	2.48 *J*		
K-M	KCORE01SD	--	0	46	1,200	140 *J*	1,210 *J*	2.59		
K-M	KCORE02SD	1	46	152	130	150 *U*	750 *J*	0.130 *U*		
K-M	KCORE02SD	2	46	152	150	150 *U*	850 *J*	0.14 *U*		
K-M	KCORE03SD	--	152	183	340	250 *J*	2,110 *J*	0.160 *U*		
K-N	ECH-E-KN01	1	0	10	650 *J*	46.0 *J*	600 *J*	0.140 *UJ*		
K-N	ECH-E-KN01	2	0	10	380 *J*	66.0 *J*	430 *J*	0.140 *UJ*		
K-S	ECH-E-KS01	--	0	10	4,100 *J*	235 *J*	2,700 *J*	3.90 *J*		
K-S	ECH-E-KS02	--	10	20	6,400 *J*	560	2,700 *J*	4.45 *J*		
K-S	ECH-E-KS03	--	20	30	4,300 *J*	520	2,200 *J*	3.98 *J*		
SD009	SD009	--	0	0						

Table B1-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Pentachloro-phenol (µg/kg dry)	Phenols (mg/kg dry)	Hydraulic Conductivity (cm/s dry)
A-M	ACORE01SD	1	0	69		2.30	
A-M	ACORE01SD	2	0	69		1.70	
A-M	ACORE02SD	--	69	122		1.00 *U*	
A-M	ACORE03SD	--	122	200		0.3 *U*	
A-M	ECH-E-AM01	--	0	10	1,200 *U*	0.530 *J*	
A-M	ECH-E-AM02	--	10	20	2,300 *U*	2.50	
A-M	ECH-E-AM03	--	20	30	12,000 *U*	0.330 *U*	
A-N	ECH-E-AN01	1	0	10	1,400 *U*	1.50	
A-N	ECH-E-AN01	2	0	10	1,300 *U*	0.720 *J*	
A-S	ECH-E-AS01	--	0	10	2,300 *U*	0.670 *J*	
B-M	BCORE01SD	--	0	55	2,300 *U*	6.60	
B-M	BCORE02SD	1	55	120	780 *U*	1.10 *U*	
B-M	BCORE02SD	2	55	120		3.60	
B-M	BCORE03SD	--	120	173	200 *U*	1.23	
B-M	ECH-E-BM01	--	0	10		0.740 *J*	
B-N	ECH-E-BN01	--	0	10	1,400 *U*	1.05	
B-S	ECH-E-BS01	--	0	10	9,500 *U*	1.70	
C-CORE	CCORE01SD	--	0	135		1.60	
C-CORE	CCORE02SD	--	135	269		2.30	
C-CORE	CCORE03SD	--	269	460		0.670 *J*	
C-N	ECH-E-CN01	--	0	10		1.42 *J*	
C-N	ECH-E-CN02	--	10	20		1.54 *J*	
C-N	ECH-E-CN03	1	20	30		1.44 *J*	
C-N	ECH-E-CN03	2	20	30		0.600 *U*	
C-S	ECH-E-CS01	--	0	10		0.520 *U*	
D-M	DCORE01SD	--	0	103		1.82	
D-M	DCORE02SD	--	103	180		0.950 *J*	
D-M	DCORE03SD	--	180	208		1.96	
D-M	ECH-E-DM01	--	0	10		0.330 *J*	
D-N	ECH-E-DN01	--	0	10	2,200 *UJ*	0.98 *J*	
D-S	ECH-E-DS01	--	0	10	2,800 *U*	1.86 *J*	
E-CORE	ECORE01SD	--	0	45		0.420 *J*	
E-CORE	ECORE02SD	--	45	118		1.23 *J*	
E-CORE	ECORE03SD	--	118	165		0.420 *J*	

Table B1-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Pentachloro-phenol (µg/kg dry)	Phenols (mg/kg dry)	Hydraulic Conductivity (cm/s dry)
E-N	ECH-E-EN01	--	0	10		0.500 *UJ*	
E-N	ECH-E-EN02	--	10	20		2.00 *J*	
E-N	ECH-E-EN03	--	20	30		15.8 *J*	
E-S	ECH-E-ES01	--	0	10		1.12 *J*	
E-S	ECH-E-ES02	--	10	20		3.90 *J*	
E-S	ECH-E-ES03	--	20	30		1.70 *J*	
F-CORE	FCORE01SD	--	0	55		1.90	
F-CORE	FCORE02SD	--	55	150		1.00 *U*	
F-CORE	FCORE03SD	1	150	205		0.380 *U*	
F-CORE	FCORE03SD	2	150	205		2.20	
F-N	ECH-E-FN01	--	0	10		28.6	
F-S	ECH-E-FS01	--	0	10		1.00 *U*	
G-M	GCORE01SD	--	0	64	1,800 *U*	1.15	
G-M	GCORE02SD	--	94	208	580 *U*	1.30 *J*	
G-M	GCORE03SD	1	208	259	490 *U*	0.680 *U*	
G-M	GCORE03SD	2	208	259	520 *U*	0.720 *U*	
G-N	ECH-E-GN01	--	0	10		0.440 *U*	
G-N	ECH-E-GN02	--	10	20		0.34 *U*	
G-N	ECH-E-GN03	--	20	30		0.360 *U*	
G-N	G-N-1	--	25.3	45.73			0.0000022
G-N	G-N-2	--	91.5	122			0.00000047
G-S	ECH-E-GS01	1	0	10		0.630 *U*	
G-S	ECH-E-GS01	2	0	10		0.650 *U*	
G-S	ECH-E-GS02	--	10	20		2.10	
G-S	ECH-E-GS03	--	20	30		7.90	
H-CORE	HCORE01SD	--	0	36		0.640 *U*	
H-CORE	HCORE02SD	--	36	89		0.70 *U*	
H-CORE	HCORE03SD	--	89	124		0.300 *U*	
H-N	ECH-E-HN01	--	0	10		2.3	
H-S	ECH-E-HS01	--	0	10		0.300 *U*	
I-M	ICORE01SD	--	0	74	1,900 *U*	2.20	
I-M	ICORE02SD	--	74	155	560 *U*	0.70 *U*	
I-M	ICORE03SD	--	155	183	210 *U*	0.290 *U*	
I-M	ECH-E-IM01	--	0	10	1,400 *U*	2.40	

Table B1-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Pentachloro-phenol (µg/kg dry)	Phenols (mg/kg dry)	Hydraulic Conductivity (cm/s dry)
I-M	ECH-E-IM02	1	10	20	1,900 *U*	1.25	
I-M	ECH-E-IM02	2	10	20	1,900 *U*	2.50	
I-M	ECH-E-IM03	--	20	30	2,700 *U*	6.30	
I-N	ECH-E-IN01	--	0	10	2,400 *U*	1.74 *J*	
I-N	ECH-E-IN02	--	10	20	2,200 *U*	1.48 *J*	
I-N	ECH-E-IN03	--	20	30	4,800 *U*	1.61 *J*	
I-S	ECH-E-IS01	--	0	10	2,200 *U*	1.58 *J*	
I-S	ECH-E-IS02	--	10	20	3,000 *U*	2.50	
I-S	ECH-E-IS03	--	20	30	1,200 *U*	0.850 *J*	
J-CORE	JCORE01SD	--	0	30		0.910 *J*	
J-CORE	JCORE02SD	--	30	86		0.550 *J*	
J-CORE	JCORE03SD	--	86	178		0.700 *U*	
J-N	ECH-E-JN01	--	0	10		1.90	
J-N	ECH-E-JN02	--	10	20		1.1 *J*	
J-N	ECH-E-JN03	--	20	30		2.40	
J-S	ECH-E-JS01	--	0	10		0.410 *J*	
K-M	ECH-E-KM01	--	0	10		0.550 *J*	
K-M	KCORE01SD	--	0	46		13.1	
K-M	KCORE02SD	1	46	152		3.10	
K-M	KCORE02SD	2	46	152		1.85	
K-M	KCORE03SD	--	152	183		1.60	
K-N	ECH-E-KN01	1	0	10		0.340 *J*	
K-N	ECH-E-KN01	2	0	10		0.930 *J*	
K-S	ECH-E-KS01	--	0	10		0.940 *J*	
K-S	ECH-E-KS02	--	10	20		1.80	
K-S	ECH-E-KS03	--	20	30		3.50	
SD009	SD009	--	0	0			

Note: *J* - estimated
R - rejected
U - undetected at detection limit shown

Table B1-5. Oil and grease results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Oil and grease (mg/kg dry)
A-M	ACORE01SD	1	0	69	24,900 *J*
A-M	ACORE01SD	2	0	69	31,700 *J*
A-M	ACORE02SD	--	69	122	4,900 *J*
A-M	ACORE03SD	--	122	200	760 *UJ*
A-M	ECH-E-AM01	--	0	10	8,100
A-M	ECH-E-AM02	--	10	20	17,700
A-M	ECH-E-AM03	--	20	30	68,500
A-N	ECH-E-AN01	1	0	10	11,400
A-N	ECH-E-AN01	2	0	10	11,000
A-S	ECH-E-AS01	--	0	10	9,500
B-M	BCORE01SD	--	0	55	17,000
B-M	BCORE02SD	1	55	120	5,500 *J*
B-M	BCORE02SD	2	55	120	9,000 *J*
B-M	BCORE03SD	--	120	173	730 *U*
B-M	ECH-E-BM01	--	0	10	27,500
B-N	ECH-E-BN01	--	0	10	16,700
B-S	ECH-E-BS01	--	0	10	137,000
C-CORE	CCORE01SD	--	0	135	41,100
C-CORE	CCORE02SD	--	135	269	40,000
C-CORE	CCORE03SD	--	269	460	30,500
C-N	ECH-E-CN01	--	0	10	118,000
C-N	ECH-E-CN02	--	10	20	93,600
C-N	ECH-E-CN03	1	20	30	93,200
C-N	ECH-E-CN03	2	20	30	92,400
C-S	ECH-E-CS01	--	0	10	134,000
D-M	DCORE01SD	--	0	103	6,000
D-M	DCORE02SD	--	103	180	1,500 *U*
D-M	DCORE03SD	--	180	208	800 *U*
D-M	ECH-E-DM01	--	0	10	6,100
D-N	ECH-E-DN01	--	0	10	20,000
D-S	ECH-E-DS01	--	0	10	39,800
E-CORE	ECORE01SD	--	0	45	48,600 *J*
E-CORE	ECORE02SD	--	45	118	45,100 *J*
E-CORE	ECORE03SD	--	118	165	770 *UJ*
E-N	ECH-E-EN01	--	0	10	5,100
E-N	ECH-E-EN02	--	10	20	13,800
E-N	ECH-E-EN03	--	20	30	36,400
E-S	ECH-E-ES01	--	0	10	74,000
E-S	ECH-E-ES02	--	10	20	23,200
E-S	ECH-E-ES03	--	20	30	23,500
F-CORE	FCORE01SD	--	0	55	27,100 *J*
F-CORE	FCORE02SD	--	55	150	3,600 *J*
F-CORE	FCORE03SD	1	150	205	3,400 *J*
F-CORE	FCORE03SD	2	150	205	1,400 *J*
F-N	ECH-E-FN01	--	0	10	44,300
F-S	ECH-E-FS01	--	0	10	147,000
G-M	GCORE01SD	--	0	64	11,500
G-M	GCORE02SD	--	94	208	3,700 *J*
G-M	GCORE03SD	1	208	259	1,800 *U*

Table B1-5. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Oil and grease (mg/kg dry)
G-M	GCORE03SD	2	208	259	1,900 *U*
G-N	ECH-E-GN01	--	0	10	28,800
G-N	ECH-E-GN02	--	10	20	13,000
G-N	ECH-E-GN03	--	20	30	10,800
G-S	ECH-E-GS01	1	0	10	27,500
G-S	ECH-E-GS01	2	0	10	20,000
G-S	ECH-E-GS02	--	10	20	36,000
G-S	ECH-E-GS03	--	20	30	51,800
H-CORE	HCORE01SD	--	0	36	11,800 *J*
H-CORE	HCORE02SD	--	36	89	2,700 *J*
H-CORE	HCORE03SD	--	89	124	770 *UJ*
H-N	ECH-E-HN01	--	0	10	43,700
H-S	ECH-E-HS01	--	0	10	15,600
I-M	ICORE01SD	--	0	74	59,600 *J*
I-M	ICORE02SD	--	74	155	2,900 *J*
I-M	ICORE03SD	--	155	183	750 *UJ*
I-M	ECH-E-IM01	--	0	10	24,000
I-M	ECH-E-IM02	1	10	20	40,800
I-M	ECH-E-IM02	2	10	20	42,300
I-M	ECH-E-IM03	--	20	30	50,500
I-N	ECH-E-IN01	--	0	10	11,100
I-N	ECH-E-IN02	--	10	20	10,300
I-N	ECH-E-IN03	--	20	30	14,500
I-S	ECH-E-IS01	--	0	10	24,600
I-S	ECH-E-IS02	--	10	20	7,800
I-S	ECH-E-IS03	--	20	30	1,210 *J*
J-CORE	JCORE01SD	--	0	30	11,700 *J*
J-CORE	JCORE02SD	--	30	86	16,000 *J*
J-CORE	JCORE03SD	--	86	178	2,500 *J*
J-N	ECH-E-JN01	--	0	10	30,500 *J*
J-N	ECH-E-JN02	--	10	20	34,600 *J*
J-N	ECH-E-JN03	--	20	30	24,000 *J*
J-S	ECH-E-JS01	--	0	10	20,000 *J*
K-M	ECH-E-KM01	--	0	10	65,500 *J*
K-M	KCORE01SD	--	0	46	133,000
K-M	KCORE02SD	1	46	152	3,800
K-M	KCORE02SD	2	46	152	3,600
K-M	KCORE03SD	--	152	183	13,200
K-N	ECH-E-KN01	1	0	10	7,100 *J*
K-N	ECH-E-KN01	2	0	10	5,700 *J*
K-S	ECH-E-KS01	--	0	10	38,700 *J*
K-S	ECH-E-KS02	--	10	20	52,200 *J*
K-S	ECH-E-KS03	--	20	30	46,400 *J*

Note: *J* - estimated
U - undetected at detection limit shown

Table B1-6. PAH results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Naphthalene (µg/kg)	2-Methyl-naphthalene (µg/kg)	Acenaph-thylene (µg/kg)	Acenaphthene (µg/kg)	Fluorene (µg/kg)	Phenanthrene (µg/kg)
A-M	ECH-E-AM01	--	0	10	1,200 *J*	810 *J*	5,100	4,100	4,900	26,000
A-M	ECH-E-AM02	--	10	20	7,400	120,000	36,000	330,000	370,000	1,300,000
A-M	ECH-E-AM03	--	20	30	110,000	840,000	150,000	1,400,000	1,600,000	6,100,000
A-N	ECH-E-AN01	1	0	10	1,800 *J*	2,100 *J*	5,000	2,900	4,100	31,000
A-N	ECH-E-AN01	2	0	10	2,000 *J*	2,200 *J*	5,200	2,900	4,000	31,000
A-S	ECH-E-AS01	--	0	10	820 *J*	460 *J*	560 *J*	970 *J*	2,200 *J*	19,000
B-M	BCORE01SD	--	0	55	5,600	2,900 *J*	4,300 *J*	13,000	22,000	71,000
B-M	BCORE02SD	1	55	120	160 *U*	160 *U*	160 *U*	160 *U*	200 *J*	480 *J*
B-M	BCORE03SD	--	120	173	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*
B-N	ECH-E-BN01	--	0	10	1,400 *J*	900 *J*	1,500 *J*	3,300	2,400 *J*	8,800
B-S	ECH-E-BS01	--	0	10	5,700 *J*	3,600 *J*	6,100 *J*	36,000	30,000	100,000
D-N	ECH-E-DN01	--	0	10	6,600 *J*	3,400 *J*	4,800	6,900	5,700	15,000 *J*
D-S	ECH-E-DS01	--	0	10	1,500 *J*	960 *J*	3,300 *J*	5,000 *J*	16,000	250,000
G-M	GCORE01SD	--	0	64	820 *J*	740 *J*	1,700 *J*	2,200 *J*	1,400 *J*	6,100
G-M	GCORE02SD	--	94	208	120 *U*	120 *U*	120 *U*	120 *U*	120 *U*	130 *J*
G-M	GCORE03SD	1	208	259	98.0 *U*	98.0 *U*	98.0 *U*	98.0 *U*	98.0 *U*	98.0 *U*
G-M	GCORE03SD	2	208	259	100 *U*	100 *U*	100 *U*	100 *U*	100 *U*	100 *U*
I-M	ICORE01SD	--	0	74	2,900 *J*	5,700	3,900	20,000	98,000 *J*	1,200,000
I-M	ICORE02SD	--	74	155	110 *U*	110 *U*	110 *U*	110 *U*	110 *U*	400 *J*
I-M	ICORE03SD	--	155	183	42.0 *U*	42.0 *U*	42.0 *U*	42.0 *U*	50.0 *J*	790
I-M	ECH-E-IM01	--	0	10	2,200 *J*	1,300 *J*	2,300 *J*	3,200	2,800 *J*	8,900
I-M	ECH-E-IM02	1	10	20	2,800 *J*	6,600	4,200	11,000	53,000	570,000
I-M	ECH-E-IM02	2	10	20	2,900 *J*	7,500	4,000	9,100	53,000	720,000
I-M	ECH-E-IM03	--	20	30	3,700 *J*	1,700 *J*	3,300 *J*	4,100 *J*	24,000	220,000
I-N	ECH-E-IN01	--	0	10	2,700 *J*	1,500 *J*	3,800 *J*	5,300	4,500 *J*	14,000
I-N	ECH-E-IN02	--	10	20	3,800 *J*	3,400 *J*	2,400 *J*	13,000	23,000	230,000
I-N	ECH-E-IN03	--	20	30	15,000	8,400 *J*	5,300 *J*	23,000	59,000	100,000
I-S	ECH-E-IS01	--	0	10	1,000 *J*	490 *J*	1,200 *J*	1,000 *J*	950 *J*	2,200 *J*
I-S	ECH-E-IS02	--	10	20	600 *U*	600 *U*	600 *U*	600 *U*	600 *U*	1,100 *J*
I-S	ECH-E-IS03	--	20	30	240 *U*	240 *U*	240 *U*	240 *U*	240 *U*	240 *U*

Table B1-6. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Anthracene (µg/kg)	Pyrene (µg/kg)	Fluoranthene (µg/kg)	Chrysene (µg/kg)	Benzo[a]pyrene (µg/kg)	Benz[a]-anthracene (µg/kg)
A-M	ECH-E-AM01	--	0	10	11,000	35,000	46,000	25,000	24,000	24,000
A-M	ECH-E-AM02	--	10	20	520,000	700,000	860,000	400,000	240,000	350,000
A-M	ECH-E-AM03	--	20	30	2,100,000	2,900,000	3,500,000	1,400,000	930,000	1,400,000
A-N	ECH-E-AN01	1	0	10	6,700	36,000	35,000	30,000	22,000	23,000
A-N	ECH-E-AN01	2	0	10	6,800	36,000	36,000	31,000	22,000	23,000
A-S	ECH-E-AS01	--	0	10	2,300 *J*	20,000	9,400	18,000	4,800	8,200
B-M	BCORE01SD	--	0	55	19,000	69,000	59,000	32,000	18,000 *J*	25,000
B-M	BCORE02SD	1	55	120	200 *J*	920 *J*	840 *J*	230 *J*	160 *UJ*	240 *J*
B-M	BCORE03SD	--	120	173	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*
B-N	ECH-E-BN01	--	0	10	2,800	18,000	19,000	12,000	9,300	9,600
B-S	ECH-E-BS01	--	0	10	20,000	87,000	84,000	54,000	30,000	37,000
D-N	ECH-E-DN01	--	0	10	6,100	28,000 *J*	31,000 *J*	25,000 *J*	23,000 *J*	19,000 *J*
D-S	ECH-E-DS01	--	0	10	22,000	230,000	82,000	210,000	43,000	90,000
G-M	GCORE01SD	--	0	64	5,000	33,000	17,000	29,000	10,000	13,000
G-M	GCORE02SD	--	94	208	120 *U*	250 *J*	210 *J*	120 *U*	120 *UJ*	120 *U*
G-M	GCORE03SD	1	208	259	98.0 *U*	98.0 *U*	98.0 *U*	98.0 *U*	98.0 *U*	98.0 *U*
G-M	GCORE03SD	2	208	259	100 *U*	100 *U*	100 *U*	100 *U*	100 *UJ*	100 *U*
I-M	ICORE01SD	--	0	74	71,000 *J*	360,000	180,000 *J*	380,000	73,000 *J*	140,000 *J*
I-M	ICORE02SD	--	74	155	110 *U*	600 *J*	470 *J*	260 *J*	190 *J*	210 *J*
I-M	ICORE03SD	--	155	183	48.0 *J*	260 *J*	130 *J*	270 *J*	50.0 *J*	100 *J*
I-M	ECH-E-IM01	--	0	10	3,200	18,000	15,000	18,000	11,000	10,000
I-M	ECH-E-IM02	1	10	20	60,000 *J*	230,000	150,000	190,000	60,000	97,000
I-M	ECH-E-IM02	2	10	20	30,000 *J*	230,000	100,000	220,000	46,000 *J*	90,000
I-M	ECH-E-IM03	--	20	30	13,000	83,000	51,000	65,000	21,000 *J*	35,000
I-N	ECH-E-IN01	--	0	10	5,200	34,000 *J*	26,000	26,000	18,000 *J*	17,000
I-N	ECH-E-IN02	--	10	20	22,000	95,000	50,000	79,000	19,000	36,000
I-N	ECH-E-IN03	--	20	30	33,000	47,000	59,000	24,000	13,000	21,000
I-S	ECH-E-IS01	--	0	10	1,600 *J*	23,000	9,900	12,000	5,500 *J*	8,300
I-S	ECH-E-IS02	--	10	20	650 *J*	12,000	3,600 *J*	3,100 *J*	3,300 *J*	4,100 *J*
I-S	ECH-E-IS03	--	20	30	240 *U*	390 *J*	240 *U*	240 *U*	240 *UJ*	240 *U*

Table B1-6. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Benzo[b]-fluoranthene (µg/kg)	Benzo[k]-fluoranthene (µg/kg)	Indeno-[1,2,3-cd] pyrene (µg/kg)	Benzo[ghi]-perylene (µg/kg)	Dibenz[a,h]-anthracene (µg/kg)	Total polyaromatic hydrocarbons (µg/kg)
A-M	ECH-E-AM01	--	0	10	24,000	9,500	15,000	12,000	3,700	270,000
A-M	ECH-E-AM02	--	10	20	250,000	67,000	130,000	62,000	25,000	5,600,000
A-M	ECH-E-AM03	--	20	30	950,000	270,000	360,000	260,000	110,000	24,000,000
A-N	ECH-E-AN01	1	0	10	23,000	7,800	15,000	13,000	4,000	260,000
A-N	ECH-E-AN01	2	0	10	22,000	8,700	14,000	12,000	3,600	260,000
A-S	ECH-E-AS01	--	0	10	5,600	1,200 *J*	3,000 *J*	4,000 *J*	1,300 *J*	100,000
B-M	BCORE01SD	--	0	55	26,000 *J*	9,300 *J*	7,500 *J*	6,300 *J*	460 *UJ*	390,000
B-M	BCORE02SD	1	55	120	160 *UJ*	160 *UJ*	160 *UJ*	160 *UJ*	160 *UJ*	3,800
B-M	BCORE03SD	--	120	173	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*	330
B-N	ECH-E-BN01	--	0	10	10,000	3,900	6,700	6,200	1,600 *J*	120,000
B-S	ECH-E-BS01	--	0	10	11,000 *J*	1,900 *U*	19,000 *J*	17,000 *J*	5,400 *J*	540,000
D-N	ECH-E-DN01	--	0	10	26,000 *J*	8,800 *J*	19,000 *J*	18,000 *J*	4,700	250,000
D-S	ECH-E-DS01	--	0	10	49,000	560 *U*	23,000	33,000	13,000	1,100,000
G-M	GCORE01SD	--	0	64	12,000	360 *U*	5,400	360 *U*	2,300 *J*	140,000
G-M	GCORE02SD	--	94	208	120 *UJ*	120 *UJ*	120 *UJ*	120 *UJ*	120 *UJ*	1,400
G-M	GCORE03SD	1	208	259	98.0 *U*	98.0 *U*	98.0 *U*	98.0 *U*	98.0 *U*	780
G-M	GCORE03SD	2	208	259	100 *UJ*	100 *UJ*	100 *UJ*	100 *UJ*	100 *UJ*	800
I-M	ICORE01SD	--	0	74	83,000 *J*	17,000 *J*	14,000 *J*	22,000 *J*	10,000 *J*	2,600,000
I-M	ICORE02SD	--	74	155	110 *UJ*	110 *UJ*	110 *UJ*	110 *UJ*	110 *UJ*	2,700
I-M	ICORE03SD	--	155	183	42.0 *U*	42.0 *U*	42.0 *U*	42.0 *U*	42.0 *U*	1,900
I-M	ECH-E-IM01	--	0	10	15,000	5,200	4,700	4,700	1,400 *J*	130,000
I-M	ECH-E-IM02	1	10	20	69,000	24,000 *J*	20,000 *J*	20,000 *J*	8,800 *J*	1,600,000
I-M	ECH-E-IM02	2	10	20	50,000 *J*	12,000 *J*	12,000 *J*	16,000 *J*	6,900 *J*	1,600,000
I-M	ECH-E-IM03	--	20	30	30,000 *J*	7,300 *J*	6,600 *J*	8,000 *J*	2,800 *J*	570,000
I-N	ECH-E-IN01	--	0	10	24,000 *J*	8,500 *J*	8,700 *J*	8,200 *J*	2,700 *J*	210,000
I-N	ECH-E-IN02	--	10	20	25,000	5,100	6,700	8,800	3,800 *J*	620,000
I-N	ECH-E-IN03	--	20	30	20,000	7,300 *J*	6,700 *J*	5,500 *J*	1,600 *J*	440,000
I-S	ECH-E-IS01	--	0	10	9,000 *J*	3,300 *J*	1,900 *J*	1,700 *J*	430 *UJ*	83,000
I-S	ECH-E-IS02	--	10	20	5,600 *J*	2,000 *J*	1,400 *J*	1,200 *J*	600 *UJ*	39,000
I-S	ECH-E-IS03	--	20	30	240 *UJ*	240 *UJ*	240 *UJ*	240 *UJ*	240 *UJ*	2,200

Table B1-6. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	2-Chloro-phenol (µg/kg)	2,4-Dichloro-phenol (µg/kg)	2,4,5-Trichloro-phenol (µg/kg)	2,4,6-Trichloro-phenol (µg/kg)	2-Nitro-phenol (µg/kg)	4-Nitro-phenol (µg/kg)
A-M	ECH-E-AM01	--	0	10	230 *U*	470 *U*	470 *U*	470 *U*	470 *U*	1,200 *U*
A-M	ECH-E-AM02	--	10	20	450 *U*	900 *U*	900 *U*	900 *U*	900 *U*	2,300 *U*
A-M	ECH-E-AM03	--	20	30	2,400 *U*	4,800 *U*	4,800 *U*	4,800 *U*	4,800 *U*	12,000 *U*
A-N	ECH-E-AN01	1	0	10	280 *U*	560 *U*	560 *U*	560 *U*	560 *U*	1,400 *U*
A-N	ECH-E-AN01	2	0	10	270 *U*	530 *U*	530 *U*	530 *U*	530 *U*	1,300 *U*
A-S	ECH-E-AS01	--	0	10	450 *U*	900 *U*	900 *U*	900 *U*	900 *U*	2,300 *U*
B-M	BCORE01SD	--	0	55	460 *U*	910 *U*	910 *U*	910 *U*	910 *U*	2,300 *U*
B-M	BCORE02SD	1	55	120	160 *U*	310 *U*	310 *U*	310 *U*	310 *U*	780 *U*
B-M	BCORE03SD	--	120	173	41.0 *U*	81.0 *U*	81.0 *U*	81.0 *U*	81.0 *U*	200 *U*
B-N	ECH-E-BN01	--	0	10	280 *U*	560 *U*	560 *U*	560 *U*	560 *U*	1,400 *U*
B-S	ECH-E-BS01	--	0	10	1,900 *U*	3,800 *U*	3,800 *U*	3,800 *U*	3,800 *U*	9,500 *U*
D-N	ECH-E-DN01	--	0	10	440 *U*	870 *U*	870 *U*	870 *U*	870 *U*	2,200 *U*
D-S	ECH-E-DS01	--	0	10	560 *U*	1,100 *U*	1,100 *U*	1,100 *U*	1,100 *U*	2,800 *U*
G-M	GCORE01SD	--	0	64	360 *U*	720 *U*	720 *U*	720 *U*	720 *U*	1,800 *U*
G-M	GCORE02SD	--	94	208	120 *U*	230 *U*	230 *U*	230 *U*	230 *U*	580 *U*
G-M	GCORE03SD	1	208	259	98.0 *U*	200 *U*	200 *U*	200 *U*	200 *U*	490 *U*
G-M	GCORE03SD	2	208	259	100 *U*	210 *U*	210 *U*	210 *U*	210 *U*	520 *U*
I-M	ICORE01SD	--	0	74	380 *U*	760 *U*	760 *U*	760 *U*	760 *U*	1,900 *U*
I-M	ICORE02SD	--	74	155	110 *U*	230 *U*	230 *U*	230 *U*	230 *U*	560 *U*
I-M	ICORE03SD	--	155	183	42.0 *U*	83.0 *U*	83.0 *U*	83.0 *U*	83.0 *U*	210 *UJ*
I-M	ECH-E-IM01	--	0	10	290 *U*	580 *U*	580 *U*	580 *U*	580 *U*	1,400 *U*
I-M	ECH-E-IM02	1	10	20	380 *U*	770 *U*	770 *U*	770 *U*	770 *U*	1,900 *U*
I-M	ECH-E-IM02	2	10	20	370 *U*	750 *U*	750 *U*	750 *U*	750 *U*	1,900 *U*
I-M	ECH-E-IM03	--	20	30	540 *U*	1,100 *U*	1,100 *U*	1,100 *U*	1,100 *U*	2,700 *U*
I-N	ECH-E-IN01	--	0	10	480 *U*	950 *U*	950 *U*	950 *U*	950 *U*	2,400 *U*
I-N	ECH-E-IN02	--	10	20	450 *U*	900 *U*	900 *U*	900 *U*	450 *U*	2,200 *U*
I-N	ECH-E-IN03	--	20	30	960 *U*	1,900 *U*	1,900 *U*	1,900 *U*	1,900 *U*	4,800 *U*
I-S	ECH-E-IS01	--	0	10	430 *U*	860 *U*	860 *U*	860 *U*	860 *U*	2,200 *U*
I-S	ECH-E-IS02	--	10	20	600 *U*	1,200 *U*	1,200 *U*	1,200 *U*	1,200 *U*	3,000 *U*
I-S	ECH-E-IS03	--	20	30	240 *U*	480 *U*	480 *U*	480 *U*	480 *U*	1,200 *U*

Table B1-6. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	2,4-Dinitro-phenol (µg/kg)	2-Methyl-phenol (µg/kg)	2,4-Dimethyl-phenol (µg/kg)	3- and 4-Methyl-phenol (µg/kg)	4,6-Dinitro-2-methylphenol (µg/kg)	4-Chloro-3-methylphenol (PCMC) (µg/kg)
A-M	ECH-E-AM01	--	0	10	1,400 *U*	230 *U*	470 *U*	470 *U*	1,200 *U*	470 *U*
A-M	ECH-E-AM02	--	10	20	2,600 *U*	450 *U*	900 *U*	900 *U*	2,300 *U*	900 *U*
A-M	ECH-E-AM03	--	20	30	14,000 *U*	2,400 *U*	4,800 *U*	4,800 *U*	12,000 *U*	4,800 *U*
A-N	ECH-E-AN01	1	0	10	1,600 *U*	280 *U*	560 *U*	560 *U*	1,400 *U*	560 *U*
A-N	ECH-E-AN01	2	0	10	1,600 *U*	270 *U*	530 *U*	530 *U*	1,300 *U*	530 *U*
A-S	ECH-E-AS01	--	0	10	2,600 *U*	450 *U*	900 *U*	900 *U*	2,300 *U*	900 *U*
B-M	BCORE01SD	--	0	55	2,700 *U*	460 *U*	910 *U*	910 *U*	2,300 *U*	910 *U*
B-M	BCORE02SD	1	55	120	910 *UJ*	160 *U*	310 *U*	310 *U*	780 *U*	310 *U*
B-M	BCORE03SD	--	120	173	240 *U*	41.0 *U*	81.0 *U*	81.0 *U*	200 *U*	81.0 *U*
B-N	ECH-E-BN01	--	0	10	1,600 *U*	280 *U*	560 *U*	560 *U*	1,400 *U*	560 *U*
B-S	ECH-E-BS01	--	0	10	11,000 *U*	1,900 *U*	3,800 *U*	3,800 *U*	9,500 *U*	3,800 *U*
D-N	ECH-E-DN01	--	0	10	2,500 *U*	440 *U*	870 *U*	870 *U*	2,200 *UJ*	870 *U*
D-S	ECH-E-DS01	--	0	10	3,300 *U*	560 *U*	1,100 *U*	1,100 *U*	2,800 *U*	1,100 *U*
G-M	GCORE01SD	--	0	64	2,100 *U*	360 *U*	720 *U*	720 *U*	1,800 *U*	720 *U*
G-M	GCORE02SD	--	94	208	670 *U*	120 *U*	230 *U*	230 *U*	580 *U*	230 *U*
G-M	GCORE03SD	1	208	259	570 *U*	98.0 *U*	200 *U*	200 *U*	490 *U*	200 *U*
G-M	GCORE03SD	2	208	259	610 *UJ*	100 *U*	210 *U*	210 *U*	520 *U*	210 *U*
I-M	ICORE01SD	--	0	74	2,200 *U*	380 *U*	760 *U*	760 *U*	1,900 *U*	760 *U*
I-M	ICORE02SD	--	74	155	660 *UJ*	110 *U*	230 *U*	230 *U*	560 *UJ*	230 *U*
I-M	ICORE03SD	--	155	183	240 *U*	42.0 *U*	83.0 *U*	83.0 *U*	210 *U*	83.0 *U*
I-M	ECH-E-IM01	--	0	10	1,700 *UJ*	290 *U*	580 *U*	580 *U*	1,400 *U*	580 *U*
I-M	ECH-E-IM02	1	10	20	2,200 *UJ*	380 *U*	770 *U*	770 *U*	1,900 *U*	770 *U*
I-M	ECH-E-IM02	2	10	20	2,200 *UJ*	370 *U*	750 *U*	750 *U*	1,900 *U*	750 *U*
I-M	ECH-E-IM03	--	20	30	3,200 *UJ*	540 *U*	1,100 *U*	1,100 *U*	2,700 *U*	1,100 *U*
I-N	ECH-E-IN01	--	0	10	2,800 *UR*	480 *U*	950 *U*	950 *U*	2,400 *UR*	950 *U*
I-N	ECH-E-IN02	--	10	20	2,700 *UJ*	450 *U*	450 *U*	900 *U*	2,200 *U*	450 *U*
I-N	ECH-E-IN03	--	20	30	5,600 *UJ*	960 *U*	1,900 *U*	1,900 *U*	4,800 *U*	1,900 *U*
I-S	ECH-E-IS01	--	0	10	2,500 *UJ*	430 *U*	860 *U*	860 *U*	2,200 *U*	860 *U*
I-S	ECH-E-IS02	--	10	20	3,500 *UJ*	600 *U*	1,200 *U*	1,200 *U*	3,000 *U*	1,200 *U*
I-S	ECH-E-IS03	--	20	30	1,400 *UJ*	240 *U*	480 *U*	480 *U*	1,200 *U*	480 *U*

Note: All results reported in dry weight.

J - estimated
PAH - polycyclic aromatic hydrocarbon
R - rejected
U - undetected at detection limit shown

Table B1-7. Pesticides and PCBs results for sediment samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	α-Hexachloro-cyclohexane (μg/kg)	β-Hexachloro-cyclohexane (μg/kg)	δ-Hexachloro-cyclohexane (μg/kg)	γ-Hexachloro-cyclohexane (lindane) (μg/kg)	α-Chlordane (μg/kg)	γ-Chlordane (μg/kg)
A-M	ECH-E-AM01	--	0	10	9.40 *U*	16.3 *J*	9.40 *U*	9.40 *U*	9.40 *U*	9.40 *U*
A-M	ECH-E-AM02	--	10	20	9.10 *U*	162 *J*	12.9 *J*	9.10 *U*	24.2 *R*	9.10 *U*
A-M	ECH-E-AM03	--	20	30	9.60 *U*	9.60 *U*	9.60 *U*	9.60 *U*	32.6 *R*	9.60 *U*
A-N	ECH-E-AN01	1	0	10	11.0 *U*	11.0 *U*	11.0 *U*	11.0 *U*	20.0 *J*	11.0 *U*
A-N	ECH-E-AN01	2	0	10	11.0 *U*	38.0 *J*	11.0 *U*	12.0 *R*	11.0 *J*	11.0 *U*
A-S	ECH-E-AS01	--	0	10	18.0 *U*	18.0 *U*	18.0 *U*	18.0 *U*	18.0 *U*	18.0 *U*
B-M	BCORE01SD	--	0	55	1.80 *UJ*	1.80 *UJ*	18.0 *UR*	1.80 *UJ*	1.80 *U*	1.80 *U*
B-M	BCORE02SD	1	55	120	3.10 *UJ*	3.10 *UJ*	3.10 *UR*	3.10 *UJ*	3.10 *U*	6.10 *J*
B-M	BCORE03SD	--	120	173	0.820 *UJ*	0.820 *UJ*	0.820 *UR*	0.820 *UJ*	0.820 *U*	0.820 *U*
B-N	ECH-E-BN01	--	0	10	11.0 *U*	16.0 *J*	11.0 *U*	11.0 *U*	11.0 *U*	11.0 *U*
B-S	ECH-E-BS01	--	0	10	15.0 *U*	175 *J*	15.0 *U*	35.0 *R*	20.0 *J*	15.0 *U*
D-N	ECH-E-DN01	--	0	10	18.0 *U*	18.0 *U*	18.0 *U*	18.0 *U*	18.0 *U*	28.0 *R*
D-S	ECH-E-DS01	--	0	10	23.0 *U*	23.0 *U*	23.0 *U*	23.0 *U*	23.0 *U*	108 *R*
G-M	GCORE01SD	--	0	64	1.40 *UJ*	5.40 *J*	2.80 *J*	1.40 *UJ*	1.40 *U*	23.8 *J*
G-M	GCORE02SD	--	94	208	2.30 *UJ*	2.30 *UJ*	2.30 *UR*	2.30 *UJ*	2.30 *U*	2.30 *U*
G-M	GCORE03SD	1	208	259	2.00 *UJ*	2.00 *UJ*	2.00 *UR*	2.00 *UJ*	2.00 *U*	2.00 *U*
G-M	GCORE03SD	2	208	259	2.10 *UJ*	2.10 *UJ*	2.10 *UR*	2.10 *UJ*	2.10 *U*	2.10 *U*
I-M	ICORE01SD	--	0	74	1.50 *UJ*	15.0 *R*	1.50 *UR*	7.80 *J*	1.50 *U*	165 *J*
I-M	ICORE02SD	--	74	155	2.30 *UJ*	2.30 *U*	2.30 *UR*	2.30 *UJ*	2.30 *U*	2.30 *U*
I-M	ICORE03SD	--	155	183	0.840 *UJ*	0.840 *UJ*	0.840 *UR*	0.840 *UJ*	0.840 *U*	1.00 *J*
I-M	ECH-E-IM01	--	0	10	12.0 *U*	12.0 *U*	12.0 *U*	12.0 *U*	12.0 *U*	12.0 *U*
I-M	ECH-E-IM02	1	10	20	15.0 *U*	25.0 *J*	15.0 *U*	15.0 *U*	15.0 *U*	118 *R*
I-M	ECH-E-IM02	2	10	20	15.0 *U*	15.0 *U*	15.0 *U*	17.0	15.0 *U*	272 *R*
I-M	ECH-E-IM03	--	20	30	22.0 *U*	22.0 *U*	22.0 *U*	22.0 *U*	22.0 *U*	67.0 *R*
I-N	ECH-E-IN01	--	0	10	19.0 *U*	19.0 *U*	19.0 *U*	19.0 *U*	19.0 *U*	37.0 *R*
I-N	ECH-E-IN02	--	10	20	18.0 *U*	18.0 *U*	18.0 *U*	18.0 *U*	18.0 *U*	56.0 *R*
I-N	ECH-E-IN03	--	20	30	19.0 *U*	36.0 *J*	19.0 *U*	19.0 *U*	19.0 *U*	48.0 *R*
I-S	ECH-E-IS01	--	0	10	17.0 *U*	17.0 *U*	17.0 *U*	17.0 *U*	17.0 *U*	17.0 *U*
I-S	ECH-E-IS02	--	10	20	24.0 *U*	24.0 *U*	24.0 *U*	24.0 *U*	24.0 *U*	24.0 *U*
I-S	ECH-E-IS03	--	20	30	9.60 *U*	9.60 *U*	9.60 *U*	9.60 *U*	9.60 *U*	9.60 *U*

Table B1-7. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Heptachlor (µg/kg)	Heptachlor epoxide (µg/kg)	Methoxychlor (µg/kg)	α-Endosulfan (Endosulfan I) (µg/kg)	β-Endosulfan (Endosulfan II) (µg/kg)	Endosulfan sulfate (µg/kg)
A-M	ECH-E-AM01	--	0	10	9.40 *U*	40.8 *R*	94.0 *U*	9.40 *U*	18.0 *U*	44.0 *J*
A-M	ECH-E-AM02	--	10	20	9.10 *U*	9.10 *U*	91.0 *U*	9.10 *U*	18.0 *U*	163 *J*
A-M	ECH-E-AM03	--	20	30	9.60 *U*	9.60 *U*	96.0 *U*	9.60 *U*	19.0 *U*	361 *J*
A-N	ECH-E-AN01	1	0	10	11.0 *U*	11.0 *U*	110 *U*	16.0 *J*	22.0 *U*	35.0 *J*
A-N	ECH-E-AN01	2	0	10	11.0 *U*	39.0 *R*	110 *U*	11.0 *U*	21.0 *U*	34.0 *J*
A-S	ECH-E-AS01	--	0	10	18.0 *U*	18.0 *U*	180 *U*	18.0 *U*	35.0 *U*	35.0 *U*
B-M	BCORE01SD	--	0	55	1.80 *U*	1.80 *U*	18.0 *U*	4.80 *J*	3.60 *U*	36.0 *UJ*
B-M	BCORE02SD	1	55	120	3.1	3.10 *U*	31.0 *UJ*	3.10 *U*	6.10 *U*	6.10 *U*
B-M	BCORE03SD	--	120	173	0.820 *U*	0.820 *U*	8.20 *UJ*	0.820 *U*	1.60 *U*	1.60 *U*
B-N	ECH-E-BN01	--	0	10	11.0 *U*	11.0 *U*	110 *U*	11.0 *U*	22.0 *U*	22.0 *U*
B-S	ECH-E-BS01	--	0	10	15.0 *U*	772 *R*	150 *U*	15.0 *U*	30.0 *U*	30.0 *U*
D-N	ECH-E-DN01	--	0	10	18.0 *U*	18.0 *U*	180 *U*	18.0 *U*	34.0 *U*	34.0 *U*
D-S	ECH-E-DS01	--	0	10	23.0 *U*	23.0 *U*	230 *U*	23.0 *U*	44.0 *U*	44.0 *U*
G-M	GCORE01SD	--	0	64	4.00 *J*	4.20 *J*	33.0 *J*	1.40 *U*	2.80 *U*	2.80 *U*
G-M	GCORE02SD	--	94	208	2.30 *U*	2.30 *U*	23.0 *UJ*	2.30 *U*	4.50 *U*	4.50 *U*
G-M	GCORE03SD	1	208	259	2.00 *U*	2.00 *U*	20.0 *UJ*	2.00 *U*	3.80 *U*	3.80 *U*
G-M	GCORE03SD	2	208	259	2.10 *U*	2.10 *U*	21.0 *UJ*	2.10 *U*	4.00 *U*	4.00 *U*
I-M	ICORE01SD	--	0	74	1.50 *U*	15.1 *J*	15.0 *UJ*	1.50 *U*	39.0	8.70 *J*
I-M	ICORE02SD	--	74	155	2.30 *U*	2.30 *U*	23.0 *UJ*	2.30 *U*	4.40 *UJ*	4.40 *U*
I-M	ICORE03SD	--	155	183	0.840 *U*	0.840 *U*	8.40 *UJ*	0.840 *U*	1.60 *U*	1.60 *U*
I-M	ECH-E-IM01	--	0	10	12.0 *U*	12.0 *U*	120 *U*	12.0 *U*	23.0 *U*	23.0 *U*
I-M	ECH-E-IM02	1	10	20	15.0 *U*	15.0 *U*	150 *U*	15.0 *U*	30.0 *U*	30.0 *U*
I-M	ECH-E-IM02	2	10	20	15.0 *U*	15.0 *U*	150 *U*	15.0 *U*	29.0 *U*	29.0 *U*
I-M	ECH-E-IM03	--	20	30	22.0 *U*	22.0 *U*	220 *U*	22.0 *U*	42.0 *U*	42.0 *U*
I-N	ECH-E-IN01	--	0	10	19.0 *U*	19.0 *U*	190 *U*	19.0 *U*	37.0 *U*	37.0 *U*
I-N	ECH-E-IN02	--	10	20	18.0 *U*	18.0 *U*	180 *U*	18.0 *U*	35.0 *U*	35.0 *U*
I-N	ECH-E-IN03	--	20	30	19.0 *U*	19.0 *U*	190 *U*	19.0 *U*	38.0 *U*	38.0 *U*
I-S	ECH-E-IS01	--	0	10	17.0 *U*	17.0 *U*	170 *U*	17.0 *U*	34.0 *U*	34.0 *U*
I-S	ECH-E-IS02	--	10	20	24.0 *U*	24.0 *U*	240 *U*	24.0 *U*	47.0 *U*	47.0 *U*
I-S	ECH-E-IS03	--	20	30	9.60 *U*	9.60 *U*	96.0 *U*	9.60 *U*	19.0 *U*	19.0 *U*

Table B1-7. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	DDT (µg/kg)	DDE (µg/kg)	DDD (µg/kg)	Aldrin (µg/kg)	Endrin (µg/kg)	Endrin aldehyde (µg/kg)	Endrin ketone (µg/kg)
A-M	ECH-E-AM01	--	0	10	18.0 *U*	18.0 *U*	18.0 *U*	9.40 *U*	18.0 *U*	31.0 *J*	18.0 *U*
A-M	ECH-E-AM02	--	10	20	18.0 *U*	18.0 *U*	18.0 *U*	9.10 *U*	18.0 *U*	68.0 *J*	18.0 *U*
A-M	ECH-E-AM03	--	20	30	47.0 *J*	19.0 *U*	19.0 *U*	9.60 *U*	19.0 *U*	144 *J*	19.0 *U*
A-N	ECH-E-AN01	1	0	10	22.0 *U*	22.0 *U*	22.0 *U*	11.0 *U*	33.0 *R*	23.0	22.0 *U*
A-N	ECH-E-AN01	2	0	10	21.0 *U*	21.0 *U*	21.0 *U*	11.0 *U*	21.0 *U*	21.0 *U*	21.0 *U*
A-S	ECH-E-AS01	--	0	10	35.0 *U*	35.0 *U*	35.0 *U*	18.0 *U*	35.0 *U*	35.0 *U*	35.0 *U*
B-M	BCORE01SD	--	0	55	36.0 *U*	36.0 *U*	36.0 *UJ*	1.80 *U*	3.60 *U*	36.0 *UJ*	3.60 *U*
B-M	BCORE02SD	1	55	120	6.10 *U*	6.10 *U*	6.10 *UJ*	3.10 *U*	6.10 *U*	6.10 *U*	22.7 *J*
B-M	BCORE03SD	--	120	173	1.60 *U*	1.60 *U*	1.60 *U*	0.820 *U*	1.60 *U*	1.60 *U*	1.60 *U*
B-N	ECH-E-BN01	--	0	10	37.0 *R*	22.0 *U*	22.0 *U*	11.0 *U*	22.0 *U*	22.0 *U*	22.0 *U*
B-S	ECH-E-BS01	--	0	10	30.0 *U*	320 *R*	30.0 *U*	15.0 *U*	30.0 *U*	146 *J*	30.0 *U*
D-N	ECH-E-DN01	--	0	10	67.0 *R*	34.0 *U*	34.0 *UJ*	18.0 *U*	34.0 *U*	37.0 *J*	34.0 *U*
D-S	ECH-E-DS01	--	0	10	44.0 *U*	44.0 *U*	44.0 *UJ*	23.0 *U*	44.0 *U*	44.0 *U*	44.0 *U*
G-M	GCORE01SD	--	0	64	2.80 *UJ*	2.80 *UJ*	2.80 *UJ*	1.40 *U*	19.0	2.80 *U*	2.80 *U*
G-M	GCORE02SD	--	94	208	4.50 *U*	4.50 *U*	4.50 *U*	2.30 *U*	4.50 *U*	4.50 *U*	4.50 *U*
G-M	GCORE03SD	1	208	259	3.80 *U*	3.80 *U*	3.80 *U*	2.00 *U*	3.80 *U*	3.80 *U*	3.80 *U*
G-M	GCORE03SD	2	208	259	4.00 *U*	4.00 *U*	4.00 *U*	2.10 *U*	4.00 *U*	4.00 *U*	4.00 *U*
I-M	ICORE01SD	--	0	74	5.40 *J*	29.0 *R*	2.90 *U*	1.50 *U*	2.90 *U*	2.90 *U*	43.0
I-M	ICORE02SD	--	74	155	4.40 *U*	4.40 *U*	4.40 *U*	2.30 *U*	4.40 *U*	4.40 *U*	4.40 *U*
I-M	ICORE03SD	--	155	183	1.60 *U*	1.60 *U*	1.60 *U*	0.840 *U*	1.60 *U*	1.60 *U*	1.60 *U*
I-M	ECH-E-IM01	--	0	10	23.0 *U*	23.0 *U*	23.0 *UJ*	12.0 *U*	23.0 *U*	23.0 *U*	23.0 *U*
I-M	ECH-E-IM02	1	10	20	30.0 *U*	30.0 *U*	30.0 *UJ*	15.0 *U*	30.0 *U*	30.0 *U*	30.0 *U*
I-M	ECH-E-IM02	2	10	20	29.0 *U*	92.0 *R*	29.0 *UJ*	15.0 *U*	49.0 *J*	29.0 *U*	29.0 *U*
I-M	ECH-E-IM03	--	20	30	42.0 *U*	42.0 *U*	42.0 *UJ*	22.0 *U*	42.0 *U*	42.0 *U*	42.0 *U*
I-N	ECH-E-IN01	--	0	10	37.0 *U*	37.0 *U*	37.0 *UJ*	19.0 *U*	37.0 *U*	37.0 *U*	37.0 *U*
I-N	ECH-E-IN02	--	10	20	35.0 *U*	35.0 *U*	35.0 *UJ*	18.0 *U*	35.0 *U*	35.0 *U*	35.0 *U*
I-N	ECH-E-IN03	--	20	30	38.0 *U*	38.0 *U*	38.0 *UJ*	19.0 *U*	38.0 *U*	38.0 *U*	38.0 *U*
I-S	ECH-E-IS01	--	0	10	34.0 *U*	34.0 *U*	34.0 *UJ*	17.0 *U*	34.0 *U*	34.0 *U*	34.0 *U*
I-S	ECH-E-IS02	--	10	20	47.0 *U*	47.0 *U*	47.0 *UJ*	24.0 *U*	47.0 *U*	47.0 *U*	47.0 *U*
I-S	ECH-E-IS03	--	20	30	19.0 *U*	19.0 *U*	19.0 *UJ*	9.60 *U*	19.0 *U*	19.0 *U*	19.0 *U*

Table B1-7. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Carbazole (µg/kg)	Dieldrin (µg/kg)	Toxaphene (µg/kg)	Dibenzofuran (µg/kg)	Aroclor® 1016 (µg/kg)	Aroclor® 1221 (µg/kg)
A-M	ECH-E-AM01	--	0	10	640 *J*	18.0 *U*	940 *U*	2,100 *J*	460 *U*	460 *U*
A-M	ECH-E-AM02	--	10	20	15,000	18.0 *U*	910 *U*	190,000	450 *U*	450 *U*
A-M	ECH-E-AM03	--	20	30	140,000	20.0 *J*	960 *U*	890,000	470 *U*	470 *U*
A-N	ECH-E-AN01	1	0	10	1,100 *J*	22.0 *U*	1,100 *U*	2,200 *J*	560 *U*	560 *U*
A-N	ECH-E-AN01	2	0	10	1,100 *J*	21.0 *U*	1,100 *U*	2,200 *J*	530 *U*	530 *U*
A-S	ECH-E-AS01	--	0	10	450 *U*	35.0 *U*	1,800 *U*	950 *J*	890 *U*	890 *U*
B-M	BCORE01SD	--	0	55	460 *U*	6.40 *J*	180 *U*	2,200 *J*	90.0 *U*	90.0 *U*
B-M	BCORE02SD	1	55	120	160 *U*	6.10 *U*	310 *U*	160 *U*	150 *U*	150 *U*
B-M	BCORE03SD	--	120	173	41.0 *U*	1.60 *U*	82.0 *U*	41.0 *U*	40.0 *U*	40.0 *U*
B-N	ECH-E-BN01	--	0	10	280 *U*	22.0 *U*	1,100 *U*	1,600 *J*	550 *U*	550 *U*
B-S	ECH-E-BS01	--	0	10	1,900 *U*	51.0 *J*	1,500 *U*	6,100 *J*	750 *U*	750 *U*
D-N	ECH-E-DN01	--	0	10	440 *U*	34.0 *U*	1,800 *U*	6,400 *J*	860 *U*	860 *U*
D-S	ECH-E-DS01	--	0	10	560 *U*	44.0 *U*	2,300 *U*	3,100 *J*	1,100 *U*	1,100 *U*
G-M	GCORE01SD	--	0	64	1,400 *J*	2.80 *U*	140 *U*	1,900 *J*	71.0 *U*	71.0 *U*
G-M	GCORE02SD	--	94	208	120 *U*	4.50 *U*	230 *U*	120 *U*	110 *U*	110 *U*
G-M	GCORE03SD	1	208	259	98.0 *U*	3.80 *U*	200 *U*	98.0 *U*	97.0 *U*	97.0 *U*
G-M	GCORE03SD	2	208	259	100 *U*	4.00 *U*	210 *U*	100 *U*	100 *U*	100 *U*
I-M	ICORE01SD	--	0	74	2,400 *J*	18.0 *J*	150 *U*	19,000	2,300 *U*	75.0 *U*
I-M	ICORE02SD	--	74	155	110 *U*	4.40 *U*	230 *U*	110 *U*	110 *U*	110 *U*
I-M	ICORE03SD	--	155	183	42.0 *U*	1.60 *U*	84.0 *U*	42.0 *U*	41.0 *U*	41.0 *U*
I-M	ECH-E-IM01	--	0	10	290 *U*	23.0 *U*	1,200 *U*	1,900 *J*	570 *U*	570 *U*
I-M	ECH-E-IM02	1	10	20	2,600 *J*	30.0 *U*	1,500 *U*	5,500	760 *U*	760 *U*
I-M	ECH-E-IM02	2	10	20	2,800 *J*	29.0 *U*	150 *U*	6,300	74.0 *U*	74.0 *U*
I-M	ECH-E-IM03	--	20	30	540 *U*	42.0 *U*	220 *U*	1,500 *J*	110 *U*	110 *U*
I-N	ECH-E-IN01	--	0	10	480 *U*	37.0 *U*	1,900 *U*	2,800 *J*	940 *U*	940 *U*
I-N	ECH-E-IN02	--	10	20	450 *U*	35.0 *U*	1,800 *U*	1,300 *J*	890 *U*	890 *U*
I-N	ECH-E-IN03	--	20	30	960 *U*	38.0 *U*	1,900 *U*	3,200 *J*	950 *U*	950 *U*
I-S	ECH-E-IS01	--	0	10	430 *U*	34.0 *U*	1,700 *U*	820 *J*	850 *U*	850 *U*
I-S	ECH-E-IS02	--	10	20	600 *U*	47.0 *U*	2,400 *U*	600 *U*	1,200 *U*	1,200 *U*
I-S	ECH-E-IS03	--	20	30	240 *U*	19.0 *U*	960 *U*	240 *U*	470 *U*	470 *U*

Table B1-7. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Aroclor® 1232 (µg/kg)	Aroclor® 1242 (µg/kg)	Aroclor® 1248 (µg/kg)	Aroclor® 1254 (µg/kg)	Aroclor® 1260 (µg/kg)	Total PCBs (µg/kg)
A-M	ECH-E-AM01	--	0	10	460 *U*	460 *U*	2,600	460 *U*	460 *U*	2,600
A-M	ECH-E-AM02	--	10	20	450 *U*	450 *U*	450 *U*	450 *U*	450 *U*	450 *U*
A-M	ECH-E-AM03	--	20	30	470 *U*	470 *U*	470 *U*	470 *U*	470 *U*	470 *U*
A-N	ECH-E-AN01	1	0	10	560 *U*	560 *U*	4,600	560 *U*	560 *U*	4,600
A-N	ECH-E-AN01	2	0	10	530 *U*	530 *U*	3,900	530 *U*	530 *U*	3,900
A-S	ECH-E-AS01	--	0	10	890 *U*	890 *U*	890 *U*	890 *U*	890 *U*	890 *U*
B-M	BCORE01SD	--	0	55	90.0 *U*	90.0 *U*	90.0 *U*	90.0 *U*	90.0 *U*	90.0 *U*
B-M	BCORE02SD	1	55	120	150 *U*	150 *U*	150 *U*	150 *U*	150 *U*	150 *U*
B-M	BCORE03SD	--	120	173	40.0 *U*	40.0 *U*	40.0 *U*	40.0 *U*	40.0 *U*	40.0 *U*
B-N	ECH-E-BN01	--	0	10	550 *U*	550 *U*	6,300	550 *U*	550 *U*	6,300
B-S	ECH-E-BS01	--	0	10	750 *U*	750 *U*	68,500	750 *U*	750 *U*	68,500
D-N	ECH-E-DN01	--	0	10	860 *U*	860 *U*	10,700	860 *U*	860 *U*	10,700
D-S	ECH-E-DS01	--	0	10	1,100 *U*	1,100 *U*	1,100 *U*	1,100 *U*	1,100 *U*	1,100 *U*
G-M	GCORE01SD	--	0	64	650 *U*	430 *U*	1,100 *U*	860 *U*	370 *U*	1,100 *U*
G-M	GCORE02SD	--	94	208	110 *U*	110 *U*	110 *U*	110 *U*	110 *U*	110 *U*
G-M	GCORE03SD	1	208	259	97.0 *U*	97.0 *U*	97.0 *U*	97.0 *U*	97.0 *U*	97.0 *U*
G-M	GCORE03SD	2	208	259	100 *U*	100 *U*	100 *U*	100 *U*	100 *U*	100 *U*
I-M	ICORE01SD	--	0	74	2,500 *U*	2,300 *U*	2,300 *U*	1,000 *U*	450 *U*	2,500 *U*
I-M	ICORE02SD	--	74	155	110 *U*	110 *U*	110 *U*	110 *U*	110 *U*	110 *U*
I-M	ICORE03SD	--	155	183	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*	41.0 *U*
I-M	ECH-E-IM01	--	0	10	570 *U*	570 *U*	5,700	570 *U*	570 *U*	5,700
I-M	ECH-E-IM02	1	10	20	760 *U*	760 *U*	5,900	760 *U*	760 *U*	5,900
I-M	ECH-E-IM02	2	10	20	74.0 *U*	74.0 *U*	4,740	74.0 *U*	74.0 *U*	4,740
I-M	ECH-E-IM03	--	20	30	110 *U*	110 *U*	110 *U*	110 *U*	110 *U*	110 *U*
I-N	ECH-E-IN01	--	0	10	940 *U*	940 *U*	940 *U*	940 *U*	940 *U*	940 *U*
I-N	ECH-E-IN02	--	10	20	890 *U*	890 *U*	890 *U*	890 *U*	890 *U*	890 *U*
I-N	ECH-E-IN03	--	20	30	950 *U*	950 *U*	950 *U*	950 *U*	950 *U*	950 *U*
I-S	ECH-E-IS01	--	0	10	850 *U*	850 *U*	850 *U*	850 *U*	850 *U*	850 *U*
I-S	ECH-E-IS02	--	10	20	1,200 *U*	1,200 *U*	1,200 *U*	1,200 *U*	1,200 *U*	1,200 *U*
I-S	ECH-E-IS03	--	20	30	470 *U*	470 *U*	470 *U*	470 *U*	470 *U*	470 *U*

Note: All results reported in dry weight.

J - estimated
PCB - polychlorinated biphenyl
R - rejected
U - undetected at detection limit shown

Table B1-8. SEM and AVS results for sediment samples in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Cadmium (μmol/g)	Copper (μmol/g)	Lead (μmol/g)	Total mercury (μmol/g)
A-M	ECH-E-AM01	--	0	10	0.0138 *J*	0.981	0.677	0.00000900 *U*
A-M	ECH-E-AM02	--	10	20	0.0147 *J*	0.287	1.60	0.00000500 *UJ*
A-M	ECH-E-AM03	--	20	30	0.0446 *J*	0.0321	1.06	0.00000500 *UJ*
A-N	ECH-E-AN01	1	0	10	0.0264 *J*	2.17 *J*	1.99 *J*	0.00000600 *UJ*
A-N	ECH-E-AN01	2	0	10	0.0203 *J*	0.840 *J*	0.967 *J*	0.00000600 *U*
A-S	ECH-E-AS01	--	0	10	0.0413 *J*	1.34	1.83	0.00001000 *UJ*
B-M	BCORE01SD	--	0	55	0.0380 *J*	2.22 *J*	2.98	0.0000420 *U*
B-M	BCORE02SD	1	55	120	0.0230 *J*	0.819 *J*	0.973	0.0000670 *U*
B-M	BCORE03SD	--	120	173	0.000140 *UR*	0.0274 *J*	0.0153	0.0000120 *U*
B-N	ECH-E-BN01	--	0	10	0.0146 *J*	0.675	1.08	0.00000600 *UJ*
B-S	ECH-E-BS01	--	0	10	0.0304 *J*	0.454	1.96	0.00000800 *UJ*
D-N	ECH-E-DN01	--	0	10	0.00338 *U*	1.57	1.65	0.00001000 *U*
D-S	ECH-E-DS01	--	0	10	0.0261 *J*	0.903	1.18	0.0000120 *U*
G-M	GCORE01SD	--	0	64	0.0402 *J*	3.80 *J*	4.47	0.0000270 *U*
G-M	GCORE02SD	--	94	208	0.000380 *UR*	0.265 *J*	0.408	0.0000280 *U*
G-M	GCORE03SD	1	208	259	0.000330 *UR*	0.135 *J*	0.0359	0.0000110 *UR*
G-M	GCORE03SD	2	208	259	0.000350 *UR*	0.121 *J*	0.0324	0.0000290 *U*
I-M	ICORE01SD	--	0	74	0.108 *J*	2.20 *J*	3.96	0.0000270 *U*
I-M	ICORE02SD	--	74	155	6 *J*	0.33 *J*	700	0.000 *U*
I-M	ICORE03SD	--	155	183	0.000790 *U*	0.0360 *J*	0.0412	0.0000120 *U*
I-M	ECH-E-IM01	--	0	10	0.0414 *J*	1.01	1.75	0.00000600 *U*
I-M	ECH-E-IM02	1	10	20	0.155 *J*	2.25	9.26	0.00000800 *U*
I-M	ECH-E-IM02	2	10	20	0.262 *J*	2.14	7.86	0.00000800 *U*
I-M	ECH-E-IM03	--	20	30	0.139 *J*	0.544	9.55	0.0000120 *U*
I-N	ECH-E-IN01	--	0	10	0.251 *J*	2.70	9.75	0.00001000 *U*
I-N	ECH-E-IN02	--	10	20	0.243 *J*	2.37	7.44	0.00001000 *U*
I-N	ECH-E-IN03	--	20	30	0.365 *J*	2.89	7.87	0.0000110 *U*
I-S	ECH-E-IS01	--	0	10	0.267 *J*	1.36 *J*	18.9	0.0000160 *U*
I-S	ECH-E-IS02	--	10	20	0.370 *J*	5.20 *J*	24.9	0.0000500 *U*
I-S	ECH-E-IS03	--	20	30	0.0414 *J*	0.321 *J*	1.67	0.0000180 *U*

Table B1-8. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Nickel (µmol/g)	Zinc (µmol/g)	Total SEM (µmol/g)	Acid-volatile sulfide (µmol/g)	SEM - AVS (µmol/g)
A-M	ECH-E-AM01	--	0	10	0.223	8.32	10.2	16.1	-5.9
A-M	ECH-E-AM02	--	10	20	0.254	16.1	18.3	37.8 *J*	-19.5
A-M	ECH-E-AM03	--	20	30	0.120 *J*	19.9	21.2	56.7 *J*	-35.5
A-N	ECH-E-AN01	1	0	10	0.504 *J*	18.1 *J*	22.8	38.6	-15.8
A-N	ECH-E-AN01	2	0	10	0.303 *J*	9.39 *J*	11.5	28.5 *J*	-17.0
A-S	ECH-E-AS01	--	0	10	0.463	18.5	22.2	26.6 *J*	-4.4
B-M	BCORE01SD	--	0	55	0.646	57.1	63.0	203 *J*	-140.0
B-M	BCORE02SD	1	55	120	0.232	14.0	16.0	46.6 *J*	-30.6
B-M	BCORE03SD	--	120	173	0.0353	0.317	0.4	1.40 *J*	-1.0
B-N	ECH-E-BN01	--	0	10	0.369	10.6	12.7	14.9 *J*	-2.16
B-S	ECH-E-BS01	--	0	10	0.774	18.7	21.9	112 *J*	-90.1
D-N	ECH-E-DN01	--	0	10	0.627	21.1	25.0	10.7 *J*	14.3
D-S	ECH-E-DS01	--	0	10	0.344	14.3	16.8	42.6 *J*	-25.8
G-M	GCORE01SD	--	0	64	0.231	21.9	30.4	36.6 *J*	-6.2
G-M	GCORE02SD	--	94	208	0.156	8.02	8.8	263 *J*	-254.2
G-M	GCORE03SD	1	208	259	0.182	0.894	1.2	129 *J*	-127.8
G-M	GCORE03SD	2	208	259	0.189	0.885	1.2	131 *J*	-129.8
I-M	ICORE01SD	--	0	74	0.144	46.6	53.0	74.3 *J*	-21.3
I-M	ICORE02SD	--	74	155	2.3	800	1,508.6	41 *J*	1,467.6
I-M	ICORE03SD	--	155	183	0.0676	0.584	0.7	0.250 *UJ*	0.5
I-M	ECH-E-IM01	--	0	10	0.356	20.2	23.4	42.9 *J*	-19.5
I-M	ECH-E-IM02	1	10	20	0.357 *J*	61.0	73.0	106 *J*	-33.0
I-M	ECH-E-IM02	2	10	20	0.655 *J*	67.9	78.8	136 *J*	-57.2
I-M	ECH-E-IM03	--	20	30	0.376 *J*	100	110.6	293 *J*	-182.4
I-N	ECH-E-IN01	--	0	10	0.696 *J*	98.1	111.5	66.7 *J*	44.8
I-N	ECH-E-IN02	--	10	20	0.249 *J*	63.3	73.6	78.7 *J*	-5.1
I-N	ECH-E-IN03	--	20	30	0.147 *J*	74.2	85.5	71.1 *J*	14.4
I-S	ECH-E-IS01	--	0	10	0.222 *J*	144	164.7	160 *J*	4.7
I-S	ECH-E-IS02	--	10	20	0.211 *J*	156	186.7	204 *J*	-17.3
I-S	ECH-E-IS03	--	20	30	0.0374 *J*	10.9	13.0	16.1 *J*	-3.1

Note: All results reported in dry weight.

AVS - acid-volatile sulfide
J - estimated
R - rejected
SEM - simultaneously extracted metals
U - undetected at detection limit shown

Appendix B2

Analytical Results for Surface or Subsurface Wetland Soil Samples

Contents

Table B2-1. BTEX results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

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Table B2-5. Organic compounds results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B2-6. SEM and AVS results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B2-1. BTEX results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Benzene (μg/kg)	Toluene (μg/kg)	Ethylbenzene (μg/kg)	Xylene isomers (total) (μg/kg)
WETLAND1	ECH-E-W101	--	0	0.33	6.00 *U*	6.00 *U*	6.00 *U*	6.00 *U*
WETLAND2	ECH-E-W102	1	0	0.33	9.00 *U*	9.00 *U*	9.00 *U*	9.00 *U*

Note: All results reported in dry weight.

BTEX - benzene, toluene, ethylbenzene, and xylenes
U - undetected at the detection limit shown

Table B2-2. Grain size and TOC results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 0.001 mm (percent wet)	Particles smaller than 0.002 mm (percent wet)	Particles smaller than 0.005 mm (percent wet)	Particles smaller than 0.020 mm (percent wet)	Particles smaller than 0.050 mm (percent wet)	Particles smaller than 0.064 mm (percent wet)	Particles smaller than 0.075 mm (percent wet)
WETLAND1	ECH-E-W101	--	0	0.33	7.00	10.0	16.0	47.0	69.0	70.0	70.0
WETLAND2	ECH-E-W102	1	0	0.33							
WETLAND2	ECH-E-W102	2	0	0.33	7.00	10.0	15.0	34.0	66.5	67.0	67.0
WETLAND3	ECH-E-W103	--	0	0.33	6.00	7.50	12.0	31.5	61.0	67.0	71.3
WETLAND4	ECH-E-W104	--	0	0.33	5.00	8.50	15.0	46.0	73.0	76.0	79.7
WETLAND5	ECH-E-W105	--	0	0.33	9.00	12.0	20.0	50.5	73.0	77.5	79.6
WETLAND6	ECH-E-W106	--	0	0.33	4.00	6.00	12.0	36.0	59.0	64.5	68.4

Table B2-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 0.150 mm (percent wet) (sieve #100)	Particles smaller than 0.3 mm (percent wet)	Particles smaller than 0.6 mm (percent wet)	Particles smaller than 1.18 mm (percent wet)	Particles smaller than 2.36 mm (percent wet)	Particles smaller than 3.35 mm (percent wet)	Particles smaller than 4.75 mm (percent wet) (sieve #4)
WETLAND1	ECH-E-W101	--	0	0.33	75.9	82.1	86.9	90.4	92.3	99.3	99.9
WETLAND2	ECH-E-W102	1	0	0.33							
WETLAND2	ECH-E-W102	2	0	0.33	74.8	83.2	90.3	96.0	98.4	99.6	99.8
WETLAND3	ECH-E-W103	--	0	0.33	76.5	82.2	86.9	90.1	91.0	96.1	97.2
WETLAND4	ECH-E-W104	--	0	0.33	85.6	91.3	95.1	97.8	98.1	99.1	99.5
WETLAND5	ECH-E-W105	--	0	0.33	85.2	90.7	94.6	97.6	97.9	99.2	99.6
WETLAND6	ECH-E-W106	--	0	0.33	75.9	86.5	92.2	96.3	98.2	99.5	99.9

Table B2-2. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Particles smaller than 19.0 mm (percent wet)	Particles smaller than 37.5 mm (percent wet)	Particles smaller than 75 mm (percent wet)	Total organic carbon (mg/kg dry)
WETLAND1	ECH-E-W101	--	0	0.33	100	100	100	71,000
WETLAND2	ECH-E-W102	1	0	0.33				82,000 *J*
WETLAND2	ECH-E-W102	2	0	0.33	100	100	100	97,000 *J*
WETLAND3	ECH-E-W103	--	0	0.33	100	100	100	79,000
WETLAND4	ECH-E-W104	--	0	0.33	100	100	100	49,000 *J*
WETLAND5	ECH-E-W105	--	0	0.33	100	100	100	75,000
WETLAND6	ECH-E-W106	--	0	0.33	100	100	100	81,000

Note: *J* - estimated
TOC - total organic carbon

Table B2-3. Metals results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Antimony (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Magnesium (mg/kg)
WETLAND1	ECH-E-W101	--	0	0.33	1.0 *U*	20.5 *J*	0.17 *J*	230 *J*	175	400 *J*	5,100
WETLAND2	ECH-E-W102	1	0	0.33	2.60 *U*	29.1	0.310 *UJ*	295	209	605 *J*	5,650
WETLAND2	ECH-E-W102	2	0	0.33	5.10 *U*	28.9	0.320 *UJ*	277	207	553 *J*	5,120
WETLAND3	ECH-E-W103	--	0	0.33	15.9 *J*	35.2	0.280 *J*	439	278 *J*	906	7,730 *J*
WETLAND4	ECH-E-W104	--	0	0.33	25.9 *J*	46.4	1.07 *J*	513	327 *J*	2,080	7,840 *J*
WETLAND5	ECH-E-W105	--	0	0.33	67.7 *J*	343	9.82	493	377 *J*	2,540	4,360 *J*
WETLAND6	ECH-E-W106	--	0	0.33	51.0 *J*	276	3.54 *J*	601	415 *J*	2,660	3,690 *J*

Table B2-3. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Total mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Silver (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
WETLAND1	ECH-E-W101	--	0	0.33	0.28 *U*	11.1	53	3.2	37	1,540 *J*
WETLAND2	ECH-E-W102	1	0	0.33	0.532 *U*	20.4	68.0	3.10	56.1	2,110 *J*
WETLAND2	ECH-E-W102	2	0	0.33	0.680 *U*	19.9	61.7	3.00	52.0	2,000 *J*
WETLAND3	ECH-E-W103	--	0	0.33	0.990 *J*	21.3 *J*	85.5 *J*	5.30 *J*	67.2	6,860
WETLAND4	ECH-E-W104	--	0	0.33	1.38 *J*	27.6 *J*	90.1 *J*	7.44 *J*	78.0	2,800
WETLAND5	ECH-E-W105	--	0	0.33	1.86 *J*	25.1 *J*	92.4 *J*	5.67 *J*	78.5	3,410
WETLAND6	ECH-E-W106	--	0	0.33	1.60 *J*	37.3 *J*	73.4 *J*	7.89 *J*	78.9	2,570

Note: All results reported in dry weight.

J - estimated
U - undetected at detection limit shown

Table B2-4. Miscellaneous results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Moisture (percent wet)	Total Residue (percent wet)	pH (pH wet)	Fluoride (mg/kg dry)	Total Phosphorus (mg/kg dry)	Ammonia-nitrogen (mg/kg dry)	Total Kjeldahl nitrogen (mg/kg dry)
WETLAND1	ECH-E-W101	--	0	0.33	73.5	26.5	6.85	10.1 *J*	1,800	1,570	8,200
WETLAND2	ECH-E-W102	1	0	0.33	83.6	16.4	6.19		2,900	1,900	20,000
WETLAND2	ECH-E-W102	2	0	0.33	84.1	15.9	6.21	20.1 *J*	2,600	1,860	21,000
WETLAND3	ECH-E-W103	--	0	0.33	81.1	18.9	6.77	14.0 *J*	5,100 *J*	830	14,000 *J*
WETLAND4	ECH-E-W104	--	0	0.33	76.6	23.4	6.60	17.5 *J*	3,200 *J*	1,110	12,500 *J*
WETLAND5	ECH-E-W105	--	0	0.33	75.1	24.9	6.28	15.2 *J*	4,400 *J*	1,240	10,600 *J*
WETLAND6	ECH-E-W106	--	0	0.33	78.1	21.9	6.51	4.9	3,200 *J*	710	7,300 *J*

Table B2-4. (cont.)

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Sulfate (mg/kg dry)	Acid-volatile sulfide (μmol/g dry)	Sulfide Titration (MOD) (mg/kg dry)	Cyanide (mg/kg dry)
WETLAND1	ECH-E-W101	--	0	0.33	1,020	0.7 *UJ*	21.0 *UJ*	2.1
WETLAND2	ECH-E-W102	1	0	0.33		1.20 *UJ*	33.0 *UJ*	1.90
WETLAND2	ECH-E-W102	2	0	0.33	7,670	1.30 *U*	34.0 *UJ*	2.00
WETLAND3	ECH-E-W103	--	0	0.33	23,200 *J*	59.7 *J*	1,700	8.70 *J*
WETLAND4	ECH-E-W104	--	0	0.33	11,900 *J*	43.9 *J*	667	0.30 *UJ*
WETLAND5	ECH-E-W105	--	0	0.33	4,400 *J*	0.800 *UJ*	55.0 *J*	3.20 *J*
WETLAND6	ECH-E-W106	--	0	0.33	2,840	52.5 *J*	608	6.90 *J*

Note: *J* - estimated
U - undetected at detection limit shown

Table B2-5. Organic compounds results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Field replicate	Upper depth (cm)	Lower depth (cm)	Oil and grease (mg/kg dry)	Phenols (mg/kg dry)	2,4-D (µg/kg dry)
WETLAND1	ECH-E-W101	--	0	0.33	6,200	1.00 *J*	120 *U*
WETLAND2	ECH-E-W102	1	0	0.33		2.80 *J*	200 *U*
WETLAND2	ECH-E-W102	2	0	0.33	14,000	1.40 *U*	210 *U*
WETLAND3	ECH-E-W103	--	0	0.33	47,000 *J*	13.1	350 *U*
WETLAND4	ECH-E-W104	--	0	0.33	25,600 *J*	2.50 *J*	280 *U*
WETLAND5	ECH-E-W105	--	0	0.33	28,400 *J*	1.04 *J*	270 *U*
WETLAND6	ECH-E-W106	--	0	0.33	101,000 *J*	18.1	300 *U*

Note: 2,4-D - (2,4-dichlorophenoxy) acetic acid
J - estimated
U - undetected at detection limit shown

Table B2-6. SEM and AVS results for surface or subsurface wetland soil samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Sample ID	Upper Depth (cm)	Lower Depth (cm)	Cadmium (μmol/g)	Copper (μmol/g)	Lead (μmol/g)	Total Mercury (μmol/g)	Nickel (μmol/g)	Zinc (μmol/g)	Total SEM (μmol/g)	Acid-Volatile Sulfide (μmol/g)	SEM - AVS (μmol/g)
ECH-E-W101	0	0.33	0.39 *J*	19	50	0.000 *U*	3.1	130	202	0.7 *U*	201.79
ECH-E-W102	0	0.33	0.0258 *J*	2.97	2.48	0.000074 *J*	0.612	23.0	29	1.20 *UJ*	27.89
ECH-E-W102 Dup	0	0.33								1.30 *UJ*	
ECH-E-W103	0	0.33								59.7 *J*	
ECH-E-W104	0	0.33								43.9 *J*	
ECH-E-W105	0	0.33	0.103 *J*	4.07 *J*	8.56	0.000108 *J*	0.815 *J*	29.8	43	0.800 *UJ*	42.55
ECH-E-W106	0	0.33								52.5 *J*	

Note: All results reported in dry weight.

Blank space indicates no analysis performed

AVS - acid-volatile sulfide
J - estimated
SEM - simultaneously extracted metals
U - undetected at the detection limit shown

Appendix B3

Analytical Results for Surface Water Samples

Contents

Table B3-1. Fecal coliform bacteria results for surface water samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B3-2. Metals results for surface water samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B3-3. Phenols results for surface water samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B3-4. Conventional water quality analyses for surface water samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Table B3-1. Fecal coliform bacteria results for surface water samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

		Field replicate	Fecal Coliform Bacteria/100 mL unfiltered
Criterion[a]			**125**
Station	**Sample ID**		
B1	ECHWLF1BFC	1	40
B1	ECHWLF1BFC	2	70
B1	ECHWHF1BFC	--	730
B1	ECHWLF2BFC	1	70
B1	ECHWLF2BFC	2	80

[a] Criterion for bacteriological quality for recreational use from Indiana Department of Environmental Management, Indiana Administrative Code, Title 327, Water Pollution Control Board, Article 2, Water Quality Standards (www.ai.org/legislative/iac/VC.html#T327, accessed on August 17, 1999).

Table B3-2. Metals results for surface water samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

		Antimony (mg/L dissolved)	Antimony (mg/L unfiltered)	Arsenic (mg/L dissolved)	Arsenic (mg/L unfiltered)	Cadmium (mg/L dissolved)	Cadmium (mg/L unfiltered)	Chromium (mg/L dissolved)	Chromium (mg/L unfiltered)
AWQC (CCC)[a]				**0.150**		**0.0022**		**0.074**	
Station	**Sample ID**								
B1	ECHWLF1BC1	0.0053 *U*	0.0053 *U*	0.0400 *U*	0.0400 *U*	0.000630 *U*	0.000630 *U*	0.00200 *U*	0.00170 *U*
B1	ECHWLF1BC2	0.0053 *U*	0.0053 *U*	0.0400 *U*	0.0400 *U*	0.000630 *U*	0.000630 *U*	0.00170 *U*	0.00170 *U*
B1	ECHWLF1BC3	0.0053 *U*	0.0053 *U*	0.0400 *U*	0.0400 *U*	0.000630 *U*	0.000630 *U*	0.00250 *U*	0.00170 *U*
B1	ECHWLF1BC4		0.005 *U*		0.010 *U*		0.0006 *U*		0.0033 *U*
B1	ECHWHF1BC1	0.0053 *U*	0.0053 *U*	0.0400 *U*	0.0400 *U*	0.000630 *U*	0.000630 *U*	0.00170 *U*	0.00470 *U*
B1	ECHWHF1BC2	0.0053 *U*	0.0053 *U*	0.0400 *U*	0.0400 *U*	0.000630 *U*	0.000630 *U*	0.00170 *U*	0.00200 *U*
B1	ECHWHF1BC3	0.0053 *U*	0.0053 *U*	0.0400 *U*	0.0400 *U*	0.000630 *U*	0.000630 *U*	0.00170 *U*	0.00230 *U*
B1	ECHWHF1BC4	0.0053 *U*	0.0053 *U*	0.0400 *U*	0.0400 *U*	0.000630 *U*	0.000630 *U*	0.00170 *U*	0.00170 *U*
B1	ECHWLF2BC1	0.005 *U*	0.005 *U*	0.00700 *UJ*	0.00700 *UJ*	0.000630 *U*	0.000630 *U*	0.00170 *U*	0.00170 *U*
B1	ECHWLF2BC2	0.0053 *U*	0.0053 *U*	0.00700 *UJ*	0.007 *UJ*	0.000630 *U*	0.0006 *U*	0.00170 *U*	0.0026 *J*
B1	ECHWLF2BC3	0.0053 *U*	0.0053 *U*	0.00700 *UJ*	0.00700 *UJ*	0.000630 *U*	0.000630 *U*	0.00170 *U*	0.00260 *J*
B1	ECHWLF2BC4	0.0053 *U*	0.0053 *U*	0.00700 *UJ*	0.00700 *UJ*	0.000630 *U*	0.000630 *U*	0.00170 *U*	0.00170 *U*

Table B3-2. (cont.)

		Copper (mg/L dissolved)	Copper (mg/L unfiltered)	Lead (mg/L dissolved)	Lead (mg/L unfiltered)	Magnesium (mg/L unfiltered)	Total mercury (mg/L dissolved)	Total mercury (mg/L unfiltered)	Molybdenum (mg/L unfiltered)
AWQC (CCC)[a]		**0.009**		**0.0025**			**0.00077**		
Station	**Sample ID**								
B1	ECHWLF1BC1	0.00470 *U*	0.00340 *U*	0.00650 *UJ*	0.00650 *UJ*		0.00004 *U*	0.0000420 *U*	
B1	ECHWLF1BC2	0.00400 *U*	0.00330 *U*	0.00650 *UJ*	0.00650 *UJ*		0.0000420 *U*	0.0000420 *U*	
B1	ECHWLF1BC3	0.00470 *U*	0.00250 *U*	0.00650 *UJ*	0.00650 *UJ*		0.0000420 *U*	0.0000420 *U*	
B1	ECHWLF1BC4		0.0048 *U*		0.006 *UJ*	12		0.0000420 *U*	0.0087
B1	ECHWHF1BC1	0.00220 *U*	0.00910 *U*	0.00650 *UJ*	0.0100 *J*		0.0000430 *U*	0.0000540 *U*	
B1	ECHWHF1BC2	0.00270 *U*	0.00410 *U*	0.00650 *UJ*	0.00650 *UJ*		0.0000420 *U*	0.0000420 *U*	
B1	ECHWHF1BC3	0.00260 *U*	0.00480 *U*	0.00650 *UJ*	0.00650 *UJ*		0.0000420 *U*	0.0000420 *U*	
B1	ECHWHF1BC4	0.00310 *U*	0.00450 *U*	0.00650 *UJ*	0.00650 *UJ*		0.0000420 *U*	0.0000420 *U*	
B1	ECHWLF2BC1	0.00170 *UJ*	0.00240 *J*	0.00650 *U*	0.00650 *U*		0.00004 *U*	0.00004 *U*	
B1	ECHWLF2BC2	0.00170 *UJ*	0.0050 *J*	0.00650 *U*	0.006 *U*		0.0000420 *U*	0.0000420 *U*	
B1	ECHWLF2BC3	0.00170 *UJ*	0.00250 *J*	0.00650 *U*	0.00650 *U*		0.0000420 *U*	0.0000420 *U*	
B1	ECHWLF2BC4	0.00170 *UJ*	0.00170 *UJ*	0.00650 *U*	0.00650 *U*		0.0000420 *U*	0.0000420 *U*	

Table B3-2. (cont.)

		Nickel (mg/L dissolved)	Nickel (mg/L unfiltered)	Silver (mg/L unfiltered)	Vanadium (mg/L unfiltered)	Zinc (mg/L dissolved)	Zinc (mg/L unfiltered)
AWQC (CCC)[a]		**0.052**				**0.120**	
Station	**Sample ID**						
B1	ECHWLF1BC1	0.00470 *J*	0.00440 *J*			0.0115 *U*	0.0183 *U*
B1	ECHWLF1BC2	0.00370 *J*	0.00430 *J*			0.0122 *U*	0.0147 *U*
B1	ECHWLF1BC3	0.00300 *U*	0.00300 *U*			0.0174 *U*	0.00530 *U*
B1	ECHWLF1BC4		0.0030 *U*	0.0020 *U*	0.0020 *U*		0.022 *U*
B1	ECHWHF1BC1	0.0110	0.0136			0.00800 *U*	0.0510
B1	ECHWHF1BC2	0.00630	0.00660			0.0117 *U*	0.0174 *U*
B1	ECHWHF1BC3	0.00320 *J*	0.00380 *J*			0.00860 *U*	0.0200 *U*
B1	ECHWHF1BC4	0.00310 *J*	0.00420 *J*			0.00660 *U*	0.0220
B1	ECHWLF2BC1	0.00300 *U*	0.00330 *J*			0.0106 *U*	0.0114 *J*
B1	ECHWLF2BC2	0.00300 *U*	0.0043 *J*			0.0109 *U*	0.019 *J*
B1	ECHWLF2BC3	0.00300 *U*	0.00320 *J*			0.0108 *U*	0.0240
B1	ECHWLF2BC4	0.00300 *U*	0.00300 *U*			0.0131 *U*	0.0162 *J*

Note: AWQC - ambient water quality criteria (criterion continuous concentration)
J - estimated
U - undetected at detection limit shown

[a] U.S. EPA. 1999. National recommended water quality criteria - Correction. EPA 822-Z-99-001. April 1999. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Table B3-3. Phenols results for surface water samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Phenols mg/L unfiltered
B1	ECHWHF1BC1	0.00440 *U*
B1	ECHWHF1BC2	0.00800 *U*
B1	ECHWHF1BC3	0.00660 *U*
B1	ECHWHF1BC4	0.00660 *U*
B1	ECHWLF2BC1	0.00660 *U*
B1	ECHWLF2BC2	0.0570
B1	ECHWLF2BC3	0.00860 *J*
B1	ECHWLF2BC4	0.00660 *U*

Note: *J* - estimated
U - undetected at detection limit shown

Table B3-4. Conventional water quality analyses for surface water samples collected in September–October 1998 for the sediment characterization study for the DuPont East Chicago facility

Station	Sample ID	Total Suspended Solids (mg/L)	Hardness (mg/L as $CaCO_3$)	Total Phosphorus (mg/L)	Ortho-phosphate (mg/L)	Total NO_2-N (Nitrite nitrogen) (mg/L)	Total NO_3-N (Nitrate nitrogen) (mg/L)	Ammonia-Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Chemical Oxygen Demand (mg/L)	Biochemical Oxygen Demand-5 Day Test (mg/L)	Oil and grease (mg/L)
B1	ECHWLF1BC1	2.60 *U*	155	0.0400 *U*	0.06 *U*	0.400 *UJ*	1.40 *J*	0.18		36.5 *U*	5 *J*	5.00 *U*
B1	ECHWLF1BC2	2.60 *U*	155	0.0400 *U*	0.06 *U*	0.400 *UJ*	1.76 *J*	0.24		70.0	4 *J*	5.00 *U*
B1	ECHWLF1BC3	12.7 *J*	157	0.0400 *U*	0.12	0.400 *UJ*	1.64 *J*	0.18		30.3 *U*	7 *J*	5.00 *U*
B1	ECHWLF1BC4				0.06 *U*						10 *UJ*	
B1	ECHWHF1BC1	17.2	151	0.12	0.06	0.400 *UJ*	1.51 *J*	0.23	1.60 *U*	57.0 *U*	4 *UR*	2.50 *U*
B1	ECHWHF1BC2	36.8	160	0.0470 *J*	0.06	0.400 *UJ*	2.86 *J*	0.18	1.18 *U*	28.2 *U*	4 *J*	5.00 *U*
B1	ECHWHF1BC3	32.8	161	0.0470 *J*	0.06 *U*	0.400 *UJ*	2.18 *J*	0.34	1.24 *U*	26.1 *U*	5 *J*	5.10 *J*
B1	ECHWHF1BC4	2.60 *U*	154	0.0400 *U*	0.06 *U*	0.400 *UJ*	1.14 *J*	0.22	1.35 *U*	24.0 *U*	4 *J*	5.00 *U*
B1	ECHWLF2BC1	2.80 *J*	157	0.0400 *U*	0.06 *UJ*	0.40 *UR*	1.3 *J*	0.23	0.410 *U*	32.3 *U*	5 *J*	3.20 *J*
B1	ECHWLF2BC2	2.60 *U*	150	0.0400 *U*	0.11	0.400 *UR*	1.57 *J*	0.21	0.930 *U*	26.1 *U*	222	3.50 *J*
B1	ECHWLF2BC3	2.60 *U*	146	0.0800	0.27	0.400 *UR*	1.71 *J*	0.22	0.580 *U*	46.9 *U*	20	3.60 *J*
B1	ECHWLF2BC4	2.60 *U*	158	0.0400 *U*	0.1	0.400 *UJ*	1.62 *J*	0.24	0.200 *J*	28.2 *U*	465	4.40 *J*

Note: All results are for unfiltered samples.
J - estimated
R - rejected
U - undetected at detection limit shown

Appendix C

Sediment Core Logs and Photo Composites

Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number K-Middle

Project No.

Date 9/30/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde / ASCI

Core Type/Method 3" Alum. / Vibrator

Samples collected
1 0-18"
2 18-60"
3 60-72"

Munsell color Chart
1 for Gley

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-18" Black 2.5/N, medium grain sand	Recovery 72 1/2"
									w/ some gravel & fine sand, material	
									appears saturated w/ oily liquid -	HNU w/ 11.7 probe
									no sheen noted. Top 0-2"	minor fluctuations
									several small clams 1/2" width	1-2 ppm with
									this material isn't as sandy to	no steady reading
									touch as appears. material feels	and could be
									Fine sand to silty w/ some gravel.	reacting w/ moisture
									18-30" Black 2.5/N, medium grain sand	
									w/ some coarse sand, material	Odor (hydrocarbon)
									appears less saturated w/ oily liquid	throughout Core
									30-34" Grey 5/N, Fine - Medium Sand	
									w/ minor amount of oil staining	
									34-34 1/2" Black 2.5/N Fine grain sand	
									w/ staining	

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Exponent

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number K - Middle

Project No.

Date 9/30/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde / ASCI

Core Type/Method 3" Alum / Vibrator

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									34½"-38" Grey 3/N Fine sand	
									38"-46" Grey 3/N & Black 2.5/N, Fine, sand varved w/o staining. At 44" Black material is slick (slimy) to touch	
									46-58½" Grey 3/N & Black 2.5/N Fine Sand w/ thin 1/8"-3/16" lenses of wood @ 48", 51", 54", 54½", 55½". Some twigs observed	
									58½-59" Black 2.5/N Fine Sand	
									59-61" Grey 3/N Fine sand	

Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner: Dupont E. Chicago Station Number: K - middle

Project No.:

Date: 9/30/98

Field Scientist: William Clayton

Contractor/Operator: Woodward-Clyde / ASCI

Core Type/Method: 3" Alum / Vibrator

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									61-70 1/2" Dark grey - Black (A/N, 2.5/N)	
									fine Sand	
									70 1/2" - 72 1/2" Grey Fine Sand (5/5GY)	
									[Exponent Notes ↓]	These Notes on
									69 1/2 lighter Sands [illegible]	Plastic sheeting
									60 1/2 Transition to darker seds	during Photographs
									57 1/2 Dark Horizon	
									Wood detritus 51, 53, 53 1/2, 54, 55	All notes on
									48" Wood debris horizon	exponent were
									34-46 Vars	on plastic for
									34 distinctive dark horizon	photos.
									30 discontinuity between oil stain	
									& sand	Jane Sexton/Lucinda Jacobs
									18" Texture change from coarse	
									black to finer Black	

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Exponent

FIELD SEDIMENT CORE FORM

Client/Owner: Dupont E. Chicago Station Number: J-middle

Project No.:

Date: 9/30/98

Field Scientist: William E. Clayton

Contractor/Operator: Woodward-Clyde / ASCI

Core Type/Method: 3" Alum / Vibrator

Samples Collected
1 0-12"
2 12-34"
3 34-70"

Munsell Color Chart
1 for Glev

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-12 Loose, Black 2.5/N, Fine - Med sand w/ black staining. 1/2" wide clams present, some gravel	Recovery 70" No readings w/ HnV
									12-23" Loose, Grey 3/N - Black 2.5/N Fine Sand - Silt w/ sheen, w/ slick-slimy texture (w/ surgical gloves) saturate w/ oil	odor appears strongest near surface and near absent @ 34-70" horizon
									23-34" Dense, Grey 3/N and Black 2.5/N, Med. Sand w/ varves. slight staining but predominately dry	
									34-70" Stiff, Black 2.5/N - Grey Black 4/N Silt - Clay @ 48" fiberous root material present. this horizon Indicated stiff material from inserting core splitters.	

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FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number J-middle

Project No.

Date 9/30/98

Field Scientist Jane Sexton / Lucinda Jacobs

Contractor/Operator Woodward-Clyde / ASCI

Core Type/Method 3" Alum / Vibrator

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									[Exponent Descriptions] Jane Sexton/Lucinda Jacobs	
									0-12 Dark	
									12" Discontunity between Fine	
									Coarse Sand and varved	
									12-24 Oily textured Varves	
									stronger Petro odor	
									24-34" Non oily textured	
									Varves - Mild Petro Odor	
									34" Discontinuunty between	
									varved sand and dark clay-	
									silt	
									34-70". Normal Odor of hydric	
									sediments	

Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner: Dupont E. Chicago Station Number: I-middle

Project No.:

Date: 10/1/98

Field Scientist: William E. Clayton

Contractor/Operator: Woodward-Clyde / ASCI

Core Type/Method: 3" dia Alum / Vibrator

Samples Collected
1 0-29"
2 29"-61"
3 61"-72

Sample Time 9:15
duplicate Time 9:45

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-10" Loose, Black (2.5/N) Fine Sand ~~silt~~ w/ petro. product. numerous shell halves, to whole clams ½" in width	Recovery 72" HNU readings <1 response only near top portion of sample
									10-18" Loose Black (2.5/N) & Grey (3/N) silt w/ some Fine Sand. Some varving present, saturated w/ oil giving a slimy/slick feel	Petro odor strongest 0-29"
									18-29" Loose-dense, Black (2.5/N) silt w/ petro. product (oil) w/ some Fine sand saturated w/ oil but not having slick/slimy feel	This description is of "sample" duplicate correlation was good.
									29-59 Loose-dense, Black (2.5/N) silt w/ Fine Sand Root hairs throughout. Between 43"-45" lighter layers (varve)	

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Exponent

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number I-middle

Project No.

Date 10/1/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde / ASCI

Core Type/Method 3" Alum / Vibrator

Munsell Color Chart 1 for Gley

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									59-68" Dense, Grey 2.5/5GY, Medium-Fine	
									Sand with numerous shell fragments	
									shell fragments light grey-	
									white. oil staining absent.	
									Large shell @ 59" collected &	
									placed in sample jar	
									68-72" Dense, Grey 5/10Y, Med.-Fine	
									Sand. Uniform color & grain	
									size	
									[Exponent Description] Jane Sexton/Lucinda Jacobs	
									0-10 dark gritty, Sandy silt w/	
									strong petro odor, less consolidated	
									than →	
									10-18" Sandy silt w/ medium petro odor	
									18-29" Silt w/ apparent oily matrix mild petro odor	
									@29" distinctive light horizon	
									29-45 dark silt w/ occasional varve	
									45 double varve	
									45-59 Dark silt	
									59-68 Fine Sand w/ shell fragments	
									68-72 Sand only	

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FIELD SEDIMENT CORE FORM

Client/Owner: Dupont E. Chicago Station Number: G-middle

Project No.:

Date: 10/1/98

Field Scientist: William E. Clayton

Contractor/Operator: Woodward-Clyde / ASCI

Core Type/Method: 3" Alum / Vibrator

Samples collected
1 0-25"
2 37-82"
3 82-102"
opp. sample @ 25-30.5"
Sample time
11:50

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-4" Very loose, Black 2.5/N, F-M sand, stained, numerous shell fragments and clams	Recovery 105"
										HNU readings > 1 w/ occasional hits
									4-7" Loose, Brown, Medium Sand unstained Hue 10YR 3/3	> 1, < 3 between 0-24"
									7-25" Loose Black 2.5/N F-M sand saturated w/ petro. slick/slimy texture w/ surgical gloves. Several pieces of gravel 1-2"ϕ	
									25-33" dense, light grey 6/10B ?? may be man made material, does not appear to be sediment	Munsell color chart 2 for Gley
									33-42" dense black 2.5/N and grey 3/N Fine Sand & silt This area is varved alternating black and grey.	
									@ 38" 1/2" x 1/2" x ? white ceramic ?	

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Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number G-middle

Project No.

Date 10/1/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde / ASCI

Core Type/Method 3" Alum. / Vibrator

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									42-81" loose-dense black, Fine Sand. This horizon although black does not have Petro odor but a natural? hydric sediment odor (2.5/N)	
									81'-105 loose-dense black & grey (2.5/N, 3/N) Fine sand. alternating bands of colors, varves	
									[Exponent Description] Jane Sexton / Lucinda Jacobs	
									5-7" Layer brown Sand	
									7-25" Dark silty sand strong petro odor	
									25-30" Distinctive layer of light varves	
									31-33½" Distinctive layer of light varves	
									36" white ceramic rectangle	
									37-42" some varving	
									47-82" Dark silt no distinctive features	
									82-102" light and dark varves and inter layers	
									102-105" Brown silt dark varve @ 105"	

Exponent

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number H-middle

Project No.

Date 10/1/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde / ASCI

Core Type/Method 3" Alum / Vibrator

Samples Collected
1 0-14"
2 14-35"
3 35-49"

Sample Time
15:20

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-4" Loose, black, medium Sand	Recovery 49"
									w/ shell fragments and clams	
									No apparent Petro. odor	No Apparent
									4-5" Loose, black, medium sand.	petro odor.
									5"-18 loose, Medium black, Fine	Reading on HNU
									Sand, some root fibers	steady @ background
										No response when
										core screened
									18-35 loose, black & grey (alternating)	
									Fine Sand, to silt. @ 29 1/2-30" brown	
									zone w/ wood. Horizon (18-35")	
									is slimy/slick texture in entirety	
									35-46 Loose-dense Grey & black	
									medium Sand w/ numerous shell	
									fragments.	
									46-49" Loose-dense Grey silt, medium	HUE 7.5 YR
									sand without shell fragments.	

Exponent

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number H-middle

Project No.

Date 10/1/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde / ASCI

Core Type/Method 3" Alum / Vibrato

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									Top-shells	Exponent Notes
									0-13" sand & silt, some varves	for Photographs
									mild Petro odor	by Lucinda Jacobs
									13-35" Fine sand to silt	
									Dark/light layers, No Petro	
									odor but oily texture	
									@29" brown horizon	
									35-49" Sandy with dark/light	
									layers and shell fragments	

Exponent

FIELD SEDIMENT CORE FORM

Client/Owner: Dupont E. Chicago Station Number: F. middle

Project No.:

Date: 10/2/98

Field Scientist: William Clayton

Contractor/Operator: Woodward-Clyde

Core Type/Method: 3" Alum / Vibrator

Samples Collected
1 0-22"
2 22-60"
3 60-82

sample collection 7:30

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
			Hue 2.5Y						0-10" Loose, dark grey 3/1, Fine-medium Sand numerous shell fragments and clams (0-2" depth)	Recovery 82"
										Petro odor strongest @ 0.24"
									10-19" Loose black 2.5/N Fine-medium sand. saturated with oil	
										Hnu readings 1-3ppm spikes @ sample
									19-22" Loose, black 2.5/N, Fine Sand-Silt with oil sheen this zone is slick/slimy texture	
									22-36" Loose-dense black 2.5/N and grey 3/N (alternating) Fine sand. varves or banding	
									36-53" Loose-dense, black 2.5/N, Fine Sand-silt	

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Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number F-middle

Project No.

Date 10/2/98

Field Scientist Willian Clayton

Contractor/Operator Woodward-Clyde

Core Type/Method 3" Alum / Vibrator

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									53-61 Loose-dense black 2.5/N, Fine	
									sand w/ grey layers predominately	
									black	
									61-73" Loose-dense, black 2.5/N and brown	
									Fine sand	
									73-82" Loose-dense grey 4/1	Hue 2.5Y
									Fine - Medium Sand w/ shell	
									fragments	
									[Exponent Description] Jane Sexton / Lucinda Jacobs	
									~~Fin~~ 0-11" Fine to med dark brown sand	
									11-19 Fine to med dark grey sand	
									19-21 distinctive dark oily horizon	
									21-36 Light + dark varves; no petro odor	
									36-53 Dark grey materials	
									53-60 Light + predominately dark layers	
									60-82 Light + dark layers: predom light layers	
									76-82 shell frags	

Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner: Dupont E. Chicago Station Number: D-middle

Project No.:

Date: 10/2/98

Field Scientist: William Clayton

Contractor/Operator: Woodward-Clyde

Core Type/Method: 3" Alum / Vibrator

Samples Collected
1 0-44"
2 44-72"
3 72-83"

Sample Collection Time
8:30

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-13" Loose dark grey-black 2.5/N	Recovery 83"
									Fine-medium Sand @ 13" a 1/2"	
									thick medium sand lens. Shell	HnV readings -
									fragments and clams 0-4" dark grey 3/1	no sustained
									13-29" Loose-dense, Fine-med	readings.
									sand @ 29" 1/2 thick medium ~~coarse~~	Hue 10YR ↓ chart
									sand, and shell fragments	Petro ~~order~~ odor
										0-41"
									29-41" Loose-dense, dark grey 3/1 medium sand	
									@ 39-41" medium sand w/ black	
									staining, oily appearance	
									41-72" dense dark grey 3/1 Fine sand-Silt	
									with shell fragments throughout	
									and some root fibers.	
									72"-83" Loose-dense grey 5/1 Fine-medium	
									sand with shell fragments.	
									fragments are 1/8-1/16" highly decayed	
									or decomposed - No whole shells	

Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number D-middle

Project No.

Date 10/2/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde

Core Type/Method 3" Alum / Vibrator

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									[Exponent Notes] Jane Sexton / Lucinda Jacobs	
									4-8" Fine - Med Sand	
									13" distinctive dark coarse horizon	
									19-24" Fine to medium sand	
									29" distinctive dark coarse horizon	
									33 medium Sand	
									39-41 distinctive dark coarse horizon	
									41-~~44~~ dark silt w/ some layering	
									~~51-53~~ dark silt with some layering	
									72" " " " " "	
									72-83 Fine to medium sand with some layering	
									and shell fragments	

FF Rev 09/98

Exponent

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number E-middle

Project No.

Date 10/2/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde

Core Type/Method 3" Alum / Vibrator

Samples Collected
1 1-17"
2 17-47"
3 47-66"

Sample Collection Time 9:50

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-17" Loose, black (2.5/N) coarse sand - Fine gravel numerous shells and clams. well sorted material. appears to possibly be cinders?	Recovery 66" Hnu readings not over back-ground
									17-21" loose, grey (5/N) - light grey (6/N) horizon - not sediment	
									21-30" loose, black (2.5/N) Fine Sand - Silt w/ oil sheen. Hnu spikes of 1-4ppm from this area. Slick/ slimy texture.	
									30-39" loose, black (2.5/N) Fine sand - Silt w/ minor amounts of very thin varves (paper thin)	
									39-48" loose-dense Fine sand brown (4/2) - dark grey (3/1)	2.5 Hue - brown 10YR Hue - Grey

FF Rev 09/98

Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Ch. 2950 Station Number E-middle

Project No.

Date 10/2/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde

Core Type/Method 3" Alum / Vibrator

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									48-66" Loose-dense, grey (3/1) & brown (4/2) medium sand w/ shell fragments	
									[Exponent Description for Photo]	Jane Sexton / Lucinda Jacobs
									0-17" Coarse oily material strong Petro odor	
									20-21" Distinctive light horizon	
									21-31" oily sheen	
									31-39" Dark Grey	
									39" distinctive interface	
									39-47" light Grey-brown	
									47" Fine to medium sand w/ shell fragments	
									grading to Medium sand with shell fragments to 66"	

Exponent

FIELD SEDIMENT CORE FORM

Client/Owner: Dupont, E. Chicago Station Number: B-middle

Project No.:

Date: 10/2/98

Field Scientist: William Clayton

Contractor/Operator: Woodward-Clyde

Core Type/Method: 3" Alum. / Vibrator

Samples Collected
1 0-21
2 21-48"
3 48-68"

Sample Collection Times
11:10 ~~- 10:45~~

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-7" Loose, brownish black (2/2, Hue 10YR) Fine-Med Sand w/ numerous shell fragments and clams	Recovery 68"
										Hnu reading on core <1
									7-13" Loose, brown (2.5/2) silt w/ Fine sand	Hue 7.5YR
									13-20" Loose black (2.5/N) silt w/ Fine sand, some sheen	Petro odor strongest above 20"
									20-48" Loose-dense, ~~dark grey~~ (3/1) Silt-Fine Sand Some root fibers	Hue 7.5YR
									48-68" dense, grey (3/1), medium sand w/ shell fragments. Sand appears relatively free of silt	

Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner Dupont E. Chicago Station Number B-middle

Project No.

Date 10/2/98

Field Scientist William Clayton

Contractor/Operator Woodward-Clyde

Core Type/Method 3" Alum / Vibrator

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									[Exponent Description]	
									Shells on surface	
									4-9" Grey light	
									9-14 Shiny	
									14-20 Black (dark)	
									20-48 Dark silt w/ Fine sand	
									48-68 Fine to medium coarse grain sand w/ shell frags	

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Exponent

FIELD SEDIMENT CORE FORM

Client/Owner: Dupont E Chicago Station Number: C-middle

Project No.:

Date: 10/2/98

Field Scientist: William Clayton

Contractor/Operator: Woodward-Clyde

Core Type/Method: 3" Alum / Vibrator

Samples collected
1 0-53"
2 53-106
3 106-181

Sample Collection Time
1400

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0 53" Loose, black medium (2.5/N)	Recovery 106 75 181"
									Sand, strong odor (Coal Tar)	
									no shell fragments or clams	HnV readings in
										breathing zone
										3-5 ppm spikes
									53-136 Loose-dense, dark grey (3/1)	
									Silt w/ Fine Sand	
									136-160 Loose-dense, grey (3/N)	
									medium sand w/ random stainins	
									This zone appears relatively free	
									of silts. Minor amount of varves.	
									160-181" dense, dark olive ~~grey~~ brown (2.5/2)	Hue 7.5YR
									silt w/ Fine sand. Shell fragments from	
									176-181"	
									Exponent Jane Sexton / Lucinda Jacobs	
									0-53 Fine to med sand	
									53-106 Fine sand w/ silt	
									106-181 Dark material of varing texture	

FF Rev 09/98

Exponent™

FIELD SEDIMENT CORE FORM

Client/Owner: Dupont E. Chicago Station Number: A-middle

Project No.:

Date: 10/2/98

Field Scientist: William Clayton

Contractor/Operator: Woodward-Clyde

Core Type/Method: 3" Alum / Vibrator

Samples Collected
1 0-27"
2 27-48"
3 48-79"

Sample Collection Time
1500

Sample No.	Photo No.	Odor	Sheen			-H20 Breaks	Depth Scale	Unified Symbol	Sediment Description	Comments
									0-27" Loose, black 2.5/N medium-coarse material slight sheen w/ shell fragments	Recovery 79"
									27-49" Loose-dense, black 2.5/N Fine sand with silt. varies @ 31-35"	Petro odor strongest @ 0-27"
										Hav screens
									49-79" dense, grey 3/N Fine-medium sand minor amounts of shell frags from 49-52" Numerous shell fragments from 66-79"	<1
									[Exponent Descriptions] Jane Sexton/Lucinda Jacobs	
									Surface shell fragments	
									0-27 Medium to coarse dark material Petro odor decreasing w/ depth to 27"	
									27-48 Fine Sand w/ silt	
									48-79 Fine to medium sand: some shell frags	
									66-79 Numerous shell frags	

A-M

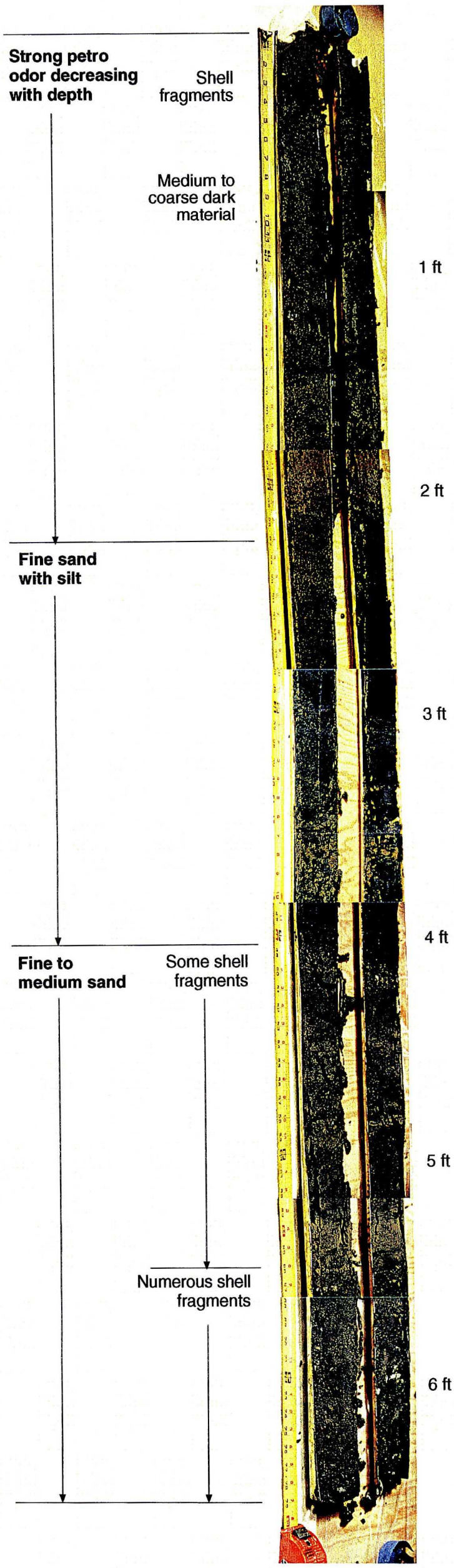

Figure C-1.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION A–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

B-M

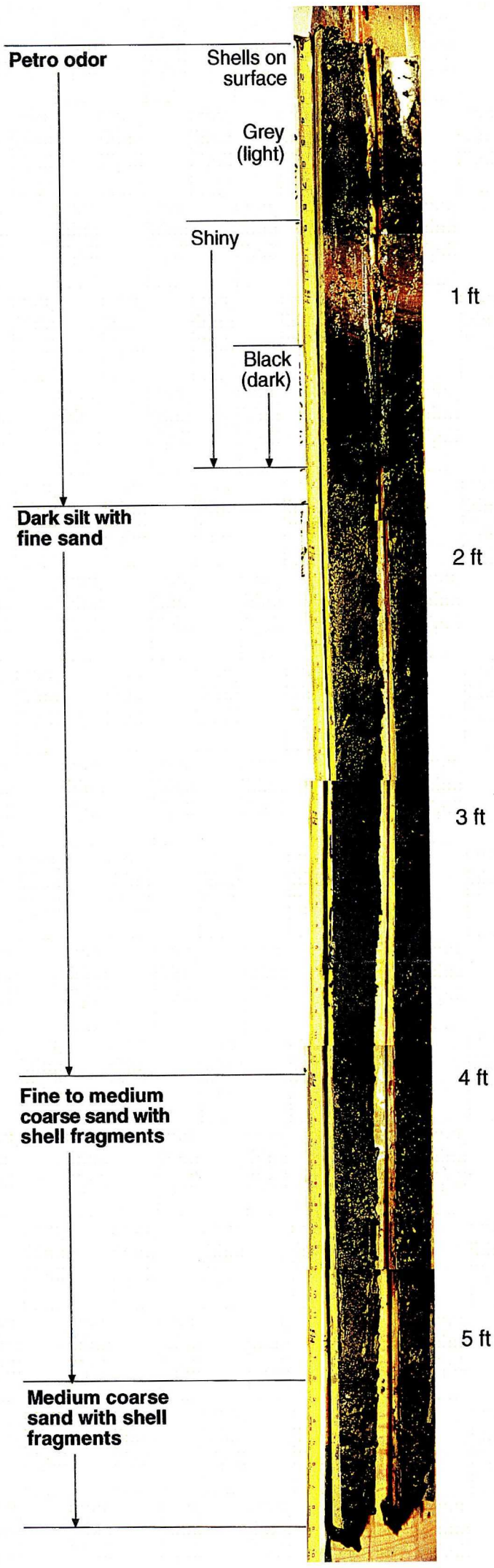

Figure C-2.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION B–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent™

C-M

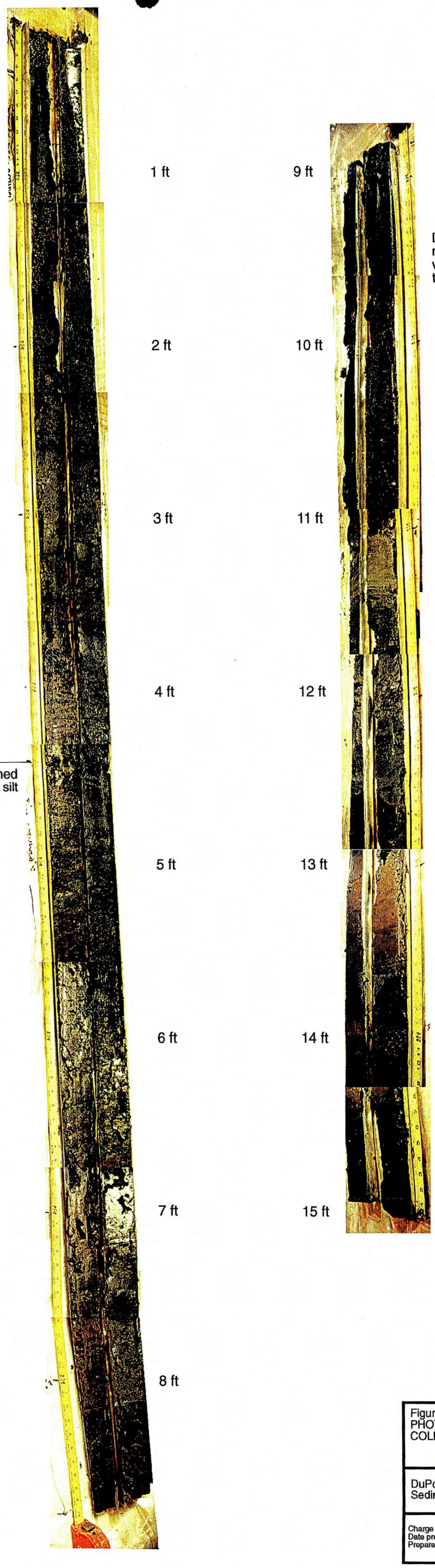

Figure C-3.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION C–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

D-M

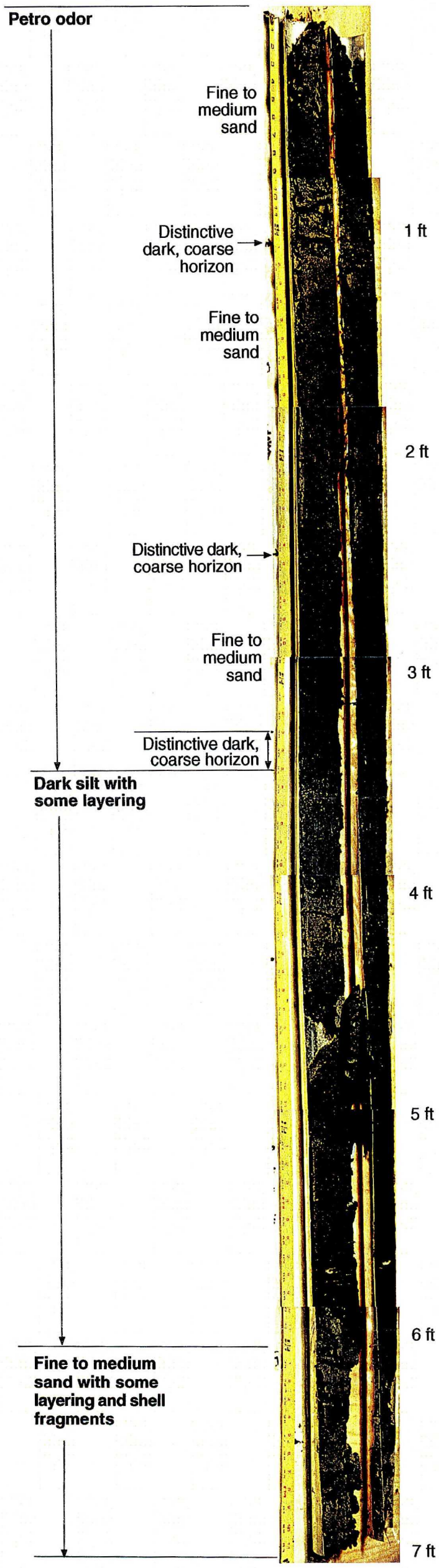

Figure C-4.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION D–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

E-M

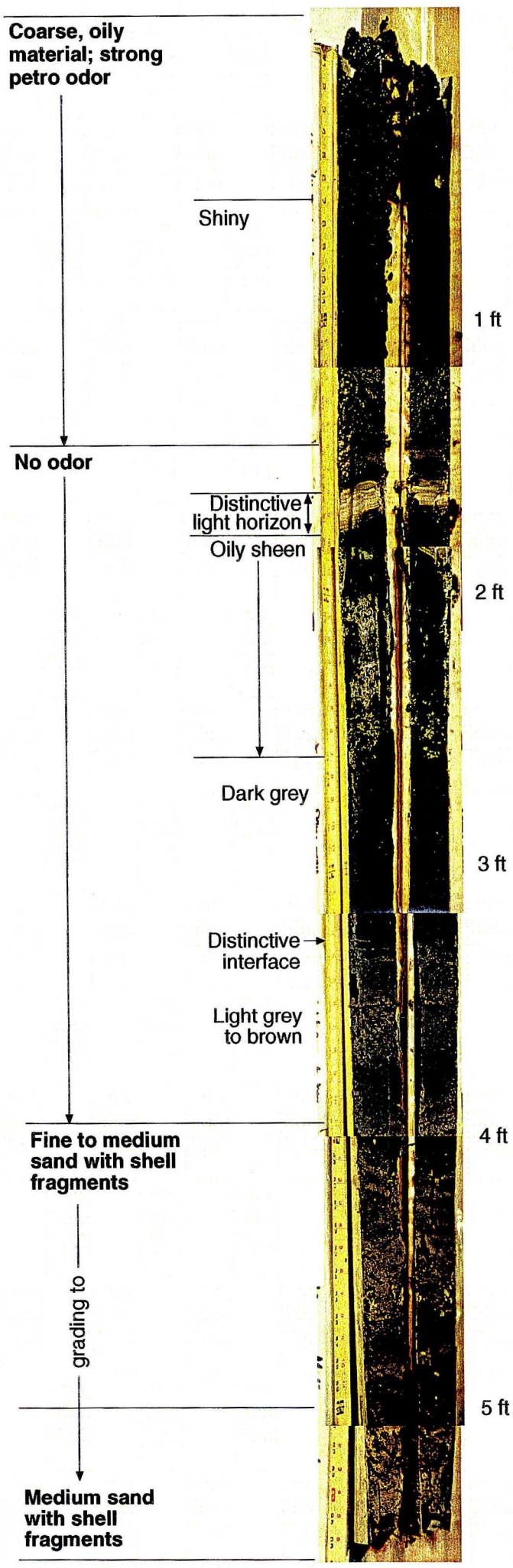

Figure C-5.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION E–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

F-M

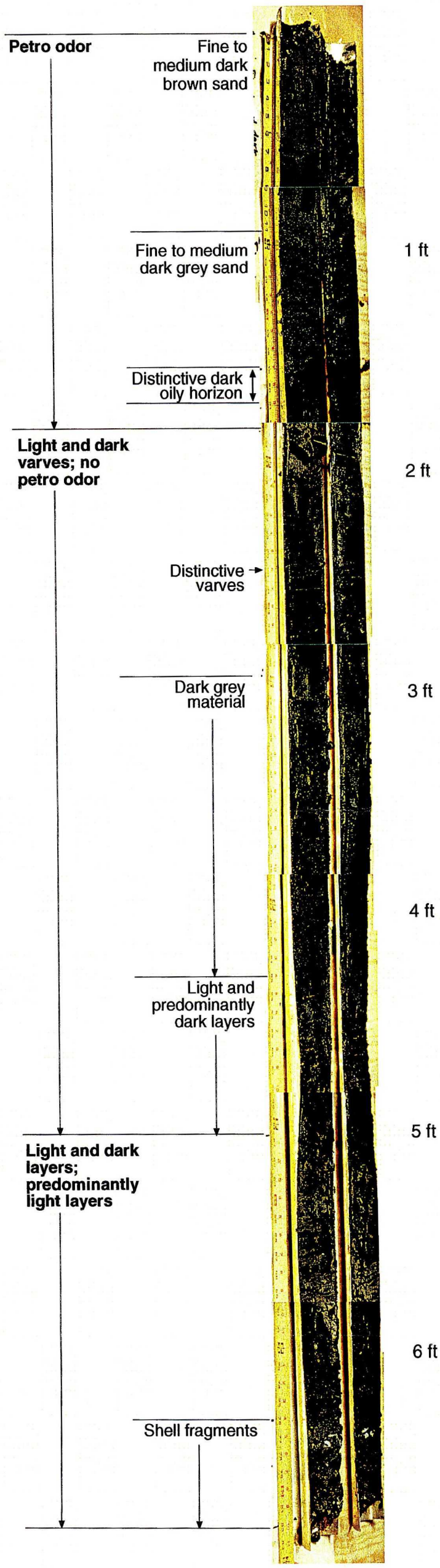

Figure C-6.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION F–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

G-M

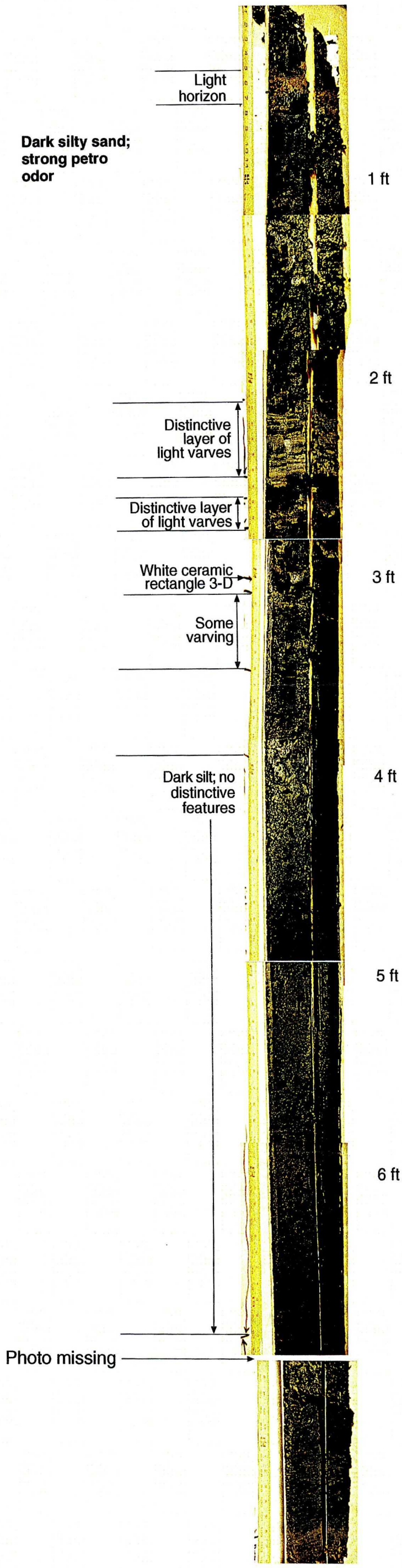

Figure C-7.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION G–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

H-M

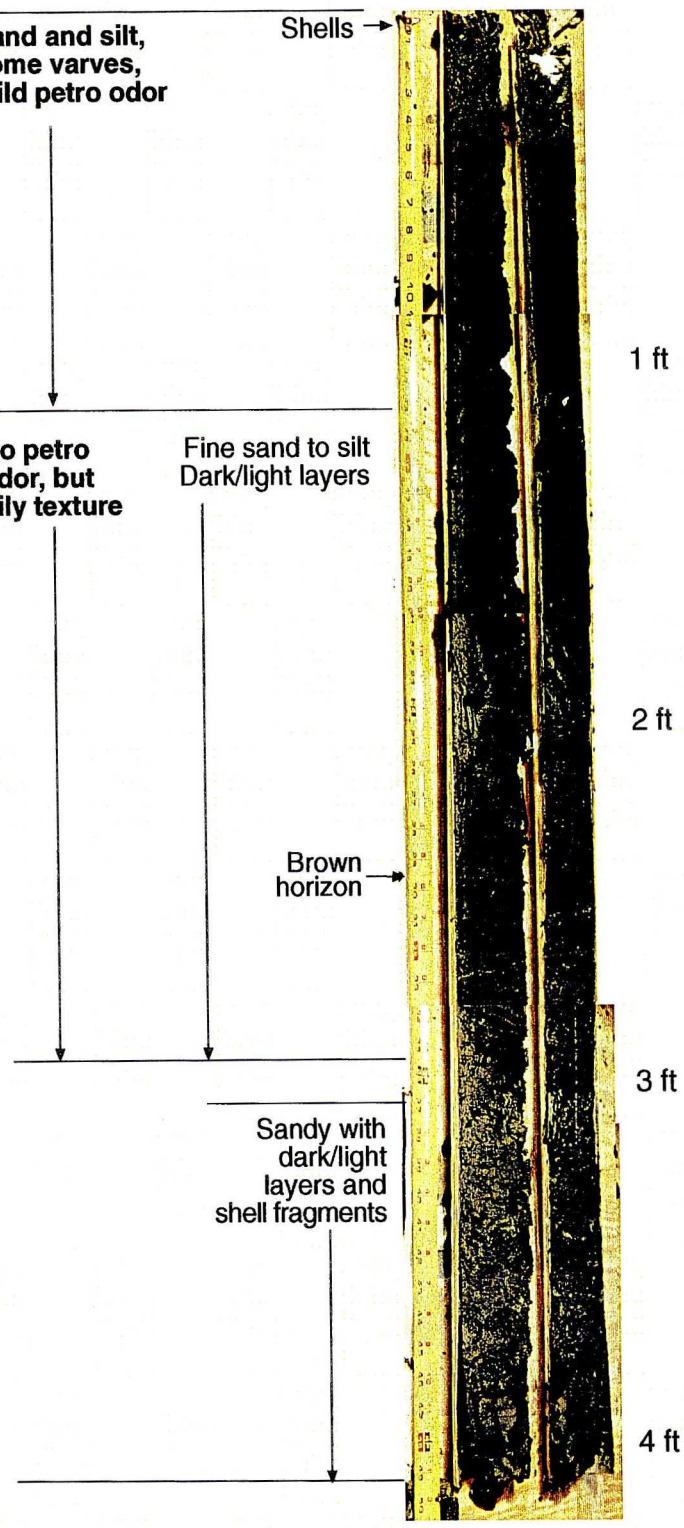

Figure C-8.
PHOTO COMPOSITE OF CORE
COLLECTED AT STATION H–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

I-M

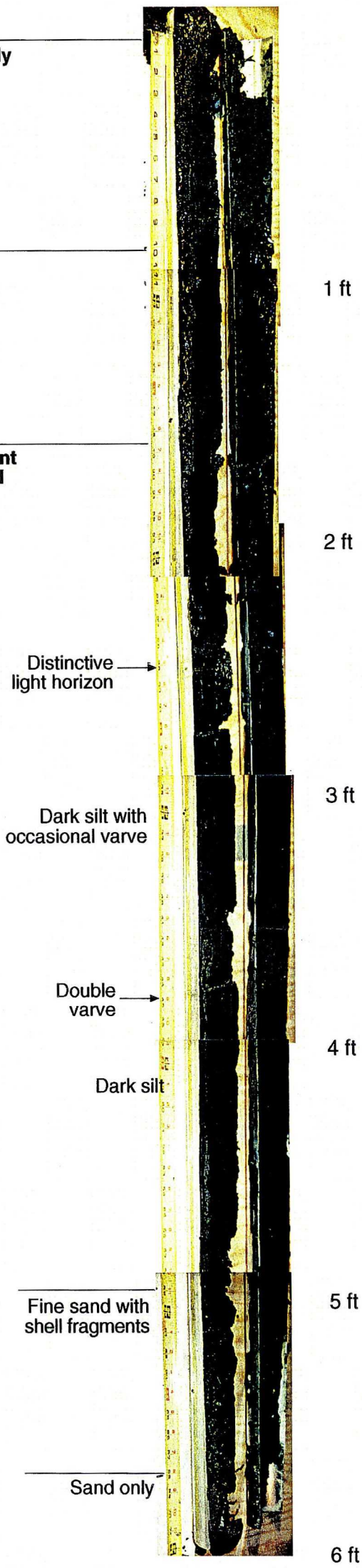

Figure C-9.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION I–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

J-M

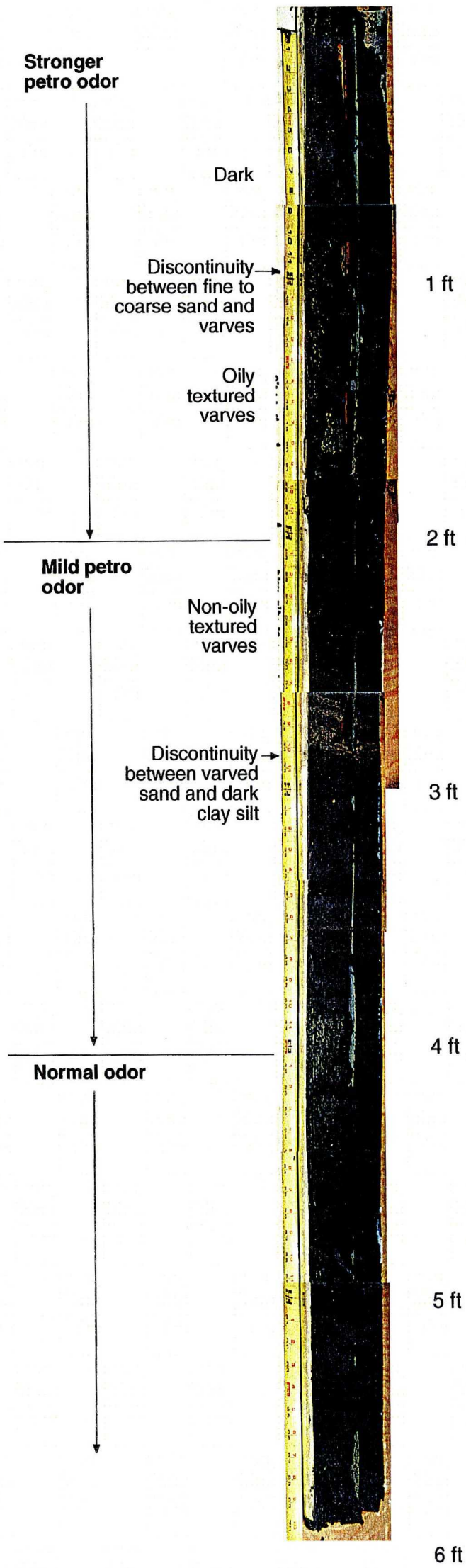

Figure C-10.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION J–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent

K-M

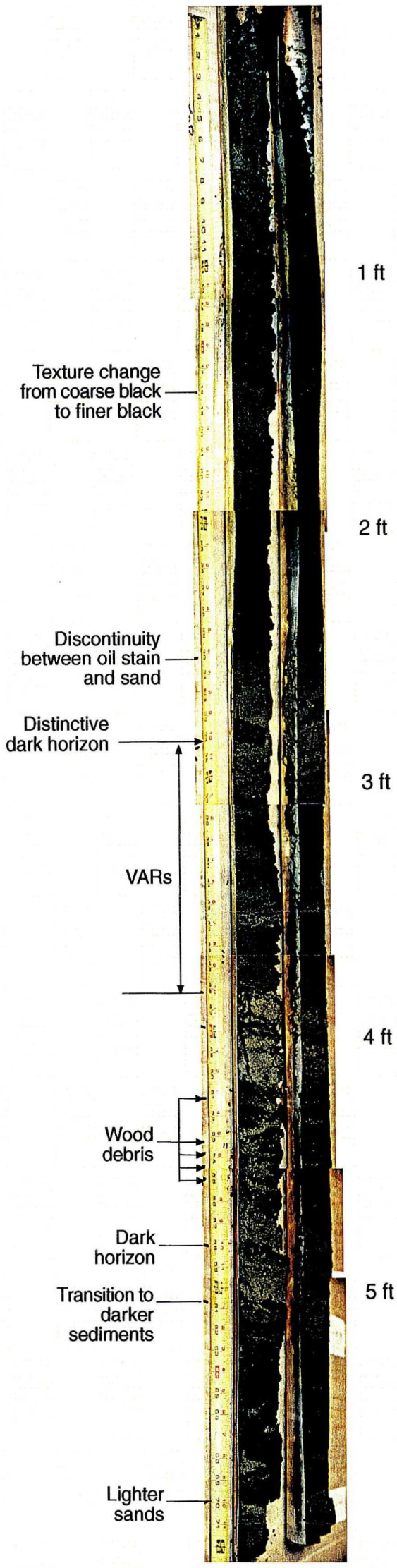

Figure C-11.
PHOTO COMPOSITE OF CORE COLLECTED AT STATION K–M.

DuPont East Chicago Facility
Sediment Characterization Study

Charge number: 8601058.001 0501
Date prepared: 08/23/99
Prepared by: Betty Dowd

Exponent