

WEST BRANCH
OF THE GRAND CALUMET RIVER
LAKE COUNTY, INDIANA

FINAL

SITE CHARACTERIZATION REPORT

August 2003
Revision 1

Prepared by

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Contract No.: FWS 1448-98695-98-C008
Task Order No. 02-Y037

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ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
atm-m ³	atmospheres cubic meter
ATSDR	Agency for Toxic Substances and Disease Registry
AVS	Acid Volatile Sulfide
bp	boiling point
C _c	Compression Index
CAD	Confined Aquatic Disposal
CAS	Columbia Analytical Services
cm	centimeter
CdS	Greenockite
COCs	Condensable Organic Compounds
CS	Core Sediment
CSM	Conceptual Site Models
CSO	Combined Sewer Overflow
CDF	Confined Disposal Facility
DAF	Dissolved Air Flotation
DDD	dichloro-diphenyl-dichloro-ethane
DDE	dichloro-diphenyl-dichloro-ethylene
DDT	dichloro-diphenyl-trichloro-ethane
DGPS	Differential Global Positioning System
DNAPL	Dense Non-Aqueous Phase Liquids
DRET	Dredging Elutriate Test
EBGCR	East Branch of the Grand Calumet River
Eh	Redox potential
EM	Engineer Manual
EPA	U.S. Environmental Protection Agency
Fe-Mn	iron-manganese
Foster Wheeler Environmental	Foster Wheeler Environmental Corporation
FW	Foster Wheeler Environmental
FSAP	Field Sampling and Analysis Plan
GC/MS	gas chromatography/mass spectrometry
GCR	Grand Calumet River

ACRONYMS AND ABBREVIATIONS (CONTINUED)

GCRRF	Grand Calumet River Restoration Fund
HNTB	Howard, Needles, Tammer & Bergendoff
ICP	Inductively Coupled Plasma
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
IHC	Indiana Harbor Canal
IUPAC	International Union of Pure and Applied Chemistry
LCS	Laboratory Control Sample
LDC	Laboratory Data Consultants, Inc.
LNAPL	Light Non-aqueous Phase Liquids
LPAH	low molecular weight polynuclear aromatic hydrocarbons
MET	Modified Elutriate Test
µg/kg	micrograms per kilogram
mg/kg	milligrams per kilogram
MGP	manufactured gas plant
mp	melting point
MS	Matrix Spike
MSD	Matrix Spike Duplicate
NAD	North American Datum
NAPL	Non-Aqueous Phase Liquids
NAVD	North American Vertical Datum
NCDF	Nearshore Confined Disposal Facilities
NGVD	National Geodetic Vertical Datum
OD	Outer Diameter
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCF	pounds per cubic foot
PDR	Precision Depth Recorder
PEC	Probable Effect Concentrations
PSI	pound per square inch
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
R	Reach

ACRONYMS AND ABBREVIATIONS (CONTINUED)

RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
SEM	Simultaneously Extracted Metals
SOP	Standard Operating Procedure
SOW	Scope of Work
STI	Soil Technologies, Inc.
STL	Severn Trent Laboratories
STP	Sewage Treatment Plant
SVOC	semivolatile organic compound
T	Transect
TDL	Target Detection Limit
TOC	total organic carbon
TSS	Total Suspended Solids
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USCS	Unified Soil Classification System
USGS	U.S. Geological Survey
UU	Unconsolidated Undrained
VOC	volatile organic compound
WB	West Branch
WBGCR	West Branch of the Grand Calumet River
WES	Waterways Experiment Station

ACKNOWLEDGEMENTS

This document was compiled by Foster Wheeler Environmental Corporation (Foster Wheeler Environmental) under contract with the U.S. Fish & Wildlife Service (USFWS) in accordance with the requirements of the Scope of Work (SOW) for Task Order 02-Y037 of Contract 1448-98695-98-C008, dated August 5, 2002. This project was funded by The Grand Calumet River Restoration Fund (GCRRF) Council. Mr. Dan Sparks was the USFWS project manager; Dr. Jim Smith was the Indiana Department of Environmental Management (IDEM) council representative; Mr. Michael Mikulka was the U.S. Environmental Protection Agency, Region 5, council representative; Dr. Wayne C. Faatz was the Indiana Department of Natural Resources council representative; and Mr. Mark Herrenkohl was the Foster Wheeler Environmental project manager. The overall program manager for Foster Wheeler Environmental was Mark Griswold.

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1. INTRODUCTION

This site characterization report has been prepared by Foster Wheeler Environmental Corporation (Foster Wheeler Environmental) in accordance with the requirements of the Scope of Work (SOW) for Task Order 02-Y037 of Contract 1448-98695-98-C008, dated August 5, 2002. The report was prepared for the U.S. Fish & Wildlife Service (USFWS) Environmental and Facility Compliance Branch at the request and direction of the USFWS – Bloomington Field Office as part of the summary of the chemical, physical, and toxicological characterization of the West Branch of the Grand Calumet River (WBGCR), Indiana. The USFWS is acting as the contracting agency on behalf of the Grand Calumet River Restoration Fund (GCRRF) Council, which is composed of USFWS, Indiana Department of Environmental Management (IDEM), U.S. Environmental Protection Agency (EPA), and Indiana Department of Natural Resources (IDNR).

This report summarizes the historical and Phase 2 data collected in the field and analyzed by the chemistry and geotechnical testing laboratories following methods described in the Field Sampling and Analysis Plan (FSAP) and Quality Assurance Project Plan (QAPP) (Foster Wheeler Environmental 2002a, 2002b). The objective of this study was to conduct a bathymetry survey of the river and a topographic survey of the riverbanks and adjacent uplands, and to further characterize surficial and subsurface historical sediments within portions of the river. The results of these additional data will be used to complete a Restoration Alternatives Development and Evaluation Report for the WBGCR (identified as Phase 3).

1.1 PROJECT HISTORY AND SUMMARY

The Great Lakes Water Quality Agreement of 1978 identified the Grand Calumet River (GCR) and Indiana Harbor Canal (IHC) as one of 43 areas of concern having one or more specific impairments to beneficial uses of Great Lakes waters. The Agreement directed that a Remedial Action Plan (RAP) be developed and implemented at each area of concern in order to restore the beneficial uses. IDEM submitted a Stage 1 RAP to the International Joint Commission in 1991 and a Stage 2 RAP in 1997.

Following settlement with Industrial Users of the Hammond Sanitary District in February 1997, a Trust Agreement for GCRRF was established by a Memorandum of Understanding among EPA, USFWS, IDNR and IDEM. At this time, the GCRRF Council was established.

Payments to the GCRRF by settling parties were to address the effects of sediment contamination in the WBGCR.

1.1.1 Site History

The GCR comprises two east-west oriented branches that meet at the southern end of the Indiana Harbor Ship Canal. The site vicinity and project area are shown in Figure 1-1 (full-size figure contained in map pocket at the end of the report). The East Branch of the Grand Calumet River (EBGCR) originates at the Grand Calumet Lagoons, just east of the United States Steel Gary Works facility. The EBGCR flows west from this point for approximately 10 miles to its confluence with the IHC. The WBGCR usually flows both east and west, with a hydraulic divide typically present in the vicinity of the Hammond Sanitary District outfall just east of Columbia Avenue. Historically, the volume and direction of water flow through the river were determined by Lake Michigan water levels. During periods of high lake levels, flow may be to the west throughout the WBGCR. Drops in the level of Lake Michigan since 1997 have resulted in reduced water levels in the river.

Prior to about 1850, the GCR flowed east from a point near the GCR to the area now encompassed by Marquette Park in Miller, Indiana, where the river emptied into Lake Michigan. As the western end of the river was developed for navigation at the confluence with the Little Calumet River, the mouth of the GCR at Marquette Park became permanently closed by sand dunes. Construction of the IHC began in 1903. The U.S. Army Corps of Engineers (USACE) dredged the river in the late 1800s, keeping the river navigable on the western portion with movable bridges east to Hammond. USACE abandoned dredging of the river after 1895 due to the large volumes of waste being dumped, primarily from the slaughterhouse/packing plant. The river was navigable in the West Branch as far east as Columbia Avenue as late as 1917 (USACE 1997).

1.1.2 Environmental Setting

Approximately 2-1/2 miles of the WBGCR, located between Indianapolis Boulevard and the Indiana/Illinois state line, was evaluated in this study. Based on a preliminary analysis of potential remedial technologies, the physical site conditions, and waterway setting, Foster Wheeler Environmental divided the WBGCR into the following project reaches:

- Reach 1: from the Indianapolis Boulevard Bridge to the Interstate 90 Bridge,
- Reach 2: from the Interstate 90 Bridge to the Columbia Avenue Bridge,
- Reach 3: from the Columbia Avenue Bridge to the Calumet Avenue Bridge,

- Reach 4: from the Calumet Avenue Bridge to the Sohl Road Bridge,
- Reach 5: from the Sohl Road Bridge to the Hohman Avenue Bridge,
- Reach 6: from the Hohman Avenue Bridge to the railroad bridge, and
- Reach 7: from the railroad bridge to the Indiana/Illinois state line.

Phase 2 work and historical results presented in this report are discussed in relation to these divisions of the WBGCR.

1.2 PURPOSE OF STUDY

The review of existing information in the literature and databases in Phase 1 led to the identification of several data gaps that needed to be filled before the remedial alternatives evaluation process can be completed (Foster Wheeler Environmental 2002c). These data gaps included the following six types of data and information:

- 1) Bathymetric/topographic survey data
- 2) Preparation of engineering base drawings
- 3) Transfer of historical sediment core data to base drawings
- 4) Collection of additional core samples for chemical and physical property tests
- 5) Gathering information on access to the river for implementation of the Restoration Plan
- 6) Need for local sources of services and material

Foster Wheeler Environmental has addressed these data gaps in this study.

1.3 FIELD AND LABORATORY DATA REPORT ORGANIZATION

In addition to this introduction, the following sections are included in this report:

- Section 2 presents the field and laboratory methods used during sample collection and laboratory analysis.
- Section 3 summarizes the physical characteristics of the study area, including the results of the bathymetric and topographic surveys.
- Section 4 discusses the nature and extent of chemical concentrations in the river as well as the geotechnical properties of sediment collected during this investigation.

- Section 5 discusses the fate and transport of chemicals frequently detected in sediments.
- Section 6 presents recommendations for further study in Phase 3.
- Section 7 provides the references used to prepare this report.
- Appendix A provides the data tables.
- Appendix B includes photo documentation of cores and field events.
- Appendix C includes the core logs.
- Appendix D provides the chain-of-custody forms.
- Appendix E provides the data validation reports.
- Appendix F includes the laboratory data reports.
- Appendix G includes the WBGCR database.

2. METHODS

This section presents the field and laboratory methodology for completing the bathymetry, topography and sampling tasks for Phase 2. The objective of the bathymetry/topography surveys was to establish the topography of the riverbed and banks and adjacent uplands. The primary objective of the sediment sampling and analysis was to provide spatial resolution of contaminant distribution and collection of toxicity information necessary to develop and evaluate restoration alternatives in the WBGCR. Together, these data will be used to identify areas and volumes of sediment that may require active remediation or that may be appropriate for restoration.

2.1 UTILITY SURVEY/ACCESS

Access agreements for public and private property owners were acquired by IDEM prior to implementation of the fieldwork.

Foster Wheeler Environmental located and marked proposed sampling locations using a Trimble AG 132 Differential Global Positioning System (DGPS). Prior to commencing intrusive field activities, Foster Wheeler Environmental conducted a utility survey to identify all known underground utilities within the study area. Foster Wheeler Environmental used the information provided in the *Grand Calumet River/Indiana Harbor Ship Canal Sediment Sampling Project – Draft Utility Survey Results* (Maxim Technologies 1999) as the baseline for the utilities survey.

Based on the results of the Draft Utility Survey, up to five underground utilities were determined to be present within or near the study area. These included two 16-inch pipelines owned by Wolverine Pipeline, BP/Amoco/Badger Pipeline Company, Buckeye/NORCO Pipeline, and NIPSCO, and buried and overhead cables owned by Ameritech Telephone Company.

Foster Wheeler Environmental contacted each of the utilities known to have pipelines/cables present in or near the study area prior to mobilization to confirm the pipeline/cable locations. In addition, Foster Wheeler Environmental contacted the Indiana Underground Plant Protection Service or “one-call service” at 1-800-382-5544 two business days prior to the start of field activities. A Foster Wheeler Environmental representative attended an on-site meeting with the utility locators on October 11, 2002, and had the locations of all known underground utilities marked and recorded on a site map.

The utilities present for the on-site locate meeting included Wolverine Pipeline, Ameritech Telephone Company, NIPSCO, Westshore Pipeline, and Buckeye/NORCO Pipeline. The description of each location is included below.

Wolverine Pipeline: Foster Wheeler Environmental met Mr. Ken Dybel of Wolverine Pipeline (815-838-8160). Mr. Dybel located a river crossing of underground pipelines in Reach 1 approximately 100 feet (ft) east of the I-90 Bridge. He was able to flag the pipelines up to the water's edge on both sides of the river and was present during sample collection of the nearest transect (WB-7, 8, and 9). Sample locations were moved east to avoid pipelines.

Ameritech Telephone Company: Foster Wheeler Environmental met Mr. Jack Coughlin on site to locate cable in the area. The first river crossing occurs in Reach 1 above ground in a conduit alongside Indianapolis Boulevard Bridge. The cables were buried underground approximately 100 ft from the bank of the river on both the north and south sides. It shows on his map as being between 24 and 58 ft below ground. No sample locations were proposed closer than 200 ft to the bridge. The second crossing occurred in Reach 5, below ground approximately 100 ft east of Hohman Avenue Bridge. No samples were proposed in the vicinity.

NIPSCO: Foster Wheeler Environmental met Mr. Pat Seamster (877-390-8993) on site. Overhead utilities in Reach 1 were evident on the east side of the I-90 Bridge in the vicinity of the Wolverine and BP/Amoco pipelines. Sample locations were moved east to avoid utilities. A gas main was located underground approximately 50 ft west of Indianapolis Boulevard in Reach 1. No samples were proposed in that vicinity.

Westshore Pipeline: Foster Wheeler Environmental met Mr. Jerry Phillips (847-878-2531). The pipeline in the general vicinity was just east of Indianapolis Boulevard by the Sunoco station. This was not of concern since it was outside of the project area.

Buckeye/NORCO Pipeline: Foster Wheeler Environmental met Mr. Paul Meyers (219-924-4107). Two 8-inch pipelines cross the river in Reach 2 at Roxana Park. The crossing was well marked. No samples were proposed in that vicinity.

BP/Amoco Pipeline: Personnel did not arrive onsite for the original locate meeting. Foster Wheeler Environmental contacted Mr. Steve Reeder at BP/Amoco regarding their pipelines at 800-210-3844. Mr. Charles Ruffin (219-736-5866) arrived at the site for the first day of sampling. He was able to flag the pipelines from the access road to the edge of the river. The pipelines run in the same general direction as Wolverine, just east of the I-90 Bridge in

Reach 1. As previously discussed, the sample locations were moved east to avoid underground utilities. Amoco signs flag the routes of the underground pipes along Roxana Drive in Reach 1 and at the river crossing at Roxana Park in Reach 2.

All overhead utilities were avoided in a manner to provide a minimum of a 15-foot (ft) distance between overhead utilities and all sampling equipment, and underground utilities were avoided by moving sample locations if proposed locations occurred within 50 ft of the utilities.

2.2 SAMPLING PROCEDURES

The following sections describe the procedures used for navigation, sampling, and analysis for the sediment investigation.

2.2.1 Horizontal and Vertical Location Control

Sediment sampling stations were located using a Trimble Ag 132 DGPS and a computer running HYPACK[®] hydrographic survey software. Stations were located and marked with stacks during the bathymetric survey (discussed below). Actual locations where sediment cores were collected were recorded at the time of core collection. If it was necessary to move a station because it was not accessible by the coring raft or as requested by an onsite representative from USFWS or IDEM, the new location was surveyed.

To maintain system accuracy, land surveyors from Plum Tuckett and Associates established two or more accessible and recoverable survey control points per river reach. Generally two control points were established per reach: a vertical control point that was usually located at the base of a bridge or culvert where a staff gauge(s) was installed, and a horizontal control point that was established along the road or bridge at the end the reach. Quality control (QC) checks conducted by positioning the DGPS antenna on the horizontal control point, recording the differentially corrected location, and comparing the coordinates to the known land-surveyed coordinates verified that the DGPS was providing sub-meter positioning accuracy. Northing and easting coordinates were recorded in State Plane Indiana West, North American Datum (NAD) 83 coordinate system to the nearest 0.1 ft.

Vertical control parameters measured at all sediment sampling locations included depth to sediment if there was overlying water at a sample location and river surface elevation. The depth to sediment was measured before each sampling event, using a lead line, which consisted of an 8-pound mushroom anchor. The incremented and weighted tape was dropped to the bottom, pulled taut, and read to the nearest 0.1 ft.

After sampling was completed, the elevation of sediment at each sample point was determined from lead line sounding data and using the water surface elevations recorded at the vertical control points established by the land surveyors. Sediment elevations at the sampling locations were recorded in North American Vertical Datum 1929 (NAVD 29).

The following parameters were documented at every sample location:

- Horizontal location in NAD 83 state plane coordinates, as appropriate
- Depth to mud line (if overlying water)
- Time and date
- Surface elevation referenced to National Geodetic Vertical Datum 1929 (NGVD) 29

Parameters listed above were measured using combinations of the following:

- DGPS
- Lead line

2.2.2 Bathymetry Survey

Bathymetric work in support of the characterization of the WBGCR was conducted in accordance with the applicable guidelines specified for navigation and dredging support surveys in USACE Engineer Manual (EM) 1110-2-1003 (USACE 2002). This section details the project-specific survey methods.

In open areas where DGPS positioning was reliable and the river could be navigated by a flat-bottom boat, an Innerspace 448 single-frequency (3rd, 208 KHz transducer) precision depth recorder (PDR) with shallow water modifications was used to record the acoustic bottom. A Trimble Ag 132 DGPS capable of providing location coordinates to an accuracy of ± 1.0 meter was used to determine horizontal position. Positions were differentially corrected in real time using a signal broadcast from a U.S. Coast Guard beacon. The DGPS and PDR were installed in a shallow-draft flat-bottom boat, which was powered by an electric motor. Data collected by the DGPS and PDR were recorded with HYPACK[®] hydrographic survey software.

During the bathymetric survey, the accuracy of the DGPS was verified by comparing the position determined by the DGPS to a position of known accuracy (i.e., a horizontal control point). No discrepancies greater than ± 1.0 meter between the DGPS recorded coordinates and the land-surveyed coordinates were observed. The USACE EM 1110-2-1003 requires that a minimum of two bar checks be performed each day that hydrographic surveying is

conducted, one prior to the start of the survey and one after completing surveying for the day. Calibrations are required at 5 ft intervals or a minimum of two depths if the water depth in the project area does not exceed 10 ft. Because the river was generally shallower than 1.5 ft, it was necessary to modify this requirement. For this survey, the PDR was calibrated to the depth determined by lead line.

In areas where the water was too shallow to use the PDR, depth measurements were made from a flat-bottom boat using a lead line. The boat was motored, paddled, or pulled across the river. In areas where the river was too shallow for the flat-bottom boat, the bathymetric survey crew donned snowshoes and walked up and down the river recording lead line measurements. The lead line consisted of an 8-pound mushroom anchor with a 6-inch-diameter crown attached to a line and survey tape measure. It was slowly lowered to the bottom, pulled taut, and read to the nearest 0.1 ft. Lead line measurements at sediment sampling locations were combined with the bathymetric survey data. The following data were recorded with each lead line sounding:

- Horizontal location in NAD 83 state plane coordinates, Indiana west (U.S. survey ft), recorded with DGPS
- Depth to mud-line (if overlying water was present)
- Time and date
- Surface elevation referenced to NGVD 29 (U.S survey feet)

Areas that could not be surveyed with a PDR include the west end of Reach 2 (approximately 550 ft east of the Columbia Avenue Bridge), the east end of Reach 3 (approximately 950 ft west of the Columbia Avenue Bridge), the east end of Reach 4 (approximately 50 ft west of Calumet Avenue Bridge), all of Reach 5, and the east and west ends of Reach 6 (approximately 50 ft west of the Holman Avenue Bridge and approximately 50 ft east of the railroad bridge). Soundings were taken as frequently as possible, but sounding density depended upon the shape of the river cross-section and the density of the river bottom. In many of the reaches, little change in water depth was encountered and fewer soundings were taken in these areas. In areas with greater variability in water depth, more closely spaced measurements were collected when it was possible and safe to do so. In many of the reaches, the density of the sediment did not support the weight of a surveyor. In these areas, data from the topographic survey and the aerial survey were used to fill data gaps.

After the bathymetric survey and sampling effort were complete, the lead line measurement and PDR data were converted to elevations based on the water surface elevations recorded at the vertical control points established by the land surveyors.

2.2.2.1 Water Surface Elevation

River water surface elevations were measured and recorded from staff gauges that were installed at either end of each river reach. The staff gauges were marked in increments of 0.1 ft and were referenced to NGVD 29. These gauges remained in place for the duration of the project and were left installed at the end of the field investigation. Water surface elevations were recorded daily, sometimes multiple times during the day, for the reach that was being surveyed. Recorded river surface elevations were used to correct bathymetric and lead line soundings to elevations. Figures 2-1 through 2-12 include locations for water surface elevation tide gauges. Tide gauge locations and elevations that were used for the survey include the following:

- Reach 1 surveyed elevation point 581.00 ft NGVD 29 was set at the 3.00 foot mark on the pre-existing staff gauge located on the west side of the Indianapolis Blvd. Bridge on the north side of the river.
- Reach 2 surveyed elevation point 583.33 ft NGVD 29 was set at the 3.33 foot mark on the pre-existing staff gauge located on the dock at the end of Roosevelt Street west of the I-90 bridge on the north side of the river (North of Roxana Park).
- Reach 4 East (used for Reach 3 water surface elevations) surveyed elevation point 580.64 ft NGVD 29 was set at the 2.00 foot mark on the staff gauge located on the west side of the walkway bridge, on the north side of the river, west of the Calumet Bridge. (The walkway bridge was temporary.)
- Reach 4 West (used for Reach 4 water surface elevations) surveyed elevation point 583.09 ft NGVD 29 is located at the top of the southernmost of three culverts at the west end of Reach #4, east of Sohl Ave.
- Reach 5 surveyed elevation point 582.54 ft NGVD 29 is located at the west end of Reach #5 on the box cut at the top of the headwall between two culverts, on the east side of Hohman Ave.
- Reach 6 surveyed elevation point 582.79 ft NGVD 29 is located at the east end of Reach #6 on the box cut at the top of the headwall between two culverts, on the west side of Hohman Ave.

- Reach 7 surveyed elevation point 582.28 ft NGVD 29 is located at the east end of Reach #7 on the box cut at the top of the headwall between four culverts, on the west side of the railroad tracks.

2.2.3 Topographic Survey

Plumb Tuckett and Associates conducted a topographic survey of the WBGCR study area. The survey area extended from the Indianapolis Boulevard Bridge to the Indiana-Illinois state line and from the waterline of the river up to a hard surface elevation such as a road or building. If no such features existed, the survey extended approximately 200 ft from the waterline. The equipment used in the topographic survey included a Topcon GTS 302 total station, a Sokkia B20 auto level, and a Leica system 500 real-time kinematic GPS unit.

The survey recorded the Easting, Northing, elevation, and description of a sufficient number of points to allow the generation of accurate topographic maps of the study area if such maps were required. In addition, significant topographic features within the survey area were mapped. These included manmade features, such as drainage ditches and roads, and natural features, such as ridges, streambeds, and breaks in slope. The topographic survey data were used to fill in any data gaps between the bathymetric data and the digital elevation data generated from aerial photographs.

The surveyors also determined the elevations of the staff gauges used to monitor water surface elevation in each river reach during surveying and sampling.

To supplement the land-based topographic survey, Chicago Aerial Survey conducted aerial photography and digital mapping of the study area. The aerial survey was conducted on December 10, 2002, and included the WBGCR and EBGCR boundaries. A digital terrain model with one-ft contours was developed for a corridor along the river approximately 600 ft wide. This work was performed in accordance with American Society for Photogrammetry and Remote Sensing standards.

Data from these three techniques (bathymetry, topographic, and photogrammatic) were integrated and form the basis of the evaluations presented in Figures 2-1 to 2-12.

2.2.4 Core Sample Collection for Chemistry Analysis

Foster Wheeler Environmental identified the approximate locations after review of the historical data available for the 2-1/2 miles of the river (Foster Wheeler Environmental 2002a). There are extensive surface and subsurface sediment data for Reach 6, which is located between the Hohman Avenue Bridge and the railroad bridges to the east (Figure 2-11);

therefore, further sampling by Foster Wheeler Environmental was not necessary. Sediment sampling was proposed at 51 locations (WB-1 through WB-51) to evaluate the nature and extent of contamination in Reaches 1, 2, 3, 4, 5, and 7, where historical sampling was sparse. Three station locations were distributed along transects within each of six river reaches. Proposed and actual locations are listed in Table 2-1. Each transect was numbered within each reach as indicated in Table 2-1 and on the sample location figures (Figures 2-1 through 2-12).

Core depth was proposed to range from 8 ft to a maximum of approximately 12 ft, or refusal. The primary objective of the subsurface sediment samples was to determine the vertical extent of sediment requiring remediation.

Subsurface sampling was performed using a vibracore coring system as the primary sample collection system. The vibracore is an electric system that vibrates and drives a length of 4-inch outer diameter (OD) aluminum tube into the sediment. A continuous sediment sample was retained within a cellulose acetate butyrate (CAB) tube liner with the aid of a stainless steel core cutter/catcher. Prior to sampling, the core catcher was decontaminated following the procedures outlined in Section 3.12 of the FSAP. A new decontaminated core tube and liner were used for each station and core.

The vibracore coring system was capable of collecting a continuous core to the maximum sediment depth expected at the site, 12 ft. The standard 4-inch-diameter core tube provided sufficient volume of sediment for analysis of intervals of 2 ft, the proposed sampling interval in the FSAP. Vibracore sampling procedures are outlined in standard operating procedure (SOP) 4 of Appendix A of the FSAP.

2.2.4.1 Core Sample Acceptability

Depth of penetration versus depth of recovery was closely monitored during the collection of the cores. During core collection, penetration and sediment retention were measured to the nearest tenth of a foot. The core tube was monitored during extraction to evaluate if sediment was lost. After the core was extracted, the core catcher was inspected for rocks or other obstacles that may have plugged the core while penetrating. Caution was taken to prevent disturbance of the surface of the sediment when the core was laid at an angle during removal from the drive head. Cores were rejected if it was determined that sediment was lost, the core catcher was plugged, or there was doubt about their representativeness. The actual penetration depth and sample recovery were compared and documented on core log forms. A sample recovery of 75 percent or greater was considered acceptable and representative of an individual location.

Table 2-1. Sediment Core Locations

Location ID	Reach	Transect	Proposed Northing (NAD 83)	Proposed Easting (NAD 83)	Actual Northing (NAD 83)	Actual Easting (NAD 83)	Actual UTM Easting (UTM)	Actual UTM Northing (UTM)	Mud Line Elevation (NGVD 29)	<i>In situ</i> Core Depth (ft bgs) ^U
WB-01	1	2	2319560	2843667	2319865.7	2843535.9	459780.9	4607305.71	577.5	11
WB-02 *	1	2	2319549	2843626	2319857.5	2843505.1	459771.53	4607303.23	577.8	11
WB-03	1	2	2319538	2843586	2319863.3	2843475.2	459762.39	4607304.98	578.7	11.9
WB-04	1	3	2320646	2842818	2320627.4	2842911.2	459590.78	4607537.97	578.4	11.3
WB-05	1	3	2320624	2842810	2320602.6	2842892.4	459585.03	4607530.43	578.2	10.6
WB-06	1	3	2320602	2842803	2320565.4	2842892.3	459585	4607519.09	578.5	11.9
WB-07	1	4	2320454	2841821	2320632.8	2841993.4	459311.14	4607539.9	576.9	11.5
WB-08	1	4	2320441	2841854	2320603.7	2841996.2	459311.98	4607531.03	577.9	11.4
WB-09 *	1	4	2320428	2841887	2320590.6	2842016.7	459318.24	4607527.01	578.7	11.5
WB-10	2	1	2319705	2841015	2319706.9	2840998.5	459007.72	4607258.07	579.3	11.4
WB-11	2	1	2319679	2841022	2319668.9	2841001.5	459008.64	4607246.49	577.6	11.4
WB-12 *	2	1	2319653	2841024	2319628.9	2841004.3	459009.46	4607234.29	578.8	10.9
WB-13	2	2	2319892	2839931	2319901.1	2839937.2	458684.43	4607317.57	579.2	11.4
WB-14	2	2	2319862	2839911	2319863.0	2839916.1	458677.99	4607305.94	578.3	11.5
WB-15	2	2	2319832	2839891	2319824.4	2839890.2	458670.08	4607294.19	579.2	11.4
WB-16	3	1	2320836	2838223	2320828.3	2838305.1	458187.41	4607600.53	~ 579.08	10.7
WB-17	3	1	2320812	2838223	2320801.5	2838317.6	458191.22	4607592.36	579.2	10.4
WB-18 *	3	1	2320788	2838223	2320776.3	2838311.7	458189.42	4607584.69	579.3	10.8
WB-19	3	2	2320908	2837511	2320927.9	2837530.4	457951.39	4607631.12	579.0	11
WB-20	3	2	2320889	2837511	2320893.3	2837521.9	457948.79	4607620.58	579.0	10.8
WB-21	3	2	2320869	2837510	2320852.9	2837512.1	457945.8	4607608.28	578.9	11
WB-22	3	3	2321140	2836759	2321153.4	2836764.6	457718.12	4607700.06	578.5	10.9
WB-23	3	3	2321125	2836753	2321132.0	2836767.8	457719.09	4607693.54	578.6	11
WB-24	3	3	2321109	2836747	2321097.7	2836744.8	457712.08	4607683.09	579.2	10.7
WB-25	4	1	2321486	2836210	2321501.0	2836232.8	457556.21	4607806.11	578.9	11.9
WB-26	4	1	2321468	2836200	2321464.6	2836209.2	457548.99	4607795.03	578.7	11.3
WB-27	4	1	2321450	2836190	2321435.9	2836188.2	457542.59	4607786.29	578.8	11.1

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Table 2-1. Sediment Core Locations (continued)

Location ID	Reach	Transect	Proposed Northing (NAD 83)	Proposed Easting (NAD 83)	Actual Northing (NAD 83)	Actual Easting (NAD 83)	Actual UTM Easting (UTM)	Actual UTM Northing (UTM)	Mud Line Elevation (NGVD 29)	In situ Core Depth (ft bgs) ^{1/}
WB-28	4	2	2321846	2835710	2321853.3	2835704.5	457395.33	4607913.63	578.6	10.8
WB-29 *	4	2	2321831	2835701	2321829.4	2835697.6	457393.23	4607906.33	577.9	10.5
WB-30	4	2	2321815	2835693	2321816.9	2835690.3	457390.98	4607902.53	578.4	10.4
WB-31	5	1	2322270	2834860	2322303.8	2834352.8	456983.61	4608051.27	577.3	10.4
WB-32	5	1	2322252	2834853	2322277.2	2834839.4	457131.86	4608043.02	~ 579.28	10.8
WB-33	5	1	2322234	2834845	2322249.3	2834826.4	457127.9	4608034.52	~ 582.46	11
WB-34 *	5	2	2322522	2834476	2322548.4	2834461.3	457016.75	4608125.79	577.4	11
WB-35	5	2	2322508	2834468	2322523.8	2834452.8	457014.16	4608118.28	577.6	11.3
WB-36	5	2	2322495	2834460	2322497.3	2834440.9	457010.51	4608110.22	577.7	11.3
WB-37	7	1	2323309	2832778	2323307.9	2832863.0	456529.98	4608357.67	577.1	11
WB-38	7	1	2323299	2832778	2323294.9	2832856.0	456527.86	4608353.7	575.9	10.4
WB-39	7	1	2323289	2832778	2323271.3	2832860.4	456529.17	4608346.51	575.9	10
WB-40	7	2	2323435	2832088	2323421.0	2832310.0	456361.51	4608392.28	576.5	10.8
WB-41	7	2	2323424	2832087	2323378.3	2832301.8	456359.01	4608379.28	575.9	9.4
WB-42	7	2	2323414	2832086	2323355.2	2832291.0	456355.72	4608372.25	577.2	11.7
WB-43	1	1	2319215	2843914	2319219.8	2843900.8	459891.89	4607108.8	578.3	11.5
WB-44	1	1	2319191	2843899	2319193.8	2843879.2	459885.3	4607100.89	577.8	11
WB-45	1	1	2319167	2843883	2319167.7	2843865.7	459881.19	4607092.95	578.3	11.4
WB-46	2	3	2320507	2839314	2320500.1	2839349.9	458505.64	4607500.24	579.0	11
WB-47	2	3	2320476	2839296	2320460.4	2839321.7	458497.04	4607488.14	579.3	11.4
WB-48	2	3	2320444	2839279	2320420.3	2839284.5	458485.7	4607475.95	579.1	11.1
WB-49 *	7	3	2323501	2831742	2323449.6	2831962.3	456255.58	4608401.09	577.1	11
WB-50	7	3	2323492	2831741	2323423.9	2831967.4	456257.15	4608393.28	576.0	8.7
WB-51	7	3	2323483	2831740	2323408.5	2831971.7	456258.43	4608388.59	~ 577.82	11

* Indicates Geotech core collected

~ Indicates elevation estimated from topography map

1/ Depths are in ft bgs (feet below ground surface); the depths were corrected for compaction from the logged core lengths.

Sediment depth and stratigraphy within the core were used to determine if the desired depth had been sampled. If recovery was below 75 percent or the core showed signs of disturbance, another coring attempt was usually made at that station. The longer core of the two was logged and analyzed. Cores from five station locations were collected with recoveries less than 75 percent; these cores are described in more detail in Section 2.2.9.

2.2.4.2 Core Compaction

Compaction of the sediment that occurred during the coring process was assessed by calculating the percent sediment recovery for each core. Compaction was assumed to be linear for the entire core and was estimated by dividing the measured sediment recovery by the measured core penetration depth. The resulting percent recovery was applied to the measured features and intervals in each recovered core to account for compaction. Both the recovered/observed and expanded cores are shown on the core logs in Appendix C.

2.2.5 Geotechnical Sample Collection

Prior to the field investigation, review of the existing historical data determined that insufficient geotechnical data were available to evaluate the engineering properties of the sediment that will be needed for remedial alternatives analysis and design. The sediment characteristics help in determining the range of dredging equipment and the capacity of the sediments to support equipment and placement of an isolation cap. Sediment samples from seven coring locations were selected for geotechnical testing. Geotechnical cores were collected using a vibrocore at locations indicated in Table 2-1.

2.2.6 Surface Water Sample Collection

Surface water samples were collected from two representative locations in the river (one on each side of the Hammond Sanitary District) as supply water for the column settling and elutriate tests. The first water sample was collected from the western end of Reach 1 (FW-WB-WS-1) and was used for composite samples from Reaches 1 and 2 for elutriate and column settling tests. The second water sample (FW-WB-WS-2) was collected in Reach 4 and was used for composite samples from Reaches 3 and 4 for elutriate testing and column settling, and Reaches 5 and 7 for elutriate testing.

The water was collected from approximately 6 inches to 1 foot below the water surface but above the bottom using a peristaltic pump with weighted Teflon-lined tubing. A total of 60 liters of water was required for each column-settling test. Approximately 4 liters of water were required for the elutriate testing at each location. Water for the column-settling test was

stored in pre-cleaned polyethylene containers. Water for chemical and elutriate testing was collected and stored in pre-cleaned 1-liter amber glass bottles.

Prior to delivery to the laboratories, water carboys and bottles were stored on ice in coolers at the field processing area to maintain a temperature of approximately 4°C. The containers of water were delivered to the appropriate laboratories and either analyzed or stored in a refrigerator at approximately 4°C until the initiation of elutriate and column-settling testing.

2.2.7 Core Processing

After the core was removed from the drive head but before the tube was cut, the tube was marked with an indelible marker identifying the station. As soon as possible after collection, the cores were transported to the processing area located in Roxana Marsh, where logging, sample processing, and sub-sampling were completed. Core sections collected for chemical sampling were extruded at the core processing station by cutting the CAB liner. Each subsurface core was logged using the visual-manual classification method described in American Society for Testing and Materials (ASTM) D 2488. Each core was photographed and divided up into intervals depending on stratigraphy. Sediment within the cores was visually classified, and changes from the top to the bottom of each section of the tube were noted and recorded on the core log sheets. A minimum of two samples was taken from each sample location. If multiple sediment strata were encountered, additional sediment intervals were collected and archived for future analysis, if needed. These archived samples can be used to fill data gaps if the extent of contamination was not reached.

Sediment intervals were processed according to the following step-by-step procedure:

1. Transferred sediment section from core to a clean stainless steel bowl and covered with aluminum foil.
2. Stirred the sample until there was uniform color and texture. If any material (e.g., shells, rocks) had to be removed from the sample, it was noted in the field logbook or on the sample description sheet.
3. Jars for physical, chemical, and biological analyses were filled.
4. Each glass container was put in a plastic bag and then placed in cooler with ice. Samples were packed to minimize the chances of breaking.
5. Decontaminated the equipment.

Sediment chemical characterization consisted of core increments from 51 locations within the six river reaches. Severn Trent Laboratories (STL) of Chicago, Illinois (STL-Chicago)

analyzed a total of 104 sediment core increments for chemistry parameters listed in Table 2-2 except for polychlorinated biphenyl (PCB) congeners. STL of Knoxville, Tennessee (STL-Knoxville) analyzed 18 core increments for PCB congeners. Additional sediment was required for laboratory quality assurance (QA) samples (i.e., matrix spikes). Matrix spikes (MS)/matrix spike duplicates (MSD) were collected and analyzed at a frequency of 1 per 20 field samples. Field duplicates were also collected periodically throughout the sampling program at a frequency of 1 per 20 field samples. Equipment rinse blanks were collected once a day.

Table 2-2. Analytical Methodology and Target Detection Limits (TDL) for Sediment Samples

Parameters	Analysis	Sediment Target Detection Limit^a
Conventionals		
TOC	EPA SW 9060M	500 mg/kg
Inorganic		
RCRA Metals plus Cu and Zn	SW846 6010B, 7471A	0.2 – 5 mg/kg
Oil and Grease	SW846 9071A	500 mg/kg
AVS-SEM	EPA Draft 1629	0.002 – 0.02 μ mole/g
Organics		
PCB Aroclors ^b	SW846 8082	60-160 μ g/kg
PCB Congeners ^c	SW846 8082	1-2000 μ g/kg
Pesticides	SW846 8081A	8-80 μ g/kg
SVOCs	SW846 8270C	330 μ g/kg

(a) Detection limits are on wet weight basis. Detection limits on dry weight basis are dependent on total solids content.

(b) PCB Aroclors analyzed include 1016, 1221, 1232, 1242, 1248, 1254, 1260. Detected Aroclors are summed to find total PCBs.

(c) PCB Congeners analyzed include 56 congeners.

Notes: Samples with high moisture contents or matrix interference may have detection limits higher than those listed.

EPA test methods are found in SW-846. Test methods for the evaluation of solid waste physical/chemical methods.

TOC = total organic carbon

RCRA = Resource Conservation and Recovery Act

AVS = acid volatile sulfide

SEM = simultaneously extracted metals

PCB = polychlorinated biphenyl

Cu = copper

Zn = zinc

SVOC = Semivolatile organic compound

Sediment was set aside in 1-liter glass jars for elutriate testing and in buckets for column-settling testing. Representative portions of each reach were sampled for later compositing in the laboratory. Columbia Analytical Services (CAS) analyzed the site water, composites, and elutriate samples for chemistry parameters listed in Table 2-5.

2.2.8 Sample Identification

Core sediment samples were assigned an individual sample identification number in the following manner:

FW-WB-##-CS-## - ##

Where: FW = Foster Wheeler Environmental

WB-## = WBGCR Station ID

CS = Core sediment

- ## = top and bottom depths of core increment in feet

Water samples, field blanks, and sediment composite samples were assigned an individual sample identification number in the following manner:

FW-WB-WS-## — Where WS-## = Water Sample Number

FW-WB-FB-## — Where FB-## = Field Blank Sample Number

FW-WB-Comp-## — Where Comp-## = Composite Sample Number for elutriate testing

CS-Comp-# — Where CS is Column-Settling Test Composite Number.

2.2.9 Deviations from the FSAP

Methods described in the FSAP were followed for collecting bathymetry data and topography data. Sediment cores were collected and processed as required by the plan, although five cores had recoveries less than 75 percent, as described below.

Cores with recoveries below 75 percent were collected from stations WB-23, 24, 32, 33, and 51. The recoveries for cores collected at WB-23 and 24, located in Reach 3, Transect 3, were 72 and 74 percent, respectively. In both cores, what was thought to be native material was encountered, so the cores were accepted and sub-sampled. The recovery for the core collected at WB-32 was 63 percent. This core was located in Reach 5, Transect 1. Due to limited access (low water prevented use of the coring raft) and presence of non-aqueous phase liquid (NAPL) in the area, the core was accepted and sub-sampled. Also, WB-33 located in Reach 5, Transect 1, had a low recovery, 70 percent. There seemed to be little disturbance in the sediment of the core, and it appeared that the native material was reached. Due to the limited access, this core was accepted and sub-sampled. The core collected at WB-51 in Reach 7, Transect 3, had a recovery of 74 percent. The access at this location was restricted due to low water levels, preventing use of the coring raft, so the core was accepted and sub-sampled.

Several proposed core locations were relocated during the field investigation. Transect 4 on the west end of Reach 1 was moved 200 ft east due to the presence of underground utilities. In Reach 2, Transect 3 was moved east approximately 25 ft due to shallow water preventing accessibility for sampling equipment. All of the transects on Reach 7 were adjusted. Transect 3 was moved east approximately 200 ft to the state line; therefore, Transect 2 was moved 200 ft east to compensate for spatial distribution of samples. Transect 1 in Reach 7 was moved west approximately 125 ft because the coring raft would not fit underneath the railroad bridge. Table 2-1 includes proposed versus actual sampling locations.

2.3 LABORATORY ANALYSES

This section describes the laboratory procedures associated with physical and chemical testing applicable to this project in accordance with the Technical Specifications for the GCRRF Council (GCRRF 2001) and the project QAPP.

2.3.1 Sediment Chemistry Protocols

A total of 104 sediment samples (refer to Section 2.3.5) were analyzed by STL Chicago for the chemistry parameters listed in Table 2-2. A total of 18 sediment samples were analyzed for PCB congeners. Analytical methods are listed for each compound or compound group with additional method and QA information provided in Section 6 of the QAPP.

2.3.2 Geotechnical Testing

After sampling in the field, all sediment samples for geotechnical analyses were shipped to Soil Technology, Inc. (STI) of Bainbridge Island, Washington, per ASTM 4220.

The suite of geotechnical laboratory tests will be used to evaluate dredging and capping methods, dredged material transport and placement, dredge material behavior in the disposal site, potential short-term impacts at the dredge and disposal sites, and capacity of existing sediments to provide foundation support for capping material.

All geotechnical soil testing was performed by STI. Table 2-3 indicates the tests and standard methods used to test the selected field samples. Table 2-4 includes the schedule of geotechnical testing performed on selected field samples. The testing schedule is also reflected on the coring logs included in Appendix C. A total of 76 field samples from 38 cores were analyzed for geotechnical testing. In addition, three duplicate samples and five composite samples were evaluated for geotechnical index parameters.

Table 2-3. Geotechnical Methodology and Target Detection Limits (if applicable)

Parameters	Method	Sediment Target Detection Limit
Grain Size	ASTM D 422-63 with Hydrometer	0.1% retained
Atterburg Limits	ASTM D 4318-95	NA
Specific Gravity	ASTM D 854-92	NA
Bulk Density	USACE EM 1110-2-1906, Appendix II	NA
Moisture Content	ASTM D 2216	NA
Direct Shear	ASTM D 3080	NA
UU Triaxial Shear Strength	ASTM D 2850-95 with modifications in USEPA/USACE 1998	NA
Consolidation	ASTM D 2435-90	NA

ASTM = American Society for Testing and Materials

USACE = U.S. Army Corps of Engineers

EM = Engineering Manual

UU = unconsolidated, undrained

NA = not applicable

2.3.3 Contaminant Mobility Testing

Mobility and dredgeability testing was performed on representative sediments in the WBGCR to provide an assessment of contaminant mobility during dredging and placement operations (Table 2-5). The dredging elutriate test (DRET) and modified elutriate test (MET) are used to predict the potential short-term contaminant release at the point of dredging and at the point of disposal. The MET is used to predict the quality of effluent from the filling of an upland or nearshore confined disposal facility or dewatering facility using hydraulic dredging. These data may be required for final design if a temporary stockpile or other dredged material confinement is required during transfer to final disposal, or for a confined disposal alternative. The DRET method is particularly effective for examining the short-term impacts at the point of dredging. This test is required for point of dredging assessment. The tests were conducted in accordance with Waterways Experiment Station (WES) recommended procedures (USACE 2003, EPA/USACE 1998; DiGiano et al. 1995).

Representative sediment from all six reaches were collected for elutriate testing. A total of four composites were homogenized at STI for elutriate testing, including composites from Reaches 1, 2, 3/4, and 5/7. A sub-sample of each of the four composites was sent to CAS for analytical testing of the parameters in Table 2-5. The MET and DRET test were completed on each composite at STI, then the elutriate was sent to CAS for analysis of total and dissolved fractions of all parameters listed in Table 2-5. Samples comprising each composite are listed in Table 2-6.

Table 2-4. Geotechnical Laboratory Testing Schedule

Sample Location Identification Number	Sample Depth (ft)	Grain Size	Atterberg Limits	Specific Gravity	Bulk Density	Moisture Content	UU Shear Strength	Direct Shear	Consolidation
FW-WB-02-CS	2.9-6.0	X	X	X	X	X			
FW-WB-02-GEO	3.0-5.0						X		X
FW-WB-02-GEO	6.0-7.6						X		X
FW-WB-03-CS	9.5-11.2	X							
FW-WB-05-CS	7.5-10.0	X							
FW-WB-07-CS	2.0-4.0	X	X	X	X	X			
FW-WB-07-CS	7.1-9.4	X	X	X	X	X			
FW-WB-08-CS	0.0-2.0	X	X	X	X	X			
FW-WB-08-CS	4.0-7.6	X	X	X	X	X			
FW-WB-09-GEO	3.8-5.5						X		X
FW-WB-09-GEO	7.8-9.5						X		X
FW-WB-10-CS	0.0-3.2	X	X	X	X	X			
FW-WB-10-CS	3.2-6.0	X	X	X	X	X			
FW-WB-12-GEO	3.5-5.0						X		X
FW-WB-12-GEO	5.0-6.5						X		X
FW-WB-12-GEO	6.5-7.8							X	
FW-WB-13-CS	4.0-6.1	X	X	X	X	X			
FW-WB-13-CS	6.1-9.6	X	X	X	X	X			
FW-WB-16-CS	1.9-5.2	X	X	X	X	X			
FW-WB-17-CS	0.0-3.8	X							
FW-WB-18-GEO	4.5-6.0						X		X
FW-WB-18-CS	6.5-9.3	X							
FW-WB-18-GEO	7.5-9.0							X	
FW-WB-20-CS	2.8-5.5	X	X	X	X	X			
FW-WB-21-CS	0.0-3.5	X							
FW-WB-21-CS	3.5-6.0	X							
FW-WB-22-CS	3.6-6.0	X							
FW-WB-22-CS	6.0-8.2	X							
FW-WB-23-CS	0.0-2.7	X	X	X	X	X			
FW-WB-23-CS	4.3-6.5	X							
FW-WB-25-CS	5.9-7.7	X	X	X	X	X			
FW-WB-27-CS	6.9-8.2	X							
FW-WB-28-CS	0.0-7.0	X	X	X	X	X			
FW-WB-29-GEO	5.0-6.4						X		X
FW-WB-29-GEO	6.6-7.6							X	
FW-WB-29-CS	6.6-8.8	X	X	X	X	X			

Table 2-4. Geotechnical Laboratory Testing Schedule (continued)

Sample Location Identification Number	Sample Depth (ft)	Grain Size	Atterberg Limits	Specific Gravity	Bulk Density	Moisture Content	UU Shear Strength	Direct Shear	Consolidation
FW-WB-30-CS	5.8-6.6	X	X	X	X	X			
FW-WB-31-CS	7.8-9.2	X							
FW-WB-32-CS	0.0-2.0	X	X	X	X	X			
FW-WB-32-CS	2.0-4.0	X	X	X	X	X			
FW-WB-34-GEO	2.0-3.5						X		X
FW-WB-34-CS	4.6-6.4	X							
FW-WB-34-GEO	5.0-6.3						--		--
FW-WB-34-GEO	6.3-7.9							X	
FW-WB-34-CS	6.4-8.7	X							
FW-WB-37-CS	5.7-8.0	X							
FW-WB-38-CS	7.2-8.4	X							
FW-WB-39-CS	3.1-5.3	X	X	X	X	X			
FW-WB-40-CS	6.9-9.5	X							
FW-WB-41-CS	4.7-6.1	X	X	X	X	X			
FW-WB-42-CS	1.5-6.0	X	X	X	X	X			
FW-WB-45-CS	2.0-3.9	X	X	X	X	X			
FW-WB-45-CS	6.9-10.0	X							
FW-WB-46-CS	2.0-5.2	X							
FW-WB-46-CS	5.2-8.0	X							
FW-WB-47-CS	0.0-2.4	X							
FW-WB-47-CS	5.0-6.8	X							
FW-WB-48-CS	4.0-6.0	X	X	X	X	X			
FW-WB-49-CS	1.6-4.5	X	X	X	X	X			
FW-WB-49-GEO	2.8-4.5						X		X
FW-WB-49-GEO	5.2-7.0						X		X
FW-WB-50-CS	5.0-7.8	X	X	X	X	X			
FW-WB-51-CS	6.0-8.1	X							
FW-WB-60-CS	6.1-9.6	X	X	X	X	X			
FW-WB-61-CS	6.0-8.2	X							
FW-WB-62-CS	6.9-9.5	X							
FW-WB-COMP-1		X	X	X	X	X			
FW-WB-COMP-3		X	X	X	X	X			
FW-WB-COMP-4		X	X	X	X	X			
CS-COMP-1		X	X	X	X	X			
CS-COMP-2		X	X	X	X	X			

Table 2-5. Analytical Methodology and Target Detection Limits for Contaminant Mobility Testing

Parameters	Analysis	Sediment TDL
Column Settling	USEPA/USACE 1998	NA
Dredge Elutriate Test	DiGiano et al. 1995	NA
Modified Elutriate Test	USEPA/USACE 1998	NA
Parameters	Analysis	Water TDL
Conventionals		
TOC/DOC	EPA 415.1	0.5 mg/L
TSS	EPA 160.2	5 mg/L
RCRA Metals^a		
Arsenic	EPA 200.8	50 µg/L
Barium	EPA 200.8	50 µg/L
Cadmium	EPA 200.8	1 µg/L
Chromium	EPA 200.8	5 µg/L
Copper	EPA 200.8	1 µg/L
Lead	EPA 200.8	1 µg/L
Mercury	EPA 245.2	0.5 µg/L
Selenium	EPA 270.2	2 µg/L
Silver	EPA 200.8	1 µg/L
Zinc	EPA 200.8	50 µg/L
Organics		
PCB Aroclors ^b	SW846 8082	0.010 µg/L
Chlorinated Pesticides	SW846 8081	0.001 µg/L for DDT and derivatives ^c
SVOC	SW846 8270	10 µg/L

(a) RCRA = As, Ba, Cd, Cr, Pb, Hg, Se, Ag plus Cu and Zn

(b) PCB Aroclors analyzed include 1016, 1221, 1232, 1242, 1248, 1254, 1260. Detected Aroclors were summed to find total PCBs.

(c) Chlordane = 0.004 µg/L, toxaphene = 0.0002 µg/L, endrin = 0.030 µg/L, heptachlor/heptachlor epoxide = 0.003 µg/L, and all others 0.050 µg/L or less. (Foster Wheeler Environmental 2002c)

EPA test methods are found in SW-846. Test methods for the evaluation of solid waste physical/chemical methods.

NA = not applicable

TOC = total organic carbon

DOC = dissolved organic carbon

SVOC = semivolatiles organic compound

Table 2-6. Composite Samples Analyzed for Elutriate Testing and Column Settling

Elutriate Testing Samples	Core Increments	Reach
Sediment Composite ID	FW-WB-02-CS-0-2.9	1
FW-WB-COMP-1	FW-WB-02-CS-2.9-6	1
	FW-WB-05-CS-2-4.2	1
Elutriate Sample ID	FW-WB-05-CS-4.2-7.5	1
FW-WB-COMP-1-DRET-T	FW-WB-08-CS-0-2	1
FW-WB-COMP-1-DRET-D	FW-WB-08-CS-2-4	1
FW-WB-COMP-1-MET-T	FW-WB-08-CS-4-7.6	1
FW-WB-COMP-1-MET-D	FW-WB-09-CS-0-2	1
	FW-WB-09-CS-2-4	1
	FW-WB-09-CS-4-6	1
	FW-WB-44-CS-0-1.2	1
	FW-WB-44-CS-2-4	1
Sediment Composite ID	FW-WB-11-CS-0-4	2
FW-WB-COMP-2	FW-WB-11-CS-4-6	2
Elutriate Sample ID	FW-WB-14-CS-0-2	2
FW-WB-COMP-2-DRET-T	FW-WB-14-CS-2-3.8	2
FW-WB-COMP-2-DRET-D	FW-WB-14-CS-3.8-6.2	2
FW-WB-COMP-2-MET-T	FW-WB-47-CS-0-2.4	2
FW-WB-COMP-2-MET-D	FW-WB-47-CS-2.4-5.6	2
Sediment Composite ID	FW-WB-23-CS-0-2.7	3
FW-WB-COMP-3	FW-WB-23-CS-2.7-4.3	3
	FW-WB-24-CS-0-2	3
Elutriate Sample ID	FW-WB-24-CS-2-4.2	3
FW-WB-COMP-3-DRET-T	FW-WB-24-CS-4.2-5.6	3
FW-WB-COMP-3-DRET-D	FW-WB-26-CS-0-5	4
FW-WB-COMP-3-MET-T	FW-WB-26-CS-5-6.5	4
FW-WB-COMP-3-MET-D	FW-WB-27-CS-0-5.4	4
	FW-WB-27-CS-5.4-6.9	4
	FW-WB-28-CS-0-7	4
Sediment Composite ID	FW-WB-31-CS-0-2.5	5
FW-WB-COMP-4	FW-WB-31-CS-4-6.5	5
	FW-WB-32-CS-0-2	5
Elutriate Sample ID	FW-WB-32-CS-2-4	5
FW-WB-COMP-4-DRET-T	FW-WB-35-CS-0-1.5	5
FW-WB-COMP-4-DRET-D	FW-WB-35-CS-1.5-5	5
FW-WB-COMP-4-MET-T	FW-WB-38-CS-0-5	7
FW-WB-COMP-4-MET-D	FW-WB-38-CS-5-7.2	7
	FW-WB-41-CS-0.8-4.7	7
	FW-WB-41-CS-4.7-6.1	7
	FW-WB-42-CS-0-1.5	7
	FW-WB-42-CS-1.5-6	7
	FW-WB-50-CS-0.9-2.3	7
	FW-WB-50-CS-2.3-5	7

Table 2-6. Composite Samples Analyzed for Elutriate Testing and Column Settling (continued)

Column Settling	Core Increment	Reach
CS-Comp-1 Used FW-WB-WS-1 as site water	FW-WB-01-CS-5-7	1
	FW-WB-02-CS-2.9-6	1
	FW-WB-03-CS-1.2-4	1
	FW-WB-03-CS-4-6	1
	FW-WB-04-CS-0-8	1
	FW-WB-05-CS-2.4-2	1
	FW-WB-05-CS-4.2-7.5	1
	FW-WB-06-CS-6-7.8	1
	FW-WB-07-CS-0-2	1
	FW-WB-08-CS-2-4	1
	FW-WB-08-CS-4-7.6	1
	FW-WB-09-CS-0-2	1
	FW-WB-09-CS-2-4	1
	FW-WB-09-CS-4-6	1
	FW-WB-45-CS-2-3.9	1
	FW-WB-10-CS-0-3.2	2
	FW-WB-10-CS-3.2-6	2
	FW-WB-11-CS-0-4	2
	FW-WB-12-CS-0-4	2
	FW-WB-12-CS-4-6	2
	FW-WB-13-CS-0-2.1	2
	FW-WB-13-CS-2.1-4	2
	FW-WB-13-CS-4-6.1	2
	FW-WB-14-CS-2-3.8	2
	FW-WB-14-CS-3.8-6.2	2
	FW-WB-15-CS-0.9-3	2
	FW-WB-15-CS-3-5	2
	FW-WB-46-CS-0-2	2
	FW-WB-46-CS-2-5.2	2
	FW-WB-47-CS-0-2.4	2
FW-WB-47-CS-2.4-5.6	2	
FW-WB-48-CS-0-1.8	2	
FW-WB-48-CS-1.8-4	2	
FW-WB-48-CS-4-6	2	
CS-Comp-2 Used FW-WB-WS-2 as site water	FW-WB-16-CS-0-1.9	3
	FW-WB-16-CS-1.9-5.2	3
	FW-WB-17-CS-0-3.8	3
	FW-WB-17-CS-3.8-5.6	3
	FW-WB-18-CS-0-3.7	3
	FW-WB-18-CS-3.7-6.5	3
	FW-WB-19-CS-0-2	3
	FW-WB-19-CS-2-4	3
FW-WB-19-CS-4-6	3	

Table 2-6. Composite Samples Analyzed for Elutriate Testing and Column Settling (continued)

Column Settling	Core Increment	Reach
	FW-WB-20-CS-0-2.8	3
	FW-WB-20-CS-2.8-5.5	3
	FW-WB-21-CS-0-3.5	3
	FW-WB-21-CS-3.5-6	3
	FW-WB-22-CS-0-1.9	3
	FW-WB-22-CS-1.9-3.6	3
	FW-WB-23-CS-0-2.7	3
	FW-WB-23-CS-2.7-4.3	3
	FW-WB-24-CS-0-2	3
	FW-WB-24-CS-2-4.2	3
	FW-WB-24-CS-4.2-5.6	3
	FW-WB-25-CS-0-4.4	4
	FW-WB-25-CS-4.4-5.9	4
	FW-WB-26-CS-0-5	4
	FW-WB-26-CS-5-6.5	4
	FW-WB-27-CS-0-5.4	4
	FW-WB-27-CS-5.4-6.9	4
	FW-WB-28-CS-0-7	4
	FW-WB-29-CS-0-5	4
	FW-WB-29-CS-5-6.6	4
	FW-WB-30-CS-0-1.2	4
	FW-WB-30-CS-3.1-4.9	4

Site water needed for the elutriate test was sent to CAS for chemical analysis for contaminants of concern listed in Table 2-5 to evaluate the concentrations prior to using it in the elutriate tests. Site water sent to STI was used in the elutriate tests, then sent to CAS for analysis for both dissolved and total contaminants of concern listed in Table 2-5.

Two column-settling samples were analyzed at STI, consisting of representative sediment from two reaches. The first column-settling sample, CS-Comp-1, contained sediment from Reaches 1 and 2 and the second column settling sample, CS-Comp-2, contained sediment from Reaches 3 and 4. Site water used in the column-settling test was analyzed at STI.

2.3.4 Bioassay Testing

Sufficient sample volume (i.e., 1 liter) of selected composite samples was collected and sent to U.S. Geological Survey (USGS) Biological Research Division, in Columbia, Missouri, for sediment toxicity testing. A 28-day survival and growth test using *Hyalella azteca* was performed. A total of 43 samples were tested during the Phase 2 sampling effort. The preliminary data report is included in Appendix F as a separate report prepared by the USGS.

2.3.5 Deviations from FSAP

Methods and reporting limits listed in the FSAP and QAPP were generally followed for the chemistry analysis. Exceptions to reporting limits occurred when dilution was necessary to reduce interference, or there was high moisture content. Reporting limits that were not met involved the background water samples analyzed by CAS for contaminant mobility testing. The two water samples were analyzed for all parameters listed in Table 2-5, but reporting limits were not met for selenium (5µg/L instead of 2 µg/L), PCB Aroclors (reporting limits ranged from 0.005 to 0.07 µg/L), pesticides (reporting limits ranged from 0.009 to 0.5 µg/L) and semivolatile organic compounds (SVOCs) (reporting limits ranged from 10 to 49 µg/L). There was insufficient volume of elutriate from samples FW-WB-COMP-2-MET-T and FW-WB-COMP-4-MET-T to adequately analyze all the parameters necessary for the MET. When site water was added to the sediment samples, the samples expanded, which reduced the final volume of elutriate. All analyses were performed except total organic carbon (TOC) and total suspended solids (TSS).

The unconsolidated, undrained (UU) triaxial shear strength and consolidation tests proposed for FW-WB-34-GEO-5.0-6.3 were not performed because the material was too sandy to qualify as cohesive soil. No samples were selected to substitute for the proposed samples.

Sediment from Reaches 5 and 7 were not included in the column-settling testing. These sediments had excessive NAPL materials and there was concern that they would cause irreparable harm to STI laboratory equipment.

Upon review of the QAPP, STL-Chicago returned comments on differences between methods and reporting limits required in the QAPP compared to the laboratory capabilities. The following items are not considered deviations from the FSAP or QAPP, but additional edits were needed according to the laboratory comments.

PCB Congeners

PCB congeners listed in Table 6-2 of the QAPP are correct, except 2,2',3,4,4',5-Hexachlorobiphenyl (PCB 137) was changed to 2,2',3,4,4',5'-Hexachlorobiphenyl (PCB 138).

PCB congener results are labeled with International Union of Pure and Applied Chemistry IUPAC numbers and compound names in Appendix A.1.

Reporting limits listed in Table 6-2 of the QAPP are incorrect for PCB congeners. At STL-Knoxville, the reporting limits for most PCB congeners was 100 µg/Kg, except for 4,4'-

dichlorobiphenyl, which had a reporting limit of 500 µg/Kg and 2-chlorobiphenyl and 4-chlorobiphenyl, which had a reporting limit of 2000 µg/Kg.

Laboratory QA/QC samples listed in Table 9-1 of the QAPP included MSB, QC Check Sample, and LCS for PCB congeners. These terms are interchangeable terms at STL-Knoxville and are referred to as LCS.

Total organic carbon (TOC) was analyzed by STL-Chicago using a modified SW846- 9060 method called Lloyd Kahn for the sediment samples. The Lloyd Kahn method and STL-Chicago SOP is included in Appendix F.1. STL-Chicago used Method SW846-9060 for water analysis, as specified in their comments to the QAPP.

The oil and grease reporting limit is 500 milligrams per kilogram (mg/kg), not 0.05 mg/Kg as listed in the QAPP.

STL-Chicago does not analyze for 1-4-Dinitrobenzene, 1,2,3,4-Tetrachlorobenzene, although it was listed in Table 6-2 of the QAPP.

Upon review of the QAPP, CAS had comments on parameters they were able to report as well as reporting limits they were able to meet. CAS comments are included in Appendix F.3. There were two different chemistry laboratories involved in the project (STL for sediment chemistry analysis and CAS associated with the geotechnical lab for contaminant mobility analysis); the two laboratories did not have the same parameter list nor the same reporting limits. When possible, the laboratory reported down to the method detection limit and qualified a quantifiable result between the reporting limit and method detection limit as estimated.

Figure 2-1. Sample Station Locations (Reach 1)

Figure 2-2. Sample Station Locations (Reach 1 and Roxana Marsh)

Figure 2-3. Sample Station Locations (Reach 1 and Roxana Marsh)

Figure 2-4. Sample Station Locations (Reach 2)

Figure 2-5. Sample Station Locations (Reach 2)

Figure 2-6. Sample Station Locations (Reach 2 and 3)

Figure 2-7. Sample Station Locations (Reach 3)

Figure 2-8. Sample Station Locations (Reach 3 and 4)

Figure 2-9. Sample Station Locations (Reach 4)

Figure 2-10. Sample Station Locations (Reach 5)

Figure 2-11. Sample Station Locations (Reach 6)

Figure 2-12. Sample Station Locations (Reach 7)

3. PHYSICAL CHARACTERISTICS

This section describes the physical characteristics of the WBGCR, including the geology, hydrogeology, hydrology, bathymetry, topography, and sediment stratigraphy.

3.1 REGIONAL GEOLOGIC SETTING

In northwest Indiana, the WBGCR lies within the Calumet Lacustrine Plain, a subdivision of the Northern Moraine and Lake Region, as defined by the Indiana Geological Survey (Schneider 1966). A flat to undulating surface that slopes gently toward Lake Michigan characterizes this plain, which represents the former location of glacial Lake Chicago. Land-surface altitudes on the lake plain range from about 640 ft above sea level along the northern edge of the Valparaiso Moraine to about 580 ft above sea level, the approximate stage of Lake Michigan.

Schneider and Keller (1970) mapped the geology of the bedrock and surficial deposits at the GCR in Lake County, and Gray and others (1987) mapped bedrock deposits in Indiana. Gray (1989) mapped the topography of the bedrock surface, thickness of unconsolidated deposits, and surficial geology in Indiana. Kay et al. (1996) mapped the topography of the bedrock, the thickness of clay, and the thickness of sand in the GCR area. The maps and the references cited form the basis for the following description of geology in the WBGCR.

3.1.1 Surficial Geology

The geography of northwest Indiana is largely a product of extreme climatological and geological events that have shaped the surficial geology and topography of the Lake Michigan Region in the GCR area.

The Wisconsin Age glaciers of the Pleistocene Epoch had the most significant influence on the surficial geology of this region through several stages of glacial deposition and erosion. The Lake Michigan lobe of the Wisconsin glacier experienced three major advances and retreats about 25,000 years ago to what is now the northern Lake County area in northwestern Indiana (USGS 1996). As a result, much of the state is veneered by sediment deposits of Pleistocene age, most of which were derived from glaciers and laid down as lake-bottom and nearshore deposits of glacial Lake Chicago near the end of the Wisconsin glacial stage (Hartke et al. 1975). Subsequent lowering of the lake exposed the unconsolidated glacial, eolian, lacustrine, and paludial sediments to erosion and deposition by water and wind. The unconsolidated sediments range in thickness from less than 5 ft to more than 350

ft (Kay et al. 1996). These glacial outwash deposits are typically pale brown, well sorted, calcareous, medium to fine grained and are known as the Atherton Formation in Indiana (Kay et al. 1996). They may contain thin, discontinuous layers of mud, peat, and organic material. They effectively mask much of the bedrock geology, particularly in the northwestern corner of the state; at WBGCR, these surficial sands and fill deposits are typically 25 ft thick (Cohen et al. 2002) and, in other areas, are as much as 350 ft thick. Two-thirds of the state is covered with glacial material.

3.1.2 Bedrock Geology

The WBGCR is underlain by Silurian and Devonian bedrock, primarily composed of dolomite, limestone, and shale. These rocks are the result of consolidation of sediments originally deposited in shallow to moderately shallow water (Hartke et al. 1975). The erosional bedrock surface has about 70 ft of relief and slopes gently north and northeast to Lake Michigan. In Indiana, bedrock surface elevations range from less than 425 ft to more than 625 ft above sea level. The bedrock elevations at WBGCR range from 450 ft to 475 ft (Cohen et al. 2002). The high points are associated with historical reef deposits; the low points are bedrock valleys that mark the paths of preglacial drainage that flowed northward toward the Michigan Basin from a divide to the south and west.

3.2 REGIONAL HYDROGEOLOGY

Two geohydrologic units underlie the WBGCR: an unconsolidated surficial sand aquifer (Calumet aquifer) and a carbonate-bedrock aquifer (Silurian-Devonian aquifer). In most of the area, these aquifers are separated by a confining unit of silty clay (Kay et al. 1996). The surficial sand deposits in the study area were described by Rosenshein and Hunn (1968) and were designated the Calumet aquifer by Hartke and others (1975). The Calumet aquifer is described as an unconfined, or water table, aquifer.

The Calumet aquifer is recharged by direct infiltration of precipitation. The average depth to water is probably less than 10 ft. The saturated thickness of the aquifer is approximately 40 ft (Watson et al. 1989). Discharge from the Calumet aquifer is primarily to surface water, including rivers, ditches, wetlands, and lakes (Kay et al. 1996). Evapotranspiration probably constitutes a major part of the discharge during spring and summer (Rosenshein and Hunn 1968). Fenelon and Watson (1993) reported that, in some urban areas, a substantial amount of water in the Calumet aquifer may discharge to sewers. The horizontal hydraulic conductivity of the Calumet aquifer previously was estimated from 10 to 130 feet per day (ft/d) (Rosenshein and Hunn 1968).

Although the aquifer is not used extensively, records on file at the IDNR indicate that several wells drilled for commercial, industrial, irrigation, and drinking-water uses are supplied from the Calumet aquifer. These wells in the aquifer are outside municipal corporation limits. Most municipalities obtain water from Lake Michigan.

A clay-confining unit separates the Calumet aquifer and the Silurian-Devonian aquifer. The confining unit is primarily silty clay but may contain sand and gravel in small, discontinuous zones. Confined sand aquifers are within and beneath the confining unit (Shedlock et al. 1994). The upper surface of the confining unit slopes toward Lake Michigan. The confining unit restricts flow between the Calumet aquifer and the Silurian-Devonian aquifer.

The Silurian-Devonian aquifer underlies the entire WBGCR area. The aquifer is semiconfined. The Silurian-Devonian aquifer is a source of water for industrial and commercial uses and, to a lesser extent, a source of drinking water. The aquifer is used extensively in the Illinois area, but is not used substantially in Indiana. The Silurian-Devonian aquifer is recharged by percolation of groundwater from the Calumet aquifer through the clay-confining unit. In places where the confining unit is absent, recharge is by infiltration of precipitation directly to the bedrock or through overlying deposits of sand. Within the study area, discharge from the Silurian-Devonian aquifer is primarily due to active pumping.

3.3 REGIONAL HYDROLOGY

The GCR is approximately 14 miles east-west and 8 miles north-south at its widest points (Brannon et al. 1989) and has a basin area of approximately 50 square miles. The GCR is an important drainage basin that flows through northwestern Indiana and northeastern Illinois. The EBGCR flows west from the origin at Grand Calumet Lagoons for approximately 10 miles to its confluence with the IHC. The EBGCR ranges in depth from about 3 to 4 ft in the upstream reaches to about 8 to 10 ft near its confluence with the ship canal and has an average stream velocity of approximately 1 foot per second (ft/s). The WBGCR usually flows both east and west, with a hydraulic divide typically present in the vicinity of the Hammond Sanitary Treatment Plant (STP), located west of Indianapolis Boulevard. The WBGCR is atypical from a hydrological perspective in that the river usually flows in a westerly direction from Columbia Avenue to the confluence with the Little Calumet River. However, the river can flow in either an easterly or westerly direction between Columbia Avenue and the IHC, depending on water level in Lake Michigan (USACE, Chicago District, and EPA, Region V, 1999). The WBGCR is 6 miles long and has a depth of about 2 ft. Stream velocity in the WBGCR ranges from 0.2 to 1 ft/s (Crawford and Wangness

1987). The location of the flow summit varies due to lake-level fluctuations and industrial discharges and withdrawals.

The GCR system has a complex flow regime with flow characteristics driven by several factors. The primary factor affecting river flow and direction is the daily and seasonal lake-level fluctuations in Lake Michigan. For the most part, high lake levels control the flows in the IHC and can strongly affect flows in the GCR, causing water to flow from the EBGCR to the WBGCR. Under certain conditions, this effect can extend to the extreme eastern end of the GCR. At the western end of the system in Illinois, the O'Brien Lock and Dam, located on the Little Calumet River, just 0.5 miles upstream of where the WBGCR joins the Little Calumet, keeps the westernmost portion of the GCR artificially below Lake Michigan levels. The combined effect of these flow conditions results in a flow summit (split) typically located approximately 2 miles east of the Illinois-Indiana state line, near the Hammond STP. The GCR flows both east and west from that location. In addition, over 90 percent of the flow in the EBGCR and WBGCR is effluent from industries and municipal wastewater-treatment plants. Specifically, major discharges in the WBGCR are the Hammond Sewage Treatment Plant (STP) and the East Chicago STP.

The drainage area for the river system is unknown because of the extensive modifications from dredging and urbanization; however, it is relatively small (less than 62 square miles), and the sandy texture of the soils results in small contributions to streamflow from surface runoff. The contribution to streamflow from discharge of groundwater was determined to be less than 10 percent of the total streamflow (Crawford and Wangsness 1987).

Streamflow data have been collected since October 1991 on the WBGCR at Hohman Avenue Bridge in Hammond. Streamflow records are rated poor (outside 15 percent of the true streamflow) for the period of study (Stewart et al. 1997, 1998, 1999, 2000). The following lists summary statistics for daily mean streamflow data at WBGCR. The amount of organic material at Hammond averaged 34 percent.

Summary Statistics for Daily Mean Streamflow Data at WBGCR

Statistic	WBGCR
Number of observations	791
Daily Mean streamflow, ft ³ /s	70.1
Standard deviation, ft ³ /s	33.9
Lowest daily mean streamflow, ft ³ /s	16
Highest daily mean streamflow, ft ³ /s	464

(Renn 2000)

The USGS collected suspended sediment samples from the WBGCR seven times from July 1996 through June 1998 at the downstream side of Hohman Avenue Bridge (Renn 2000). The concentrations of suspended sediment are listed below, along with associated streamflows. Loads of suspended sediment for the WBGCR were estimated by use of the rating-curve method. The estimated average daily suspended-sediment load for the study was 2.9 tons per day at Hammond.

Concentrations of Suspended Sediment and Streamflows

Date	Time	Suspended-Sediment	
		Concentration (mg/L)	Streamflow (ft ³ /s)
July 31, 1993	1345	2	61.3
August 27, 1996	1230	5	38.5
January 22, 1997	1430	9	55.2
June 9, 1998	1200	7	53.4
June 11, 1998	1330	7	75.8
June 24, 1998	1200	8	34.1
June 25, 1998	945	7	36.6

(Renn 2000)

Flow conditions and subsequent velocities that are experienced throughout the system primarily drive sediment transport in the GCR. Significant accumulation of sediment has occurred in several river reaches over the years, necessitating the need for dredging. These reaches are the focus of this study and ongoing dredge studies, including the federal channel on the IHC and the EBGCR along the United States Steel Gary Works facility property. There are several concerns relating to flow regime and sediment transport characteristics of the GCR system. Among these are the volumes of water and sediment crossing the state line from Indiana to Illinois.

3.4 WBGCR SITE BATHYMETRY

The results of the bathymetry survey are shown in Figures 2-1 through 2-12. The river channel is broad and shallow without a well-defined thalweg (or stream channel). The wetted section of the river varied from less than 10 ft to approximately 100 ft wide. Culverts between some reaches restricted flow, and a few were dammed with debris so there was little to no flow between reaches. The average water depth was 1.2 ft, with the shallowest water in Reach 5 and the deepest water in Reach 4 where the culvert was blocked. Bathymetric data were not collected in Reach 5 because the river was too shallow for the inflatable raft

and unsafe to wade in to perform lead line measurements. Therefore, mudline elevations were determined at sampling stations only.

Bottom elevations varied by less than 10 ft throughout the study area. The two deepest areas were in Reach 2, where an outfall discharged into the river, and at the west end of Reach 4, just east of the Sohl Road Bridge. Minimum bottom elevations in these locations were 570.4 ft and 571.0 ft, respectively. Overall, bottom elevations in the study area, excluding Reach 5, ranged from 570.4 ft to 579.1 ft, with an average bottom elevation of 577.8 ft. Reach 3 had the highest average elevation, 578.9 ft. Elevation decreased monotonically in either direction from this reach. The two lowest reaches were Reaches 1 and 7 with average bottom elevations of 577.9 ft and 576.0 ft, respectively. Hence, the bottom elevations reflect the split flow with Reach 3 as the highest and Reaches 1 and 7 as the lowest. Comparing the average elevations, the difference between the highest reach (Reach 3) and the lowest reach (Reach 7) was 2.9 ft.

3.5 WBGCR SITE TOPOGRAPHY

The results of the topographic and aerial survey are shown in Figures 2-1 through 2-12. In general, topography in the study area varied little. During data collection, the water level in the study area varied from approximately 578 ft to 580 ft. Both riverbanks sloped upward from this elevation to an elevation of between 582 ft and 585 ft. Beyond this point, the ground slope became much more shallow. Above this slope break, the study area is urbanized with residential and industrial development. Excluding manmade objects, ground elevations in the study area did not exceed 590 ft. There was no pronounced slope to the topography along the alignment of the river, and elevations of the flood plains on both sides of the river were similar.

3.6 SURFACE SEDIMENTS

Sediment particles in the WBGCR range in size from the very finest clays to sands and gravel. Different sizes of particles are found in suspension and on the riverbed, and the interrelationships between the sediments being transported in suspension and those stored or being transported along the riverbed are complex and variable. The finest particles likely play the largest role in the transport and storage of toxic contaminants (refer to Section 5.0).

Because the WBGCR is shallow, with water depths averaging less than 2 ft, currents and wind-generated waves cause mixing of bottom sediments with overlying water. Likewise, human activities, such as boating (to a limited extent), and increased flows of stormwater

and STP discharges, can also resuspend sediments. Nutrients and pollutants in sediments may be released into the water column during resuspension, thus affecting overlying water chemistry.

Based on the results of this study, most surface sediments in WBGCR were described as fine-grained, composed primarily of clays and silts with fine sands (ML or OH by the Unified Soil Classification System [USCS]). A large percentage (39 percent) of the surface sediment was observed to be clayey silt with fine sand. The second most common sediment type observed in the surface was clayey sandy silt (17 percent) or sandy clayey silt (12 percent) (also described as ML/OH). Silty, fine to medium sands (16 percent), sandy silts with clay (2 percent), clay silt with shell (2 percent), and peat (2 percent) were observed to occur in lesser amounts along the WBGCR. The areal distribution of the different sediment types reflects river basin geometry, energy conditions, and proximity to sediment source (e.g., sewer outfalls). Deposition of fine-grained sediments occurs in low-velocity water environments, such as the inside bend of the meanders, where the river widens, or behind bridges and culverts. Coarser-grained sediments were observed where the river narrows and within historical or current locations of channels.

The colors of material in the surface sediment indicate organic content and chemical composition, including whether the sediments are oxic (olive or brown in color) or anoxic (black in color). In all reaches, the surface sediments were generally black to dark brown with high organic content. The character of surface sediments was reported to be similar in historical sampling results (Burton 1994, Cahill 1992, Dorkin 1993, HNTB 1989, 1990, 1991, Maxim 1999, ThermoRetec 1999, URS 1999).

3.6.1 Reach 1

In Reach 1, surface sediments were composed primarily of clayey silt with fine sand (42 percent). These sediments were typically found in pockets along marshy shorelines where Roxana Marsh is located and along the boundaries between sands and clayey silts. During periods of higher flow, the finer grained material is selectively removed, suspended, and deposited in areas where wave action or currents are minimal, such as in the protected marshy areas of Roxana Marsh where there are areas of limited fetch.

Surface sediment samples in Roxana Marsh were characterized as light to dark sandy silt saturated under a mat of vegetation (Foster Wheeler Environmental 2002b). There was a sheen noted in sediments at location RM-01.

3.6.2 Reach 2

Similar to Reach 1, clayey silts with fine sands dominate the surface sediments of the WBGCR in Reach 2. In one core, WB47, surface sediments were primarily silty fine to medium sand (SM). Station WB47 is located in the middle of the river, where the river flow velocity is expected to be the highest.

3.6.3 Reach 3

Clayey sandy silts were observed in 44 percent of the surface sediment samples in Reach 3. However, surface sediments observed in Transect 1 (stations WB16, 17, 18) were described as silty fine to medium sand. Transect 1 is located west of the Columbia Avenue Bridge, and cores were collected in the deepest part of the river.

3.6.4 Reach 4

As observed in Reach 3, surface sediments are composed of organic silts with various contributions of clay and sand size particles.

3.6.5 Reach 5

Surface sediment in Reach 5 was either silty fine to medium sand or clayey sandy silt. The higher sand content of these sediments may be due to discharges from the CSO at Sohl road as well as incoming stormwater from streets in close proximity to this reach.

3.6.6 Reach 6

The surface sediments described at Reach 6 are from historical data presented in ThermoRetec (1999). Because there has been extensive historical sampling in Reach 6, no sediment samples were collected in this reach during the October 2002 sampling event.

Particle size distribution results were consistent between the samples. The average surface sediment grain size distribution in Reach 6 was 54 percent fines and 46 percent sand in the upper 0 to 2 ft of sediments, which is consistent with other portions of the river.

3.6.7 Reach 7

Clayey silts with fine sands dominate the surface sediments of the WBGCR in Reach 7 (67 percent of the samples). Peat material was found in surface sediments of one core (WB51).

3.7 SEDIMENT STRATIGRAPHY

Sediment stratigraphy is largely affected by transport processes such as surface water transport, sediment deposition, sediment transport, and bioturbation, which are discussed further in Section 5.2.

As previously mentioned, resuspension of sediment via water turbulence and fetch may disturb the surface sediments in WBGCR. From observations made during sampling, bioturbation in surface sediments is relatively insignificant, due in large part to the chemical contamination in the sediments. There were rarely any benthic organisms observed in the sediments. Before the river was impacted by industrial pollution, bioturbation may have been more significant in mixing the sediments at depth.

The stratigraphy of the upper 12 ft is described primarily from this sediment investigation and includes visual descriptions of sediment, core photographs, and grain size data. Textural, lithological, and color variations allow the sediments to be distinguished from one another in lateral and vertical sequences. The environmental changes at WBGCR result in a variety of sediment sequences, from peat to very fine to coarse sediments and what may be erosional and depositional contacts.

During the WBGCR sampling, NAPL materials or significant petroleum sheen were encountered in many of the cores, primarily in the upper 4 to 8 ft of sediments. Mobile NAPL encountered during the sampling is shown on the core logs and on the cross-sections, based on visual observance of samples. NAPL described as visible product in the pore space of sediment samples is assumed to be mobile NAPL, while sheen or odor alone was assumed to indicate residual or sorbed NAPL. Pockets of mobile NAPL were observed at the base of several cores in Reach 4 (Transect 2) and Reach 5 (Transect 1), located on either side of the Sohl Avenue Bridge. The mobile NAPL appears to be moving in groundwater through permeable sands encountered at depth in the sediments.

Appendix C presents the core logs used to describe the stratigraphy, and Figures 3-1 through 3-17, located at the end of this section, contain stratigraphic cross-sections based on visual observations in the field. (Grain size was conducted on a limited number of samples and results are included in Appendix A.) The USCS according to ASTM D2487 was used to describe the sediment lithology in the following sections and as shown in the core logs and figures. The cross sections are labeled by reach, transect number, and orientation (i.e., 1T1 to 1T1' for Reach 1 Transect 1 is labeled on aerial Figure 2-1 for the cross section on Figure 3-1). Transects are oriented with the prime symbol (') on the south bank as shown in Figures 2-1 through 2-12.

3.7.1 Reach 1

There is lateral continuity between transects in Reach 1, as similar stratigraphic sequences occur between transects (Figures 3-1 through 3-4). There is clayey, sandy silt with lenses of organics throughout the top layer of Transects 1 and 4. This type of sediment is identified as OH in the stratigraphic cross-sections. At Transect 3, the top layer of center core WB-05 is described as mostly silty sand (SM). This core was collected in the middle of the channel where coarser-grained sediments are expected during increased flows of the river. The fine-grained sediments are winnowed out of the sediments and carried further downstream, leaving behind the sand. Below the OH layer, in Transects 1, 2, and 4, native silty sands (SM) or fine to medium sands (SW) were observed in one or more of the cores. The sand layers were likely deposited in high-velocity water environments and may represent the location of historical channels or outside bends in the river.

Consideration of the term “native” in this report is based on initial visual inspection in the field while logging the cores. The area has been dredged several times and great amounts of raw sewage have been dumped into the river over the years. Further consideration is needed to determine what sediments may actually be native.

Localized NAPL layers or sheen were observed in most surface sediments to a maximum depth of 9 ft below mud line (WB-43). Petroleum products were not found in the native fines and sand units at the base of the cores.

Three historical cores (Foster Wheeler Environmental 2002b) are located in close proximity to Transects 2, 3, and 4 in Reach 1 at Roxana Marsh (Figures 3-1 through 3-4). The predominant lithology in the marsh cores was a dark peat layer at the surface, underlain by sandy silts and fine-grained sands. This unit can be laterally connected to the adjacent layers in the transect (Figures 3-1 through 3-4). A hydrocarbon odor was observed in the peat layer in all Roxana Marsh cores mentioned.

3.7.2 Reach 2

In Reach 2, the general vertical sequence of sediments was a black, organic, clayey silt with sand (either OH or ML) overlying a native brown to olive ML (Figures 3-5 to 3-7). A black, silty sand (SM) was observed in the surface of core WB-47, located in the center of the river channel. Petroleum sheen or mobile NAPL was found in this upper black layer to depths of 8 ft below mud line.

A tan, native fine to medium sand was observed at the bottom of two borings in Reach 2: WB-12 in Transect 2 and WB-46 in Transect 3. The location of these sands is along the

boundaries of the existing river channel and may represent the outside bends of a historical downstream channel. No visual contamination was observed in these native sands.

3.7.3 Reach 3

Transects 1 and 2 have lateral similarities, as they both were observed to have a silty sand (SM) at the surface, overlying an ML or ML/OH layer (Figures 3-8 to 3-10). Surface sediments in Transect 3 cores were organic clays and silts with sands (OH) overlying either a native olive ML/OH layer or tan clay layer (CL). Petroleum sheen or NAPL was observed to a depth of 7 ft (Transect 1 WB-16 and WB-17).

At two locations (WB-18 and WB-22) in Reach 3, below the native fine-grained sediments, was a tan, silty sand unit (SM). These stations are located near the current banks of the river. No petroleum sheen was observed in these native sediments.

3.7.4 Reach 4

There are lithological similarities laterally between stratigraphic layers in the transects at Reach 4 (Figures 3-11 and 3-12). There are three texturally recognizable and distinguishable lithostratigraphic units. At the surface of each transect, there is a black OH layer, overlying a dark olive ML layer, and then overlying a native olive to brown SM with possible gradational contacts. NAPL or petroleum sheen was observed in the upper black OH layer (Transect 1) to a depth of approximately 5 ft below mud line (WB-25 Transect 1). However, a different source of NAPL was observed in the bottom sand unit in Transect 2 (WB-30) between 8 and 9 ft deep. Figure 3-12 shows the geology of the Reach 4 Transect 2 cross section, and core log WB-30 in Appendix C includes the sediment descriptions. The presence of the deeper pockets of NAPL could be associated with a shallow groundwater source rather than a depositional anthropogenic source.

3.7.5 Reach 5

There were three dominant texturally recognizable and distinguishable lithostratigraphic units in both transects of Reach 5 (Figure 3-13 and 3-14). At the top of each transect, there was a black OH, overlying a black to olive ML/OH layer, overlying a native tan SM, SW or GM (primarily sands and gravels). One exception was at station WB-35 located in the middle of the river. At this location, there was a thin layer of silty sand on the surface. NAPL or petroleum sheen was observed to a depth of 10 ft (WB-32). The NAPL may be associated with groundwater in the area.

3.7.6 Reach 6

The sediment stratigraphy described for Reach 6 is from a geotechnical cross-section presented by ThermoRetec (2000). Three distinct geologic units are evident from the cross-section, based on its sampling results in 1998 and 1999 (ThermoRetec 1999, 2000). The upper 3 ft of sediment was described as organic silt mixed with well-sorted fine sand. Below the top layer, from 3 to 7 ft, was soft, peaty clay mixed with silt overlying a fine sand unit, which may be native sediments. This is similar to the vertical profile of sediments in Reaches 5 and 7.

3.7.7 Reach 7

There are also lithological similarities between sediment stratigraphic layers in transects at Reach 7 (Figures 3-15 to 3-17). There are three recognizable and evident units. At the top of each core, the sediments were described as either a black OH or ML with either a petroleum sheen or NAPL material present. Below this layer was an olive ML overlying a native, tan silty sand (SM). A native tan clay unit was observed at the bottom of all cores in Transect 1 and one core in Transect 3 (WB-49). No petroleum products were observed in the native materials.

Figure 3-1. Reach 1, Transect 1, Generalized Stratigraphy

Figure 3-2. Reach 1, Transect 2, Generalized Stratigraphy

Figure 3-3. Reach 1, Transect 3, Generalized Stratigraphy

Figure 3-4. Reach 1, Transect 4, Generalized Stratigraphy

Figure 3-5. Reach 2, Transect 1, Generalized Stratigraphy

Figure 3-6. Reach 2, Transect 2, Generalized Stratigraphy

Figure 3-7. Reach 2, Transect 3, Generalized Stratigraphy

Figure 3-8. Reach 3, Transect 1, Generalized Stratigraphy

Figure 3-9. Reach 3, Transect 2, Generalized Stratigraphy

Figure 3-10. Reach 3, Transect 3, Generalized Stratigraphy

Figure 3-11. Reach 4, Transect 1, Generalized Stratigraphy

Figure 3-12. Reach 4, Transect 2, Generalized Stratigraphy

Figure 3-13. Reach 5, Transect 1, Generalized Stratigraphy

Figure 3-14. Reach 5, Transect 2, Generalized Stratigraphy

Figure 3-15. Reach 7, Transect 1, Generalized Stratigraphy

Figure 3-16. Reach 7, Transect 2, Generalized Stratigraphy

Figure 3-17. Reach 7, Transect 3, Generalized Stratigraphy

4. NATURE AND EXTENT OF DETECTED CHEMICALS

4.1 DATA QUALITY EVALUATION

Evaluation of the data quality was based on goals and objectives presented in the Final QAPP for WBGCR (Foster Wheeler Environmental 2002c). Overall findings concerning data quality are summarized in the following sections. Independent data validation reports and a summary table showing all validated sample results are provided in Appendix E.

4.1.1 Field Quality Control Evaluation

Analytical data have been reviewed for overall validity based on field Quality Control (QC) checks. The evaluation steps include verifying field QC sampling (i.e., collection of field duplicates and rinsate blanks), analysis of field QC samples, and comparison of field QC results to environmental sample results. Comparing field QC results to environmental samples results reduces the possibility of erroneously attributing chemical detections to environmental contamination by identifying other potential sources of contamination inherent to environmental sampling.

Field duplicates were collected to assess the precision of field sampling efforts. Six core field duplicate sets were collected and analyzed as follows:

FW-WB-03-CS-1.2-4 and FW-WB-52-CS-1.2-4

FW-WB-16-CS-1.9-5.2 and FW-WB-70-CS-1.9-5.2

FW-WB-22-CS-6-8.2 and FW-WB-54-CS-6-8.2

FW-WB-40-CS-5.4-6.9 and FW-WB-56-CS-5.4-6.9

FW-WB-47-CS-0-2.4 and FW-WB-53-CS-0-2.4

FW-WB-50-CS-5.7-8 and FW-WB-55-CS-5.7-8

There were a total of 668 paired data points for the six field duplicate sets. Of these, 500 paired data points were reported as “not detected” for both members of the field duplicate set. There were 29 instances in which a compound was detected in one member of the field duplicate set, but not in the other. For all 29 cases, the concentration for the detected compound is within a factor of five of the reporting limit for the not detected compound. Thus, the not detected and detected values for the paired data points were not indicative of a significant problem with precision. There were 139 paired data points in which target analytes in both members of a field duplicate set were detected. The relative percent

difference (RPD) value for each detected compound was reviewed to assess sample collection and laboratory analytical techniques. The RPD values are summarized in the data validation reports (Appendix E). Most (95 out of 139) paired results were within acceptable limits (RPD value of ≤ 35 percent for inorganics and ≤ 50 percent for organics). More variability was found for FW-WB-47-CS-0-2.4/FW-WB-53-CS-0-2.4 (20 outliers), FW-WB-50-CS-5.7-8/FW-WB-55-CS-5.7-8 (11 outliers), and FW-WB-22-CS-6-8.2/FW-WB-54-CS-6-8.2 (8 outliers) in which RPD values were greater than acceptable limits. The higher RPD values were due to comparing low concentrations (near the reporting limits) where more variability would be expected and to non-homogeneity in a sediment matrix (despite proper sampling technique, which entailed mixing the sediment before placing it in containers). As field duplicate results generally exhibited very good agreement, overall sample reproducibility was judged acceptable.

The six rinsate blanks (FW-WB-FB-01 through FW-WB-FB-06) did not have many detected concentrations. Each rinsate blank contained a few metals, simultaneously extracted metals (SEMs), and TOC at low concentrations. Additionally, three rinsate blanks contained oil and grease and one rinsate blank contained acid volatile sulfide (AVS) at a low concentration. Since the only detected compounds were metals, SEMs, and wet chemistry parameters at very low concentrations, contamination during sampling was not considered to be a problem.

4.1.2 Laboratory Quality Assurance Evaluation

The data validation reports are included as Appendix E. Data were validated by Laboratory Data Consultants, Inc. (LDC) in Carlsbad, California, using guidance from EPA Contract Laboratory Program National Functional Guidelines (NFG) (EPA 1994, 1999), Test Methods for Evaluating Solid Waste (EPA 1996), and the Final QAPP.

Most of the data are usable. Only a very small percentage of the data (approximately one percent: 191 data points out of a total of 18,452 data points) were rejected during validation. Thus, a sufficient amount of data were obtained to meet the project objective.

Sediment samples, water samples, and QC field blanks for most parameters were prepared and analyzed within the method-specified holding times. Parameters with holding time exceedances for one or more samples include AVS, PCB Aroclors, PCB congeners, and semivolatile organic compounds (SVOCs). Positive results and non-detected results for samples analyzed outside holding times were qualified as estimated (J/UJ), with one exception. More stringent action (i.e., rejection of non-detected results) was taken for the

SVOC analysis of one sample (the reextracted analysis of FW-WB-39-CS-3.1-5.3) because the reextraction was performed 29 days after sampling (i.e., exceeding the 14-day extraction holding time by more than a factor of two). This sample required reextraction because of surrogate recovery outliers in the original analysis. The laboratory reported usable (but estimated) results from the original extraction and analysis for this sample; thus, the rejection of results from the reextraction did not adversely affect data completeness.

The laboratory performed initial and continuing calibrations at appropriate frequencies. Most initial and continuing calibration criteria were met. Some PCB congener, pesticide, and SVOC results for samples were qualified as estimated (J/UJ) due to calibration outliers.

Method blanks were performed at the method-specified frequencies. Most were free from contamination, but a few target analytes were detected in some blanks. During validation, sample concentrations were compared to concentrations detected in the method blanks. Sample concentrations in the range (within a factor of five) of the method blank were qualified as not detected (U). Parameters for which one or more sample results were qualified due to method blank contamination include oil and grease, metals, SEMs, and TOC.

Most recoveries for surrogates (organics only), laboratory control samples, and MS were within control limits. When recoveries were greater than the upper control limit, positive results for associated samples were qualified as estimated (J). When recoveries were less than the lower control limit but greater than a lower bound criterion specified in NFG (30 percent for inorganic MS and sediment laboratory control samples, 50 percent for inorganic water laboratory control samples, 10 percent for organic surrogates, and 0 percent for organic laboratory control samples and MS), positive results and not detected analytes were qualified as estimated (J/UJ). There were some instances when a recovery was less than the lower bound criterion; in these cases, positive results were qualified as estimated (J) and not detected results were rejected (R). Rejection of results due to poor recovery included one or more samples for each of the following parameters: acid volatile sulfide (AVS), PCB Aroclors, SEMs, and SVOCs.

When very low recovery was obtained for surrogates and laboratory control samples for PCB Aroclors and SVOCs, the laboratory reextracted and reanalyzed the affected samples. Results from both analyses were submitted for each of these samples. After LDC applied qualifiers, Foster Wheeler Environmental selected which result was preferable in order to reduce the data set so that one valid result remained per target analyte per sample. For most cases, the original sample had low recovery and the reextracted sample was performed

outside of holding time; thus, both data sets were assigned qualifiers by LDC. Following are the guiding principles that were applied when selecting which result would be used when multiple results were reported:

1. If one result was qualified as estimated (J or UJ) and the other was rejected (R), the estimated value was selected.
2. When both results were qualified as estimated (J or UJ), the highest value for a detected analyte was selected and the lowest reporting limit for a not detected analyte was selected.
3. If one result indicated a detection and the other result was not detected, the detected value was selected.

Most RPD values for laboratory duplicate, laboratory control sample duplicate, and MSD sets were within control limits. When RPD values were outside control limits, associated positive results and reporting limits for not detected analytes were qualified as estimated (J/UJ).

Parameter-specific QC samples were generally within control limits. However, some data were qualified as estimated (J or J/UJ) due to outliers for graphite furnace atomic absorption QC checks, inductively coupled plasma (ICP) interference check samples and serial dilutions, percent difference values from two gas chromatograph columns greater than 40 percent, internal standard areas, and omission of balance checks for oil and grease.

Analytical quality was generally acceptable; thus, the project objective (i.e., to characterize the nature and extent of contamination in support of restoration alternatives development and evaluation for the WBGCR) was met. When data for this project were qualified as estimated (J/UJ) due to QC outliers, reported results represent approximate concentrations but can be used for site characterization. When data were rejected (R) during validation, the data user should use caution or refrain from making decisions based on the reported concentrations.

4.2 SEDIMENT CHEMISTRY RESULTS

This section discusses the results of chemical and physical tests performed on sediment cores collected in October 2002 and incorporates historical data collected by others (included in Ingersoll and MacDonald 1999, MacDonald and Ingersoll 2000 and Foster Wheeler Environmental 2002b). Tests for chemical and physical properties were performed on samples collected in October 2002 from sediments in six of seven identified reaches

along the WBGCR (Reaches 1, 2, 3, 4, 5, and 7). These analyses were conducted to evaluate the type, distribution, transport, and fate of chemicals; the potential risks to human health or the environment; and the degree of impairment and injury to natural resources associated with these chemicals. The results of this data evaluation will also be used to develop remediation alternatives for managing impacted sediments and evaluate options for natural resources restoration in the WBGCR (i.e., Phase 3).

In general, sediments in the river had elevated concentrations of heavy metals, PCB Aroclors, SVOCs (primarily PAHs), and pesticides (e.g., DDT and degradation products). Table 4-1 presents a summary of these chemicals detected at elevated concentrations (above probable effects concentrations [PECs] as described below) in WBGCR sediments. Appendix A.1 presents summary tables of all chemical and physical testing results by individual reach.

Most of the chemicals detected in WBGCR have associated consensus-based PECs developed by Ingersoll and MacDonald (1999) and MacDonald et al. (2000). PECs are intended to identify the concentrations of contaminants in whole sediment above which adverse effects to sediment-dwelling organisms are likely to be observed. The sediment effects concentrations for most of the chemicals of concern detected in the GCR have been demonstrated to provide a reliable basis for predicting the presence and absence of sediment toxicity in field-collected sediments (Ingersoll and MacDonald 1999, MacDonald et al. 2000). Threshold effect concentrations (TECs) are included in the data tables for reference. The TECs identify the concentration below which adverse effects are unlikely to occur (MacDonald et al. 2000).

Results were compared to PECs to evaluate the relative degree of contamination. PECs and TECs are included in the data tables in Appendix A to provide a reference to sediment concentrations for assessing the severity of elevated concentrations. PECs were selected in this report as an initial contaminant screening reference to be consistent with prior studies. More in-depth toxicological evaluations or comparisons to regulatory concentrations levels will be completed in the next phase of evaluations (risk assessment and restoration option analysis). In the following discussions, the term “elevated concentration” indicates a concentration above the associated PEC value. The term “detected concentrations” indicates that sample concentrations were detected but were lower than the PEC. Samples collected in October 2002 were designated for analysis based on the cross-section of each transect. At least one surface, middle, and bottom sample was analyzed in each transect to characterize the sediment in the vertical profile of the river at that location. Therefore, discussion of the nature and extent of elevated concentrations will be discussed by transect and reach. Depths

Table 4-1. Summary of PEC Exceedances

Parameter	Total Number of Samples Analyzed	Samples Exceeding PEC	% of Samples Exceeding PEC
4,4-DDD	210	35	17%
4,4'-DDE	210	33	16%
4,4-DDT	210	19	9%
Acenaphthene	297	127	43%
Acenaphthylene	297	41	14%
Anthracene	297	128	43%
Arsenic	298	60	20%
Benzo(a)anthracene	306	151	49%
Benzo(a)pyrene	316	142	45%
Cadmium	320	117	37%
Chromium	308	81	26%
Chrysene	306	155	51%
Copper	233	96	41%
Dibenz(a,h)anthracene	281	64	23%
Dieldrin	224	19	8%
Endrin	201	0	0%
Fluoranthene	313	154	49%
Fluorene	297	130	44%
gamma-BHC (Lindane)	220	28	13%
Heptachlor Epoxide	201	3	1%
Lead	320	166	52%
Mercury	242	86	36%
Naphthalene	313	115	37%
Nickel	124	33	27%
Total PAH	317	170	54%
Total PCB	234	54	23%
Phenanthrene	309	160	52%
Pyrene	310	174	56%
Total Chlordane	220	54	25%
Total DDT	210	35	17%
Zinc	233	114	49%

of cores are discussed as in situ depths at feet below ground surface. In situ depths were extrapolated by assuming linear compaction of the core. Measurements of the extracted, compacted core were multiplied by the compaction rate to estimate in situ depths.

Generally, elevated concentrations of parameters with corresponding PECs (PAHs, metals, pesticides, and total PCBs) were found in sediments to a depth of 11.5 feet below ground surface (east side of Reach 1). In a few cases, the bottom increment contained elevated concentrations of one or more parameters, and therefore the depth of the affected sediment

cannot be determined at this time. Generally, elevated concentrations were found down to an average depth of 8 feet below ground surface in the river channel. Figures 4-1 to 4-17 present the concentrations of metals, detected concentrations of SVOCs (essentially only PAHs), and detected concentrations of pesticides and PCBs (as the sum of Aroclors) in each sediment sample increment in a cross section view by transect. Sums are included in each regardless of detection. Each transect is shown on three pages: Reach 1 Transect 1 metals results are shown on Figure 4-1a, PAH results are shown on Figure 4-1b, and pesticides and Total PCBs are shown in Figure 4-1c.

Metals were detected and occurred at elevated concentrations in each reach. The bioavailability (and hence toxicity) of metals in the sediment depends on a number of factors, including pH, Eh, total organic carbon (TOC), iron-manganese oxide complexation, and speciation (available anions). It has also been empirically determined that a key partitioning phase controlling cationic metal activity and toxicity in the sediment-interstitial water system is acid volatile sulfide (AVS). AVS is a measurement of one form of reduced sulfur typically found in sediments under anaerobic conditions. AVS binds, on a mole-to-mole basis, with several cationic metals of environmental concern, including cadmium, copper, nickel, lead, and zinc. The result is the formation of insoluble sulfide complexes with minimal biological availability (Ankley et al. 1996). Hence, when these metals are extracted and measured simultaneously with AVS (the simultaneously extracted metal, or SEM), a quick screen for toxicity can be performed. A molar concentration of AVS greater than the molar concentration of SEM indicates that there is excess sulfide in the system, the metals are bound, and metal toxicity is not expected. A molar concentration of AVS less than the molar concentration of SEM indicates a potential metal toxicity in sediments. Therefore, assessing the molar concentration of AVS to SEM in WBGCR sediment samples as well as Roxana Marsh sediment samples in conjunction with toxicity data may assist with the interpretation of the data.

Elevated metals concentrations were apparent in each reach in both surface and subsurface sediment of the WBGCR. In Roxana Marsh samples, the concentration of AVS was less than the concentration of SEM in most samples (showing a positive number in the SEM-AVS column of Table A.1-3). However, in the WBGCR samples collected as part of this study, most of the samples contain AVS concentrations greater than SEM concentrations, indicating an excess of sulfide, and the metals are bound and not readily available, and are therefore not expected to be toxic.

A total of 56 PCB congeners were analyzed in 19 sediment samples (including one duplicate). PCB congener results are labeled with IUPAC numbers and compound names in

Appendix A.1. Only eight of the 56 congeners were not detected in the 19 samples. Congeners were detected in most samples, regardless of concentrations of Aroclors. The analyses of PCB congeners should agree to some degree with the analyses of PCB Aroclors. However, both the sum of the limited number of congeners and the sum of Aroclors are estimates of total PCBs. If the sums are not relatively close, it could be that it is related to the sample matrix and analytical techniques (i.e., gas chromatography versus gas chromatography/mass spectrometry [GC/MS]) and not the fact that the analyses were conducted at two different locations.

Releases and discharges from historical industry have likely contributed to the elevated concentrations of chemicals observed in sediments of the river. Industries such as steel mills, foundries, glue and cornstarch factories, packing plants, railroad car fabricators, chemical plants, non-ferrous foundries (source of lead, aluminum, copper), a concrete/cement fabricator, oil refineries, and milling/machining companies were established along the GCR for over a century. Factories, mills and STPs have historically discharged or pumped their effluent directly into the WBGCR, with little or no treatment. Prior to the 1920s, there was no treatment of sewage or industrial effluents discharged to the river. The Hammond and East Chicago STP facilities were not built until the 1940s (USACE 1997). Historically, the STPs accepted industrial discharges which may have passed through the STP untreated and been discharged into the WBGCR, or were discharged directly to the WBGCR during CSO events. Hospitals routinely flushed medical wastes (e.g., mercury-bearing wastes) into the sewer system. The USACE abandoned the practice of dredging the river after 1895 due to the continued dumping by local industries of large volumes of waste. As late as 1917, the river was navigable in the West Branch as far east as Columbia Avenue, prior to being filled in with sediment and wastes and the building of bridges and culverts.

The combination of the long duration of historical and recent discharges into the river; the emplacement of flow restrictions in the WBGCR channel, such as culverts and bridges, which act as sediment traps; as well as the intermittent condition where the flow in the river switches directions have all contributed to the condition of elevated concentrations of various parameters in subsurface sediments in each reach. Patterns show that the contaminants are generally deeper in the center of the channel than on either side.

Besides the contributions of direct discharges to the surface water in the waterway itself as described above, the recognition of NAPLs saturating some sediment strata suggests that some contaminants are contributed to the subsurface sediments from the local groundwater flow system. The groundwater flow pathway and its relative contribution to the total contaminant load in the system have not been fully determined.

The nature and extent of affected areas is discussed by reach below. The discussion of possible historical sources for each reach relies substantially on the 1997 USACE Industrial history document. This inclusion of historical industries and activities is by no means complete. Mentions of possible sources (not proven) give context to interpret the data with regard to constituents that were detected, relative concentration levels that were reported, and gradients that are observed, given the very complicated history, hydrology, and contaminants in the sediments.

4.2.1 Reach 1

Reach 1 extends from Indianapolis Boulevard on the east to I-90 on the west (Figure 2-1 through 2-3). On the east end of Reach 1, PAHs, metals, and pesticides (i.e., DDT) are detected at elevated concentrations down to nearly 5 feet in the river channel and down to 3 feet in Roxana Marsh (RM-19). Approximate locations of utilities are shown on Figure 1-1. Petroleum pipelines run under the river near Indianapolis Boulevard as well as on either side of the I-90 bridges, and in recent history there was one or more reported petroleum pipeline breaks in Reach 2 at White Oak Avenue by Roxana Park and a crude oil spill by Indianapolis Boulevard (D. Sparks 2002, personal communication). Aerial photographs of Roxana Marsh in 1939 show oil sheens on the River. Whether the sources are from recent pipeline breaks and crude oil spills or from historical leaks and spills, there is a high occurrence of petroleum sheen, odor, and NAPL products (e.g., coal tar-looking materials) found in the black silt in the surface sediments of varying depths in Reaches 1 and 2. Figures 4-1 through 4-4 show concentrations of metals, PAHs, and pesticides and PCBs in Reach 1. On the east end of Reach 1, metals were detected at elevated concentrations down to 11.5 feet in the olive brown silt. There are many possible sources of heavy metals in the sediments including the effluent from industries and STPs in the area. Historical industry in the area included a steel company on the north side of Reach 1 very close to the water, and currently on the same site is a pipe fabrication company (USACE 1997). Other historical industry on the south side of WBGCR, in the vicinity of Reach 1, include two chemical companies, a steel car manufacturing plant, lead products companies, a municipal dump, and metal refinery. On the north side just east of Indianapolis Boulevard, there was a metals refining and a lead products plant (USACE 1997). Presently, the East Chicago and Hammond STPs discharge effluent into and near this portion of the WBGCR. Past production of the insecticide lead-arsenate and a zinc roaster at the DuPont facility in East Chicago and lead smelting at USS Lead at the junction of East and West Branches of the Grand Calumet River are possible sources of metals (M. Mikulka 2003, personal communication).

In the middle of Reach 1, PAHs, metals, and pesticides (in particular DDT and degradation products) were detected at elevated concentrations down to 8 feet in the black inorganic silt in Transect 3, which contained traces of NAPL and coal tar down to 8 feet. In recent history, Roxana Marsh was a mudflat with water depths that varied depending on Lake Michigan water levels. It is currently covered with cattails (*Typha* sp.) and common reed grass (*Phragmites australis*) and has considerably less water flowing through it than 6 years ago (before Lake Michigan water levels dropped in 1997). However, only the top 2 to 3 feet of marsh sediment contain elevated contaminant concentrations, which may correspond to more recent discharges into the river. On the west side of Reach 1, near the I-90 bridges, elevated concentrations of PAHs occurred in the top layer of brown/black organic silt to a depth of over 2 feet. This upper layer of mud contained moderate to high levels of petroleum odor and sheen. The sediments near the pipeline crossing at the I-90 bridges were less contaminated with PAHs and other SVOCs than other areas to the east.

4.2.2 Reach 2

Reach 2 extends from the I-90 bridges on the east end to the Columbia Avenue Bridge on the west end (Figures 2-4 through 2-6). The Hammond STP outlet forms a watershed divide in the middle of Reach 2 with the east side of the reach flowing predominantly east and the west side of the reach flowing west. SVOCs, particularly PAHs, are the prominent parameters detected in Reach 2 at elevated concentrations (above PECs).

Reach 2 includes elevated concentrations of PAHs, metals, pesticides (DDT and Lindane), and PCBs down to 9 feet. Black organic silt with heavy petroleum sheen or NAPL occurs down to 7 feet. Elevated concentrations of PAHs also occur in the olive brown to black clayey silt down to 9 feet. Figures 4-5 to 4-7 show concentrations of metals, PAHs, and pesticides and PCBs. Petroleum pipes run under the river along the east portion of Reach 2 and previous spills likely impacted this area of the river. It is also likely that discharges from the Hammond STP have contributed to the contamination observed in this reach of the river. What appeared to be human hair was found in surface sediment in several locations. Historical industry in the vicinity of Reach 1 would also have affected Reach 2. This would include sources of both metals and petroleum observed in the sediments. In addition, a machining services company and a steel company are presently located on the north side of the river (USACE 1997). Possible sources of lead in Reach 2 include Halstab and Hammond Lead, both of which directly discharge to the Hammond STP (M. Mikulka 2003, personal communication).

4.2.3 Reach 3

Reach 3 is located between Columbia Avenue Bridge and Calumet Avenue Bridge (Figures 2-6 through 2-8). Elevated concentrations in Reach 3 were observed deeper in the center of the river than near the banks. Pesticides (DDE, lindane, chlordane, and dieldrin), PCBs, metals, and PAHs were found to be elevated in the surface black silts and sands, with occurrences of petroleum sheen, odor, and NAPL products (e.g., coal tar-type material) down to 7 feet. Concentrations of metals, PAHs, and pesticides and PCBs are shown in Figures 4-8 to 4-10. Historical industry in the area include a distillery, a machine and manufacturing company, and a steel door company on the north side of Reach 3, relatively close to the river (USACE 1997). With the elevated concentrations in the surface samples, it is likely that contributions were more recent, associated with present-day industry, STPs, and petroleum pipelines in the area rather than historic sources.

4.2.4 Reach 4

Reach 4 extends from Calumet Avenue Bridge on the east end to Sohl Road Bridge on the west end (Figures 2-8 and 2-9). During the October 2002 sampling event, the water in Reach 4 was fairly stagnant, probably because the culvert leading to Reach 5 was plugged with debris. Historically, water has been observed to flow freely between Reaches 3, 4, and 5.

The east portion of Reach 4 contained PAHs and metals at elevated concentrations in the surface layer of black organic silt and dark olive inorganic silt and sand to a depth of 6 feet. No pesticides or PCBs were found to be elevated in this surface layer. The olive silt below 6 feet did not contain elevated concentrations of contaminants. Concentrations of metals, PAHs, and pesticides and PCBs are shown on Figures 4-11 and 4-12.

The west portion of Reach 4 contained PAHs, metals, pesticides, and PCBs in the surface layer of black organic silt with occurrences of petroleum sheen, odor, or NAPL products (e.g., coal tar-like material) down to 8 feet. However, PAHs and metals were found at elevated concentrations in the dark olive silt and sand with NAPL pockets down to 10 feet. Clean material was not reached at the bottom of one core (WB-30) at 10 feet. Figure 4-12b shows PAH results and general stratigraphy of the Reach 4 Transect 2 cross section. The core log for WB-30 in Appendix C includes the sediment description and depths at which evidence of NAPL was seen. The surface sediment contains sheen and NAPL-staining down to 3.6 feet, and there are deeper pockets of NAPL from 7.7 to 10.4 feet with elevated concentrations of PAHs. The lack of evidence of NAPL between 3.6 and 7.7 feet in WB-30

and high concentrations of PAHs in the silty sand layer at the bottom of each core in Transect 2 indicate that the presence of the deeper pockets of NAPL could be associated with a shallow groundwater source rather than a depositional anthropogenic source.

Historical industry located within Reach 4 includes a nail mill, steel manufacturing, a soup company, a wall paper company, and a shirt company formerly located at the present site of a screw conveyor company. Turner Park is located on the south side of the river, and children have been seen playing in and around the river (D. Sparks 2002, personal communication).

4.2.5 Reach 5

Reach 5 extends from Sohl Road Bridge and culvert to Hohman Avenue Bridge (Figure 2-10). The water levels in Reach 5 were less than a foot deep during sampling, with little to no water movement. The east end of Reach 5 contained elevated concentrations of PAHs in black inorganic silt and sand with occurrences of petroleum sheen, odor, and NAPL down to 10 feet. This contamination extended into the native tan sand with shell fragments. Concentrations of metals, PAHs, and pesticides and PCBs relative to stratigraphy are shown on Figures 4-13 and 4-14. The source may be associated with groundwater, as observed in Reach 4. The source of groundwater contamination is not known. Deeper cores into the tan sand may be needed to determine the vertical extent of contamination along this transect.

The west portion of Reach 5 (i.e., Transect T2) contained elevated concentrations of PAHs, metals, pesticides (DDT, lindane, and chlordane) and PCBs in the black organic silts down to nearly 9 feet. These sediments contained petroleum sheen, odor, and miscellaneous sewage-related materials. Below 9 feet, contaminants were generally not detected in the native olive brown inorganic silt and sand layers with shell fragments.

Historical industry within Reach 5 included a livestock yard in the late 1800s on the north side of the river. A flourmill, carriage works, a railroad appliance company, and a steel foundry operated on the same site in the last century. The steel foundry could be a source of the elevated metals detected in the sediments of this reach. On the south side of the river, at the present site of apartment buildings, there was a lumber company and boiler works company (USACE 1997). Neither operation can readily be linked to the petroleum contamination observed at depth in the sediments. However, a former manufactured gas plant (MGP) was located on the south bank in Reach 6. Possible migration of PAHs from Reach 6 could be impacting Reach 5.

4.2.6 Reach 6

Reach 6 is located between Hohman Avenue Bridge and the railroad bridge (Figure 2-11). Samples were not collected in October 2002 because of the extensive sampling efforts of others in Reach 6 (ThermoRetec 1999, 2000). Most of the samples collected previously in Reach 6 were to a depth of 4 to 5 feet. Elevated concentrations of metals and PAHs were found to these depths, indicating some uncertainty in the vertical extent of contamination in this reach of the river. Deeper cores may be required to determine the vertical extent of contamination. Pesticides were found in the surface sediment (limited data were available), and PCBs were not detected at detection limits above PEC. Historical industry in Reach 6 included an MGP located adjacent to the river on the south side owned by the Hammond Electric Company in the early 1900s and later part of NIPSCO. This industry is the source of coal tar and related NAPL products in this portion of the river. Industry located further away from the river that may have contributed to contamination of the river include a machine company, fluid power company, car manufacturing, a steel company, and, presently, a steel corporation on the north side of the river along the railroad.

4.2.7 Reach 7

Reach 7 is located between the railroad bridge and the Indiana/Illinois state line (Figure 2-12). Elevated concentrations of PAHs and metals were found in the black inorganic silts and sands containing strong petroleum sheen and odor to depths of nearly 6 feet in the east end transect. In the west portion of the reach, elevated concentrations of PAHs and metals were found in the same surface silt layer as well as deeper into the dark brown inorganic silt to at least 11 feet. Concentrations of metals, PAHs, and pesticides and PCBs are included in Figures 4-15 to 4-17. Pesticides (DDT and degradation products) were detected in historical surface and subsurface samples down to 9 feet. In samples collected during this study, only DDE was found at elevated concentrations in the tan silty sand material at a depth of 7 to 8 feet. This “clean” looking sand was thought to be native sand.

Historical industry within Reach 7 included a slaughterhouse, packing plant, and cattle shed, a chemical services company, a food company, a warehouse, a cement tile company, and, most recently, an iron and metal company (USACE 1997). The slaughterhouse was referenced in USACE (1997) as being historically responsible for dumping large volumes of animal wastes into the river. Abundant fibrous organics found 5 feet below ground surface might be remnants from waste dumping from the packing plant. The iron and metal company may be responsible for the high levels of metals in Reach 7. The highest levels of mercury were detected in sediments of this reach.

4.3 GEOTECHNICAL TESTING RESULTS

The purpose of the field investigation was to provide sufficient geotechnical data to evaluate the engineering properties of the sediments in the WBGCR for remedial alternatives analysis and design. The field samples were tested to determine sediment characteristics, which will be used to determine the type of dredging equipment and the capacity of the sediments to support equipment and possibly an isolation cap. In addition, the suite of geotechnical laboratory tests will be used to evaluate dredging and capping methods, dredged material transport and placement, dredged material behavior in the disposal site, potential short-term impacts at the dredge and disposal sites, and the capacity of existing sediments to provide foundation support for capping material.

All geotechnical soil testing was performed by STI. The testing methods are described in Section 2.3.2 and listed in Table 2.3. The schedule for the geotechnical testing is also given in Section 2.3.2 and in Table 2.4. A total of 76 field samples were taken from 37 of the vibrocore locations for geotechnical testing. In addition, three duplicate samples and five composite samples were also subjected to geotechnical testing.

Sample FW-WB-60-CS-6.1-9.6 is a duplicate of FW-WB-13-CS-6.1-9.6; Sample FW-WB-61-CS-6.0-8.2 is a duplicate of FW-WB-22-CS-6.0-8.2; and Sample FW-WB-62-CS-6.9-9.5 is a duplicate of FW-WB-40-CS-6.9-9.5.

As stated in Section 2.3.5, UU shear strength and consolidation tests on FW-WB-34-GEO-5.0-6.3 were not performed. After examination in the laboratory, the sample was judged to be too sandy for the cohesive soil tests.

The results of geotechnical laboratory testing are summarized in Appendix A.

4.3.1 Grain Size

Grain size tests were run on 47 field samples, three duplicate samples, and five composite samples. Nineteen of the samples are predominantly sand, 35 samples are predominantly silt, and one sample is predominantly clay.

Seventeen field samples, one duplicate sample, and one composite sample contain more than 50 percent sand. Twenty-four field samples, two duplicate samples, and four composite samples contain more than 50 percent silt-size particles, and one field sample is predominantly silt (contains more silt-size particles, but less than 50 percent, than any other particle size). None of the field samples contains more than 50 percent clay-sized particles,

but one field sample is predominantly clay (contains more clay-size particles, but less than 50 percent, than any other particle size).

4.3.2 Atterberg Limits

Atterberg limits (consisting of liquid limit, plastic limit, and plasticity index) were run on 26 field samples and five composite samples. Except for two field samples that tested as granular non-plastic, the liquid limits range from 50 to 214 percent, with a mean of 136 and a median of 130. The plastic limits range from 30 to 109 percent, with a mean of 61 and a median of 56. The plasticity indexes range from 20 to 130 percent, with a mean of 74 and a median of 71.

One of the granular non-plastic samples is classified as sand (SM). However, field sample FW-WB-32-CS-0.0-2.0 is classified as silt (ML).

All other fine-grained samples (predominantly silt or clay) are either elastic silts or fat clays, in other words, highly plastic cohesive soils. All of the samples that tested above the "A" line fell below the "U" line, indicating that the samples tested within the limits of a natural soil.

4.3.3 Specific Gravity

Specific gravity tests were run on 30 field samples and five composite samples. Specific gravity was also reported from the four direct shear tests. Specific gravity ranges from 2.38 to 2.70, with an average and median of 2.54.

Specific gravity tends to increase with a combination of increasing depth of the sample and increasing grain size.

4.3.4 Bulk Density

Bulk density tests (using both dry and wet methods) were run on 26 field samples and five composite samples. Dry density was also determined for an additional 11 field samples as part of the consolidation testing. Wet densities range from 71.8 pounds per cubic ft (pcf) to 110.0 pcf, with an average of 80.6 pcf and a median of 77.8 pcf. The dry densities range from 17.6 pcf to 99.8 pcf, with an average of 37.4 pcf and a median of 30.3 pcf.

Densities are generally low, but are higher for the sand samples and lower for the silt and clay samples.

4.3.5 Moisture Content

Tests for moisture content were run on 26 field samples and 5 composite samples. Moisture content was determined for an additional 11 field samples as part of the consolidation testing. Moisture contents range from 24 percent to 307 percent, with an average of 154 percent and a median of 162 percent.

The sand samples tend to have a lower moisture content and the silt samples a higher moisture content. One exception is field sample FW-WB-32-CS-0.0-2.0, which is a non-plastic silt with a moisture content of 35 percent.

4.3.6 Consolidation

Consolidation tests were run on 11 field samples. The compression index (C_c) ranges from 0.25 to 4.10, with an average of 2.14 and a median of 1.91. The corresponding initial void ratios range from 1.35 to 8.43, with an average of 4.76 and a median of 4.51.

All but one of the field samples (FW-WB-12-GEO-3.5-5.0) subjected to the consolidation test are silt samples. If the sand sample is removed from the set, the statistics change dramatically. The compression index then ranges from 1.66 to 4.10, with an average of 2.33 and a median of 1.97. The corresponding initial void ratios range from 3.21 to 8.43, with an average of 5.11 and a median of 4.65.

4.3.7 Shear Strength

UU (or Q) triaxial compression (shear strength) tests were run on 11 field samples. Maximum deviator stresses range from 40 pounds per square inch (psi) to 262 psi, with an average of 116 psi and a median of 99 psi. Corresponding axial strains range from 2.9 percent to 8.6 percent, with an average of 5.3 percent and a median of 5.8 percent.

All of the samples tested for UU triaxial compression are classified as cohesive except for FW-WB-12-GEO-3.5-5.0, which was field classified as sand (SM). The across-the-board numbers (moisture content and bulk density), however, are within the range for the other cohesive samples, suggesting that the field classification may be incorrect and the sample may actually be a silt (MH).

4.3.8 Direct Shear

Direct shear tests were run on four field samples. Failure stresses range from 0.66 kips per square ft (ksf) to 1.11 ksf, with an average of 0.90 ksf and a median of 0.91 ksf. The

corresponding failure displacements range from 0.09 inches to 0.21 inches, with an average of 0.15 inches and a median of 0.16 inches.

If one assumes that the samples are non-cohesive, the friction angles range from 39° to 50°, with an average of 44°.

4.3.9 Summary Discussion

All the samples are classified in the USCS in accordance with ASTM D 2487. If a test was not available for exact classification, the classification is based on the description in the field log, except as noted below.

The 24 field samples, two duplicate samples, and four composite samples containing more than 50 percent silt-size particles are classified as MH. Some of the grain size tests were run without Atterberg limits and classified as ML by the laboratory (Appendix A), based on grain size only. All the remaining silt samples that were subjected to Atterberg limit tests (Appendix A) fell into the MH category; with one exception, all silt samples, even those without Atterberg limits or otherwise noted in the field log, were therefore reclassified as MH on the summary table. The lone exception is field sample FW-WB-32-CS-0.0-2.0, which tests as non-plastic and is classified as a non-plastic silt (ML).

The 17 field samples, one duplicate sample, and one composite sample containing more than 50 percent sand are classified as SP, SM, or SP-SM. Five of the sandy field samples are near surface (defined as above the in situ depth of about 7 ft), and four of these are identified in the field logs as being contaminated (petroleum odor or sheen). Twelve of the sandy field samples were collected below the in situ depth of about 7 ft, and nine of these are identified in the field logs as being in native material. None of the samples below 7 ft are identified with contamination.

None of the field samples contain more than 50 percent clay-sized particles, but seven field samples fall under the classification criteria for CH.

The following summarizes the geotechnical testing results by Reach along the WBGCR.

Reach 1 – Seventeen samples from seven test holes were tested for various geotechnical properties. Four samples tested were predominantly sand (SM or SP-SM): three of these were from below 7 feet of depth and therefore from the native sediment, but one was from a sandy layer interbedded with silt adjacent to the south bank of the river. The rest of the samples consisted of very wet, highly compressible silt (MH).

The sand samples had dry unit weights ranging from 56 to 62 pcf with an average of about 60 pcf. The moisture content of the sand samples ranged from 59 percent to 70 percent with an average of about 65 percent. The liquid limits ranged from 50 percent to 53 percent; thus the moisture content was higher than the liquid limit for the sand samples tested. The plastic limit was about 30 percent and the plasticity index was 20 percent.

The silt samples had dry unit weights ranging from 18 to 44 pcf with an average of about 29 pcf. The moisture content of the silt samples ranged from 87 percent to 286 percent with an average of about 156 percent. The liquid limits ranged from 116 percent to 211 percent, with an average of about 150 percent; thus the moisture content was higher than the liquid limit for all but one of the silt samples tested. The plastic limit ranged from 53 percent to 86 percent with an average of 68 percent and the plasticity indexes ranged from 63 percent to 125 percent with an average of about 82 percent. Initial void ratios ranged from 3.2 to 8.4 with an average of 5.9. The compression index ranged from 1.8 to 4.1 with an average of 2.8.

Reach 2 – Fourteen samples from six test holes were tested from this Reach. Five of the samples were predominantly sand (SM), one sample was clay (CH), and the rest were silt (MH). Two of the sand samples were from sandy layers interbedded with silt along the south bank, possibly from native soil; but one sand sample was from the surface of the river. The clay and silt samples were very wet and highly compressible.

One of the sand samples (FW-WB-12-GEO-3.5-5.0) was identified in the field as a sand; but the laboratory results suggest it falls more in the silt range of values, and is treated as such below. The sand samples had dry unit weights ranging from 72 to 88 pcf with an average of about 80 pcf. The moisture content of the sand samples ranged from 31 percent to 43 percent with an average of about 37 percent. No Atterberg limits were run on the sand samples. One of the sand samples had an initial void ratio of 1.3 and a compression index of 0.25.

The silt samples had dry unit weights ranging from 20 to 36 pcf with an average of about 26 pcf. The moisture content of the silt samples ranged from 127 percent to 257 percent with an average of about 199 percent. The liquid limits ranged from 137 percent to 214 percent, with an average of about 163 percent; thus the moisture content was higher than the liquid limit for all of the silt samples tested. The plastic limit ranged from 60 percent to 89 percent with an average of 72 percent and the plasticity indexes ranged from 57 percent to 125 percent with an average of about 91 percent. Only one silt samples was tested for consolidation with an initial void ratio of 5.4 and a compression index 2.6.

The clay sample exhibited a dry unit weight of 23 pcf, a moisture content of 256 percent, a liquid limit of 146 percent, a plastic limit of 54 percent, and a plasticity index of 92 percent.

Reach 3 – Thirteen samples from seven test holes were subjected to geotechnical testing. Five of the samples were predominantly sand (SM or SP-SM), one sample was clay (CH), and the rest were silt (MH).

The sand samples had dry unit weights ranging from 30 to 100 pcf with an average of about 56 pcf. The moisture content of the sand samples ranged from 24 percent to 162 percent with an average of about 101 percent. The liquid limits ranged from 71 percent to 105 percent with an average of 88 percent; thus the moisture content was higher than the liquid limit for the sand samples tested. The plastic limit ranged from 43 percent to 78 percent with an average of 60 percent, and the plasticity index averaged about 28 percent.

The silt samples had dry unit weights ranging from 18 to 45 pcf with an average of about 32 pcf. The moisture content of the silt samples ranged from 99 percent to 307 percent with an average of about 185 percent. The liquid limit was about 160 percent, the plastic limit about 109 percent, thus the plastic index was about 51 percent. Note that the moisture content was higher than the liquid limit for the one silt sample tested. The initial void ratio was 4.2 and the compression index was 1.8.

The clay sample was not tested for geotechnical properties, only grain size.

Reach 4 – Eight samples from five test holes were tested from this Reach. Two of the samples were predominantly sand (SM), one sample was clay (CH), and the rest were silt (MH).

The sand samples had dry unit weights ranging from 80 to 90 pcf with an average of about 85 pcf. The moisture content of the sand samples ranged from 30 percent to 38 percent with an average of about 34 percent. The one sand sample tested for Atterberg limits was non-plastic.

The silt samples had dry unit weights ranging from 22 to 29 pcf with an average of about 27 pcf. The moisture content of the silt samples ranged from 165 percent to 222 percent with an average of about 185 percent. The liquid limits ranged from 171 percent to 194 percent, with an average of about 183 percent; thus the moisture content was slightly higher than the liquid limit for all of the silt samples tested except one. The plastic limit ranged from 70 percent to 90 percent with an average of 80 percent and the plasticity indexes ranged from 101 percent to 104 percent with an average of about 103 percent. One silt sample was tested for consolidation with an initial void ratio of 4.8 and a compression index 1.8.

The clay sample exhibited a dry unit weight of 25 pcf, a moisture content of 203 percent, a liquid limit of 182 percent, a plastic limit of 61 percent, and a plasticity index of 121 percent.

Reach 5 – Eight samples from three test holes were subjected to limited geotechnical testing. Four samples tested were predominantly sand (SM, SW, or SP), one sample was inorganic silt (ML), and three samples were very wet, highly compressible silt (MH).

Only one sand sample (SW) was tested for other than grain size. It had a dry unit weight of 91 pcf and moisture content of 27 percent.

The non-plastic silt sample (ML) had a dry unit weight of 78 pcf and moisture content of 35 percent. The plastic silts (MH) had dry unit weights ranging from 31 to 33 pcf with an average of about 32 pcf. The moisture content of the plastic silt samples ranged from 143 percent to 160 percent with an average of about 150 percent. The one measured set of Atterberg limits resulted in a liquid limit of 137 percent; thus the moisture content was higher than the liquid limit. The plastic limit was 74 percent and the plasticity index was 63 percent. The one silt sample tested for consolidation had an initial void ratio of 4.5 and a compression index 1.9.

Reach 6 – No samples were collected from this reach.

Reach 7 – Thirteen samples from nine test holes were tested for geotechnical properties. Three samples tested were predominantly sand (SM or SP-SM), six samples were very wet, highly compressible silt (MH), and four samples were very wet, highly compressible clay (CH).

The sand samples were tested only for grain size, so there is no data for other geotechnical properties for this Reach of the river.

The silt samples had dry unit weights ranging from 24 to 34 pcf with an average of about 29 pcf. The moisture content of the silt samples ranged from 131 percent to 212 percent with an average of about 163 percent. Only one sample was tested for Atterberg limits, resulted in a liquid limit of 169 percent, the plastic limit was 65 percent and the plasticity index was 104 percent. Two silt samples were tested for consolidation. They had an initial void ratio range from 4.2 to 4.5 with an average of 4.3, and a compression index ranging from 1.7 to 2.0 with an average of 1.9.

The clay samples exhibited a dry unit weight ranging from 26 to 32 pcf with and average of 29 pcf. The moisture content ranged from 150 percent to 185 percent with and average of 169 percent. The liquid limit ranged from 122 percent to 135 percent with an average of 129

percent. Consequently, the plastic limit averaged 82 percent for a range from 79 percent to 84 percent.

A picture emerges from the laboratory testing of sediments that are soft/loose, compressible, and wet. A variety of remediation alternatives are being considered: capping and mechanical and hydraulic dredging. Capping would cause the sediments to consolidate by several inches. Mechanical dredging would be difficult because the sediments have high moisture content and would tend to “run.” If sufficient water is available, hydraulic dredging appears to be feasible, but the discharge slurry would be highly contaminated as described below in Section 4.4; a large confinement area would be required, and the water would have to be treated. These issues will need to be addressed as the design proceeds.

4.4 CONTAMINANT MOBILITY TEST RESULTS

Results of the contaminant mobility testing, including the DRET, the MET, and the column-settling test, are presented herein. The DRET and MET will be used to predict the potential short-term contaminant release at the point of dredging and at the point of disposal. The MET will be used to predict the quality of effluent from the filling of the upland or nearshore confined disposal facility or de-watering facility if hydraulic dredging is used. The results of the column-settling tests will be used to evaluate the spatial and temporal variations in turbidity at the dredging site and the holding time required for settling at the disposal site if hydraulic dredging is used.

4.4.1 Elutriate Testing

The DRET and MET tests were conducted in accordance with WES-recommended procedures (DiGriano et al. 1995, Palermo 1986). The settling time for the MET was 24 hours using a sediment to water concentration of 4:1. The DRET was conducted using a solids concentration of 10-15 g/L and a settling time of 1 hour.

The site water used in the elutriate tests consisted of unfiltered samples obtained during sediment sample collection activities. The water samples were collected from the overlying water column approximately 6 inches to 1 foot below the surface using a peristaltic pump. The site water samples (both total and dissolved fractions) were analyzed for constituents as specified in Table 2.5.

The elutriate from the MET and DRET tests as well as the bulk sediment composite samples were analyzed for SVOCs, pesticides, metals, and PCBs. The analytical results for these analyses are presented in Appendix A.3 along with EPA (2002) and IDEM (2002) water

quality criteria. Bulk sediment composites used for the elutriate tests contained elevated concentrations (exceeding PECs) for PAHs, pesticides (DDD and dieldrin), metals, and PCBs. Elutriate results for each river reach (or combination of reaches) tested exceeded either acute or chronic water quality criteria for SVOCs, pesticides, and PCBs. Results for dissolved metals did not exceed dissolved metals criteria. Most of the exceedances were observed for the SVOCs in both the DRET and MET testing data.

Usually, if elutriate results exceed water quality criteria at the point of dredging and disposal as is simulated by the DRET and MET tests, respectively, a numerical mixing model is performed on the chemical data results. The model estimates contaminant concentrations that will be present in the water column after consideration of dilution hundreds of feet away from the point of dredging. If the numerical model predicts that the concentration of all contaminants of concern at the edge of the mixing zone is less than the available, applicable water quality criteria, then it is likely that the act of dredging will not be a water quality issue. Water levels at the WBGCR are shallow, typically less than 2 ft, and therefore do not allow for dilution. Considering the elevated concentrations found in the elutriate test as well as minimal dilution in the WBGCR, it is certain that dredging activities on the river and the effluent from filling a disposal site adjacent to the river would affect water quality if such actions were to be performed without the use of appropriate mitigation measures.

4.4.2 Column Settling

The two column-settling tests were conducted in accordance with the Inland Testing Manual procedures (EPA/USACE 1998) using target solids concentrations of 150 g/L. The CS-COMP-1 composite, created by mixing sediment samples from Reach 1 and Reach 2, had an initial slurry concentration measured at 143 g/L. The CS-COMP-2 composite, created by mixing sediment samples from Reach 3 and Reach 4, had an initial slurry concentration measured at 150 g/L.

The results of the tests for CS-COMP-1 and CS-COMP-2, including sample collection intervals, concentration, percent of initial concentration, and turbidity, are presented in Appendix A, and graphed results are presented in the laboratory report in Appendix F.

These data will be evaluated further in Phase 3.

Figure 4-1a. Reach 1 Transect 1, Metals Concentrations

Figure 4-1b. Reach 1 Transect 1, PAH Concentrations

Figure 4-1c. Reach 1 Transect 1, Pesticides/Total PCB Concentrations

Figure 4-2a. Reach 1 Transect 2, Metals Concentrations

Figure 4-2b. Reach 1 Transect 2, PAH Concentrations

Figure 4-2c. Reach 1 Transect 2, Pesticides/Total PCB Concentrations

Figure 4-3a. Reach 1 Transect 3, Metals Concentrations

Figure 4-3b. Reach 1 Transect 3, PAH Concentrations

Figure 4-3c. Reach 1 Transect 3, Pesticides/Total PCB Concentrations

Figure 4-4a. Reach 1 Transect 4, Metals Concentrations

Figure 4-4b. Reach 1 Transect 4, PAH Concentrations

Figure 4-4c. Reach 1 Transect 4, Pesticides/Total PCB Concentrations

Figure 4-5a. Reach 2 Transect 1, Metals Concentrations

Figure 4-5b. Reach 2 Transect 1, PAH Concentrations

Figure 4-5c. Reach 2 Transect 1, Pesticides/Total PCB Concentrations

Figure 4-6a. Reach 2 Transect 2, Metals Concentrations

Figure 4-6b. Reach 2 Transect 2, PAH Concentrations

Figure 4-6c. Reach 2 Transect 2, Pesticides/Total PCB Concentrations

Figure 4-7a. Reach 2 Transect 3, Metals Concentrations

Figure 4-7b. Reach 2 Transect 3, PAH Concentrations

Figure 4-7c. Reach 2 Transect 3, Pesticides/Total PCB Concentrations

Figure 4-8a. Reach 3 Transect 1, Metals Concentrations

Figure 4-8b. Reach 3 Transect 1, PAH Concentrations

Figure 4-8c. Reach 3 Transect 1, Pesticides/Total PCB Concentrations

Figure 4-9a. Reach 3 Transect 2, Metals Concentrations

Figure 4-9b. Reach 3 Transect 2, PAH Concentrations

Figure 4-9c. Reach 3 Transect 2, Pesticides/Total PCB Concentrations

Figure 4-10a. Reach 3 Transect 3, Metals Concentrations

Figure 4-10b. Reach 3 Transect 3, PAH Concentrations

Figure 4-10c. Reach 3 Transect 3, Pesticides/Total PCB Concentrations

Figure 4-11a. Reach 4 Transect 1, Metals Concentrations

Figure 4-11b. Reach 4 Transect 1, PAH Concentrations

Figure 4-11c. Reach 4 Transect 1, Pesticides/Total PCB Concentrations

Figure 4-12a. Reach 4 Transect 2, Metals Concentrations

Figure 4-12b. Reach 4 Transect 2, PAH Concentrations

Figure 4-12c. Reach 4 Transect 2, Pesticides/Total PCB Concentrations

Figure 4-13a. Reach 5 Transect 1, Metals Concentrations

Figure 4-13b. Reach 5 Transect 1, PAH Concentrations

Figure 4-13c. Reach 5 Transect 1, Pesticides/Total PCB Concentrations

Figure 4-14a. Reach 5 Transect 2, Metals Concentrations

Figure 4-14b. Reach 5 Transect 2, PAH Concentrations

Figure 4-14c. Reach 5 Transect 2, Pesticides/Total PCB Concentrations

Figure 4-15a. Reach 7 Transect 1, Metals Concentrations

Figure 4-15b. Reach 7 Transect 1, PAH Concentrations

Figure 4-15c. Reach 7 Transect 1, Pesticides/Total PCB Concentrations

Figure 4-16a. Reach 7 Transect 2, Metals Concentrations

Figure 4-16b. Reach 7 Transect 2, PAH Concentrations

Figure 4-16c. Reach 7 Transect 2, Pesticides/Total PCB Concentrations

Figure 4-17a. Reach 7 Transect 3, Metals Concentrations

Figure 4-17b. Reach 7 Transect 3, PAH Concentrations

Figure 4-17c. Reach 7 Transect 3, Pesticides/Total PCB Concentrations

5. FATE AND TRANSPORT

An understanding of fate and transport mechanisms for the WBGCR media is important for developing remedial action alternatives and designing a remedial action approach as well as for the ability to meet restoration objectives for natural resources. The chemical and physical properties of a compound or element, and its presence in the environment, must be evaluated to determine the environmental fate of a chemical. Chemical factors that require consideration for the WBGCR sediments include chemical mobility, persistence, and stability in sediment and water. Additional factors, such as the physical, chemical, and biological processes that may affect a chemical, must also be considered.

This section is divided into three parts. Section 5.1 provides information on relevant physical and chemical properties and the fate of the chemicals frequently detected in WBGCR sediments. Section 5.2 provides a discussion of transport mechanisms in freshwater sediment and surface water (i.e., surface water, sediment, and biota). The air pathway has been eliminated because volatile organics were not analyzed as part of this site characterization and, historically, were not detected in most sediment samples (Foster Wheeler Environmental 2002a). Section 5.3 presents site-specific fate and transport scenarios based on a conceptual site fate and transport model for the WBGCR. Conceptual site models (CSM) identify primary and secondary sources of chemicals, release mechanisms, transport mechanisms, and potential migration pathways. The purpose of the CSMs is to describe the potential source-pathway scenarios for each reach of the WBGCR. Conceptual site models that include receptors (both human and ecological) will be evaluated in the Phase 3 investigation.

5.1 PHYSIOCHEMICAL PROPERTIES AND THE ENVIRONMENTAL FATE OF SELECTED CHEMICAL CONSTITUENTS

Chemical persistence is a function of physical, chemical, and biological processes that potentially affect a chemical as it moves through air, soil, and water systems. These processes may include photolysis, hydrolysis, volatilization, sorption, bioaccumulation, biotransformation, and biodegradation.

Physiochemical properties of chemicals (for example, solubilities and partitioning tendencies) are important for evaluating chemical sources, persistence, and routes of migration; conducting risk or exposure assessments; selecting remedial actions; and evaluating restoration options. Properties of chemicals affect the nature of fate and transport

in air, soil/sediment, surface water, groundwater, and biological exposure pathways. The migration and partitioning potentials of chemical analytes identified in WBGCR sediments were evaluated on the basis of selected physiochemical properties such as chemical formula; specific gravity; solubility in water and organic solvents; log octanol/water partition coefficient (K_{ow}), log water/organic carbon partition coefficient (K_{oc}), and log soil/water partition coefficient (K_d) (which provide information on sorption characteristics and bioaccumulation potential); and vapor pressure (which provides information on volatility).

Table 5-1 provides a summary of important physiochemical properties of chemical analytes frequently detected in WBGCR sediments above PECs. In general, with reference to Table 5-1, chemical analytes with specific gravities greater than one (unity) are heavier than water and will tend to migrate deeper in the water column while analytes with specific gravities of less than one will tend to remain in the shallower portion of the water column or may even “float” on the water surface. The “floating/sinking” behavior of chemicals occurs only when separate phases are present, not dissolved materials. Solubility in water controls the amount of a chemical that can be present in the dissolved phase and is related to the degree of partitioning of a chemical into either the solid (sediment) or solution (water) phase. Chemical analytes with high solubilities readily dissolve in water, while those with solubilities of less than about 10 mg/L (such as mercury and PCBs) are only slightly soluble in water. Most metals, in elemental or inorganic form, are insoluble in water or have very low solubility; however, metal solubilities can be influenced greatly by environmental conditions such as EH/pH, the presence of salts or organic materials (e.g., wood chips), and biological activity. For example, many metals become more soluble in the presence of organic chelating agents that are common and naturally occurring in both terrestrial and aquatic systems.

Partition coefficients (determined for water/octanol, water/organic carbon, and water/solid systems) also provide an indication of the degree to which chemical analytes will be distributed between both water and soil or sediment systems. In general, high partition coefficients indicate a strong tendency for a chemical to associate with the organic (octanol) or soil/sediment (solid) phase, whereas a low partition coefficient indicates preferential association with the solution (water) phase. In general, metals and PCBs/pesticides have very high partition coefficients, indicating preferential sorption to soil/sediment particles, where more soluble chemical analytes have low partition coefficients. The vapor pressure of a chemical compound also provides an indication as to its persistence in the environment. High vapor pressures mean the compound has a high volatility rate, which indicates it will

Table 5-1. Selected Physical and Chemical Properties of Chemical Analytes Identified in WBGCR Sediments

Compound	Chemical Formula	Atomic or Molecular Weight	Specific Gravity	Boiling Point (°C)	Solubility in Water (mg/L)	Solubility in Organic Solutions	Log Octanol/Water Partition Coef.	Vapor Pressure (mm Hg)	Henry's constant (atm-m ³ /mole)
Arsenic	As	74.91	5.72	613	Not Available	Depends on chemical species	--	--	--
Cadmium	Cd	112.41	8.64	765	Not Available	Depends on chemical species	--	--	--
Mercury	Hg	200.59	13.546	356-358	0.081 @ 30°C	Depends on chemical species	--	--	--
Lead	Pb	207.19	11.3	1740	Insoluble	Depends on chemical species, soluble in some acids	--	--	--
Zinc	Zn	65.39	7.14	907	Insoluble	Strong acid or alkaline solution	--	--	--
Aroclor 1242	C ₁₂ H ₇ Cl ₃ (mixture)	266.5	1.35	325-366	0.24	Soluble in most common organic solvents	4.11	4.06 x 10 ⁻⁴	5.7 x 10 ⁻⁴
Aroclor 1248	C ₁₂ H ₆ Cl ₄ (mixture)	299.5	1.41	340-375	0.054	Soluble in most common organic solvents	5.75	4.94 x 10 ⁻⁴	3.5 x 10 ⁻³
Aroclor 1254	C ₁₂ H ₅ Cl ₅ (mixture)	328.4	1.50	365-390	0.012	Soluble in most common organic solvents	6.03	7.71 x 10 ⁻⁵	2.8 x 10 ⁻³
Aroclor 1260	C ₁₂ H ₂ Cl ₇ (mixture)	375.7	1.58	385-420	0.0027	Soluble in most common organic solvents	7.14	4.05 x 10 ⁻⁵	7.1 x 10 ⁻³
Aroclor 1268	C ₁₂ H ₂ Cl ₈ (mixture)	424.2	1.60	390-425	Not Available	Soluble in most common organic solvents	7.25	3.95 x 10 ⁻⁵	9.2 x 10 ⁻³

5-3

Table 5-1. Selected Physical and Chemical Properties of Chemical Analytes Identified in WBGCR Sediments¹

Compound	Chemical Formula	Atomic or Molecular Weight	Specific Gravity	Boiling Point (°C)	Solubility in Water (mg/L)	Solubility in Organic Solutions	Log Octanol/Water Partition Coef.	Vapor Pressure (mm Hg)	Henry's constant (atm·m ³ /mole)
DDT	C ₁₄ H ₉ Cl ₅	355.49	1.00	260	Insoluble	Soluble in most common organic solvents	6.19	3.93 x 10 ⁻⁷	5.13 x 10 ⁻⁴
DDE	C ₁₄ H ₈ Cl ₄	318.03	Not Available	Not Available	Insoluble	Soluble in most common organic solvents	7.00	5.66 x 10 ⁻⁶	6.8 x 10 ⁻⁵
DDD	C ₁₄ H ₁₀ Cl ₄	320.05	1.40	193 at 1 mm Hg	Insoluble	Soluble in most common organic solvents	6.20	8.66 x 10 ⁻⁷	2.16 x 10 ⁻⁵

¹ This table shows measured or calculated physiochemical properties from selected references (Callahan et al. 1979; Howard 1989, 1991a, 1991b; ATSDR 1997; CRC 2002). It should be acknowledged that there is a wide range of both measured and calculated values for these chemicals available in the literature.

volatilize from a solid or liquid medium to the atmosphere. Low vapor pressures (such as 10^{-3} mm Hg for PCBs) indicate a very low rate of volatilization and that loss to the atmosphere will be minimal.

Lastly, the Henry's Law Constant of a chemical compound provides an indication of the partition between air and water at equilibrium and also is used to calculate the rate of evaporation from water. For chemicals with values less than 10^{-7} atm-m³/mole, the chemical is less volatile than water and as water evaporates the concentration will increase; for chemicals around 10^{-3} atm-m³/mole, volatilization will be rapid (Howard 1989, 1991a, 1991b).

The following sections present fate and transport information on chemicals of concern detected in WBGCR sediments. These metals and organic compounds were frequently detected above the PEC levels established for sediments in the Grand Calumet River.

5.1.1 Arsenic

Arsenic is a rare but ubiquitous element in the earth's crust. Emissions from natural sources include volcanic emissions, weathering of arsenic-containing minerals, forest fires, and the terrestrial biosphere. Anthropogenic sources include its production primarily as a by-product from the operation of nonferrous smelters. Arsenic is used in metallurgy for hardening copper alloys, as a wood preservative and a chemical warfare agent, in the manufacture of some glass, and in insecticides and herbicides. At normal temperatures and pressures, elemental arsenic is a tin-white (fresh surfaces) to dark gray (tarnished surfaces), brittle, crystalline semimetal (mp = 817°C [sublimes at 613°C], sp.g = 5.72 g/cc). In the natural environment, four oxidation states are possible: -3, 0, +3 and +5 (Callahan et al. 1979, Agency for Toxic Substances and Disease Registry [ATSDR] 1997).

Arsenic is extremely mobile in the aquatic environment and cycles through the water column, sediment, and biota. This is due in part to its unusually complex chemistry, with oxidation/reduction, precipitation, and sorption reactions all taking place. The dominant dissolved species of arsenic are either uncharged or negatively charged, suggesting that adsorption and ion exchange cause little retardation along the groundwater flow path.

In aquatic systems, arsenic metal (As^0) is present only rarely. As^{-3} is stable only at extremely low Eh values. As^{+3} and As^{+5} are the most prevalent forms with As^{+3} being significantly more toxic than As^{+5} . Heavy metals in solution (e.g., barium) may reduce the mobility of arsenic.

Cycling of arsenic in the aquatic environment is dominated by adsorption and desorption to sediments. The chemical can be sorbed onto clays, aluminum hydroxides, iron oxides, and organic material. In addition, in areas where phosphate minerals occur, arsenate may isomorphously substitute for phosphate. Under most conditions, coprecipitation or sorption of arsenic with hydrous oxides of iron may be the most important process in the removal of dissolved arsenic from an aqueous system. The oxyanions of both arsenic and arsenous acid can coprecipitate with hydrous iron and manganese oxides. Most of the arsenic entering an aqueous environment can be expected to be sorbed to sediments.

Volatilization of arsenic may be a significant process in extremely reducing environments where arsine (AsH_3) is formed but is not an important mechanism under normal conditions. Arsine is probably rapidly oxidized in aerobic waters or the atmosphere. Methylated arsine derivatives may be more volatile than arsine. Trimethylarsine is quite volatile at room temperature and is oxidized very slowly to more soluble products.

Photolysis is apparently not an important process for fate and transport of arsenic.

Bioaccumulation is most significant in lower trophic levels since high toxicity reduces the overall accumulation by aquatic organisms. Arsenic is metabolized by a number of organisms to organic arsenicals, which increases its mobility in the environment.

5.1.2 Cadmium

Cadmium is a relatively rare naturally occurring element that is concentrated in zinc-bearing sulfide ores and, consequentially, in all zinc-containing products. The only important mineral containing cadmium is greenockite (CdS). Cadmium is a constituent of easily flammable alloys and is used in electroplating and nickel/cadmium batteries. It is also associated with foundry and smelting operations. At normal temperatures and pressures, cadmium is a bluish-white, soft metallic solid (mp = 321°C , bp = 765°C , sp.g. = 8.65 g/cc). It exists in the natural environment in the +2 oxidation state (Callahan et al. 1979, ATSDR 1997).

In natural waters, cadmium can be found in several chemical forms: simple aquated ions, metal-inorganic complexes, or metal-organic complexes. Cadmium forms complexes with OH^- such as CdOH^+ , $\text{Cd}(\text{OH})_2$ (aq.), $\text{Cd}(\text{OH})_2^-$, and $\text{Cd}(\text{OH})_4^{2-}$. The solubility of cadmium decreases as pH increases due to formation of solid $\text{Cd}(\text{OH})_2$. Carbonate in solution with cadmium will somewhat reduce the solubility of the element, thereby removing more of it from solution than hydroxide in solution. Under reducing conditions and in the presence of

sulfur, cadmium may react to form insoluble sulfide (CdS). Under acidic conditions, however, CdS is more soluble.

The transport of cadmium in the aquatic environment is controlled by the speciation of the ion. In most unpolluted water, cadmium will exist mainly as a divalent cation but organic material will have an overwhelming effect on the form of cadmium under other conditions.

Cadmium in association with carbonate minerals, precipitated as stable solid compounds or coprecipitated with hydrous iron oxides, will be less likely to be mobilized by resuspension of sediments or biological activity. Cadmium sorbed to mineral surfaces (e.g., clay), or organic materials will be more likely to be bioaccumulated or released in the dissolved state when sediments are disturbed.

Cadmium is not known to form volatile compounds in aquatic environments. Biomethylation of cadmium has not been reported.

There is no evidence that photolysis is an important fate mechanism for cadmium in aquatic environments.

Cadmium is strongly accumulated in all organisms. In aquatic environments, it can accumulate in tissue at concentrations hundreds to thousands of times higher than found in the water column. Cadmium can replace zinc in certain enzymes, which can disrupt normal metabolic processes. The accumulation of cadmium in aquatic organisms is related to the cation exchange capacity of soil/sediment with increasing cation exchange capacity resulting in decreasing accumulation.

Direct biotransformation is not evident, but biologically produced ligands may affect solubility and sorption of cadmium.

5.1.3 Mercury

Mercury is used in fumigicides, slimicides, and the manufacture of paint, paper, and chlorine. It also may be a byproduct from the operation of nonferrous smelters. Since mercury is used in hospitals, improper disposal of hospital waste (e.g., through the sanitary sewers) may be a source of mercury. The element is only slightly soluble in water (19 to 81 µg/L) and has a density of 13.53 g/cm³. At 20°C, its specific gravity is 13.546 (Callahan et al. 1979, ATSDR 1997).

Mercury's major removal mechanism from surface water is adsorption onto the surfaces of particulates and subsequent settling to the bed sediment. Adsorption is strongest onto organic materials. Mercury in sediment is generally complexed to organic compounds

within the sediment matrix. Most dissolved mercury (both Hg^{+1} and Hg^{+2}) will be removed in this manner within a relative short time, generally in the immediate vicinity of the source. Secondary transformations of mercury in the sediments can occur; these include precipitation as HgS (mercury sulfide) and methylation by bacteria into methyl mercury. Methylation can occur under both aerobic and anaerobic conditions, although more mercury methylation occurs when more bacteria are present. Therefore, it would be expected that highly organic sediments that favor bacterial growth have a higher methylation potential than inorganic sediments. Methyl mercury is more readily accumulated and retained than inorganic mercury. Since the mercury itself is not destroyed, these inorganic and organic forms of mercury may then release ionic or metallic mercury into the water column as part of a recycling process. Resuspension of sediments by turbulence or the activity of benthic organisms can also release these compounds of mercury directly into the water column. The primary sink for mercury released to the freshwater environment is thus the sediment.

5.1.4 Lead

Lead is commonly found in association with ores of copper, zinc, silver, arsenic, and antimony in complex vein deposits but it can also be found in lead ores in igneous, metamorphic, and sedimentary rocks. Consequently, smelters and foundry operations are a source of lead. The overwhelming anthropogenic source of lead in the environment is leaded gasoline exhaust from vehicles. The two lead compounds found in vehicle exhaust are $\text{NH}_4\text{Cl}\cdot 2\text{PbClBr}$ and $2\text{NH}_4\text{Cl}\cdot \text{PbClBr}$. Lead exists in one of three oxidation states (0, +2, and +4) (Callahan et al. 1979, ATSDR 1997).

Natural compounds of lead are not usually mobile in normal surface water or groundwater, because the lead leached from ores is adsorbed by ferric hydroxide or combines with carbonate or sulfate ions to form insoluble compounds.

Overall, metallic lead and the common lead mineral have a low solubility in water and a density of 11.34 g/cm^3 . However, some industrially produced lead compounds, such as tetraethyl lead, are readily soluble in water (Callahan et al. 1979).

Adsorption processes appear to exert a dominant effect on the distribution of lead in the environment. Adsorption to inorganic solids, organic materials, and hydrous iron and manganese oxides usually controls the mobility of lead and results in a strong partitioning of lead to the bed sediment in aquatic systems. The sorption mechanism most important in a particular system varies with geological setting, pH, Eh, availability of ligands, dissolved and particulate ion concentrations, salinity, and chemical composition.

Lead and its associated inorganic and organic complexes are transported as particulates in the atmosphere. Lead carried in the atmosphere can be removed by either precipitation or particulate disposition. Photolysis in the atmosphere occurs readily. These atmospheric processes are important in determining the form of lead entering aquatic and terrestrial systems.

The transport of lead in the aquatic environment is influenced by the speciation of the ion. Lead exists mainly as the divalent cation in most unpolluted waters and becomes adsorbed into particulate phases. However, in polluted waters, organic complexation is the most important factor. Little evidence is available concerning the photolysis of lead compounds in natural waters. Volatilization (bp = 1,740°C) of lead compounds is not important in most aquatic environments.

The equilibrium solubility of lead with carbonate, sulfate, and sulfide is low. Over most of the normal pH range, lead carbonate and lead sulfate control the solubility of lead in aerobic conditions, and lead sulfide and metallic lead control solubility in anaerobic conditions. Lead is strongly complexed to organic materials present in aquatic systems and soil.

Bioaccumulation of lead has been demonstrated for a variety of organisms, and bioconcentration factors are within the range of 100 to 1,000. Plants do not easily take up lead in soil, and therefore its availability to terrestrial organisms is somewhat limited. Biomethylation of lead by microorganisms can remobilize lead to the environment.

5.1.5 Zinc

Zinc commonly occurs as a sulfide, oxide, carbonate, and silicate. Zinc is used in making galvanized iron, alloys such as brass and die-casting metal, as an element in voltaic cells, and rolled into sheets and used as protective covering (e.g., for roofs).

Sorption is the dominant reaction of zinc, resulting in enrichment of zinc in suspended and bed sediment (Callahan et al. 1979, ATSDR 1997). The tendency of zinc to be adsorbed is affected not only by the nature and concentration of the sorbent (i.e., organic content and percentage of clay-size sediment) but by pH and salinity as well (Callahan et al. 1979). Zinc tends to be more readily adsorbed at higher pH (>7) than at lower pH (Callahan et al. 1979). Desorption of zinc from sediment occurs as salinity increases.

In surface water, zinc may occur in both suspended and dissolved forms. Dissolved zinc may occur as the free (hydrated) zinc ion or as dissolved complexes and compounds with varying degrees of stability, whereas suspended zinc may be dissolved by small changes in the water chemistry or be sorbed to suspended matter.

Zinc is accumulated by all organisms as an essential nutrient. However, as with most metals, it can be harmful in large doses. Although biota appears to be a minor reservoir of zinc relative to the sediment, biological activity can affect the mobility of zinc in the aquatic environment (Callahan et al. 1979). In the aquatic environment, the transport of zinc is controlled by the speciation of the ion. In natural waters, two reactions can occur: competition for complexation sites between metal ions and competition between different ligands for the same metal ion.

Volatilization is not an important transport process for zinc (Callahan et al. 1979).

5.1.6 Polychlorinated Biphenyls (PCBs)

Commercial production of PCBs was initiated in the United States in 1929 in response to the electrical industry's need for an improved dielectric insulating fluid for use in transformers and capacitors that would also provide increased fire-resistant benefits. The fire-resistant nature and thermal stability of PCBs made them very attractive for use as hydraulic and heat transfer fluids. PCBs can be formed when combustion occurs in the presence of chlorine and as an impurity. PCBs are found in some effluents from chemical manufacturing plants, tanneries, Kraft-pulp mills, wood-processing plants, and sewage treatment plants. They were also used in surface coatings, manufacture of carbonless copy paper, printing inks, plasticizers, adhesives, and vacuum pump fluids. Aroclor is the most familiar trademark in the United States, but PCBs have also been marketed as Chloretol, Dyknol, Askyerol, Inerteem, Noflamol, and Pyranol. Domestic production of PCBs was stopped in October 1977 (Callahan et al., 1979, ATSDR 1997).

PCBs are colorless to light yellow, oily to viscous to resinous liquids, with increasing chlorine content resulting in mixtures with increasing viscosity up to that of sticky resins. Water solubility is extremely low, although PCBs are soluble in oils and organic solvents. PCBs are prepared commercially by the chlorination of biphenyl with anhydrous chlorine in the presence of a catalyst, such as iron filings or ferric chloride. The products are a complex mixture of chlorobiphenyls whose degree of chlorination depends principally on the amount of time the biphenyl is in contact with anhydrous chlorine. Almost without exception, PCBs contain polychlorinated dibenzofurans at varying concentrations.

All PCB compounds include a central biphenyl molecule with two benzene rings and from 1 to 10 chlorine atoms attached to the rings. Different PCB compounds (congeners) are formed based on the number and position of the chlorine atoms, resulting in 209 congeners. PCBs with the same number of chlorine atoms are referred to as homologs, (for example, the

dichlorobiphenyls contain two chlorine atoms) and because PCBs contain from 1 to 10 chlorines, there are 10 homolog groups. The PCB compounds within a homolog are isomers because they differ only by the positions of the chlorines on the benzene rings (for example, the dichlorobiphenyl homolog includes 12 isomers). (ATSDR 2000)

Some of the PCBs are of particular toxicological interest because they have shown toxic effects (to the immune, endocrine, and reproductive systems, dermal effects, birth defects, carcinogenicity, and tumor promotion) similar to one of the major dioxin compounds (2,3,7,8-tetrachlorodibenzodioxin) and they are thought to have the same mechanism of action. There are 13 PCB congeners in this group referred to as dioxin-like PCBs. All of these congeners are classified as planar PCBs because the benzene rings are positioned such that they are in the same plane. The World Health Organization (WHO) has developed toxicity equivalency factors (TEFs) for these compounds that provide a measure of their toxicity relative to 2,3,7,8-TCDD. TEFs have been developed for humans and other mammals, and birds and fish. There is considerable variability in toxicity between these congeners and between the different vertebrate classes. For example, congener 81 (a tetrachlorobiphenyl) is relatively toxic to birds (TEF = 0.1), but of significantly lower toxicity to mammals and fish (TEFs = 0.0001 and 0.0005, respectively). Whereas, congener 126 (a pentachlorobiphenyl) is relatively toxic to mammals and birds (TEFs = 0.1), but of much lower toxicity to fish (TEF = 0.005) (EPA 1998). The other PCB congeners, or nondioxin-like PCBs, have their own toxicities that contribute to the overall toxicity and should be considered when assessing the risks of PCB mixtures (EPA 1996). The toxicity of the PCBs will be evaluated in further detail during the risk assessment phase.

All Aroclor products are identified by a four-digit number; the first two digits, for example 12, represent the 12 carbons of the biphenyl skeleton, and the second two digits the percentage of chlorine in the mix. Thus, Aroclor 1254 is a PCB mixture in which chlorine constitutes 54 percent of the total weight. Any given Aroclor mixture is made up of many congeners at varied concentrations. The main constituents (by weight) of Aroclors 1016, 1221, 1232, and 1242 are homologs with 1 to 4 chlorines. Whereas, the main constituents of Aroclors 1248, 1254, 1260, and 1262 are homologs with 5 to 7 chlorines (ATSDR 2000).

The relative importance of environmental fate mechanisms for PCBs generally depends on the degree of chlorination, with persistence generally increasing with increasing chlorination. Mono-, di-, and trichlorinated biphenyls (the primary composition of Aroclor-1221, -1232, and -1016) biodegrade relatively rapidly, tetrachlorinated biphenyls (Aroclor-1242) biodegrade slowly, and higher chlorinated biphenyls (Aroclor-1248, -1254, -1260, and -1268) are resistant to biodegradation. Although biodegradation of higher chlorinated

congeners may occur very slowly, no other degradation mechanisms are significant in natural soil and waters, making PCBs very persistent in the environment. Biodegradation may be the ultimate degradation process in the natural environment. Biodegradation of heavier PCB congeners (e.g., tetra-, penta-, hexa-, and higher chlorobiphenyls) is not an important process in freshwater sediments (Callahan et al. 1979). Consequently, the residual concentration of these congeners is expected to be higher in weathered PCB Aroclors in the sediments.

If released to aquatic systems, PCBs adsorb tightly to the sediment, with adsorption generally increasing with the degree of chlorination. PCBs generally do not leach significantly to the water, although in the presence of organic solvents, co-solvency may occur, allowing PCBs to leach quite rapidly through sediment. Vapor loss of PCBs from soil/sediment surfaces does not appear to be an important fate mechanism, with the rate of volatilization decreasing with increasing chlorination. Enrichment of the low-chlorine PCBs occurs in the vapor phase relative to the original Aroclor, so that residues tend to be enriched in higher chlorinated PCBs.

PCB mobility in aqueous soil-sediment systems has reported experimental K_{OC} values ranging from 510 to 13,300,000 for a variety of Aroclors and PCB congeners. Most reported K_{OC} values are above 5,000. These extremely high values are reflected in the predilection of PCBs for surfaces and lipids. Of particular importance are the surface boundaries of contaminated water and sediment. Since the highest biological activities in a water column are at the air-water and water-sediment boundaries, accumulation of PCBs at these surfaces facilitates their bioaccumulation by bacteria and plankton, resulting in the introduction of halogenated biphenyls into the food web (Callahan et al. 1979, Waid 1986, Bruijn et al. 1989).

If PCBs are released to water (both fresh and marine), adsorption to sediment and suspended matter will be an important fate process. The highly nonpolar nature of PCBs causes them to be transported in association with the seston of an aquatic environment and to be primarily localized in the sediments. PCBs found in sediments can be removed from an ecosystem via transport downstream as well as by diffusional loss to the water column. However, PCB concentrations in sediment and suspended matter tend to be higher than in the associated water column. The PCB composition in the water will be enriched in the lower chlorinated PCBs because of their greater water solubility, with the higher chlorinated (less water soluble) PCBs remaining adsorbed to the sediment. This strong adsorption reduces volatilization, with the higher chlorinated PCBs persisting in the environment longer than the lower chlorinated PCBs.

5.1.7 Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are a class of compounds consisting of substituted and unsubstituted polycyclic aromatic rings commonly formed by the incomplete combustion of organic materials. PAHs are the major components of creosote, road tars, and incomplete combustion of petroleum hydrocarbons (e.g., waste oils). These compounds include acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,cd)pyrene, naphthalene, phenanthrene, and pyrene. Their chemical, physical, and biological properties vary with their molecular weight and structure. (For this reason, PAHs are not included in Table 5-1.) Solubility generally decreases with increasing molecular weight. The less soluble a PAH compound, the more likely it is to remain in the sediment (Callahan et al. 1979, ATSDR 1997).

PAHs will adsorb to organic material in soil, as well as to sediment and suspended matter in aquatic media. The degree of adsorption depends on the amount of organic matter in the specific medium and the particular PAH's affinity to organic matter, defined as the log octanol/water partition coefficient ($\log K_{ow}$). $\log K_{ow}$ increases with increased adsorptivity and increased molecular weight.

Biodegradation and biotransformation are the ultimate fate processes for PAHs in sediment. PAHs are quickly metabolized and eliminated from most organisms. Bioaccumulation, especially in vertebrate organisms, is usually short term and is not considered an important fate process in most multicellular organisms. High-molecular-weight PAHs are degraded slowly by microbes and readily metabolized by multicellular organisms. Microbes have been reported to degrade PAHs much more completely than mammals. The half-life of PAHs in sediment can range from less than 1 day to several years (Callahan et al. 1979, ATSDR 1997).

5.1.8 DDT and Degradation Products

Dichlorodiphenyltrichloroethane (DDT) is the common name for the pesticide of which 4,4'-DDT is the predominant component. DDT may also contain up to 30 percent of the 2,4'-DDT isomer. Dichlorodiphenyldichloroethane (DDD) is also a pesticide. The technical grade of DDD contains related compounds in small amounts, with 4,4'-DDD being one of the isomers. The compound 4,4'-dichlorodiphenyl-dichloroethene (4,4'-DDE) is an impurity and degradation product of DDT. Emissions resulted from discharge of wastewaters from production and its use as a pesticide. At normal temperatures and

pressures, DDT is a colorless to white, odorless to fruit-like odor, tasteless, crystalline solid (mp = 108.5°C; bp = 260°C) (Callahan et al. 1979, Howard 1991b).

With their high K_{ow} range of 6.19 to 7.00, both sorption and bioaccumulation are important fate processes in removal and immobilization of DDT, DDD, and DDE. Biotransformation and biodegradation are slow but important fate processes.

Volatilization of DDT, DDD, and DDE is an important fate process ($HC = 6.8 \times 10^{-5}$ to 5.13×10^{-4} atm-m³/mole; $P_v = 8.66 \times 10^{-7}$ to 5.66×10^{-6} mm Hg at 30°C).

Photolysis of DDT may be significant but will be slow. Photolysis of DDD in water is expected to be insignificant. Photolysis of DDE is a significant fate process, with an estimated half-life of DDE ranging from 1 to 6 days. Hydrolysis of DDT may be significant under some conditions but will be slow. Hydrolysis of DDD and DDE is insignificant.

5.2 GENERAL TRANSPORT PROCESS

This section describes the processes by which chemical analytes are transported from their source(s) to potential human and environmental exposure points. Principal transport mechanisms are surface water and sediment transport downstream in the WBGCR. After the compounds enter the environment, physical, chemical, and biological processes control how they will be transported and transformed at the site (Section 5.1). In general, these processes tend to decrease concentrations with increasing distance from the source areas.

5.2.1 Surface Water Transport

Surface water transport characteristics are highly dependent on the type of water body present. In flowing water, as in the case of portions of the WBGCR, the direction of chemical transport is typically downstream. In the case of marshes or lakes (e.g., Roxana Marsh), chemical transport may be directed inland as well as downstream. Dispersion is a rapid process because of turbulent eddying (advection) and diffusion along concentration gradients. Comparing rates of chemical introduction to river flow discharge rates can approximate the amount of dilution. In stagnant water bodies, such as marshes, advective forces are less important, and primary attenuation may be through diffusion.

The water solubility of a chemical partly determines how that substance is transported by surface waters. Because water is a polar solvent, polar covalent and ionic compounds are more likely to dissolve than nonpolar compounds. If a chemical dissolves in surface water, its chemical transport properties will be identical to those of water. Conversely, an immiscible liquid phase will either sink or float on water, depending on its specific gravity.

NAPLs with a specific gravity of less than one will tend to remain close to, or “float” on the surface and may become susceptible to attenuation by volatilization and photolysis.

Immiscible liquids more dense than water will move along the river bottom or become absorbed onto sediment particles.

Substances dissolved in surface waters can also partition out of the dissolved phase to a liquid phase or adsorb onto particles suspended in the water or onto bottom sediment. The latter process transfers the substances from the water to the sediment matrix. Conversely, chemicals may desorb from sediment and enter solution.

Chemicals in river sediment can be transported downgradient as part of the bed or suspended load, depending on particle size and river energy (discussed in Section 5.2.2). They may settle and accumulate in river-bed sediment (e.g., behind culverts, bridges) and become buried over time. Resuspension can occur during large storm events. In general, flowing water transport mechanisms in the WBGCR would tend to move contaminated sediment downstream, depending on the flow direction at that time. The flow of the WBGCR has changed directions several times over the last 100 years due to changes in Lake Michigan water levels and discharges of local sanitary systems (USACE 1997).

5.2.2 Sediment Transport

Sediment transport is considered to be the primary transport mechanism for chemicals of concern after they enter WBGCR surface waters. Because of their low solubilities in water, chemicals of concern (metals, PCBs, PAHs, and DDT) tend to be adsorbed to fine-grained organic material in the water column and are either deposited on the bottom or transported by physical processes such as river currents. After deposition, bottom sediments are subject to resuspension by currents and transport as bedload; mostly fine-grained material will be entrained in the water column as suspended load. The other important processes that affect long-term contaminant presence are biological, including bioturbation of sediments, bioaccumulation, and biomagnification. Sediment bioturbation will improve degradation rates of PCBs and PAHs through oxygenation of surface sediments but will not greatly affect metals (e.g., mercury) concentrations. The latter two processes are important in exposure pathways and will be discussed further in the Phase 3 investigation.

Once contaminants are adsorbed to fine-grained sediments and organics, the material may be transported in suspension or bedload by wind-driven and downstream river currents. It is probable that these currents may be sufficient to move coarse-grained material (medium to

coarse-grained sand or larger) at particular times of the year (e.g., spring) and during storm events.

5.2.2.1 Sediment Deposition

Most of the WBGCR reaches appear to be stable and depositional in nature during low flow regimes, based on the sediment distribution observed during the bathymetry and sounding investigations. The high accumulation of sediment in the river reaches is explained by the many bridges and culverts controlling water discharge along the WBGCR. The highest levels of accumulation occur behind these obstructions in the form of delta deposits. Sediment deposition is less in the river channels where bottom currents tend to scour the sediment.

5.2.2.2 Sediment Bioturbation

Benthic infauna occurs in the upper strata of sediment, although only in the upper 1 to 2 cm (Phase 2 field observations). Sediment is mixed by these organisms throughout their life cycles. The depth of sediment that is susceptible to mixing by various infaunal organisms varies with the sediment grain size, density, sediment chemistry, bottom current velocity, and type of habitat available. During the sediment collections for the site investigation, various oligochaetes (worms) and chironomid larvae (insects) were occasionally found in the upper few centimeters of freshwater sediments. On the basis of these observations, the upper 2 cm is assumed to be the maximum depth of the biological mixing zone in these sediment deposits.

5.3 SITE-SPECIFIC FATE AND TRANSPORT SCENARIOS

The principal chemicals of concern in WBGCR sediments are arsenic, cadmium, lead, mercury, zinc, PAHs, DDT, and PCBs, as discussed in Section 4. The media of interest include sediment and freshwater biota such as benthic infauna, fish, and predatory birds.

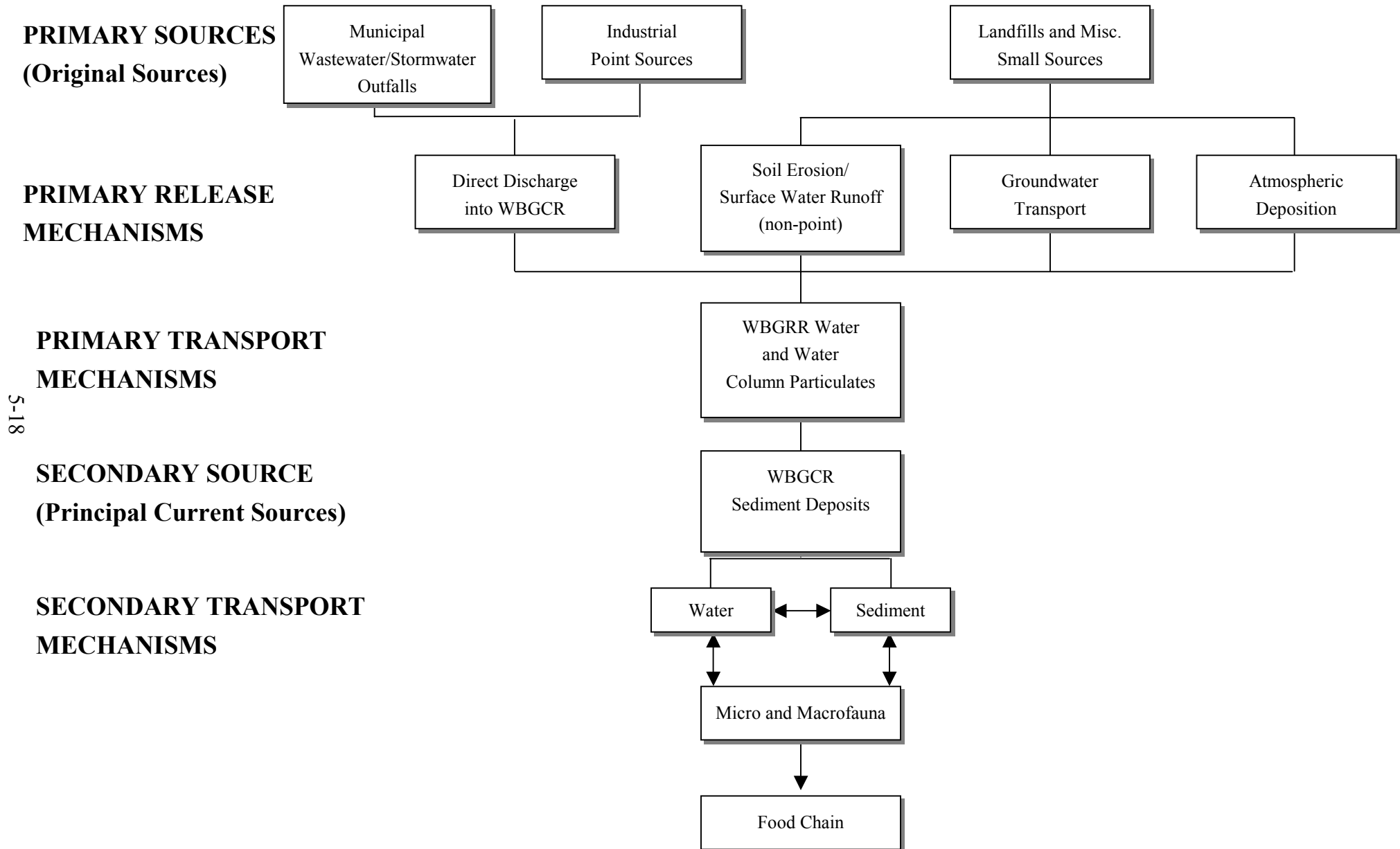
Potential sources of chemicals of concern were discussed in Section 4 and include sources such as industries (e.g., foundry, smelters), municipal wastewater, stormwater discharges, and landfills. The principal current source of these chemicals is the sediment of the river. Figure 5-1 presents the site-specific fate and transport scenario for the WBGCR. Once these chemicals enter a freshwater ecosystem, as indicated by the anthropogenic sources listed in Figure 5-1, they have numerous abiotic interactions with a freshwater ecosystem. The highly nonpolar nature of PCBs, PAHs and DDT, and low water solubility of all chemicals of concern, causes them to be transported in association with the seston of an aquatic

environment and to be primarily localized in the sediments. These chemicals found in sediments can be removed from an ecosystem via transport downstream as well as diffusional loss to the water column. These chemicals in the water column can also be removed by transport downstream and may be subject to photodegradation and volatility losses while in transit.

Additional information on the physical characteristics and behavior of the WBGCR sediment deposits and on deposit-specific patterns in contaminant occurrence is presented in Section 4.

Secondary transport mechanisms include partitioning to interstitial waters and overlying surface waters. For example, mercury can be methylated, transported into surface waters, and bioconcentrated in the food web of the water column. To a small extent, some low molecular weight polycyclic aromatic hydrocarbons, low molecular weight (LPAHs), and PCBs may volatilize or biodegrade. In addition, bioturbation and partitioning return a small fraction of these chemicals to the water column.

Numerous biotic interactions also occur in freshwater (Figure 5-1). Because of the nonpolar nature of PCBs, PAHs and DDT, they tend to accumulate in the lipids of the freshwater biota. As previously mentioned, mercury in the form of methyl mercury is readily accumulated by freshwater biota from their food and adsorption through the water. Figure 5-1 illustrates bioaccumulation as energy flow from chemical sources to the various organisms found in a freshwater ecosystem. Since most of these chemicals are lipophilic and resistant to breakdown, these compounds can biomagnify as they move up the food chain.



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Figure 5-1. Fate and Transport Conceptual Site Model for Chemicals in WBGCR

6. RECOMMENDATIONS FOR PHASE 3 EVALUATION

Phase 3 of the WBGCR project will include updating the sediment injury of the WBGCR (MacDonald and Ingersoll 2000) and the development of a Restoration Alternatives Report similar to that prepared for the EBGCR and IHC (Foster Wheeler Environmental 2000). This will involve the development of the restoration alternatives, an evaluation of the alternatives, and preparation of a draft and final report. A short description of the proposed Phase 3 tasks is presented below.

Before Phase 3, additional testing may be required to further evaluate the extent of contamination in some locations in WBGCR (e.g., Reach 4). A short discussion of these potential data gaps is provided before the sections on Phase 3.

6.1 ADDITIONAL TESTING

Table 6-1 presents the station locations where the vertical extent of contamination remains a question after the Phase 2 sampling and testing. A total of 13 stations are listed in the table. Archive samples at greater depths are available for four stations (WB-11, 32, 35, 47) and should be tested for contaminants exceeding PECs. These samples are currently being stored frozen at STL-Chicago. The source of contamination observed at the bottom of eight of the remaining locations is unknown. Sampling methods were used to avoid the possibility of cross-contamination from “draw down” such as excluding sediments that had come in contact with the core liner. Below the contaminated sediments, there was little visual contamination observed in these cores during the core processing. Consequently, there appears to be enough information available for eight of nine stations without archive samples.

Deeper sediments at one station (WB-30) appear to have been contaminated by groundwater influences. The nature and extent of the NAPL in this area of the river is considered a data gap with regard to developing effective and compliant restoration alternatives for managing contaminated sediments in this portion of the WBGCR.

6.2 SEDIMENT INJURY

An assessment of sediment injury in the GCR was previously evaluated by MacDonald and Ingersoll (2000). In light of this new data set, that report will likely require updating due to added surface and subsurface data in the WBGCR describing the extent of affected sediment. Geotechnical information and sediment chemistry in Reaches 1 through 5 and 7

Table 6-1. Potential Data Gaps in Evaluating Vertical Extent of Sediment Contamination in WBGCR

Station	Depth (feet bgs) (compacted)	Chemicals Exceeding PEC	Archive Available	Comment and Depth (feet bgs) of Archive (compacted)
FW-WB-05	7.5-10	Metals	No	Bioassay passed
FW-WB-11	4-6	Arsenic, cadmium, lead, mercury, PAHs	Yes	6-8, 8-9.4, given to EPA
FW-WB-16	5.2-8	Lead, Zinc	No	Analyzed sample is considered native
FW-WB-28	8-8.9	PAHs, DDD	No	
FW-WB-29	6.6-8.8	PAHs	No	Bioassay failed
FW-WB-30	7.9-8.9	PAHs, DDD	No	NAPL observed in bottom of core, maybe associated with groundwater
FW-WB-31	7.8-9.2	PAHs	No	Analyzed sample is considered native
FW-WB-32	2-4	PAHs, metals, pesticides, PCBs	Yes	4-6.4 NAPL observed in archive but 6.4-6.8 appears to be clean, with no visual contamination. Given to EPA
FW-WB-33	6-7.4	Metals, PCBs, DDT, PAHs	No	Native sediments described below, with no visual contamination
FW-WB-35	5-7	Metals, PCBs, PAHs, pesticides	Yes	7-8.6, 8.6-9.2 Archive is considered native. Given to EPA
FW-WB-43	7.7-9-9	Metals	No	
FW-WB-47	5.6-8	Metals	Yes	8-10 Archive is considered native. Given to EPA
FW-WB-51	6-8.1	Lead, PAHs	No	Bioassay passed

6-2

will expand MacDonald and Ingersoll's assessment of the sediment. The database associated with the injury report can be expanded to include all samples collected to date on the WBGCR.

6.3 DEVELOPMENT OF RESTORATION ALTERNATIVES

6.3.1 Development of Restoration Alternatives

Once the nature and extent of contamination has been evaluated for the WBGCR, development of restoration alternatives for each reach of the river is needed. Based on current knowledge of the proposed project reaches (stretches of the West Branch between bridges), potential sediment management actions that will be considered for each project reach include:

- No action
- Natural recovery with monitoring
- Dredging with upland onsite disposal
- Dredging with upland disposal at a regional landfill, including onsite stockpiling and dewatering
- Thin capping (also termed as enhanced natural recovery)
- Isolation capping
- Dredging and capping
- In-situ remediation
- Sediment treatment

Upland disposal will be in a confined disposal site(s) if suitable sites are made available, or in commercial regional landfills. These alternatives will be preliminarily screened using factors of technical feasibility, implementability, environmental acceptability, and cost. Alternatives will consist of individual, or a combination of, sediment management actions for each project reach.

Sediment management actions and alternatives that are infeasible, unavailable, or have too high a cost to implement will be eliminated during the screening process. The candidate list of potential alternatives will then be narrowed down to the three most promising alternatives that will be carried forward for further evaluation.

6.3.2 Evaluation of Restoration Alternatives

A comparative analysis of the restoration alternatives will be completed in cooperation with USFWS and the Council. That evaluation can be further broken down into determination of evaluation criteria and evaluation of alternatives against the selected criteria. Before performing the comparative analysis of the restoration alternatives and applying them to each reach of the project, a summarized list of appropriate evaluation criteria will be developed. Fourteen criteria developed for the East Branch and main stem of the river (Appendix E of the Grand Calumet River/Indiana Harbor Canal Restoration Alternatives Development and Evaluation Report, Foster Wheeler Environmental 2000) can be used as a starting point; these criteria were derived from those in the Grand Calumet River Interim Restoration Compensation Determination Plan (IRCDP) (IDEM et al. 1998). Those 14 criteria were classified as threshold (3), ranking (6), and other NRDA (5) criteria, and developed for future use in identifying a preferred alternative from the four alternatives retained for analysis in the eastern reaches of the river. As directed by USFWS and IDEM, these criteria will be retained and brought forward for this evaluation or modified, if appropriate. Consideration will be given to eliminating, to the extent possible, overlaps and/or duplication. The approved criteria will be available to perform the comparative analysis after the alternatives undergo a first-level screening using factors of technical feasibility, implementability, environmental acceptability, and cost.

Starting with the materials, evaluations, and approaches previously developed for the EBGCR and IHC, a list of potential alternatives, up to three, or as appropriate, will be carried forward for each reach. Alternatives will be evaluated using the list of criteria developed in the previous task. Guidance contained in the source documents for individual evaluation factors will be used. The evaluation will be provided in a format acceptable to the Council. The approved evaluation criteria will be listed and the comparative analysis will be performed for the three most promising alternatives under each criterion. The draft evaluation will be submitted to the USFWS for review. After the USFWS comments have been incorporated into the document, the draft will be submitted to the Council for its review and comment. USFWS, IDEM, and the Council's comments will be incorporated into the evaluation document. The comparative analysis will then become part of the draft evaluation report.

6.3.3 Preparation of Draft Report

Using the comparative analysis criteria, a draft report will be prepared that describes the most technically feasible primary restoration alternatives (up to three alternatives) for each

reach. The report will present a summary of each alternative's strong points and weaknesses as they relate to each evaluation criterion. It will also clearly describe the rationale supporting the recommendation of the preferred alternative for each reach of the assessment area. The preferred alternative may vary, depending on the area and the level of contamination. For instance, isolation capping may be the preferred remedial technique in certain areas having relatively low levels of contamination that could support the establishment of a healthy benthic habitat. On the other hand, areas with high levels of constituents of concern may be more effectively remediated by dredging and placement of the dredged sediments in an upland confined disposal facility (CDF) (monofill) site, where they would be contained and isolated. The number of project reaches for which remediation alternatives will be developed will be determined as described previously.

6.3.4 Preparation of Final Report

After the Council has reviewed the draft report, a meeting will be held to present the results contained in the draft report and respond to preliminary oral comments from the Council. After this meeting, the Council will finalize its comments and provide them in writing to the USFWS. A final draft report will incorporate the Council's comments. The final draft will then be submitted to the Council for review and concurrence or inclusion of any final comments. The final report will then be submitted to the Council for approval. After the report is approved, it will be distributed in accordance with the Council's instructions.

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