An Assessment of Sediment Injury in the Grand Calumet River, Indiana Harbor Canal, Indiana Harbor, and the Nearshore Areas of Lake Michigan

Volume I

Prepared for:

U.S. Fish and Wildlife Service
Bloomington Field Office
620 South Walker Street
Bloomington, Indiana 47403

Prepared – October 2000 – by:

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List of Acronyms

%	percent
10-d	10 days
12-d	12 days
14-d	14 days
15-min	15 minutes
20-d	20 days
2,3,7,8-TCDD	tetrachlorodibenzo-*p*-dioxin
28-d	28 days
30-min	30 minutes
48-h	48 hours
7-d	7 days
8-d	8 days
96-h	96 hours
AOC	Area of Concern
ARCS Program	Assessment and Remediation of Contaminated Sediments in the Great Lakes Program
ASTM	American Society for Testing and Materials
AVS	acid volatile sulfides
BSAF	biota-sediment bioaccumulation factor
CCBP	Central Corn Belt Plain
CCME	Canadian Council of Ministers of the Environment
CCREM	Canadian Council of Resource and Environment Ministers
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601 et seq.
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CI	confidence interval
CSO	combined sewer overflow
DDTs	*p,p*'-DDT, *o,p*'-DDT, *p,p*'-DDE, *o,p*'-DDE, *p,p*'-DDD, *o,p*'-DDD, and any metabolite or degradation product
DELT	deformities, fin erosion, lesions, and tumors
DL	detection limit
DO	dissolved oxygen
DQO	data quality objective
DuPont	E.I. du Pont de Nemours
DW	dry weight
EB	east branch
EBGCR	East Branch of the Grand Calumet River
EBGCR-I	East Branch of the Grand Calumet River I
EBGCR-II	East Branch of the Grand Calumet River II
EC	Environment Canada

EC_{50}	median effective concentration
ECBP	Eastern Corn Belt Plain
EPT	Ephemeroptera, Plecoptera, Trichoptera (mayflies, stoneflies, caddisflies)
FIELDS	Fully Integrated Environmental Location Decision Support
gamma-BHC	gamma-hexachlorocyclohexane (lindane)
GCRL	Grand Calumet River Lagoons
GIS	geographic information system
HC	Health Canada
HNTB	Howard, Needles, Tammen and Bergendoff Architects, Engineers, and Planners
IBI	Index of biotic integrity
ID	insufficient data
IDEM	Indiana Department of Environmental Management
IEC	Industrial Economics, Inc.
IH	Indiana Harbor
IHC	Indiana Harbor Canal
IJC	International Joint Commission
IL	Illinois
IN	Indiana
LC_{50}	median lethal concentration
LEP	Little East Pond
LGB	Lake George Branch
LM	Lake Michigan
LTI	Limno-Tech, Inc.
LWP	Little West Pond
mean PEC-Q	mean probable effect concentration quotient
MESL	MacDonald Environmental Sciences Ltd.
mg	milligrams
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mIBI	macroinvertebrate index of biotic integrity
mm	millimeters
MS	Microsoft
n	number of samples
NA	not applicable (i.e., all <DL values were >PEC; therefore total was not calculated)
NA'	not applicable (i.e., toxicity test or chemical analyses not performed).
ND	not determined; compounds were measured as less than the detection limit, but the detection limit is unknown
ND'	not determined; toxicity not determined because mortality was > 40%
ND"	not determined; the lab considered sample to be a hazard to personnel
NE	northeast
NG	no guideline available
NH_3	unionized ammonia

NH_4^+	ionized ammonia
NIPSCO	Northern Indiana Public Service Company
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge and Elimination System
NR	not reported
NRDA	Natural Resource Damage Assessment
NT	not toxic
NW	northwest
NYSDEC	New York State Department of Environmental Conservation
OC	organic carbon
OEPA	Ohio Environmental Protection Agency
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PEC	probable effect concentration (consensus-based)
PEC-Q	probable effect concentration quotient
QA/QC	quality assurance/quality control
QHEI	qualitative habitat evaluation index
RCRA	Resource Conservation and Recovery Act
RETEC	Remediation Technologies, Inc.
S.U.	standard unit
SAB	Science Advisory Board
SE	southeast
SEC	sediment effect concentration (consensus-based)
SEM	simultaneously extracted metals
SEM-AVS	simultaneously extracted metal minus acid volatile sulfides
SETAC	Society of Environmental Toxicology and Chemistry
SOD	sediment oxygen demand
SQG	sediment quality guideline
STP	sewage treatment plant
sum DDD	*p,p*'-DDD + *o,p*'-DDD
sum DDE	*p,p*'-DDE + *o,p*'-DDE
sum DDT	*p,p*'-DDT + *o,p*'-DDT
SVOC	semi-volatile organic chemical
SW	southwest
T	toxic
TEC	threshold effect concentration (consensus-based)
ThermoRetec	ThermoRetec Consulting Corporation
TOC	total organic carbon
Total DDT	*p,p*'-DDT, *o,p*'-DDT, *p,p*'-DDE, *o,p*'-DDE, *p,p*'-DDD, and *o,p*'-DDD
TRG	tissue residue guideline
U.S. Steel	United States Steel (Division of USX Corporation)
USACE	United States Army Corps of Engineers
USC	United States Canal
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency

USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USS Lead	USS Lead Refinery, Inc.
VOC	volatile organic compound
WB	west branch
WBGCR	West Branch of the Grand Calumet River
WBGCR-I	West Branch of the Grand Calumet River I
WBGCR-II	West Branch of the Grand Calumet River II
WW	wet weight
WWTP	wastewater treatment plant
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µmol/g	micromoles per gram

List of Terms

Acute toxicity – The immediate or short-term response of an organism to a chemical substance. Lethality is the response that is most commonly measured in acute toxicity tests.

Acute toxicity threshold – The concentration of a substance above which adverse effects are likely to be observed in short-term toxicity tests.

Altered benthic invertebrate community – An assemblage of benthic invertebrates that has characteristics (i.e., mIBI score, abundance of EPT taxa, etc.) That are outside the normal range that has been observed at uncontaminated reference sites.

Aquatic organisms – The species that utilize habitats within aquatic ecosystems (e.g., aquatic plants, invertebrates, fish, amphibians and reptiles).

Aquatic ecosystem – All the living and nonliving material interacting within an aquatic system (e.g., pond, lake, river, ocean).

Aquatic invertebrates – Animals without backbones that utilize habitats in freshwater, estuaries, or marine systems.

Assessment Area – The areas within which natural resources have been affected directly or indirectly by the discharge of oil or release of a hazardous substance and that serves as the geographic basis for the injury assessment in this report. The assessment area includes the Grand Calumet River, Indiana Harbor Canal, Indiana Harbor, and the nearshore areas of Lake Michigan.

Benthic invertebrate community – The assemblage of various species of sediment-dwelling organisms that are found within an aquatic ecosystem.

Bioaccumulation – The net accumulation of a substance by an organism as a result of uptake from all environmental sources.

Bioaccumulation-based SQGs – Sediment quality guidelines that are established to protect fish and wildlife resources against effects that are associated with the bioaccumulation of contaminants in sediment-dwelling organisms and subsequent food web transfer.

Bioaccumulative substances – The chemicals that tend to accumulate in the tissues of aquatic organisms.

Biological resources – Those natural resources referred to in Section 101(16) of CERCLA as fish and wildlife and other biota. Fish and wildlife include marine and freshwater aquatic and terrestrial species; game, nongame, and commercial species; and threatened, endangered, and State sensitive species. Other biota encompass shellfish, terrestrial and aquatic plants, and other living organisms not otherwise listed in this definition.

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601 et seq.

CERCLIS – Comprehensive Environmental Response, Compensation, and Liability Information System.

Chemicals of Concern – The substances that have been identified by the Natural Resource Trustees that have the potential to cause injury to surface water or biological resources in the Assessment Area, including PCBs, oil and oil-related compounds (including alkanes, alkenes, naphthalenes, and PAHs), and metals. Other substances that were considered in this study include pesticides, sediment oxygen demand (SOD), unionized ammonia (NH_3)

Chemical benchmark – Guidelines for water or sediment quality which define the concentration of contaminants that are associated with high or low probabilities of observing harmful biological effects, depending on the narrative intent.

Chronic toxicity threshold – The concentration of a substance above which adverse effects on sediment-dwelling organisms are likely to occur in longer-term toxicity tests.

Chronic toxicity – The response of an organism to long-term exposure to a chemical substance. Among others, the responses that are typically measured in chronic toxicity tests include lethality, decreased growth, and impaired reproduction.

Consensus-based SECs – The sediment effect concentrations, including consensus-based threshold effect concentrations and probable effect concentrations, that were developed from published sediment quality guidelines.

Consensus-based TECs – The threshold effect concentrations that were developed from published sediment quality guidelines. A subset of the SECs.

Consensus-based PECs – The probable effect concentrations that were developed from published sediment quality guidelines. A subset of the SECs.

Contaminants of concern – The toxic or bioaccumulative substances that occur in sediments at concentrations that are sufficient to cause or substantially contribute to sediment injury, including injury to sediment-dwelling organisms, of fish and wildlife.

Contaminated sediment – Sediment that contains chemical substances at concentrations that could harm sediment-dwelling organisms, wildlife, or human health.

Conventional variables – A number of variables that are commonly measured in water and/or sediment quality assessments, including water hardness, DO, conductivity, total organic carbon (TOC), SOD, NH_3, temperature, dissolved oxygen (DO), pH, alkalinity.

Core sampler – A device that is used to collect both surficial and sub-surface sediments.

DELT abnormalities – A number of variables that are measured to assess fish health, including deformities, fin erosion, lesions, and tumors.

Discharge – Discharge of oil as defined in Section 311(a)(2) o f the Clean Water Act, and includes, but is not limited to, any spilling, leaking, pumping, pouring, emitting, emptying, or dumping of oil.

Ecosystem – All the living (e.g., plants, animals, and humans) and nonliving (rocks, sediments, soil, water, and air) material interacting within a specified location in time and space.

Effects-based SECs – Consensus-based sediment quality guidelines.

Endpoint – A measured response of a receptor to a potential stressor. An endpoint can be measured in a toxicity test or a field survey.

Epibenthic organisms – The organisms that live on the surface of bottom sediments.

Exposure – Co-occurrence of or contact between a stressor (e.g., chemical substance) and an ecological component (e.g., aquatic organism).

Grab (Dredge) samplers – A device that is used to collect surficial sediments (e.g., petite ponar dredge).

Hazardous substances – A hazardous substance as defined in Section 101(14) of CERCLA.

Index of Biotic Integrity (IBI) – A parameter that is used to evaluate the status of fish communities. The IBI integrates information on species composition (i.e., total number of species, types of species, percent sensitive species, and percent tolerant species), on trophic composition (i.e., percent omnivores, percent insectivores, and percent pioneer species), and on fish condition.

Indicators of environmental quality conditions – Measurable features or characteristics of an ecosystem that provide information on the status of the ecosystem as a whole.

Infaunal organisms – The organisms that live in bottom sediments.

Injury – a measurable adverse change, either long or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance, or exposure to a product of reactions resulting from the discharge to oil or release of a hazardous substance. As used in this part, injury encompasses the phrases "injury", "destruction", and "loss". Injury definitions applicable to specific resources are provided in Š 11.62 of this part.

Life cycle tests – Toxicity tests that investigate the long-term effects of one or more stressors on a receptor over two or more generations.

Macroinvertebrate Index of Biotic Integrity (IBI) – An indicator of the overall structure of benthic invertebrate communities (OEPA 1989). The scoring criteria for this metric includes such variables as number of taxa, percent dominant taxa, relative abundance of EPT taxa, and abundance of chironomids.

Mean PEC-Q – Mean PEC-Qs were calculated using the procedure that was established by USEPA (2000a). Using this method, a PEC-Q was first determined for each metal for which a reliable PEC was available. Then, an average PEC-Q for metals was calculated by summing the PEC-Qs of each metal and dividing by the number of metals that were included in the calculation. PEC-Qs were also calculated for total PAHs and total PCBs. Finally, the mean of the average PEC-Q for metals, the PEC-Q for PAHs, and the PEC-Q for PCBs was determined for each sediment sample (termed the mean PEC-Q).

Natural resources – land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the United States (including the resources of the fishery conservation zone established by the Magnuson Fishery Conservation and Management Act of 1976), and State or local government, or any foreign government, any Indian tribe, or, if such resources are subject to a trust restriction on alienation, any member of an Indiana tribe. These natural resource have been categorized into the following five groups: surface water resources, ground water resources, air resources, geologic resources, and biological resources.

Natural resources damage assessment – the process of collection, compiling, and analyzing information, statistics, or data through prescribed methodologies to determine damages for injuries to natural resources as set forth in this part.

Oil – oil as defined in Section 311(a)(1) of the Clean Water Act, of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other that dredged spoil.

Piscivorus wildlife species – The wildlife species that consume fish as part or all of their diets (e.g., herons, kingfishers, otter, mink or osprey).

Population – An aggregate of individual of a species within a specified location in time and space.

Pore water – The water that occupies the spaces between sediment particles.

Release – a release of a hazardous substance as defined in Section 101(22) of CERCLA.

Sediment quality guideline – Chemical benchmark that is intended to define the concentration of a sediment-associated contaminant that is associated with a high or a low probability of observing harmful biological effects or unacceptable levels of bioaccumulation, depending on its purpose and narrative intent.

Sediment injury – The presence of conditions that have injured or are sufficient to injure sediment-dwelling organisms, fish or wildlife.

Sediment – Particulate material that usually lies below water.

Sediment chemistry data – Information on the concentrations of chemical substances in bulk sediments or pore water.

Sediment-associated contaminants – Contaminants that are present in sediments, including bulk sediments or pore water.

Sediment-dwelling organisms – The organisms that live in, on, or near bottom sediments, including both epibenthic and infaunal species.

Surface Water Resources – the waters of the United States, including the sediments suspended in water or lying on the bank, bed, or shoreline and sediments in or transported through coastal and marine areas. This term does not include ground water or water or sediments in ponds, lakes, or reservoirs designed for waste treatment under the Resource Conservation and Recovery Act of 1976, 42 U.S.C. 6901-6987 or the Clean Water Act, and applicable regulations.

Tissue Residue Guideline – Chemical benchmark that is intended to define the concentration of a substance in the tissues of fish or invertebrates that will protect wildlife against effects that are associated with dietary exposure to hazardous substances.

Trustee – any Federal natural resources management agency designated in the National Contingency Plan and any State agency designated by the Governor of each State, pursuant to Section 107(f)(2)(B) of CERCLA, that may prosecute claims for damages under Section 107(f) or 111(b) of CERCLA; or an Indiana tribe, that may commence an action under Section 126(d) of CERCLA.

Whole sediment – Sediment and associated pore water.

Wildlife – The fish, reptiles, amphibians, birds, and mammals that are associated with aquatic ecosystems (i.e., fish and wildlife resources).

Background Information Relevant to the Preparation of this Report

Professional Qualifications

The professional experience and educational qualifications which qualify Dr. Ingersoll and Mr. MacDonald to give the opinions that included in this report are set out in the curricula vitae, which are included in Appendix 7.

Dr. Ingersoll's experience in the field of sediment quality assessment included:

- Chair of ASTM Committee E47 on Environmental Fate and Effects of Contaminants (1995 to present) and chair of chair Subcommittee E47.03: Sediment Toxicology (1988 to 1995);
- Task group leader in ASTM Subcommittee E47.03 on Sediment Toxicology for the development of standard methods for assessing sediment toxicity with freshwater invertebrates (ASTM standard test method E1706);
- Task group member in ASTM Subcommittee E47.03 on Sediment Toxicology for the development of standard methods for assessing sediment toxicity with estuarine and marine amphipod (ASTM standard guide E1367);
- Task group member in ASTM Subcommittee E47.03 on Sediment Toxicology for the development of standard methods for assessing bioaccumulation of sediment contaminants (ASTM standard guide E1688);
- Task group member in ASTM Subcommittee E47.03 on Sediment Toxicology for the development of standard methods for assessing and designing sediment toxicity assessments (ASTM standard guide E1525);
- Primary author for the USEPA (1994) standard method for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates (EPA 600/R-94/024);

- Primary author for the USEPA (2000b) standard method for measuring the chronic toxicity of sediment-associated contaminants with freshwater invertebrates (EPA/600/R-99/064);

- Co-author for the USEPA (1994) standard method for measuring the toxicity of sediment-associated contaminants with estuarine and marine invertebrates (EPA 600/R-94/025);

- Member of the USEPA Science Advisory Board (SAB) on Environmental Effects and Fate Committee - Sediment criteria subcommittee member (1988 to present; the SAB has reviewed numerous approaches for assessing sediment quality included equilibrium partitioning, apparent effects threshold, weight-of-evidence approach, and the USEPA National Sediment Inventory);

- Development of an approach for the derivation of freshwater sediment quality guidelines for the Great Lakes;

- Participation on the development of numerical sediment quality guidelines for NOAA's National Status and Trends Program;

- Participation in the development of a sediment toxicity database for evaluating matching sediment chemistry and biological effects data; and,

- Editor of the book *Ecological Risk Assessments of Contaminated Sediment*. (1997, SETAC Press. Pensacola, Florida. 389 pages).

Mr. MacDonald's experience in the field of sediment quality assessment includes:

- Development of an approach to the derivation of Canadian sediment quality guidelines;

- Development of numerical sediment quality assessment guidelines for 34 chemical substances in Florida coastal waters;

- Development of Canadian sediment quality guidelines for freshwater ecosystems;

- Development of Canadian sediment quality guidelines for marine and estuarine ecosystems;

- Participation in the development of numerical sediment quality guidelines for NOAA's National Status and Trends Program;
- Development of procedures for deriving site-specific sediment quality remediation objectives;
- Development of a sediment toxicity database for evaluating matching sediment chemistry and biological effects data;
- Development of Canadian sediment quality guidelines for toxaphene, DDTs, and PCBs;
- Development of sediment effect concentrations for assessing sediment injury in the Southern California Bight; and
- Development of a framework for assessing contaminated sediments using multiple indicators of sediment quality conditions.

Conflict of Interest

Neither Dr. Ingersoll nor Mr. MacDonald have any personal interest in this report other than as paid consultants to U.S. Fish and Wildlife Service. Our prior involvement with U.S. government sediment injury has been as paid consultants on specific projects related to hazard and environmental assessments. We have had no prior involvement with the potentially responsible parties relative to the Assessment Area. The United States Geological Survey and MacDonald Environmental Sciences Ltd. will be paid the same regardless of the outcome of this case.

Documents Used to Prepare Report

In preparing this report, we have reviewed numerous texts, articles, protocols, and publications relating to the fate and effects of sediment-associated contaminants on aquatic organisms. A list of the documents that were considered during the preparation of this report is presented in the references cited section of this report. In addition, we have relied on our knowledge of this river system, as acquired through a site reconnaissance (conducted in January, 1998) and previous investigations conducted within this Area of Concern.

Executive Summary

This investigation was conducted to determine if sediments within the Grand Calumet River, Indiana Harbor Canal, Indiana Harbor, or the nearshore areas of Lake Michigan (i.e., the Assessment Area) have been injured due to discharges of oil or releases of other hazardous substances. If the results of this assessment indicated that sediment injury has occurred within the Assessment Area, then the subsequent objectives of this investigation were to identify contaminants of concern in the Assessment Area and to evaluate the areal extent of sediment injury.

In this report, sediment injury was defined as the presence of conditions that have injured or are sufficient to injure sediment-dwelling organisms and/or fish and wildlife resources. As such, this assessment of sediment injury was intended to provide the information needed to evaluate injury to surface water resources and biological resources within the Assessment Area. Contaminants of concern were defined as those toxic or bioaccumulative substances that occur in sediments at concentrations that are sufficient to cause or substantially contribute to sediment injury, including injury to sediment-dwelling organisms, and/or fish and wildlife resources.

In accordance with the Assessment Plan (Natural Resources Trustees 1997), this assessment of sediment injury was focused on evaluating the effects on natural resources that have occurred due to discharges of oil or releases of other hazardous substances. The chemicals of concern in the Assessment Area include polychlorinated biphenyls (PCBs), oil and oil-related compounds (including alkanes, alkenes, naphthalenes, and polycyclic aromatic hydrocarbons; PAHs), and metals (Natural Resources Trustees 1997). The other substances that were considered in this study include various pesticides, phenols, and conventional variables [such as total organic carbon (TOC), sediment oxygen demand (SOD), and unionized ammonia (NH_3)]. As many of these substances tend to become associated with sediments upon release into aquatic ecosystems, sediment contamination represents a concern with respect to the restoration of beneficial uses in the Assessment Area (IDEM 1991).

To facilitate this evaluation, the Assessment Area was divided into nine separate reaches, including the Grand Calumet River Lagoons (GCRL), East Branch Grand Calumet River-I (EBGCR-I), East Branch Grand Calumet River-II (EBGCR-II), West Branch Grand Calumet River-I (WBGCR-I), West Branch Grand Calumet River-II (WBGCR-II), Indiana Harbor Canal (IHC), Lake George Branch (LGB), US Canal (USC) and Indiana

Harbor/Lake Michigan (IH/LM). In each of these reaches, the available sediment quality and related information was collected, evaluated, compiled, and used to assess injury to sediments and associated biological resources. The results of these assessments are presented in Sections 5 to 13 of this report. A summary of these results is presented below to provide an overview of sediment quality and related conditions within the Assessment Area.

Injury to Sediment-Dwelling Organisms

In total, four primary indicators were used to assess injury to sediment-dwelling organisms within the Assessment Area. These indicators included whole sediment chemistry, pore water chemistry, sediment toxicity (including whole sediment, pore water, and/or elutriates), and benthic invertebrate community structure. The status of physical habitats in each reach of the Assessment Area was also described.

Information on the concentrations of sediment-associated contaminants has been gathered for the entire Assessment Area. Collectively, these sediment chemistry data indicate that both surficial and sub-surface sediments in all of the reaches have been injured as a result of discharges of oil or releases of other hazardous substances (Figure ES.1 and ES.2). The highest frequencies of exceedance of the chronic toxicity threshold for amphipods (i.e., mean probable effect concentration-quotients; PEC-Q of ≥ 0.7; USEPA 2000a) were observed in the WBGCR-I (90%; n=31 samples), IHC (89%; n=36 samples) and, USC (89%; n=215 samples; Table ES.1). The frequency of exceedance of the chronic toxicity threshold ranged from 72% to 86% in the EBGCR-I, EBGCR-II, WBGCR-II, LGB, and the IH segment of the IH/LM reach (Table ES.1). By comparison, only one of 33 samples (3%) from the nearshore areas of the LM segment of the IH/LM reach, had chemical characteristics sufficient to cause or substantially contribute to injury to sediment-dwelling organisms. Relatively lower levels of sediment contamination were also observed in the Lake George wetlands and in the Roxana Marsh portion of the WBGCR-II (Table ES.2 and ES.3). The contaminants of concern in whole sediments from the Assessment Area included metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), PAHs (13 individual PAHs and total PAHs), and total PCBs.

The available information on pore water chemistry confirms that sediments within the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances. In particular, the levels of metals, phenol, and unionized ammonia (NH_3) frequently exceeded published toxicity thresholds for sediment-dwelling organisms. The levels of simultaneously extracted metals (SEM) frequently exceeded the concentrations of acid volatile sulfides (AVS) in sediments, indicating that elevated levels of metals are likely to occur in pore water (in 70 of 169 sediment samples in which these variables were measured; Table ES.4). The concentrations of contaminants in pore water were sufficient to cause or substantially contribute to sediment toxicity in sediments from the EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, LGB, and IH (i.e., two or more samples had contaminant concentrations in excess of the published toxicity thresholds; Table ES.1). Insufficient data were available to characterize contaminant concentrations in pore water from GCRL, USC, and LM sediments.

Information on the toxicity of whole sediments, pore water, or elutriates was available for all of the reaches in the Assessment Area. The results of the laboratory toxicity tests demonstrate that whole sediments, pore water, and elutriates were frequently toxic to aquatic organisms throughout the Assessment Area (Table ES.1; Figure ES.3). Among the various reaches that were investigated, the frequency of sediment toxicity ranged from 33% in LM to 100% in the WBGCR-I. The frequency of sediment toxicity equaled or exceeded 50% in all nine of the reaches, including GCRL (50%; n=12), EBGCR-I (73%; n=44), EBGCR-II (88% n=52), WBGCR-I (100%; n=2), WBGCR-II (83%; n=18), IHC (80%; n=5), LGB (57%; n=7), USC (80%; n=90) and IH/LM (74%; n=38; Table ES.1). The frequency of sediment toxicity tended to be lowest in the Middle and East Lagoons (GCRL), Roxana Marsh (WBGCR-II), Lake George wetlands (LGB), the wetlands associated with the IHC, and the nearshore areas of Lake Michigan. Collectively, the sediment toxicity data demonstrate that sediments and sediment-dwelling organisms have been injured throughout the Assessment Area.

Information on the structure of benthic invertebrate communities is available for all of the reaches within the Assessment Area. Evaluation of these data relative to conditions in the nearshore areas of LM indicate that the structure of benthic invertebrate communities has been altered throughout the Assessment Area (Table ES.1; Figure ES.4). In the EBGCR-I (n=14), EBGCR-II (n=5), WBGCR-I (n=3), IHC (n=6), and LGB (n=4), 100% of the samples that have been collected had characteristics that were indicative of altered benthic invertebrate communities (Table ES.1). A somewhat lower frequency of benthic community alteration was observed in the WBGCR-II (71% of samples; n=14), USC (96%; n=25 samples), IH (81%; n=16 samples), and LM (43%; n=56). Overall, average macroinvertebrate index of biotic integrity (mIBI) scores for the various reaches ranged from 0.7 to 1.4 (Table ES.5). Benthic invertebrate communities were typically dominated by pollution-tolerant species, primarily oligochaetes, throughout much of the Assessment Area. Pollution-sensitive species, such as the EPT taxa (mayflies, stoneflies, and caddisflies) were rarely present in any of the reaches within the Assessment Area. Collectively, these data confirm that environmental conditions in the Assessment Area are sufficient to injure sediments and sediment-dwelling organisms.

Most of the reaches in the Assessment Area were characterized as having altered habitats. Qualitative habitat evaluation index (QHEI) scores ranged from 16 to 65.5 within the Assessment Area, with the lowest scores reported for IHC, LGB, USC, and IH (Simon *et al.* 2000; Table ES.6). Elevated levels of TOC were observed throughout the Assessment Area; the upper limit of the 95% confidence interval of TOC for reference sites (i.e., 3.4% TOC) was frequently exceeded in the EBGCR-II, WBGCR-I, WBGCR-II, LGB, USC, and IH. The lowest levels of TOC were observed in the sediments collected from the nearshore areas of LM. Based on the levels of oil and grease and the levels of PAHs that have been measured in sediments, oil and oil-related compounds comprise much of the TOC that occurs within the Assessment Area. Together, these data confirm that sediments within the Assessment Area have been contaminated due to discharges of oil or releases of other hazardous substances.

Overall, there was a high level of concordance among the four primary indicators of sediment injury (i.e., whole sediment chemistry, pore water chemistry, sediment toxicity, and benthic invertebrate community structure; Table ES.1). All four lines of evidence indicated that conditions sufficient to injure sediment-dwelling organisms occurred within the EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, LGB, USC, and IH/LM. In the GCRL, two lines of evidence – sediment chemistry and sediment toxicity – indicated the presence of conditions sufficient to injure sediments and sediment-dwelling organisms. These conditions were most prevalent in the West Lagoon. Evaluation of the available data indicates that sediment injury is less likely to occur in the nearshore areas of LM (i.e., two lines of evidence indicate that sediment injury has occurred). Within the LM segment of the IH/LM reach, sediment toxicity and alteration of the benthic invertebrate community occurred most frequently within 0.5 miles from the entrance to IH. Collectively, this information indicates that benthic habitats throughout the Assessment Area, with a few exceptions, have been degraded due to discharges of oil or releases of other hazardous substances. Benthic habitats located in areas farther removed from the harbor entrance tended to reflect uninjured conditions.

Effects on Fish and Wildlife Resources

A total of five lines of evidence were used to assess effects on fish and wildlife resources that are associated with sediment contamination (i.e., related to the sediment injury that was demonstrated within the various reaches of the Assessment Area. The primary indicators that were used in this report to assess sediment injury relative to fish and wildlife resources included toxicity to fish, fish health, fish community structure, whole sediment chemistry, and tissue chemistry (Table ES.7).

Information of the toxicity of whole sediments, pore water, and/or elutriates to fish (i.e., fathead minnows; *Pimephales promelas*) are available for four reaches within the Assessment Area, including the GCRL, EBGCR-I, EBGCR-II, and WBGCR-II. The results of such laboratory toxicity tests demonstrate that sediments from the EBGCR-I, EBGCR-II, and WBGCR-II are frequently acutely toxic to fish. The incidence of sediment toxicity ranged from 57% (n=23) in the EBGCR-I to 100% (n=7) in the WBGCR-II (Table ES.7). In contrast, only one sample from the GCRL was toxic to fish, which indicates that conditions sufficient to cause acute toxicity to fish were observed only in the western portion of the West Lagoon.

In this report, information on incidence of deformities, fin erosion, lesions, and tumors (i.e., DELT abnormalities) in fish was used to assess fish health in the Assessment Area (Table ES.8). Based on the information that was collated for this area, fish health has been compromised (i.e., incidence of DELT abnormalities > 1.3%) in several of the reaches including the EBGCR-I, EBGCR-II and the WBGCR-I. The average incidence of DELT abnormalities ranged from 0% in the GCRL to 12.8% in IH/LM. The highest incidence of DELT abnormalities (17.4%) was observed in the EBGCR-I.

A number of field surveys have been conducted over the past 15 years to evaluate the status of fish communities in the Assessment Area. The results of these surveys demonstrate that the integrity of fish communities has been impaired (i.e., relative to reference sites in Indiana) in all of the reaches that have been examined (Table ES.9). Overall, index of biotic integrity (IBI) scores ranged from 0 to 43 in the various stream reaches, which classifies fish communities as “fair”, “poor”, “very poor”, or as having no fish (Table ES.9). The lowest average IBI scores were reported for IH/LM (14; n=1); WBGCR-II (15.9 ± 9.8; n=17); WBGCR-I (16.5 ± 10.4; n=12); IHC (17.5 ± 4.4; n=4). Based on these IBI scores, the integrity of fish communities in these four reaches would be classified as “very poor”. Somewhat higher average IBI scores were reported for the

EBGCR-I, EBGCR-II, LGB, and USC; average IBI scores in these reaches ranged from 23 to 26. As such, fish communities in these four reaches would be classified as having "poor" to "very poor" integrity. Within the LGB, the wetland areas that are located to the west of the Lake George Canal had the highest IBI score (38; Simon *et al.* 2000). Relatively higher IBI scores were also reported for the GCRL, with IBI scores ranging from 31 to 43 (mean IBI score of 38.1 ± 5.0; n=13). In the GCRL, the lowest IBI scores (i.e., 31 to 38) were reported for the West Lagoon (which is located closest to an iron and steel manufacturer's slag landfill; Simon and Stewart 1998). In contrast, IBI scores for the Middle Lagoon averaged 42 (Simon and Stewart 1998).

In this report, the sediment injury relative to wildlife was also evaluated using sediment chemistry data. More specifically, the measured concentrations of bioaccumulative substances in whole sediments were compared to bioaccumulation-based sediment quality guidelines (SQGs) for the protection of wildlife (NYSDEC 1994). The results of this evaluation demonstrated that the concentrations of various sediment-associated contaminants were sufficient to adversely affect wildlife species that utilize habitats within the Grand Calumet River watershed (i.e., through bioaccumulation of contaminants in sediment-dwelling organisms and subsequent food web transfer to wildlife species, such as green herons). Among the various reaches, the frequency of exceedance of one or more of the bioaccumulation-based SQGs ranged from 18% to 93% of the sediment samples (Table ES.7), indicating that all of the reaches have levels of bioaccumulative substances in sediments that are sufficient to cause or substantially contribute to adverse effects on wildlife. The highest incidences of exceedance of the bioaccumulation-based SQGs were observed in the GCRL (84%; n=58), IHC (93%; n=15) LGB (83%; n=29), USC (84%; n=37) and IH/LM (88%; n=33). Total PCBs represented the only bioaccumulative contaminants of concern in the Assessment Area; however, chlordane, total DDTs, endrin, heptachlor, heptachlor epoxide, lindane, and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) also exceeded the bioaccumulation-based SQGs in many sediment samples. Bioaccumulation-based SQGs were not available for metals or PAHs, which precluded an evaluation of the potential for bioaccumulation of these chemical classes.

Tissue chemistry data provide important information for determining if bioaccumulative substances pose unacceptable hazards to wildlife species. In this report, the measured concentrations of bioaccumulative substances in the tissues of fish and other aquatic organisms were compared to the tissue residue guidelines (TRGs) that have been established for the protection of piscivorus wildlife species (Newell *et al.* 1987). The results of this evaluation indicate that tissue residue levels in fish and invertebrates from the Assessment Area frequently exceeded the TRGs for piscivorus wildlife. The concentrations of one or more bioaccumulative substances exceeded the TRGs in 50% to 100% of the tissue samples, depending on which reach of the Assessment Area was considered. The highest frequencies of exceedance of the TRGs (i.e., 100%) were reported for the GCRL, EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, and USC. Eighty-six percent (n=21) of the tissue samples from IH/LM had tissue residue levels in excess of the TRGs. Total PCBs represented the bioaccumulative contaminants of concern in the tissues of aquatic organisms; however, chlordane, total DDTs, dieldrin + aldrin, and endrin were also measured at elevated levels in fish and invertebrate tissues.

In this report, five separate lines of evidence were used to assess sediment injury relative to wildlife species. Overall, the results of this assessment indicate that conditions within the GCRL, EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, LGB, USC, and IH/LM are sufficient to adversely affect wildlife species (i.e., one or more lines of evidence demonstrate effects on wildlife, including, amphibians, reptiles, fish, birds, and mammals; Table ES.7). More specifically, sediments have been demonstrated to be toxic to fish in three reaches of the Assessment Area. In addition, fish health has been compromised in three reaches of the Assessment Area. As would be expected in areas that have impaired fish health and toxic conditions, the integrity of fish communities was "poor" to "very poor" (as measured using IBI scores) throughout most of the Assessment Area (i.e., in seven of nine reaches). Finally, the available sediment chemistry data indicate that the concentrations of bioaccumulative substances are high enough to pose hazards to wildlife (i.e., as a result of bioaccumulation in the sediment-dwelling organisms and subsequent food web transport to piscivorus wildlife species) in all nine reaches. The available data on tissue chemistry confirm that bioaccumulation is occurring throughout the Assessment Area and that the concentrations of bioaccumulative substances in the tissues of aquatic organisms are sufficient to adversely affect piscivorus wildlife species (i.e., in eight of nine reaches). Therefore, sediment injury relative to wildlife resources has been demonstrated throughout the Assessment Area.

Overall Assessment of Injury to Sediments

An evaluation of the harmful effects of sediment-associated contaminants in the Assessment Area was conducted. To support this assessment, the study area was divided into nine separate reaches, including GCRL, EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, LGB, USC, and IH/LM. The results of this evaluation demonstrate that sediments throughout the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances. This conclusion is supported by up to nine of the following separate lines of evidence:

- Concentrations of metals, PAHs, and/or PCBs, in whole sediments frequently exceeded the consensus-based probable effect concentrations (PECs) throughout the Assessment Area;
- Concentrations of metals, phenol, and/or ammonia in pore water from Assessment Area sediments exceeded published toxicity thresholds at various locations;
- Whole sediments, pore water, and/or elutriates from the Assessment Area were frequently toxic to aquatic organisms, including sediment-dwelling species;
- The structure of benthic invertebrate communities throughout the Assessment Area has been severely altered relative to communities in the nearshore areas of LM or elsewhere in Indiana;
- The health of fish in the Assessment Area has been compromised, as indicated by a high incidence of deformities, fin erosion, lesions, and tumors;
- Whole sediments, pore water, and/or elutriates from the Assessment Area were frequently toxic to fish;
- The integrity of fish communities in the Assessment Area has been frequently degraded relative to reference sites in Indiana;
- Concentrations of total PCBs in sediments frequently exceeded the bioaccumulation-based SQGs for the protection of wildlife; and,
- Concentrations of total PCBs in the tissues of aquatic organisms frequently exceeded the TRGs for the protection of wildlife.

Any one of these independent lines of evidence could be used alone to support the conclusion that sediment injury has occurred in the Assessment Area. When taken together, however, these nine separate lines of evidence provide an indisputable weight-of-evidence for concluding that discharges of oil or releases of other hazardous substances have created conditions that are sufficient to severely injure sediments and the organisms that depend on these critical habitats. The levels of metals, PAHs, PCBs, unionized ammonia and phenols in whole sediments, pore water, and/or fish tissues were sufficient to cause or substantially contribute to the injury of sediments, sediment-dwelling organisms, and/or fish and wildlife resources.

Various metals (arsenic, cadmium, chromium, copper, lead, nickel, and zinc), PAHs (anthracene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, benz(a)anthracene, dibenz(a,h)anthracene, benzo(a)pyrene, chrysene, fluoranthene, pyrene, and total PAHs), PCBs (total PCBs), phenols (phenol) and unionized ammonia are considered to be the toxic and/or bioaccumulative contaminants of concern in the Assessment Area. All of these substances frequently exceeded the chemical benchmarks in surficial and sub-surface sediments throughout the Assessment Area. In addition, the concentrations of these substances in sediments often exceeded the chemical benchmarks by substantial margins, frequently by more than a factor of 100. Therefore, all of these substances were present in whole sediment and/or pore water at concentrations that are sufficient to cause or substantially contribute to injury to sediment-dwelling organisms, and/or adversely affect fish and wildlife resources. It is important to note, however, that this assessment was restricted by the availability of PECs, published bioaccumulation-based SQGs, and other benchmarks that are relevant for assessing sediment quality conditions. In certain reaches of the Assessment Area, this assessment was also restricted by limitations on the availability of data on the concentrations of chemical analytes in whole sediments and/or pore waters. Therefore, substances not included on the list of contaminants of concern can not necessarily be considered to be of low priority with respect to sediment injury.

The levels of sediment-associated contaminants are sufficient to cause or substantially contribute to injury to surficial sediments throughout most of the Assessment Area (Table ES.2). In surficial sediments, the highest levels of sediment contamination occur in the GCRL, with mean PEC-Qs of up to 23,800 calculated for this reach; the average mean PEC-Q for this reach was approximately 160. These chemical characteristics make these sediments the most contaminated and toxic surficial sediment samples that we have ever evaluated. The average mean PEC-Q in the EBGCR-II was similar (i.e., 126; range of 1.4 to 987). Lower average mean PEC-Qs were calculated for the WBGCR-I and the WBGCR-II (i.e., 29.5 and 22.6, respectively). The EBGCR-I and USC had average mean PEC-Qs of 14.0 and 11.7, respectively. Lower levels of contamination were reported in the IHC (average mean PEC-Q of 5.2), LGB (average mean PEC-Q of 4.3), and IH/LM (average mean PEC-Q of 4.4). The lowest levels of contamination in surficial sediments were observed in Roxana Marsh (in the WBGCR-II; average mean PEC-Q of 0.4), Lake

George wetlands (in the LGB; average mean PEC-Q of 0.9), East Lagoon (in the GCRL; average mean PEC-Q of 0.6), Little West Pond (in the GCRL; average mean PEC-Q of 0.3), Little East Pond (in the GCRL; average mean PEC-Q of 0.1), IHC wetlands (in the IHC; average mean PEC-Q of 0.7) and the nearshore areas of LM (in the IH/LM; average mean PEC-Q of 0.2). By comparison USEPA (2000a) reported that acute and chronic toxicity to sediment-dwelling organisms is likely to be observed when mean PEC-Qs are $ 4.0 and $ 0.7 respectively.

The levels of chemical contamination in sub-surface sediments were similar to those that were observed in surficial sediments (Table ES.3). The highest mean PEC-Qs in sub-surface sediments occurred in the EBGCR-II and the GCRL, with mean PEC-Qs of up to 937 and 2,560, respectively, calculated for these reaches (with average mean PEC-Qs of approximately 98 and 197, respectively). Based on these chemical characteristics, these sub-surface sediment samples are among the most contaminated and toxic that we have ever evaluated. Lower average mean PEC-Qs were calculated for the EBGCR-I (12.7), WBGCR-II (19.3), and USC (17.0). Indiana Harbor and the nearshore areas of LM had the lowest average mean PEC-Qs (2.4). While most of the sub-surface sediments in the Assessment Area had levels of contaminants that were sufficient to cause or substantially contribute to sediment injury, relatively low levels of contamination were observed in Roxana Marsh (in WBGCR-II; average mean PEC-Q of 0.05), Lake George wetlands (LGB; average mean PEC-Q of 0.1), Middle Lagoon (in GCRL; average mean PEC-Q of 0.03), and the nearshore areas of LM (IH/LM average mean PEC-Q of 0.1).

The results of this investigation indicated that sediments and associated sediment-dwelling organisms throughout the Assessment Area have been injured by discharges of oil or releases of other hazardous substances. Similarly, fish and wildlife resources have been adversely affected by ambient conditions within the Assessment Area. Restoration of natural resources in the Assessment will necessitate the development and implementation of a restoration plan that will improve the quality of bed and bank sediments (Natural Resource Trustees 1997).

Restoration planning is likely to involve, among other activities, the development of target clean-up levels for the various contaminants of concern. While this task was beyond the scope of this investigation, the sediment effect concentrations that were employed in this assessment represent relevant tools for deriving such target clean-up levels. More specifically, the PECs and associated mean PEC-Qs were used to identify the concentrations of sediment-associated contaminants that are likely to cause or substantially contribute to sediment toxicity. Therefore, target clean-up levels would need to be lower than the PECs to ensure that bed sediments would once again support healthy and diverse populations of sediment-dwelling organisms and associated fish and wildlife communities. USEPA (2000a) reported that the incidence of toxicity to freshwater amphipods is generally less than 20% at mean PEC-Qs of < 0.1 and increases with increasing levels of sediment contamination. If virtual elimination of sediment toxicity and restoration of the benthic invertebrate community were primary restoration goals, then target clean-up levels for sediments might be in the order of 0.25 for mean PEC-Qs. Such a level of sediment contamination would be predicted to be associated with roughly a 20% incidence of toxicity to freshwater amphipods (USEPA 2000a).

As certain contaminants of concern have the potential to bioaccumulate in the food web, target clean-up levels should be established to facilitate the restoration of fish and wildlife resources. New York State Department of Environmental Conservation (NYSDEC 1994) derived numerical sediment quality criteria for the protection of wildlife. Such criteria could be used to establish target clean-up levels for bioaccumulative substances within the Assessment Area.

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1.0 Introduction

The Grand Calumet River system is a relatively small drainage basin that flows through northwestern Indiana and northeastern Illinois (Figure 1.1 and 1.2). The Grand Calumet River is comprised of two east-west oriented branches that meet at the southern end of the Indiana Harbor Canal (IHC; Natural Resources Trustees 1997). The East Branch of the Grand Calumet River (EBGCR) originates at the Grand Calumet River Lagoons (GCRL), just east of the United States Steel Division of USX Corporation (U.S. Steel) facility in Gary, Indiana. From the headwaters, the EBGCR flows in a westerly direction for about 10 miles to its confluence with the IHC and the West Branch of the Grand Calumet River (WBGCR; Brannon *et al.* 1989). The WBGCR extends some six miles from the IHC to the confluence with the Little Calumet River in northeastern Illinois. 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 (USACE 1995). However, the river can flow in either an easterly or westerly direction between Columbia Avenue and the IHC, depending on the water level in Lake Michigan (USACE 1995).

The Grand Calumet River system is connected to Lake Michigan by the IHC, US Canal (USC), and Indiana Harbor (IH). The IHC extends in a northerly direction from the confluence of the East and West branches of the Grand Calumet River to its junction with Lake George Branch (LGB) and USC (termed the Forks), a distance of approximately two miles. From the Forks, USC extends in a northeasterly direction for about two miles to IH. The LGB of the canal extends to the west from the Forks to the I-90 toll road (Natural Resources Trustees 1997).

Information from a number of sources indicates that the Grand Calumet River drainage basin is one of the most highly industrialized areas in the United States (Bright 1988; Brannon *et al.* 1989; Ryder 1993). Some of the industries that operate, or have operated, in the area include steel mills, foundries, chemical plants, packing plants, a distillery, a concrete/cement fabricator, oil refineries, and milling and machining companies (Ryder 1993). Permitted discharges from industrial operations, municipal wastewater treatment plants (WWTPs), and other sources contribute substantial quantities of wastewater to the river system. Non-point sources of contaminants to the system include urban and industrial run-off, combined sewer overflows (CSOs), leachate or overflow from a number of wastefills or ponds, and spills of pollutants in and around industrial operations (Brannon *et al.* 1989). Releases of waste and wastewaters from these sources have resulted in the contamination of surface water, ground water, sediment, and biota with a variety of toxic and bioaccumulative substances, including heavy metals, phenols, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, cyanide, and several other organic chemicals (Crane 1996; Cohen *et al.* 2000). Concerns associated with the widespread contamination of surface waters and sediments led the International Joint Commission to designate the Grand Calumet River-Indiana Harbor complex as an Area of Concern under the Great Lakes Water Quality Agreement (IJC 1989).

To address concerns regarding historic discharges of oil and releases of other hazardous substances, the United States Fish and Wildlife Service (USFWS) and the State of Indiana (the trustees) are conducting a natural resource damage assessment (NRDA) of the Grand Calumet River, Indiana Harbor Ship Canal (including USC, IHC, and LGB), IH, and waters of nearshore Lake Michigan (Natural Resources Trustees 1997). As described in the assessment plan for the NRDA (Natural Resources Trustees 1997), the trustees are documenting the cumulative injuries resulting from exposure to multiple contaminants (i.e., due to discharges of oil and releases of other hazardous substances) and to determine the appropriate scope and scale of restoration and compensation (Natural Resources Trustees 1997). The chemicals of concern in the Assessment Area are PCBs, oils and oil-related compounds (including alkanes, alkenes, naphthalenes, and PAHs), and metals (Natural Resources Trustees 1997). Other chemicals of concern in the Assessment Area include various pesticides, cyanide, phenols, and conventional variables, such as total organic carbon (TOC), dissolved oxygen (DO), sediment oxygen demand (SOD), and unionized ammonia (NH_3). As many of the chemicals of concern tend to become associated with sediments upon release into aquatic systems, sediment contamination represents a concern with respect to the restoration of beneficial water uses in this system (Ingersoll *et al.* 1997).

This report, which was prepared collaboratively by MacDonald Environmental Sciences Ltd. (MESL), United States Geological Survey (USGS), and Industrial Economics, Inc. (IEC), is intended to support the NRDA by providing an assessment of sediment injury within the Assessment Area (including evaluations of injury to various surface water and biological resources). In the context of this report, sediment injury is defined as the presence of conditions that have injured or are sufficient to injure sediment-dwelling organisms, and/or fish and wildlife resources. As such, this investigation was conducted to:

- Determine if discharges of oil or releases of other hazardous substances have injured or are likely to have injured sediments and/or biological resources (i.e., benthic invertebrates, fish, amphibians, reptiles, birds, or mammals) within the Assessment Area;
- Identify contaminants of concern (i.e., those substances that are causing or substantially contributing to sediment injury) in the Assessment Area; and,
- Characterize the areal extent of sediment injury within the Assessment Area.

In this report, the Assessment Area is considered to include the GCRL, EBGCR, the portion of the WBGCR located east of Indianapolis Boulevard, IHC, LGB, USC, IH, and the nearshore waters of Lake Michigan. While the WBGCR from Indianapolis Boulevard to the confluence with the Little Calumet River was not included in the initial definition of the Assessment Area (i.e., as defined in the Assessment Plan; Natural Resources Trustees 1997), these reaches of the river are included in this assessment of sediment injury. More specifically, the Assessment Area is considered to include the following nine reaches in this sediment injury assessment (Figure 1.2):

- Grand Calumet River Lagoons (GCRL);
- East Branch of the Grand Calumet River I (EBGCR-I; i.e., from the first railroad bridge located upstream of Industrial Highway to the confluence with IHC; hereafter the aforementioned railway bridge is termed the ConRail Bridge);
- East Branch of the Grand Calumet River II (EBGCR-II; i.e., from the GCRL to the ConRail Bridge);
- West Branch of the Grand Calumet River I (WBGCR-I; i.e., from IHC to Indianapolis Boulevard);
- West Branch of the Grand Calumet River II (WBGCR-II; i.e., from Indianapolis Boulevard to the confluence with the Little Calumet River);
- Indiana Harbor Canal (IHC; i.e., from the confluence of the east and west branches of the Grand Calumet River to Columbus Drive);

- Lake George Branch (LGB; i.e., from the headwater areas to the Indianapolis Boulevard bridge);
- US Canal (USC; i.e., the Federal Project Area; from Columbus Drive on IHC and the Indianapolis Boulevard bridge on LGB to IH); and,
- Indiana Harbor and the waters of nearshore Lake Michigan (IH/LM; i.e., including the inner harbor, the outer harbor, and nearshore areas of the lake).

The specific boundaries of the portion of the Assessment Area that is located in Lake Michigan were not defined in the assessment plan (Natural Resources Trustees 1997). The establishment of such boundaries depends upon a better understanding of injuries to natural resources in the Grand Calumet River and elsewhere in the Assessment Area. The trustees also indicated that a better understanding of the nature of the relationship between the river, the canal, and the lake was also needed to establish these boundaries (Natural Resources Trustees1997). In this report, the portions of southern Lake Michigan that were included in the assessment of sediment injury were defined based on the availability of acceptable data on sediment quality conditions and on the proximity of the sampling stations to IH. The results of the sediment injury assessment will provide the information needed to better define the boundaries of the Assessment Area.

1.1 Role of Sediments in Aquatic Ecosystems

The particulate materials that lie below the water in ponds, lakes, stream, rivers, and other aquatic systems are called sediments (ASTM 2000a). Sediments represent essential elements of aquatic ecosystems because they support both autotrophic and heterotrophic organisms. Autotrophic (which means self-nourishing) organisms are those that are able to synthesize food from simple inorganic substances (e.g., carbon dioxide, nitrogen, and phosphorus) and the sun's energy. Green plants, such as algae, bryophytes (e.g., mosses and liverworts), and aquatic macrophytes (e.g., sedges, reeds, and pond weed), are the main autotrophic organisms in freshwater ecosystems. In contrast, heterotrophic (which means other-nourishing) organisms utilize, transform, and decompose the materials that are synthesized by autotrophic organisms (i.e., by consuming or decomposing autotrophic and other heterotrophic organisms). Some of the important heterotrophic organisms that can be present in aquatic ecosystems include bacteria, epibenthic, and infaunal invertebrates, fish, amphibians, and reptiles. Birds and mammals can also represent important heterotrophic components of aquatic food webs (i.e., through the consumption of aquatic organisms).

Sediments support the production of food organisms in several ways. For example, hard-bottom sediments, which are characteristic of faster-flowing streams and are comprised largely of gravels, cobbles, and boulders, provide stable substrates to which periphyton (i.e., the algae that grows on rocks) can attach and grow. Soft sediments, which are common in ponds, lakes, estuaries, and slower-flowing sections of rivers and streams, are comprised largely of sand, silt, and clay. Such sediments provide substrates in which aquatic macrophytes can root and grow. The nutrients that are present in such sediments can also nourish aquatic macrophytes. By providing habitats and nutrients for aquatic plants, sediments support autotrophic production (i.e., the production of green plants) in aquatic systems. Sediments can also support prolific bacterial and meiobenthic communities, the latter including protozoans, nematodes, rotifers, benthic cladocerans, copepods, and other organisms. Bacteria represent important elements of aquatic ecosystems because they decompose organic matter (e.g., the organisms that die and accumulate on the surface of the sediment, and anthropogenic organic chemicals) and, in so doing, release nutrients to the water column and increase bacterial biomass. Bacteria represent the primary heterotrophic producers in aquatic ecosystems, upon which many meiobenthic organisms depend. The role that sediments play in supporting primary productivity (both autotrophic and heterotrophic) is essential because green plants and bacteria represent the foundation of food webs upon which all other aquatic organisms depend (i.e., they are consumed by many other aquatic species).

In addition to their role in supporting primary productivity, sediments also provide essential habitats for many sediment-dwelling invertebrates and benthic fish. Some of these invertebrate species live on the sediments (termed epibenthic species), while others live in the sediments (termed infaunal species). Both epibenthic and infaunal invertebrate species consume plants, bacteria, and other organisms that are associated with the sediments. Invertebrates represent important elements of aquatic ecosystems because they are consumed by a wide range of wildlife species, including amphibians, reptiles, fish, birds, and mammals. For example, virtually all fish species consume aquatic invertebrates during all or a portion of their life cycle. In addition, many birds (e.g., dippers, sand pipers, and swallows) consume aquatic invertebrates. Similarly, aquatic invertebrates represent important food sources for both amphibians (e.g., frogs and salamanders) and reptiles (e.g., turtles and snakes). Therefore, sediments are of critical importance to many wildlife species due to the role that they play in terms of the production of aquatic invertebrates.

Importantly, sediments can also provide habitats for many wildlife species during portions of their life cycle. For example, a variety of fish species utilize sediments for spawning and incubation of their eggs and alevins (e.g., trout, salmon, and whitefish). In addition, juvenile fish often find refuge from predators in sediments and/or in the aquatic vegetation that is supported by the sediments. Furthermore, many amphibian species burrow into the sediments in the fall and remain there throughout the winter months, such that sediments provide important overwintering habitats. Therefore, sediments play a variety of essential roles in terms of maintaining the structure (i.e., assemblage of organisms in the system) and function (i.e., the processes that occur in the system) of aquatic ecosystems.

1.2 Sediment Quality Issues and Concerns

Traditionally, concerns relative to the management of aquatic resources in freshwater systems have focused primarily on water quality. However, the importance of sediments in determining the harmful effects of chemical substances on sediment-dwelling organisms (i.e., plants and invertebrates) and wildlife (amphibians, reptiles, fish, birds, and mammals) has become more apparent in recent years (Long and Morgan 1991; Ingersoll *et al.* 1997). Specifically, sediment quality is important because many toxic chemicals (such as metals, PAHs, PCBs, chlorophenols, and pesticides), found in only trace amounts in water, can accumulate to elevated levels in sediments. As such, sediments can serve both as reservoirs and as potential sources of chemical substances to the water column. In addition, sediment-associated chemicals have the potential to adversely affect sediment-dwelling organisms (e.g., by causing direct toxicity or altering benthic invertebrate community structure; Chapman 1989). Therefore, sediment quality data (i.e., information on the concentrations of chemical substances) provide essential information for evaluating ambient environmental quality conditions in freshwater systems (i.e., for determining if sediments, sediment-dwelling organisms, and/or fish and wildlife resources have been injured by discharges of oil or releases of other hazardous substances into the environment).

There has been a long history of industrial activities within the Grand Calumet River basin, with the land located north of the river being one of the most heavily industrialized areas in the United States (Natural Resources Trustees 1997). In response to concerns regarding environmental contamination and associated impairment of beneficial uses, the Indiana Department of Environmental Management (IDEM) and its partners developed a Stage One Remedial Action Plan for the IHC, the Grand Calumet River, and nearshore Lake Michigan in 1991 (IDEM 1991). As part of this effort, the IDEM (1991) compiled information on potential contaminant sources within the Area of Concern, which included:

- Four major permitted industrial point source dischargers [i.e., permitted under the National Pollutant Discharge Elimination System (NPDES), including U.S. Steel, E.I. du Pont de Nemours (DuPont), LTV Steel, and Inland Steel];
- 52 properties that were listed in the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) as containing potentially uncontrolled hazardous wastes that require investigation;
- More than 400 facilities that were subject to regulation under the Resource Conservation and Recovery Act (RCRA), which means that they generate, transport, treat, store, or dispose of hazardous wastes; and,
- Three municipal WWTP (i.e., that are operated by the Hammond, Gary, and East Chicago Sanitary Districts).

In total, it was estimated that the Grand Calumet River and the IHC also received more than 11 billion gallons/year of untreated stormwater via 12 CSO outfalls (IDEM 1991). The locations of existing and historic outfalls within the Assessment Area are shown in Figure 1.3.

Discharges of oil and releases of other hazardous substances from both historic and ongoing contaminant sources have resulted in the release of a variety of toxic and/or bioaccumulative substances into receiving water systems within the Assessment Area. Some of the substances that have been released include TOC, nutrients, metals, oil and grease, phenolics, PAHs, phthalates, pesticides, and PCBs (Bright 1988; Polls *et al.* 1993; Hoke *et al.* 1993; Dorkin 1994; Ingersoll and MacDonald 1999). However, the trustees conducting this NRDA have agreed to primarily focus the assessment on natural resource injuries and damages which are associated with releases of PCBs, oil and oil-related compounds, and metals (Natural Resources Trustees 1997). Therefore, the chemicals of concern in this assessment include PCBs, four classes of petroleum hydrocarbons (including alkanes, naphthalenes, aromatics, and alkenes), and various heavy metals (including arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc). The subcategory of aromatic hydrocarbons includes a variety of PAHs, 16 of which are classified as priority pollutants by the USEPA (Natural Resources Trustees 1997).

While some of the chemicals of concern listed above remain in the water column, many others are known to accumulate in sediments (CCME 1999). The results of numerous sediment quality assessments conducted in recent years indicate that many of these substances occur at elevated concentrations in sediments within the Assessment Area (Floyd-Browne 1993; IDEM 1994; USEPA 1996a; 1996b; Tetra Tech EM Inc. 1998; Maxim Technologies 1999; Ingersoll and MacDonald 1999). The presence of elevated concentrations of contaminants in aquatic sediments represents an environmental concern because:

- Bed sediments provide essential and productive habitats for communities of sediment-dwelling organisms, including epibenthic and infaunal organisms. These organisms include such species as scuds (amphipods), mayflies (ephemeropterans), stoneflies (plecopterans), caddisflies (trichopterans), dragonflies and damselflies (odonatans), midges (dipterans), water fleas (cladocerans), worms (oligochaetes), snails (gastropods), and clams (bivalves);
- Sediment-dwelling organisms (including epibenthic and infaunal organisms) are important elements of freshwater ecosystems, representing important sources of food for many fish and other wildlife species;
- The presence of sediment-associated contaminants in freshwater ecosystems can adversely affect sediment-dwelling organisms and other components of the ecosystem; and,

- Certain sediment-associated contaminants can bioaccumulate in the tissues of aquatic organisms and, as a result, pose a potential hazard to those species that consume aquatic organisms, including wildlife and humans.

1.3 Study Objectives

This report has been prepared to determine if sediments within the Assessment Area have been injured or are likely to have been injured due to discharges of oil or releases of other hazardous substances. If the results of this assessment indicate that injuries to sediments, including surface water resources or biological resources (as indicated by the presence of conditions that are sufficient to adversely affect sediment-dwelling organisms, and/or fish and wildlife resources; Section 2.3), have occurred within the Assessment Area, then the subsequent objective of this report is to identify contaminants of concern in the assessment (i.e., those substances that are causing or substantially contributing to sediment injury) and to evaluate the spatial extent of sediment injury.

To support completion of the overall project objectives, a number of specific project tasks were identified, including:

- Collect, evaluate, and compile information on sediment quality conditions within the Assessment Area;
- Identify chemical benchmarks for whole sediment, relevant for evaluating risks to sediment-dwelling organisms, for the chemicals of concern that have been identified in the Assessment Area;
- Identify chemical benchmarks for pore water, relevant for evaluating risks to sediment-dwelling organisms, for the chemicals of concern that have been identified in the Assessment Area;
- Identify chemical benchmarks for sediments, relevant for evaluating risks to wildlife, for the chemicals of concern that have been identified in the Assessment Area;

- Identify chemical benchmarks for tissues, relevant for evaluating risks to wildlife, for the chemicals of concern that have been identified in the Assessment Area;
- Determine if the levels of the chemicals of concern, either alone or in chemical mixtures, in sediments or pore water are sufficient to cause or substantially contribute to injury to sediments, sediment-dwelling organisms, and/or fish and wildlife resources in the Assessment Area;
- Determine if sediment-dwelling organisms and/or fish and wildlife resources have been adversely affected by exposures to contaminated sediments;
- Identify priority toxic or bioaccumulative contaminants of concern in sediments and pore water (i.e., the substances that occur at concentrations, either individually or in combination, sufficient to cause or substantially contribute to sediment injury) in the Assessment Area; and,
- Determine the areal extent of sediment injury in the Assessment Area.

Definitions of many of the terms that have been used in this document are provided in the Glossary of Terms and the List of Acronyms that appear at the beginning of this report. The extent to which contaminated sediments have caused or contributed to the issuance of fish consumption advisories in the Assessment Area is discussed in a companion document entitled, *Fish Consumption Advisories in the Grand Calumet River, Indiana Harbor Canal, Indiana Harbor, and the Nearshore Areas of Lake Michigan* (MacDonald *et al.* In preparation).

2.0 Background

This study was conducted as part of a broader NRDA that is intended to assess injuries to a variety of natural resources that are associated with discharges of oil or releases of other hazardous substances within the Assessment Area (Natural Resources Trustees 1997; Simon *et al.* 2000). To support the development and communication of a plan for assessing natural resource damages, Natural Resources Trustees (1997) compiled relevant background information on the Assessment Area. This background information included a description of the geographic scope of the Assessment Area, the history of industrial activities within that area, the nature of the hazardous substance and oil releases into the environment, and the natural resources subject to injury resulting from these releases. Portions of this Assessment Plan for NRDA (Natural Resources Trustees 1997) have been reproduced here (with minor edits) to provide the reader with enhanced access to this background information.

2.1 Geographic Scope of the Assessment Area

This NRDA focuses on the Grand Calumet River, IHC, IH, and associated Lake Michigan environments, and on the riparian and upland habitats closely associated with these waters, including lands within the boundaries of the Indiana Dunes National Lakeshore. The following descriptions establish more specific boundaries for what will be referred to as the "Assessment Area".

2.1.1 Grand Calumet River

The Grand Calumet River comprises two east-west oriented branches that meet at the southern end of the IHC. The EBGCR originates at the GCRL, just east of the U.S. 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 Columbia Boulevard. The Assessment Area includes the GCRL, the EBGCR from its origin at USX outfall 001 to the confluence with the IHC, and the reach of the WBGCR between Indianapolis Boulevard and the IHC, along with the riparian, wetland and upland habitats closely associated with these stretches of the river. In this report, the additional reach of the WBGCR (i.e., WBGCR-II) was also considered to provide a more comprehensive assessment of sediment injury (Figure 1.2).

2.1.2 Indiana Harbor Canal, US Canal, and Indiana Harbor

The IHC flows north for approximately two miles from its confluence with the east and west branches of the Grand Calumet River to the junction with LGB (which is often termed the Forks). The LGB of the canal extends to the west from the point where the main canal turns to the northeast. The USC extends in a northeasterly direction for about two miles from the Forks to IH. The Assessment Area includes USC, IH, and those portions of the IHC and LGB that are not included in the Federal Project Area (i.e., the Federal Project Area includes USC, LGB from the Forks to Indianapolis Boulevard, and IHC from the Forks to Columbus Drive).

2.1.3 Lake Michigan

The trustees have not defined a specific boundary within which Lake Michigan resources will be subject to assessment. The establishment of such a boundary depends upon a better understanding of injuries to Grand Calumet River and IHC resources and the nature of the relationship between the river and canal and the lake. At a minimum, the trustees committed to review existing information and assess the extent to which the Grand Calumet River and IHC contribute to the degradation or diminishment in value of lake resources and the services these resources provide.

2.1.4 Indiana Dunes National Lakeshore

The Indiana Dunes National Lakeshore is a unit of the National Park system comprising more than 12,000 acres east of and adjacent to the U.S. Steel Gary Works. The trustees included the Indiana Dunes National Lakeshore in the Assessment Area due to the park's proximity to known sources of contamination. The focus of trustee efforts was on the western portion of the park, including portions of the GCRL system.

2.2 Chemicals of Concern in the Assessment Area

The trustees have focused the assessment on natural resource injuries and damages which are associated with the release of PCBs, oil and oil-related compounds, and metals. The purpose of this section is to briefly describe these three categories of substances, focusing on general characteristics, sources and environmental effects.

2.2.1 Polychlorinated Biphenyls

PCBs are synthetic compounds that were produced commercially in the United States between 1929 and 1977, when their production in this country was subsequently banned. The principal manufacturer of PCBs in the United States was the Monsanto Chemical Co. Monsanto's PCBs were sold under the registered trademark of Aroclor.

PCBs found wide use in commercial and industrial applications due to their favorable properties, including chemical stability, low flammability, and ability to serve as an electrical insulator. Common uses of PCBs ranged from dielectric fluids in capacitors and transformers, to heat transfer fluids, hydraulic fluids, lubricating and cutting oils, to additives in pesticides, paints, copying paper, adhesives, sealants and plastics. Their most common use was in capacitor and transformer dielectric fluids. As a result of their widespread use, the release of PCBs to the environment can occur or has occurred through a variety of mechanisms, including past uncontrolled use, past disposal practices, illegal disposal, and accidental releases (Erickson 1997).

The chemical stability of PCBs makes them highly persistent in the environment after they have been released. Because they have relatively high octanol-water partitioning coefficients and low water solubilities, PCBs tend to accumulate in soils and sediments that contain organic carbon. Having accumulated in these environmental media, PCBs become available to biological organisms and typically move through the food chain from invertebrates to fish, birds, mammals and other wildlife. Despite general declines in observed concentrations of PCBs in wildlife since the manufacture of PCBs ceased more than twenty years ago, concentrations still occur at levels that are sufficient to cause adverse effects in exposed organisms. The results of field and laboratory studies indicate that PCBs can be associated with a range of such effects, including impaired reproductive ability in fish, mammals and birds (Beyer *et al.* 1996; Eisler 1986).

2.2.2 Oil and Oil-Related Compounds

Oil is a term used to classify a variety of complex mixtures of organic compounds and trace elements that are commonly associated with the petrochemical industry. In general, four classes of petroleum hydrocarbons make up the non-animal or plant oils: alkanes, naphthenes, aromatics, and alkenes. Crude or refined oils have the potential to enter the environment wherever they are used, manufactured, stored, or otherwise handled. Releases to the environment can occur as a result of direct discharge to the land surface or to surface water, and can move through the environment via numerous pathways, including the discharge of ground water to surface water, and surface water runoff. Oil can be harmful to the environment as a result of both its physical and chemical properties.

A subcategory of the aromatic hydrocarbons is the group of chemicals known as PAHs. In addition to their occurrence as constituents in petroleum products, PAHs are also formed as a product of incomplete combustion. Sixteen PAHs are classified as priority pollutants by the USEPA. Exposure to PAHs has been associated with a variety of adverse effects in fish, birds, mammals and other wildlife, including reduced growth, impaired reproduction, narcosis, and mortality (Beyer *et al.* 1996).

2.2.3 Metals

Metals are naturally-occurring elements that are often found, as a result of industrial and commercial activity, at elevated concentrations in the environment. The group of metals that can be toxic, particularly at high doses, are commonly referred to as the "heavy metals." These metals include arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Cadmium, lead, and mercury are among the more prominent metals which have been associated with adverse effects observed in natural resources. Adverse effects associated with exposure to metals have been observed in invertebrates, fish, birds and mammals, including reduced growth, impaired reproduction, and mortality (Beyer *et al.* 1996).

2.3 Natural Resources in the Assessment Area

Prior to the period of industrial development, the Assessment Area was characterized by a plain of coastal sediments, the most prominent features of which were the globally-rare dune and swale habitats running parallel to the shoreline. Today only scattered dune and swale remnants are preserved. Nevertheless, the Grand Calumet River and IHC environment continues to comprise a wide range of natural resources. Importantly, the area has the capacity to support a much richer and much more diverse suite of resources than are currently present.

The United States Department of the Interior regulations define five categories of natural resources for which natural resource damages may be sought: surface water resources, ground water resources, air resources, geologic resources, and biological resources. Surface water resources include both the water column and associated bed or bank sediments. The following sections briefly describe each of these categories in the context of the Assessment Area.

2.3.1 Surface Water Resources

The surface water resources in the Assessment Area are particularly important in the context of this damage assessment, as they have been and continue to be the principle receptors of hazardous substances, including oil, released to the environment. The contamination of these resources has both direct and indirect impacts on the health of biological resources. For example, contaminated sediments can cause injury to benthic invertebrate populations, which in turn can result in injuries to resident fish populations for whom the invertebrates are a source of food. Similarly, injury to invertebrates and/or fish resulting from exposure to contaminated sediments and surface water can lead to injury in local insectivorous (i.e., insect-eating) or piscivorus (i.e., fish-eating) bird populations. In addition, contaminated sediments serve as a source of continuing releases of persistent hazardous substances (such as metals, PCBs, PAHs, etc.) to the water column.

2.3.2 Ground Water Resources

Ground water resources include the water in a saturated sub-surface zone and the rocks or sediments through which this water flows. Ground water resources serve as a potential pathway for contaminants to migrate from their source to surface water resources. Since ground water within the Assessment Area is not used as a public drinking water supply (as a result of contamination), the assessment of these resources focused on establishing if the ground water resource represents a pathway for contaminants to migrate to surface water resources. The Calumet Aquifer, a shallow ground water aquifer within the Assessment Area, has been documented to be directly connected with the waters of the Grand Calumet River, IHC and Lake Michigan (IDEM 1991). Injury to ground water resources has been evaluated in a separate report.

2.3.3 Air Resources

Air resources are typically assessed in the context of their ability to serve as a pathway for hazardous substances to reach, and potentially injure, other resource categories. The trustees did not consider an assessment of the air pathway to be a cost-effective use of the resources available for natural resource damage assessment in the Assessment Area.

2.3.4 Geologic Resources

Geologic resources include soils and sediments that are not otherwise accounted for under the definition of surface water or ground water resources. In this NRDA, geologic resources include the soils and sediments located in upland and wetland areas closely associated with the Grand Calumet River, and the soils of lands within the Indiana Dunes National Lakeshore.

2.3.5 Biological Resources

Along with surface water resources, biological resources comprise a key component of this damage assessment. In this assessment, the trustees focused on evaluating injuries to four categories of biological resources: benthic invertebrates, fish, birds, and mammals. However, it was understood that fish and wildlife resources, such as amphibians and reptiles, can also be adversely affected by contaminated sediments and should be considered when sufficient information is available to do so.

3.0 Study Approach

A step-wise approach was used in this report to assess sediment injury in the Assessment Area, including injury to sediment-dwelling organisms, and other components of the ecosystem. The six main steps in this process included:

- Identification of key indicators of sediment quality conditions for assessing sediment injury;
- Collection, evaluation, and compilation of the existing information on sediment quality conditions in the Assessment Area;
- Selection of chemical benchmarks for assessing sediment quality conditions in the Assessment Area (including effects-based sediment effect concentrations, bioaccumulation-based sediment quality guidelines, toxicity thresholds in pore water, and tissue residue guidelines);
- Assessment of injury to sediments, sediment-dwelling organisms, and fish and wildlife resources in the Assessment Area;
- Identification of contaminants of concern in the Assessment Area; and,
- Determination of the areal extent of sediment injury in the Assessment Area.

Each of these steps is described in the following sections.

3.1 Identification of Key Indicators of Sediment Quality Conditions for Assessing Sediment Injury

This investigation was conducted to assess sediment injury in the GCRL, Grand Calumet River, IHC, LGB, USC, IH and the waters of nearshore Lake Michigan. This assessment of sediment injury was conducted to determine if the sediments within the Assessment Area are likely to adversely affect sediment-dwelling organisms and/or fish and wildlife resources, such as fish, amphibians, reptiles, and/or mammals. Therefore, it was necessary to identify key indicators of sediment quality conditions for assessing injury to each group of receptors. The suite of indicators that was used in this assessment is described in the following sections of the report.

3.1.1 Indicators for Assessing Injury to Sediment-Dwelling Organisms

Three types of information are commonly used to evaluate the effects of contaminated sediments on sediment-dwelling organisms, including data on sediment chemistry, sediment toxicity, and benthic invertebrate community structure (Long and Chapman 1985; Chapman 1992; Ingersoll *et al.* 1997; ASTM 2000a; USEPA 2000a). In addition, data on pore water chemistry and pore water toxicity provide important information for evaluating the hazards posed to aquatic organisms by sediment-associated contaminants (ASTM 2000a; 2000b; USEPA 1994; 2000b). While any of these indicators can be used alone to determine if sediment injury has occurred, agreement among multiple indicators of injury increases the level of confidence that can be placed on the overall evaluation. Furthermore, information on conventional variables (such as TOC and NH_3 concentrations) and on the physical characteristics of habitats should be considered in an overall evaluation of ecosystem health and productivity.

Sediment Chemistry - Sediment chemistry data provide essential information for determining if discharges of oil or releases of other hazardous substances have caused or substantially contributed to sediment injury. Sediment chemistry data provide direct measurements for determining if the concentrations of sediment-associated contaminants are sufficient to have caused or substantially contributed to injury to biological resources. Such determinations can be made by comparing the measured concentrations of chemicals of concern to published acute or chronic toxicity thresholds for sediment-dwelling organisms and other aquatic species. Importantly, such toxicity thresholds (which are also termed chemical benchmarks) can be established by determining dose-response relationships from the results of controlled laboratory experiments (i.e., spiked-sediment toxicity tests; Suedel and Rogers 1995; ASTM 2000a), from analyses of matching sediment toxicity and sediment chemistry data (USEPA 1996a; Field *et al.* 1999; USEPA 2000a), from analyses of matching benthic invertebrate community structure and sediment chemistry data (Neff *et al.* 1987; Persaud *et al.* 1993; Canfield *et al.* 1996; 1998) and from matching sediment chemistry and various types of biological effects data (Long *et al.* 1995; Smith *et al.* 1996). Alternatively, consensus-based toxicity thresholds (i.e., probable effect concentrations; PECs) can be established by estimating the central tendency of the toxicity thresholds that have been established using a variety of accepted toxicological approaches (Ingersoll and MacDonald 1999; MacDonald *et al.* 2000a). Sediment chemistry was used as an important indicator of sediment quality conditions in this report.

Pore Water Chemistry - Pore water is the water that occupies the spaces between sediment particles. Pore water is often isolated from the sediment matrix to measure the concentrations of non-particle associated chemical substances, and to conduct toxicity testing on the non-particulate phase of sediments (ASTM 2000a; USEPA 1994; 2000b). Evaluation of the concentrations of contaminants in pore water is important because sediment-dwelling organisms are directly exposed to dissolved and colloidally-associated chemical substances in this sediment phase. Importantly, the toxicity of sediments to aquatic organisms has been correlated with the concentrations of contaminants in pore water (Di Toro *et al.* 1991). Contaminants in pore water also represent hazards to water column species because these contaminants can be transported into overlying waters through diffusion, bioturbation, or resuspension processes (ASTM 2000a; USEPA 1994; 2000b).

In this report, pore water chemistry was used as an important indicator for assessing sediment injury. More specifically, the measured concentrations of contaminants in pore water were compared to published toxicity thresholds for aquatic organisms. Such toxicity thresholds identify the concentrations of contaminants in water that are likely to cause or substantially contribute to acute or chronic toxicity in aquatic organisms. Comparison of the concentration of a chemical in pore water to a median lethal concentration (LC_{50}) or a median effective concentration (EC_{50}) for that chemical provides a means of determining if the concentration of that compound in the pore water was sufficient to cause or substantially contribute to toxicity to sediment-dwelling organisms (i.e., sufficient to cause sediment injury). Additionally, information on the concentrations of simultaneously extracted metals (SEM) and acid volatile sulfides (AVS) in sediments was used to determine if metals would be expected to be bioavailable to sediment-dwelling organisms (Ankley *et al.* 1996).

Sediment Toxicity Tests - A number of laboratory toxicity tests, including acute, chronic, and life cycle tests, have been developed to evaluate the toxicological significance of contaminated sediments. These tests may be as simple as short-term tests on a single contaminant using a single species or as complex as mesocosm studies in which the long-term effects of mixtures of contaminants on ecosystem dynamics are investigated. In addition, tests may be designed to assess the toxicity of whole sediments (solid phase), elutriates, sediment extracts, or pore water. The organisms that are routinely tested include microorganisms, algae, invertebrates, and fish.

Whole sediment toxicity tests are relevant for assessing the effects of contaminants that are associated with bottom sediments. The American Society for Testing and Materials (ASTM) has developed and approved whole sediment tests for assessing the toxicity of freshwater sediments (ASTM 2000a; 2000b). For example, standard methods have been established for assessing the acute and/or short-term chronic toxicity of sediment-associated contaminants on the amphipod, *Hyalella azteca*, the midges, *Chironomus tentans* and *C. riparius*, the mayfly, *Hexagenia limbata*, and several other species. These procedures may be modified to assess toxicity to other benthic invertebrate species that occur in freshwater environments (ASTM 2000a).

In addition to whole sediment toxicity tests, various procedures are available for assessing the potential for adverse effects on aquatic organisms due to the resuspension of sediments or partitioning of contaminants into the aqueous phase. Perhaps the most sensitive and frequently used of these tests is the bacterial luminescence test (i.e., Microtox; Schiewe *et al.* 1985; Burton and Stemmer 1988). USEPA (1994) recommended the use of Microtox tests for identifying acutely toxic sediments in the Great Lakes Areas of Concern. Tests using algae and invertebrates also have been employed to assess the toxicity of the suspended and/or aqueous phases. In addition, formal procedures for conducting toxicity and bioaccumulation tests have been described by the ASTM (2000a; 2000b; 2000c; 2000d).

The results of toxicity tests conducted using whole sediments, pore waters, and/or elutriates represent important indicators for assessing sediment injury and for determining the areal extent of sediment injury for several reasons. First, the results of sediment toxicity tests provide quantitative information for discriminating between toxic and non-toxic sediments. In addition, testing procedures have been established to support the generation of reliable and repeatable data and minimize the effects of the physical characteristics of the sediments (ASTM 2000a; USEPA 1994; 2000b). These characteristics make sediment toxicity tests relevant for evaluating sediment injury in freshwater systems.

In this report, sediment toxicity, as indicated by the results of toxicity tests conducted with whole sediments, pore waters, and elutriates, was used to identify the presence of conditions that were sufficient to injure sediment-dwelling organisms. More specifically, sediments were designated as toxic to sediment-dwelling organisms if the results of one or more sediment toxicity tests demonstrated that a sediment sample was toxic. Sediment samples were designated as toxic if the response of the test organism was reported to be significantly different from the response that was observed in a control or reference sediment.

Benthic Invertebrate Community Status - Benthic communities are assemblages of organisms that live in or on the bottom sediment. In most benthic invertebrate community assessments, the primary objective is to determine the identity, abundance, and distribution of the species that are present. Because most benthic macroinvertebrates are relatively sedentary and are closely associated with the sedimentary environment, they tend to be sensitive to both short-term and long-term changes in habitat, sediment, and water quality conditions (Davis and Lathrop 1992). Therefore, data on the distribution and abundance of these species provides important information on the quality of the aquatic environment.

Assessments of benthic invertebrate community structure have been used to describe reference conditions, to establish baseline conditions, and to evaluate the effects of natural and anthropogenic disturbances (Striplin *et al.* 1992). In terms of evaluating sediment quality conditions, such assessments are focused on establishing relationships between various community metrics (e.g., species richness, total abundance, and biomass) and measures of sediment quality (e.g., chemical concentrations, organic carbon content). Data from benthic invertebrate community assessments have the potential to provide relevant information for identifying impacted sites and, with appropriate supporting data, the factors that are contributing to the adverse effects that are observed.

Information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998). The results of benthic community assessments are important for conducting assessments of sediment injury for several reasons. First and foremost, the results of these assessments provide information that is directly relevant for evaluating benthic community status (i.e., impacts on biological resources can be evaluated directly). In addition, methods for conducting such assessments have been established, facilitating unbiased random sampling, broad geographic coverage (including both contaminated and uncontaminated areas), and reducing variability in the results (i.e., by sampling under consistent hydrological conditions; Striplin *et al.* 1992; Canfield *et al.* 1996; 1998). Furthermore, the information generated is ecologically relevant because benthic invertebrates are important in carbon and nutrient cycling and represent important food organisms for many species of fish.

In this report, information on the status of benthic invertebrate communities was used as an indicator for assessing sediment injury within the Assessment Area. More specifically, three main indicators were used to evaluate the integrity of the benthic invertebrate communities including the relative abundance of pollution-tolerant species (e.g., oligochaetes; in grab samples), the macroinvertebrate index of biotic integrity (mIBI; in artificial substrate samples), and the relative abundance of pollution-sensitive species (i.e., mayflies - Ephemeroptera, stoneflies - Plecoptera, and caddisflies - Tricoptera; which are also referred to as EPT taxa; in artificial substrate samples).

The abundance of pollution-tolerant species in grab samples was used to evaluate benthic invertebrate community status in the Assessment Area. Reynoldson *et al.* (1995) derived biological guidelines for sediments by determining the normal range of benthic community characteristics at reference sites [i.e., the 95% confidence intervals (CIs) for various metrics]; the presence of conditions outside this range is considered to indicate that the system was responding to stress (rather than normal environmental variability). Such reference conditions are considered to be applicable for evaluating benthic communities in both riverine and nearshore areas (Reynoldson *et al.* 1995). In this report, a number of reference sites in Lake Michigan were selected based on their proximity to the Indiana shoreline, with sampling stations located more than 1 km from the shoreline considered to be sufficiently removed from point sources to qualify as reference stations. A total of 15 grab samples met this criterion and were used to determine the characteristics of benthic communities at the reference stations. The results of this analysis showed that, on average, oligochaetes and chironomids represented 38.3 ± 17.6% and 33.3 ± 15.4% of the total abundance of benthic invertebrates at the reference stations. Therefore, the normal range (i.e., 95% CI) of benthic community characteristics for the nearshore reference stations in Lake Michigan is 3.0% to 73.6% oligochaetes and 2.5% to 64.1% chironomids (i.e., mean ± 2 standard deviations). Grab samples with higher relative abundance of oligochaetes or chironomids than the upper limit of the normal range are considered to have conditions that are sufficient to injure sediment-dwelling organisms (Reynoldson *et al.* 1995). These benchmarks were applied to grab samples that were collected throughout the Assessment Area.

The mIBI was used to provide information on the overall structure of benthic invertebrate communities (OEPA 1989; i.e., in artificial substrate samples). The scoring criteria for this metric includes such variables as number of taxa, percent dominant taxa, relative abundance of EPT taxa, and abundance of chironomids. Using data that have been collected throughout Indiana using artificial substrate samplers, Simon *et al.* (2000) calibrated the statewide model for macroinvertebrate communities in the state. Based on the calibration of the mIBI model, the average mIBI score for Indiana was determined to be about 3.5 ± 0.29. The integrity of benthic macroinvertebrate communities in the Assessment Area, was evaluated by comparing the calculated mIBI scores (i.e., for samples collected using artificial substrates) to the normal range of mIBI scores for Indiana (i.e., mean ± 2 standard deviations; 2.93 to 4.07). In this report, artificial substrate samples with mIBI scores of #2.93 were considered to have altered benthic communities relative to those in the rest of the state. By comparison, the use support assessment criteria for Indiana indicate that benthic invertebrate communities are impaired when mIBIs below 4.0 are observed (IDEM 2000c).

Mayflies, stoneflies, and caddisflies tend to be pollution-sensitive invertebrate species. For this reason, the relative abundance of EPT taxa in artificial substrate samples has been selected as one of the variables for evaluating the status of benthic invertebrate communities in the Assessment Area. In this report, the scoring criteria for the mIBI were used to establish the relative abundance of EPT taxa that would be indicative of altered benthic communities. According to Simon *et al.* (2000), the lowest mIBI metric scores were assigned to artificial substrate samples that contain < 0.5% EPT taxa. Accordingly artificial substrate samples that contained < 0.5% EPT taxa were considered in this report to be indicative of conditions that were sufficient to injure sediment-dwelling organisms.

Habitat Status - Bed sediments and associated riverine features provide essential habitats for a diverse array of aquatic organisms. As such, maintenance of the health and productivity of communities of aquatic plants, aquatic invertebrates, and fish is dependent on the availability of sufficient quantities of high quality aquatic habitats. To support this assessment of sediment injury, information on the characteristics of aquatic habitats is described in order to better understand the secondary effects of discharges of oil or releases of other hazardous substances on the physical habitats in the river. The types of information that were used in this assessment included narrative descriptions of aquatic habitat status, habitat indices, and measurements of the levels of conventional variables. The conventional variables that were considered included the levels of NH_3 in pore water and overlying water, TOC in sediment, DO concentration in overlying water, and SOD.

3.1.2 Indicators for Assessing Injury to Fish and Wildlife Resources

Sediment-associated contaminants have the potential to adversely affect wildlife species, including fish, amphibians, reptiles, birds, and mammals. First, certain wildlife species can be exposed directly to contaminated sediments through dermal contact (e.g., benthic fish species, such as carp or sculpins) or through ingestion (e.g., bottom-feeding fish species or birds that consume sediment-dwelling organisms), potentially resulting in direct toxicity. In addition, many wildlife species can be exposed to sediment-associated contaminants as a result of food web transfers and associated bioaccumulation. The accumulation of toxic substances in the tissues of wildlife species can result in decreased growth, impaired reproduction, reduced survival, or other harmful effects. Finally, sediment-associated contaminants can be toxic to sediment-dwelling organisms and, in so doing, lead to decreased abundance of food organisms. In this report, five indicators were used to assess injury to wildlife species associated with exposure to environmental contaminants.

Sediment Toxicity Tests - Various toxicity testing procedures are available for assessing the potential for adverse effects on aquatic organisms due to the resuspension of sediments or partitioning of contaminants into the aqueous phase. Toxicity tests using fish can be used to assess the toxicity of whole sediments and elutriates by applying the procedures outlined in ASTM (2000a) and USEPA (2000a). In this report, the results of toxicity tests with fish was considered to be a primary indicator of injury to wildlife.

Sediment Chemistry - In addition to causing direct effects on aquatic biota, contaminants can also accumulate in the tissues of sediment-dwelling organisms. Because many benthic and epibenthic species represent important components of the food web, sediment-associated contaminants can be transferred to higher trophic levels. In this way, contaminated sediments represent a potential hazard to wildlife species that consume aquatic organisms. While assessments of bioaccumulation can be conducted in several ways, residue-based sediment quality guidelines (SQGs) provide practical tools for evaluating sediment quality relative to the potential for bioaccumulation (Cook *et al.* 1992).

Residue-based SQGs define the concentrations of individual chemicals or classes of chemicals in sediments that will not result in unacceptable levels of that substance in the tissues of aquatic organisms (Ingersoll *et al.* 1997). The first step in the development of such SQGs involves the derivation or selection of an appropriate tissue residue guideline (TRG) for the substance or substances under consideration [e.g., the New York State Department of Environmental Conservation (NYSDEC) fish flesh criteria for piscivorus wildlife; Newell *et al.* 1987]. In addition, relationships between concentrations of contaminants in sediments and contaminant residues in aquatic biota must be established. In general, the necessary lipid- and carbon-normalized biota-sediment bioaccumulation factors (BSAFs) are determined from field studies or estimated using various modeling approaches. The SQGs are then derived by dividing the TRG by the BSAF (Cook *et al.* 1992).

Residue-based SQGs are important tools for conducting sediment quality assessments for several reasons. First and foremost, residue-based SQGs explicitly consider the potential for bioaccumulation of sediment-associated contaminants and the resultant effects on higher trophic levels. In addition, the residue-based SQGs provide a basis for interpreting sediment chemistry data in terms of the potential for adverse effects on wildlife. Therefore, sediment chemistry data, relative to bioaccumulation-based SQGs for the protection of piscivorus wildlife (NYSDEC 1994), were used in this report as primary indicators for assessing injury to wildlife in the Assessment Area.

Tissue Chemistry - In addition to causing direct effects on aquatic biota, contaminants can also accumulate in the tissues of sediment-dwelling organisms. Because many benthic and epibenthic species represent important components of the food web, sediment-associated contaminants can be transferred to higher trophic levels, such as fish. In this way, contaminated sediments represent a potential hazard to the wildlife species that consume aquatic organisms (i.e., dietary exposure).

Data on the concentrations of chemicals of concern in the tissues of aquatic organisms provides important information for assessing the effects of discharges of oil or releases of other hazardous substances on wildlife. More specifically, tissue chemistry data provide information on the extent to which bioaccumulative substances have accumulated in the tissues of sediment-dwelling organisms and fish. Comparison of these data to TRGs provides a basis for determining if contaminants have accumulated in the tissues of aquatic organisms to such an extent that adverse effects on piscivorus wildlife species are likely to occur. Such TRGs for the protection of piscivorus wildlife have been developed by the NYSDEC (Newell *et al.* 1987) and the Canadian Council of Ministers of the Environment (CCME 1999).

Fish Health - Data on fish health provides important information for determining if fish have been adversely affected by discharges of oil or releases of other hazardous substances. Fish health represents a relevant indicator of sediment quality conditions because fish that are exposed to contaminated sediment can exhibit impaired fish health, such as an increased incidence of tumors (Malins *et al.* 1985; Goyette *et al.* 1988; Payne *et al.* 1988). In turn, impaired fish health can result in increased rates of fish mortality and associated effects on fish populations. In this report, the incidence of deformities, fin erosion, lesions and tumors (i.e., DELT abnormalities) in fish was used as an important indicator of injury to wildlife resources (Sobiech *et al.* 1994), with DELT scores of > 1.3% considered to be indicative of impaired fish health.

Status of Fish Communities - Data on the status of fish populations and fish communities provides important information for assessing injury to wildlife. Discharges of oil or releases of other hazardous substances can adversely affect fish in several ways. First, exposure to chemical contaminants can cause neurological and behavioral abnormalities, increased incidence of disease, impaired reproduction, and mortality. These effects can result in changes in the abundance of various fish species and/or alterations in the status of the fish community. In addition, elevated levels of sediment-associated contaminants can impact the benthic invertebrate community and, thereby, reduce the abundance of preferred fish food organisms. As such, affected aquatic habitats are less likely to be able to support viable populations of fish.

In this report, index of biotic integrity (IBI) scores were used as primary indicators of the status of fish communities and, hence, injury to wildlife species. The IBI integrates information on species composition (i.e., total number of species, types of species, percent sensitive species, and percent tolerant species), on trophic composition (i.e., percent omnivores, percent insectivores, and percent pioneer species), and on fish condition. Importantly, the IBI has been calibrated for use in the Central Corn Belt Plains ecoregion and, therefore, it is applicable for use in the Assessment Area (Simon *et al.* 2000). Based on this calibration, fish communities were considered to be impaired at IBI scores of #34 (which is the upper limit of the range of scores for fish communities that are classified as having "poor" integrity). This benchmark is similar to the use support assessment criteria that have been established to identify impaired waters in Indiana (IDEM 2000c). More specifically, waters with IBI scores of #34 are considered to only partially support or not support beneficial uses. Therefore, the threshold for fish community impairment (i.e., IBI score of #34) is similar to the benchmarks that have been used to evaluate the integrity of fish populations elsewhere in Indiana.

3.2 Collection, Evaluation, and Compilation of Sediment Quality Data and Related Information

Information on the chemical, toxicological, and biological characteristics of sediments in the Assessment Area was collected in three stages. In the first stage, more than 10 bibliographic databases were searched for matching sediment chemistry and biological effects data. In addition, over 300 scientists were contacted by telephone or letter to obtain additional information. This data collection effort resulted in the identification and retrieval of more than 800 references that, potentially, included information on the concentrations of contaminants in sediments from the Indiana Harbor Area of Concern and on the biological effects that have been associated with exposure to those sediments (Smith *et al.* 1996; Ingersoll and MacDonald 1999; MacDonald *et al.* 2000b; USEPA 2000a).

In the second stage of the process, several additional bibliographic databases were searched to obtain more recent information on freshwater sediments. Additionally, many researchers active in the sediment quality assessment field were contacted directly to acquire the most recent information on freshwater sediments. Approximately 700 additional reports were obtained as a result of the second stage of the data acquisition effort (MacDonald *et al.* 1996; USEPA 1996a; USEPA 1996b; Ingersoll and MacDonald 1999; USEPA 2000a). The first two stages of the data acquisition process were completed during the period January, 1992 to January, 1999 and were not conducted specifically for this study. Nonetheless, these references were reviewed to identify information on sediment quality conditions within the Indiana Harbor Area of Concern.

In the final stage of the process, sediment chemistry, biological effects, and related data specific to the Assessment Area were obtained to further support this assessment of sediment injury. Importantly, the USFWS and the IDEM provided copies of a number of reports that had not been compiled in the first two phases of the data acquisition process. In addition, the results of several recent investigations that were conducted explicitly to support the current assessment were obtained (i.e., Tetra Tech EM Inc. 1998; Maxim Technologies 1999; USGS 1999; IDEM 1999).

All of the data sets that were retrieved during the course of the study were critically reviewed to determine their applicability to the assessment of sediment injury in the Assessment Area. The criteria that were used to evaluate each of the candidate data sets are described in Appendix 1 of this report. The data sets that contained information on the Assessment Area and met the selection criteria were incorporated into electronic data files (in MS Excel format). These data were subsequently fully verified against the original data source.

Several types of data were compiled as part of this study. First, the information of the chemical composition of whole sediments (Appendix 2) was compiled for both surficial and sub-surface sediment samples. In addition, the available information on the toxicity of whole sediments, pore water, or elutriates to invertebrates and fish was assembled (Appendix 3 and 4). Information on the composition of benthic invertebrate and fish communities was also compiled from the results of studies that had been conducted within the Assessment Area. Information on the levels of chemicals of concern in the tissues of invertebrates and fish were also assembled when available (Appendix 5). Other relevant data, such as information on conventional indicators of sediment quality conditions (i.e., NH_3, SOD, TOC, and DO), and the status of physical habitats, were also obtained from the studies that were assembled on the Assessment Area.

In a number of studies, additional sediment samples were collected and/or analyzed as part of the quality assurance program. In this report, field replicate samples were treated as unique samples in the data analyses (i.e., by providing information on the small scale spatial variability in sediment quality conditions). By comparison, laboratory split samples were treated as duplicates and averaged to support subsequent data analysis.

To support subsequent interpretation of the sediment chemistry data, the total concentrations of several chemical classes were determined for each sediment sample. Specifically, the concentrations of total PAHs were calculated by summing the concentrations of up to 13 individual PAHs, including acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, benz(a)anthracene, dibenz(a,h)anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene. In one study (Risatti and Ross 1989), only total PAH concentrations were reported; in this case, the reported value was used directly. For PCBs, the concentrations of total PCBs were determined using various procedures, depending on how the data were reported in the original study. If only the concentrations of total PCBs was reported in the study, then those values were used directly. If the concentrations of various Aroclors (e.g., Aroclor1242, Aroclor 1248) were reported, then the concentrations of the various Aroclors were summed to determine the concentration of total PCBs. When the concentrations of individual congeners were reported, these values were summed to determine total PCB concentrations. For DDTs, the concentrations of p,p’-DDD and o,p’-DDD, p,p’-DDE and o,p’-DDE, and p,p’-DDT and o,p’-DDT were summed to calculate the concentrations of sum DDD, sum DDE, and sum DDT, respectively. Total DDTs was calculated by summing the concentrations of sum DDD, sum DDE, and, sum DDT. Finally, the concentrations of chlordane were determined by summing the concentrations of alpha- and gamma-chlordane isomers. If only the concentrations of total chlordane was reported in the study, then those values were used directly. In calculating the total concentrations of the various chemical classes, less than detection limit values were assigned a value of one-half of the detection, except when the detection limit was greater than the consensus-based PEC (or an alternate SQG if a PEC was not available). In this latter case, the greater than detection limit value was not used in the calculation of the total concentration of the substance.

To support the compilation and subsequent analysis of the information on sediment quality conditions in the Assessment Area, a relational project database was developed in MS Access format. All of the sediment chemistry, toxicity, and benthic community data compiled in the database were georeferenced to facilitate mapping and spatial analysis using geographic information system (GIS)-based applications (i.e., ESRI’s ArcView and Spatial Analyst programs). The database structure made it possible to retrieve data in several ways, including by data type (i.e., chemistry vs. toxicity), by sediment horizon (i.e., surficial vs. sub-surface sediments), by stream reach (i.e., EBGCR-II vs. EBGCR-I), by stream segment (i.e., confluence with WBGCR to Kennedy Avenue vs. Kennedy Avenue to Cline Avenue), and by date (i.e., data collected prior to 1996 vs. data collected in 1996 or later). As such, the database facilitated a variety of different types of data analyses.

3.3 Selection of Chemical Benchmarks for Assessing Sediment Quality Conditions

Evaluation of the potential effects of sediment-associated contaminants on sediment-dwelling organisms, and fish and wildlife resources necessitated the application of four types of chemical benchmarks, including:

- Effects-based SQGs for assessing potential effects on sediment-dwelling organisms (Table 3.1);
- Toxicity thresholds for pore water for assessing potential effects on sediment-dwelling organisms (Table 3.2);
- Bioaccumulation-based SQGs for assessing potential effects on wildlife species (Table 3.3); and,
- Tissue residue guidelines for assessing potential effects on wildlife (Table 3.4).

3.3.1 Effects-Based Sediment Quality Guidelines

Numerical benchmarks (including sediment quality criteria, sediment quality objectives, and sediment quality standards) represent useful tools for assessing the quality of freshwater sediments (MacDonald *et al.* 1992; USEPA 1992b; Adams *et al.* 1992; USEPA 1996a; USEPA 1996b; USEPA 1997; Ingersoll and MacDonald 1999; MacDonald *et al.* 2000a; 2000b). Such benchmarks have been developed by various jurisdictions in North America using a variety of approaches. The approaches that have been selected by individual jurisdictions depend on the receptors that are to be considered (e.g., sediment-dwelling organisms, wildlife, or humans), the degree of protection that is to be afforded, the geographic area to which the values are intended to apply (e.g., site-specific, regional, or national), and their intended uses (e.g., as screening tools or for remediation objectives).

In this report, two general terms are used to describe the benchmarks that are used to evaluate the potential effects of sediment-associated contaminants on sediment-dwelling organisms. First, the term *sediment quality guidelines* (SQGs) is used to describe previously published benchmarks for assessing the biological significance of contaminant concentrations in whole sediments (e.g., threshold and probable effect levels - Smith *et al.* 1996; no effect concentrations - Ingersoll *et al.* 1996). By comparison, the term *consensus-based sediment effect concentrations* (SECs) is used to describe the benchmarks that provide an estimate of the central tendency of the published SQGs (Ingersoll and MacDonald 1999; MacDonald *et al.* 2000a; USEPA 2000a). The consensus-based SECs are intended to define the concentrations of sediment-associated contaminants that would be sufficient to cause or substantially contribute to injury to sediment-dwelling organisms, including infaunal (i.e., those species that live in the sediments) and epibenthic (i.e., those species that live on the sediments) organisms.

In this report, we relied on the consensus-based SECs that were developed by Ingersoll and MacDonald (1999) and MacDonald *et al.* (2000a) for assessing sediment injury in the Assessment Area (i.e., evaluating whole sediment chemistry data). As the term implies, consensus-based SECs reflect the agreement among the various SQGs by providing an estimate of their central tendency. Importantly, the consensus-based SECs are considered to provide a unifying synthesis of the existing SQGs, reflect causal rather than correlative effects, and account for the effects of contaminant mixtures in sediment (Swartz 1999; MacDonald *et al.* 2000a; 2000b; Di Toro and McGrath 2000).

Ingersoll and MacDonald (1999) derived two consensus-based SECs for each chemical of concern in the WBGCR, including threshold effect concentrations (TECs) and PECs (Table 3.1). The TECs are intended to identify the concentrations of sediment-associated contaminants below which adverse effects on sediment-dwelling organisms are unlikely to occur. In contrast, the PECs are intended to identify the concentrations of contaminants in whole sediments above which adverse effects are likely to be observed. The SECs for most of the chemicals of concern in the Assessment Area, including metals (arsenic, cadmium, copper, chromium, lead, nickel, and zinc), total PAHs (and various individual PAHs), total PCBs, and sum DDE 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.* 2000b; USEPA 2000a). The PEC for total PAHs is higher than the equilibrium partitioning sediment guideline and the narcosis final chronic value that have been established using the equilibrium partitioning approach (Di Toro and McGrath 2000), confirming that sediment toxicity is likely to occur at concentrations of total PAHs above the PEC. While insufficient data were available to fully evaluate the PECs for mercury, certain PAHs, and several pesticides (MacDonald *et al.* 2000a), these additional PECs were used to assess sediment quality conditions in the Assessment Area.

In this report, the consensus-based PECs were used as primary benchmarks for assessing injury to sediments and sediment-dwelling organisms. The PECs were used in two ways to support the assessment of sediment injury within the Assessment Area (Table 3.1). First, the measured concentrations of each substance in whole sediment samples were compared to the corresponding PEC to determine if that substance was present at concentrations that are sufficient to cause or substantially contribute to sediment injury. The PECs were also used to support the calculation of mean PEC-quotients (PEC-Qs) for each sediment sample that was collected within the Assessment Area.

Mean PEC-Qs were calculated using the procedure that was established by USEPA (2000a). Using this method, a PEC-Q was first determined for each metal for which a reliable PEC was available (as identified in MacDonald *et al.* 2000a). Then, an average PEC-Q for metals was calculated by summing the PEC-Qs of each metal and dividing by the number of metals that were included in the calculation. PEC-Qs were also calculated for total PAHs and total PCBs. Finally, the mean of the average PEC-Q for metals, the PEC-Q for total PAHs, and the PEC-Q for total PCBs was determined for each sediment sample (termed the mean PEC-Q). The PEC-Qs for pesticides were not used in this calculation to assure that the mean PEC-Q reflected the concentrations of the chemicals of concern in the Assessment Area. It was not possible to include PEC-Qs for alkanes or alkenes in this calculation because PECs were not available for these classes of petroleum hydrocarbons. The PEC for total PAHs, rather than the PECs for individual PAHs and for total PAHs, was used to calculate the mean PEC-Qs to avoid double accounting for the PAH concentration data.

The mean PEC-Q provides a basis for assessing the potential effects of sediment-associated contaminants when they occur in complex mixtures (Swartz 1999; MacDonald *et al.* 2000a; 2000b; USEPA 2000a). Using the results of analyses conducted on a large freshwater database, USEPA (2000a) reported that sediment samples with mean PEC-Qs ≥ 0.7 are likely to be toxic to sediment-dwelling organisms (i.e., the incidence of toxicity to amphipods, in 28-day tests, was greater than 50% in sediment samples that had these chemical characteristics). In 10- to 14-day tests, the incidence of toxicity to amphipods was greater than 50% when mean PEC-Qs ≥ 4.0 in sediment samples (USEPA 2000a). In the 28-day tests, the incidence of toxicity to amphipods was 100% when mean PEC-Qs ≥ 4.0 in sediment samples (USEPA 2000a). Because sediment-dwelling organisms are likely to be exposed to contaminated sediments for extended periods of time (i.e., > 30 days), sediments with mean PEC-Qs ≥ 0.7 were considered to be sufficiently contaminated to injure sediment-dwelling organisms.

As indicated above, the mean PEC-Qs were calculated using the reliable PECs for metals, total PAHs, and total PCBs. The PECs for pesticides were not used to calculate mean PEC-Qs. In addition, PECs were not available for many of the chemicals of concern in the Assessment Area (e.g., alkanes, alkenes, other metals, and phenols). Therefore it is possible that the incidence and/or the areal extent of sediment injury has been underestimated using this approach.

In this report, evaluations of sediment injury were conducted using dry weight concentrations of chemical contaminants. This approach was used because organic carbon normalized SQGs for nonpolar organic substances (i.e., Barrick *et al.* 1998; Long *et al.* 1995; USEPA 1996a) or normalization of metal concentrations to AVS (Long *et al.* 1998) has not improved predictions of sediment toxicity in field-collected samples (USEPA 2000a).

3.3.2 Toxicity Thresholds for Pore Water

Pore water is the water that occupies the spaces between sediment particles and usually accounts for over 50% of the volume of surficial sediments (Power and Chapman 1992). Because sediment-associated contaminants have the potential to partition into pore water, this medium can represent an important source of contaminant exposure for sediment-dwelling organisms. For this reason, pore water assessments can provide useful information on the potential effects of sediment-associated contaminants, particularly on infaunal species (i.e., those species that routinely reside within the sediment matrix). While such assessments can include several components, pore water toxicity tests and evaluations of pore water chemistry represent the central elements of most pore water assessments (ASTM 2000a). Importantly, interpretation of the pore water chemistry data that is collected in such assessments is dependent on the availability of suitable benchmarks for assessing pore water quality.

A variety of benchmarks for assessing pore water chemistry are available in the published literature. For example, numerical water quality criteria, such as those that have been promulgated by the USEPA (1998), and site-specific water quality standards, such as those that have been established by the IDEM (1991), provide relevant tools for assessing pore water quality conditions. Alternatively, toxicity thresholds for pore water can be established on a *de novo* basis by compiling data from the toxicological literature (i.e., median lethal concentrations or median effective concentrations; LC_{50}s or EC_{50}s) for receptors of concern in the Assessment Area. Such toxicity thresholds identify the concentrations of contaminants in water that are likely to cause acute and chronic toxicity to aquatic plants, amphipods and other aquatic invertebrates, and fish.

In this report, toxicity thresholds for pore water were established from the toxicological data that have been published in the scientific literature. Information on the acute toxicity of the chemicals of concern to sediment-dwelling organisms was acquired from the data that are contained in the USEPA Acquire Database (USEPA 1992a) or from the data that was generated subsequently (USEPA 1994; 2000b). Information on the acute and chronic toxicity of the chemicals of concern to aquatic plants, other invertebrate species, and fish were compiled from various sources, including Spear and Pierce (1979); CCREM (1987); EC and HC (1994); Outridge *et al.* (1994); and USGS (1998). The published toxicity thresholds for the chemicals of concern in pore water in the Assessment Area are presented in Table 3.2.

Comparison of the measured concentrations of contaminants in pore water to the published toxicity thresholds provides a means of determining which substances occur at concentrations that are sufficient to cause or substantially contribute to sediment injury. By dividing the pore water concentrations of each chemical of concern in each sample by the reported LC_{50} concentration for that compound, it is possible to calculate a value that can be used to evaluate the overall toxicity of the sample. This value also provides a basis for reporting contaminant concentrations in terms of the number of toxic units that they represent. The number of toxic units of each compound can be summed to evaluate the combined toxic effect of chemicals with a similar mode of toxicity. Samples that contain $ 1 summed toxic units are likely to be toxic to sediment-dwelling organisms.

3.3.3 Tissues Residue Guidelines for the Protection of Wildlife

Tissue residue guidelines define the concentrations of individual chemicals or classes of chemicals in the tissues of aquatic invertebrates or fish that will not result in adverse biological effects on aquatic organisms, on fish and wildlife resources. As such, TRGs represent important benchmarks for assessing hazards associated with the bioaccumulation of contaminants in the tissues of aquatic organisms. In this report, TRGs for the protection of piscivorus wildlife were used to assess sediment injury in the Assessment Area. More specifically, the fish flesh criteria that were developed by the NYSDEC (Newell *et al.* 1987), were compiled and used to assess injury to wildlife associated with dietary exposure to contaminants (Table 3.4). These TRGs define the concentrations of contaminants in fish tissue which, if not exceeded, are likely to prevent carcinogenic or non-carcinogenic impacts on piscivorus wildlife, including birds and mammals. Exceedance of the TRGs is considered to indicate that the potential exists for toxic effects in wildlife due to the consumption of contaminated fish tissues (Newell *et al.* 1987).

3.4 Evaluation of Sediment Injury

Discharges of oil and releases of other hazardous substances into aquatic ecosystems have the potential to cause injury to surface water resources, and/or biological resources (Natural Resources Trustees 1997), including sediments, sediment-dwelling organisms, and/or wildlife. Contaminated sediments pose a hazard to sediment-dwelling organisms or fish and wildlife resources when concentrations of one or more contaminants exceed biological response thresholds. In this report, an injury to sediments has been identified if the measured concentrations of contaminants in sediments, pore waters, and/or tissues are sufficient to adversely affect biological resources (including sediment-dwelling organisms and/or wildlife), or if direct effects on biological resources have been demonstrated. Specifically, sediment injury is demonstrated by:

- Degradation or loss of physical habitats (as indicated by exceedances of benchmarks for conventional variables);
- Degraded sediment quality conditions (i.e., as indicated by exceedances of the effects-based PECs or bioaccumulation-based SQGs);
- Degraded pore water quality conditions (i.e., as indicated by exceedances of published toxicity thresholds for aquatic organisms);
- Acute or chronic mortality, reduced growth, impaired reproduction, or abnormal development of sediment-dwelling organisms (as indicated by the results of laboratory toxicity tests);
- Degraded benthic invertebrate communities (as indicated by the results of benthic invertebrate community assessments);
- Acute or chronic mortality, reduced growth, impaired reproduction, or abnormal development of fish (as indicated by the results of laboratory toxicity tests);
- Accumulation of contaminants in the tissues of aquatic organisms to levels that could injure wildlife species (as indicated by exceedances of TRGs);
- Increased incidence of altered organ morphology, tumors/lesions, or degraded health of fish (as indicated by the results of field surveys); or,
- Degraded or depressed fish populations or altered fish communities (as indicated by the results of field surveys).

In this report, sediments were considered to be injured if one or more of these conditions had been documented in any of the reaches identified in the Assessment Area. The presence of such conditions was evaluated using the results of chemical analyses of sediments and pore water, laboratory toxicity tests, benthic invertebrate community assessments, bioaccumulation assessments, and fisheries investigations that have been conducted in the Assessment Area.

In this report, the available sediment quality and related information was evaluated to determine if discharges of oil or releases of other hazardous substances have resulted in conditions that are sufficient to cause sediment injury within the Assessment Area. While such an assessment could be restricted to the biologically-active layer (i.e., the top 10 to

30 cm of sediment), the sediment injury assessment that is presented in this report was designed to be more comprehensive. More specifically, this report provides an assessment of sediment injury for both surficial and sub-surface sediments. In this report, surficial sediment is defined as any sample collected from the surface of the sediment to any depth (i.e., sample depth of 0 to 0.33 feet, 0 to 0.5 feet, etc.). Sub-surface sediment is defined as any sample that does not include surficial sediments (e.g., sample depth of 0.33 to 0.66 feet). This approach to sediment injury assessment was used in this report because removal of contaminated surficial sediments represents one of the options that are available for restoring beneficial uses in the Assessment Area, if sediments are found to be injured. If this remedial option were selected, then the removal of contaminated surficial sediments could result in sub-surface sediments being exposed and becoming available to sediment-dwelling organisms for colonization (i.e., sub-surface sediments would become the new surficial sediments unless the sub-surface sediments were capped by clean materials as part of the remedial actions). For this reason, it was considered necessary to evaluate the injury to sub-surface sediments in this report.

3.5 Identification of Contaminants of Concern

In this report, contaminants of concern are defined as those substances that occur in sediments at concentrations that are sufficient to cause or substantially contribute to injury to sediment-dwelling organisms, and/or fish and wildlife resources. The contaminants of concern were identified by comparing the concentrations of each substance that have been measured in sediments to the corresponding chemical benchmarks. The chemical benchmarks that were used in this evaluation included the consensus effects-based PECs (Table 3.1), the published bioaccumulation-based SQGs (Table 3.3), the published toxicity thresholds for pore water (Table 3.2), and the published TRGs for the protection of piscivorus wildlife (Table 3.4). Those substances that occurred in two or more sediment samples within the various reaches of the Assessment Area at concentrations in excess of the chemical benchmarks were identified as contaminants of concern. For metals, those substances that exceeded the PECs and upper limit of background levels were identified as contaminants of concern. The maximum background concentrations of metals in Indiana and Illinois lake and stream sediments are presented in Table 3.5.

3.6 Evaluation of the Spatial Extent of Sediment Injury

In this report, the spatial extent of sediment injury was evaluated by linking the sediment chemistry and sediment toxicity information contained in the project database with GIS-based applications (ArcView and Spatial Analyst software). To facilitate spatial analyses of these data, the Assessment Area was first divided into nine distinct reaches, as identified in Section 1.0. Next, each reach was divided into a number of segments using readily identifiable landmarks (e.g., railway bridges, roadway bridges, and major streets). In this way, it was possible to tabulate the available data for various reaches and various segments within each reach.

In this evaluation, sediment chemistry and sediment toxicity data were used as the primary indicators of sediment injury. Based on the results of a comprehensive evaluation of matching sediment chemistry and sediment toxicity data from throughout North America, USEPA (2000a) reported that there is a high probability (i.e., > 50%) of observing acute and chronic toxicity in the amphipod, *Hyalella azteca*, at mean PEC-Qs $\geq$ 4.0 and $\geq$ 0.7, respectively. Because sediment-dwelling organisms are likely to be exposed to contaminated sediments for extended time periods (i.e., > 30 days), the spatial extent of sediment injury within the Assessment Area was evaluated based on mean PEC-Qs $\geq$ 0.7. More specifically, sediments with mean PEC-Qs $\geq$ 0.7 were considered to have chemical characteristics that are sufficient to injure sediment-dwelling organisms. Sediment samples that were found to be toxic in one or more toxicity tests were also considered to have conditions that were sufficient to cause sediment injury.

The available sediment chemistry and sediment toxicity data were tabulated for each segment and reach within the Assessment Area. As such, it was possible to calculate the proportion of sediment samples within each segment and reach that had levels of chemical contamination that were sufficient to cause or substantially contribute to sediment injury (i.e., using the calculated mean PEC-Qs for each sample). Likewise, it was possible to calculate the proportion of sediment samples that were toxic to one or more of the species that were tested in toxicity tests. Segments and reaches with two or more sediment samples (separated by more than 100 feet) with elevated levels of sediment-associated contaminants (as indicated by a mean PEC-Q of $\geq$ 0.7) were considered to have been injured by discharges of oil or releases of other hazardous substances. The results of toxicity tests and benthic invertebrate community assessments were used to corroborate the conclusions that were drawn on the extent of sediment injury that were based on the sediment chemistry data.

The spatial extent of sediment injury was also evaluated using GIS-based applications. In this evaluation, the geographic distribution of sediment samples with mean PEC-Qs < 0.1, ≥ 0.1 to < 0.7, ≥ 0.7 to < 4.0, and ≥ 4.0 were plotted on base maps of the Assessment Area. Likewise, the geographic distribution of toxic and not toxic sediment samples were plotted on base maps (i.e., based on the results of laboratory toxicity tests). The distribution of samples with altered benthic invertebrate communities was also plotted. In this way, it was possible to clearly delineate the spatial extent of sediment injury within the Assessment Area. In addition, the spatial distribution of relatively less contaminated sediment samples was also determined. In this analysis, surficial and sub-surface sediments were considered separately. However, the spatial extent of sediment injury relative to wildlife was not evaluated using the GIS-based application.

In addition to these evaluations of the spatial extent of injury to sediment-dwelling organisms, an overall assessment of the spatial extent of sediment injury was conducted. In this evaluation, the information on the various indicators of sediment injury to sediment-dwelling organisms, and wildlife was compiled for each reach in tabular form. In this way it was possible to compare the relative severity of sediment injury among the various reaches in the Assessment Area. This evaluation was conducted to provide information that could be used in priority setting, should remedial actions be required to restore beneficial uses in the Assessment Area (as defined in the Remedial Action Plan; IDEM 1991).

4.0 Existing Information on Sediment Quality Conditions in the Assessment Area

This report was prepared to determine if discharges of oil or releases of other hazardous substances have caused or substantially contributed to sediment injury with the Assessment Area. The geographic scope of the Assessment Area is outlined in Figures 1.1 and 1.2. To facilitate the assessment of sediment injury, the Assessment Area was divided into nine sub-areas including:

- Grand Calumet River Lagoons (GCRL);
- East Branch of the Grand Calumet River I (EBGCR-I; i.e., from the first railroad bridge located upstream of Industrial Highway to the confluence with IHC; hereafter the aforementioned railway bridge is termed the ConRail Bridge);
- East Branch of the Grand Calumet River II (EBGCR-II; i.e., from the GCRL to the ConRail Bridge);
- West Branch of the Grand Calumet River I (WBGCR-I; i.e., from IHC to Indianapolis Boulevard);
- West Branch of the Grand Calumet River II (WBGCR-II; i.e., from Indianapolis Boulevard to the confluence with the Little Calumet River);
- Indiana Harbor Canal (IHC; i.e., from the confluence of the east and west branches of the Grand Calumet River to Columbus Drive);
- Lake George Branch (LGB; i.e., from the headwater areas to the Indianapolis Boulevard bridge);
- US Canal (USC; i.e., the Federal Project Area; from Columbus Drive on IHC and the Indianapolis Boulevard bridge on LGB to IH); and,
- Indiana Harbor and the waters of nearshore Lake Michigan (IH/LM; i.e., including the inner harbor, the outer harbor, and nearshore areas of the lake).

This assessment was conducted using data and information on sediment quality and associated environmental conditions that have been collected over the past 30 years. Over that time, a substantial quantity of data on sediment quality conditions has been collected in the Assessment Area. In total, 122 documents relating to the Assessment Area were identified and retrieved to acquire candidate data sets for possible inclusion in the project database. Each of these studies was then critically reviewed to determine if it contained relevant information for assessing sediment quality conditions within the Assessment Area (see Appendix 1 for a listing of the criteria that were used to evaluate candidate data sets). Of the 122 documents, a total of 42 contained data sets that met the evaluation criteria that were established for this study and were subsequently used to assess sediment quality conditions in the Assessment Area. A brief description of each study is provided in the following sections, including the sub-areas that were sampled and the types of data that were reported in the study.

4.1 Data Collected During the Period, 1970 to 1980

In 1972, the United States Environmental Protection Agency (USEPA) Office of Enforcement and General Counsel conducted a sampling program on the EBGCR to assess sediment toxicity (Lucas and Steinfeld 1972; Appendix 3.1). A total of 65 sediment samples were collected from 36 sampling stations that were located on the EBGCR between the GCRL and the confluence with the WBGCR (i.e., in sub-areas EBGCR-I and EBGCR-II; Figure 4.1). As part of this investigation, surficial sediment samples were collected at a total of 34 sampling stations using a dredge sampler. Another 31 samples of sub-surface sediments were obtained using a core sampler. The toxicity of the sediment samples was evaluated using 96-hour laboratory toxicity tests with two test organisms, including the amphipod, *Hyalella azteca*, and the fathead minnow, *Pimephales promelas*. While some water chemistry data were also collected as part of this study, no sediment chemistry data were reported.

In 1979, the United States Army Corps of Engineers (USACE; Waterways Experiment Station) conducted an investigation on sediment quality conditions within the Assessment Area (USACE 1980a). In total, 34 sediment samples were collected from 13 stations during this investigation. Of these, 11 sediment samples were obtained from five stations in IH/LM and another 23 sediment samples were collected from eight stations in the USC

(Figure 4.2). A sediment core was obtained at each station, with core depths ranging from 6 to 15.5 feet. Individual sediment samples were prepared by compositing three foot sections of the core. The chemical characteristics of each sample were determined by measuring the concentrations of conventional variables (e.g., total organic carbon; TOC and NH_3), total metals, and total polychlorinated biphenyls (PCBs; Appendix 2.1).

4.2 Data Collected During the Period, 1980 to 1989

The following year (1980), the USACE (Waterways Experiment Station) conducted a follow-up study to further evaluate the physical and chemical characteristics of sediment and water from the USC (USACE 1980b). In this study, sediment samples from three sites were collected and analyzed for total metals, oil and grease, total PCBs, phenols, and several conventional variables (Appendix 2.2; Figure 4.3).

In 1982 and 1986, the Metropolitan Water Reclamation District of Greater Chicago Research and Development Department conducted surveys of water and sediment quality conditions in the EBGCR-I, IHC, USC, WBGCR-II and IH/LM (Polls *et al.* 1993). The sampling program included the collection of water and sediment samples from 18 locations in the study area, including two stations in the EBGCR-I, one station in the WBGCR-II, one station in the IHC, two stations in the USC, and 12 stations in IH/LM (Figure 4.4; Appendix 2.3 and 2.4). In addition, two sampling stations were located on the Little Calumet River in Illinois. The water samples were analyzed for conventional variables (e.g., water hardness, DO, conductivity), nutrients, fats, oil and grease, cyanides, total metals, phenol, and several other variables. By comparison, total solids, total volatile solids, chemical oxygen demand, fats, oil and grease, phenol and total iron were quantified in the sediment samples. Additionally, sediment samples were collected to assess the status of benthic invertebrate communities.

In August 1983, the USACE conducted a study to evaluate sediment quality conditions in the USC (USACE 1983). More specifically, this study was designed to provide information on the distribution of PCBs in the bottom sediments and their associated toxicity to determine whether dredged materials would be considered to be "hazardous" as defined under the RCRA. To this end, sediment cores were collected from eight stations in the USC (Figure 4.5). The concentrations of total PCBs were determined in a total of 27 sediment samples, with up to four sediment horizons sampled at each station (Appendix 2.5).

In November 1983, the Metropolitan Sanitary District of Greater Chicago conducted a similar study of environmental conditions in the USC and IH/LM (Polls and Dennison 1984). In this study, 18 sampling stations were selected to obtain samples for assessing water quality conditions, including 10 stations in the USC and eight stations in IH/LM (Figure 4.6). The analyses conducted on the water samples included conventional variables, nutrients, total metals, phenol, cyanide, fats, oil and grease, and several other variables. Additionally, samples were collected to assess the status of the benthic invertebrate community and fish populations at several of these stations.

In 1984, an investigation was conducted to assess the status of benthic invertebrate communities in IH and two nearshore areas in southwestern Lake Michigan (LTI 1984). The sampling locations included one station in IH, 15 stations east of the entrance to IH, and 12 stations in the vicinity of the Whiting lakeshore (Figure 4.7). A petite Ponar dredge was used to collect the benthic macroinvertebrate samples at most of the stations; however, it was necessary to utilize divers to obtain sediment samples at one of the stations. Neither water nor sediment chemistry data were collected as part of this sampling effort.

Two years later (1986), the USEPA carried out an investigation to evaluate sediment contamination in the vicinity of LTV Steel Corporation and Inland Steel Company (USEPA 1986a). The purpose of the survey was to determine the distribution of sediment-associated polycyclic aromatic hydrocarbons (PAHs) downstream of coke plant dischargers (Figure 4.8; Appendix 2.6). Sediment samples were collected from a total of 22 sites within the Assessment Area, with sampling depths ranging from surficial samples to eight foot cores. One sample was situated in the WBGCR-II, 10 samples were from IH, and 11 samples were collected from the USC. A total of 15 different PAHs were measured in the sediment samples that were collected during this investigation.

Between July and September of 1986, the USEPA conducted an evaluation of 19 point source dischargers within the Assessment Area (Simon 1986; USEPA 1986b). Grab samples of effluent were obtained from a total of 19 outfalls, including two outfalls in the EBGCR-I [Gary sewage treatment plant (STP) and E.I. du Pont de Nemours (DuPont)], seven U.S. Steel outfalls in the EBGCR-II, one East Chicago STP outfall in the WBGCR-I, one Hammond STP outfall in the WBGCR-II, five Inland Steel outfalls in IH, and three

LTV Steel outfalls in the USC. Chronic, static embryo-larval toxicity tests were performed on a dilution series comprising five effluent concentrations using embryonic fathead minnows (*Pimephales promelas*). The endpoints evaluated were survival, hatchability and relative percent teratogenicity. Several conventional variables were measured in each of the effluent discharges, including temperature, dissolved oxygen (DO), specific conductance, pH, alkalinity, and hardness. Additional effluent chemistry data was collected for four of the dischargers (i.e., East Chicago STP outfall, DuPont outfall, and two Inland Steel outfalls), with the variables measured including total and dissolved metals, ammonia, cyanide, phenols, oil and grease, semi-volatile organic chemicals (SVOCs), and hexavalent chromium.

In September of 1987, the Metropolitan Sanitary District of Greater Chicago initiated a sediment survey to obtain information on the fate of contaminated sediments drifting from IH into Lake Michigan (Polls 1988). This study was designed to support the development of maintenance dredging plans by the USACE. Surficial sediment samples were collected from a total of 30 stations, including one in the LGB, two in the USC and 27 from IH/LM (Figure 4.9). Each sediment sample was analyzed for selected metals (total) and PCBs (Appendix 2.7).

In 1988, the Indiana Department of Environmental Management (IDEM) initiated a monitoring program to evaluate sediment quality conditions at a number of locations within the Assessment Area (IDEM 1994). Surficial sediment samples were collected at up to seven sampling stations every two years between 1988 and 1994, including Dickey Road on IHC; Cline Avenue and Kennedy Avenue on the EBGCR-I; Bridge Street on the EBGCR-II; Indianapolis Boulevard on the WBGCR-I; Hohman Avenue on the WBGCR-II; and, the confluence of the EBGCR and the WBGCR (Figure 4.10). The concentrations of conventional variables, total metals, PAHs, PCBs, pesticides and AVS were determined in each of these sediment samples (Appendix 2.8 to 2.11). In addition to the sediment quality monitoring program, periodic sampling of fish tissues was also conducted between 1982 and 1994. This program involved the collection and analysis of fish tissues (including carp, golden shiner, pumpkinseed, and goldfish) at various locations on the EBGCR-I, EBGCR-II, WBGCR-II, and USC. The tissues (whole body, skin-on fillets, or scaleless fillets) of these fish were then analyzed to determine the concentrations of chemical contaminants, including total metals, pesticides, PCBs, acid extractable compounds, base/neutral extractable compounds, and volatile organic compounds (VOCs; Appendix 5.1 to 5.5).

Between October 1988 and May 1990, Hoke *et al.* (1993) collected surficial sediment samples from a total of 13 stations within the Assessment Area, including one station each on the WBGCR-I, USC and IH, two stations each on the WBGCR-II, EBGCR-II and IHC, and four stations on the EBGCR-I (Figure 4.11). The toxicity of sediments and pore water from these locations was evaluated using a battery of toxicity tests, including one whole sediment test and three pore water tests. The whole sediment assay was a 10-day survival and growth test using the midge, *Chironomus tentans*. The pore water tests included a 30-minute Microtox test and two 48-hour survival tests with the cladoceran, *Ceriodaphnia dubia* and *Daphnia magna* (Appendix 4.1). These investigators measured the concentrations of conventional variables, total metals, PAHs, PCBs, pesticides and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in sediment samples and performed additional analyses for other organic chemicals in pore water samples.

In a related study, Unger (1992) was commissioned by The IDEM to collect sediment cores from 10 of the 13 stations that were sampled in the Hoke *et al.* (1993) investigation. This sampling program was also conducted between 1988 and 1990. Two stations were located in each the WBGCR-II and the EBGCR-II, four stations were situated in the EBGCR-I, and one station was found in each the WBGCR-I and IHC (Figure 4.12; Appendix 2.12). At each station, the sediment cores were divided into three samples that reflected conditions in the top horizon (i.e., 0 to 3 feet), the middle horizon (3 to 6 feet), and the bottom horizon (i.e., 6 to 9 feet). The concentrations of PAHs, PCBs, pesticides, and phenol were determined in each sediment sample.

As part of a five-year project dealing with the Assessment and Remediation of Contaminated Sediments in the Great Lakes (i.e., the ARCS Program), the Biological Resources Division, USGS conducted a sediment quality evaluation in the Assessment Area during 1989 (USEPA 1996a). In this study, samples were collected at a total of seven locations to assess sediment quality conditions within the Assessment Area, including five stations in the USC and two stations in IH (Figure 4.13). The chemical analyses that were conducted on the whole sediment samples included conventional variables, total metals, PAHs, PCBs, pesticides, butyltins, and dioxins and furans (Appendix 4.2). The concentrations of SEM and pore water metals were also determined in this study. Finally, the toxicity of the sediments was evaluated using a battery of tests utilizing the following test organisms: the midges, *Chironomus riparius* and *Chironomus tentans*; the amphipod, *Hyalella azteca*; the cladoceran, *Daphnia magna*; and *Vibrio spp.*

(i.e., Microtox; Burton *et al.* 1996a; 1996b; Ingersoll *et al.* 1996). Additionally, benthic community assessments were conducted at each station (Canfield *et al.* 1996).

In 1989, the Illinois State Geological Survey conducted an investigation to evaluate the potential environmental impacts associated with dredging activities within the Assessment Area (Risatti and Ross 1989). Sediment samples were collected at a total of 13 sampling stations, of which eight were located in IH/LM, three in the USC, and one in the LGB (Figure 4.14). The sediment samples were collected using a petite ponar grab sampler and analyzed for total metals, total PCBs, total PAHs, and conventional variables (Appendix 4.3). A battery of toxicity tests was also conducted to assess protozoan colonization and community respiration; algal photosynthetic inhibition (with *Selenastrum capricornutum*); nematode growth and development (with *Panagrellus redivivus*); and bacterial response (with *Vibrio*; Microtox). An evaluation of benthic macroinvertebrate community characteristics was also conducted as part of this study. Finally, the concentrations of total metals and PCBs were measured in the tissues of periphyton, plankton, invertebrates (crayfish), and fish collected from four locations within the study area (Appendix 5.6).

In the same year (1989), the Sanitary District of Hammond, Indiana commissioned a study to determine the quantity and quality of sediments in the Hammond portion of the WBGCR (HNTB 1989). The Hammond portion of the river is defined as the reach from White Oak Avenue to the Indiana-Illinois state line (i.e., WBGCR-II). In this study, 10 sediment samples were obtained from sediment cores that were collected at six stations on the river (Figure 4.15). The concentrations of sediment-associated contaminants were measured in the top sediment horizon at all six locations; chemical concentrations were also measured in sub-surface sediments at two of these stations (Appendix 2.13). The chemical contaminants that were measured in these samples principally included total metals, PAHs, PCBs, pesticides, phenols, and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8- TCDD).

As a follow-up to the initial investigation, a second study was conducted for the Sanitary District of Hammond, Indiana to further characterize sediment quantity and quality conditions in the river (HNTB 1990). In this investigation, sediment samples were collected at seven locations on the Illinois portion of WBGCR-II (i.e., from the Indiana - Illinois state line to the confluence with the Little Calumet River; Figure 4.16). The chemical contaminants that were measured in these samples included total metals, PAHs, PCBs, pesticides, phenols, and 2,3,7,8-TCDD (Appendix 2.14).

4.3 Data Collected During the Period, 1990 to Present

In November 1990, the Sanitary District of Hammond, Indiana initiated a third study on the WBGCR to further characterize the quality and quantity of sediments in the system (HNTB 1991). Sediment coring was conducted at six stations in the WBGCR-II (Figure 4.17), with multiple sediment samples obtained from five of the sediment cores (i.e., top, middle, and bottom sediments of each core). These stations corresponded to four of the six stations that were sampled in the preliminary study that was conducted in 1989 (HNTB 1989). While metals were the primary focus of this investigation, limited data on the concentrations of PAHs, pesticides and dioxins in sediments were also generated during this study (Appendix 2.15).

In December of 1990, the Central District Office of the USEPA initiated an investigation of sediment quality conditions in IH and USC (USEPA 1990). In this study, 18 sediment samples were collected from 16 sampling sites to characterize sediment quality conditions in IH. A further 21 sediment samples were obtained from 19 sample sites in the USC (Figure 4.18). The concentrations of total metals, PAHs and cyanide were measured in each of the sediment samples collected during this investigation (Appendix 2.16).

A second investigation was conducted under the ARCS Program in 1990 to evaluate sediment quality conditions in the Assessment Area (USEPA 1996b). In this survey, core samples were collected at 41 locations within the Assessment Area, including seven stations (21 samples) in IHC, five stations (12 samples) in LGB, 19 stations (48 samples) in USC, and ten stations (27 samples) in IH (Figure 4.19). The levels of conventional variables and total metals were measured in each of the 108 sediment samples that were obtained. In addition, the toxicity of sediments was evaluated using the Microtox test (i.e., with *Vibrio fisheri*; Appendix 4.4).

In 1991, U.S. Steel implemented a major study to characterize sediment quality conditions within a portion of the Assessment Area (Floyd-Browne 1993). In this study, a total of 117 sediment samples were collected from 59 sampling stations, with the majority of the sampling effort (35 of 59 stations; 66 sediment samples) conducted on the EBGCR-II between the GCRL culvert (which is located upstream of U.S. Steel permitted outfall 001) to the Industrial Highway (Highway 12) bridge. Another 29 sediment samples were collected from 14 stations on EBGCR-I and three stations (nine samples) were located in the WBGCR-I. Furthermore, 13 sediment samples were collected from seven stations located in the IHC (Figure 4.20). Three sediment horizons were sampled in this study, including 0 to 7.9 feet (65 samples), 8 to 12.9 feet (42 samples), and 13+ feet (10 samples). The chemical composition of each sediment sample was characterized by measuring the levels of conventional variables, total metals, SEM, PAHs, and PCBs (Appendix 2.17 and 2.18).

In November of the same year (1991), the USEPA implemented a sediment quality investigation to further characterize sediment quality conditions in the IH and USC (USEPA 1991). This investigation involved the collection of a total of eight surficial sediment samples from seven locations in IH and a total of 13 samples from 12 locations in the USC (Figure 4.21). As was the case in the 1990 study (USEPA 1990), the chemical analyses conducted on these samples included metals and PAHs (Appendix 2.19). The samples that were collected in this investigation were subsequently re-analyzed to determine the concentrations of arsenic and selenium in sediments (USEPA 1992c).

In the summer of 1992, the USFWS conducted an investigation to assess macroinvertebrate community structure in the WBGCR (Rainbolt 1993; Figure 2.22). A total of six stations were sampled during this investigation, with the sampling stations located at Indianapolis Boulevard on the WBGCR-I, and at Columbia Avenue, Calumet Avenue, and Hohman Avenue on the Indiana side of the WBGCR-II. In addition, one station was located at the railroad bridge crossing near Burham Avenue in Illinois (Figure 4.22). Four multi-plate artificial substrate samplers were deployed at each station to collect macroinvertebrates.

Later the same year (September 1992), USEPA conducted a study to characterize fish communities in the WBGCR (Simon 1993). Seven stations were sampled in this study, with one located in the WBGCR-I, four located in the Indiana portion of the WBGCR-II, and two located in the Illinois portion of the WBGCR. At each station, 500 meters of river was sampled using electroshocking equipment. Fish were identified, counted, and assessed for the presence of DELT abnormalities (deformities, eroded fins, lesions and tumors). The resultant data were used to assess the integrity of the fish community (i.e., using IBI scores). In addition to the fish survey, qualitative habitat evaluations were completed at all seven stations (i.e., to support the determination of QHEI scores).

To support the development of a Remedial Action Plan for the IH Area of Concern, the USACE conducted an investigation of sediment quality conditions in the Grand Calumet

River in 1993 (USACE 1994). While this study was primarily designed to obtain data on the depth of soft, unconsolidated sediments, it also provided information on the concentrations of sediment-associated contaminants in the river system. In total, 18 sediment samples were obtained from four stations located in the USC between Columbus Drive and the junction of the IHC with the LGB (Figure 4.23). At each station, sediment cores were obtained and used to prepare sediment samples that represented various sediment depths. The concentrations of conventional variables, total metals, PCBs, PAHs, and pesticides were determined in each sediment sample (Appendix 2.20).

In the same year (1993), an evaluation of sediment quality conditions was conducted in the WBGCR (Burton 1994; Dorkin 1994). In this study, a total of 61 samples of surficial and sub-surface sediments were collected from seven locations on the WBGCR-II to evaluate the toxicity of sediments on aquatic organisms. The samples were situated at Roxana Marsh (two stations), Molsberger Place, Columbia Avenue, Sohl Avenue, State Line Avenue, and Torrence Avenue (Figure 4.24). One surficial sediment sample from each station was tested using two aquatic species, including the amphipod, *Hyalella azteca*, and the fathead minnow, *Pimephales promelas*. The toxicity tests for both species were 10 days in duration, with survival and growth measured in the fathead minnow elutriate test and survival measured in the whole sediment amphipod test. Chemical characterization of the 61 sediment samples included measurements of conventional variables, total metals and PAHs (Appendix 4.5).

Between 1993 and 1996, the IDEM conducted a series of surveys to assess the status of the benthic macroinvertebrate communities within the Assessment Area (IDEM 2000a; as presented in Simon *et al.* 2000). A total of six locations were sampled in this investigation, including two stations on the WBGCR-II (Indianapolis Boulevard and Sohl Avenue), two stations on the EBGCR-I (Kennedy Avenue and Cline Avenue), one station on the EBGCR-II (Bridge Street), and one station on the USC (Dickey Road; Figure 4.25). At each sampling station, replicate samples were typically obtained for identification of benthic macroinvertebrates.

In response to concerns regarding deteriorating water quality in the EBGCR, the USFWS conducted an assessment of water and sediment quality conditions in 1994 (Sobiech *et al.* 1994). As part of this study, surficial sediments were collected from a total of 10 stations on the EBGCR, which were located between Tennessee Street and the first railroad bridge located upstream of Industrial Highway (ConRail Bridge; Figure 4.26). The toxicity of sediments from each of these locations was evaluated using 10-day survival assays with the amphipod *Hyalella azteca* (Appendix 3.2). The toxicity of overlying water was assessed using 6-day survival and reproduction assays with the cladoceran, *Ceriodaphnia dubia*. In addition to toxicity testing, the status of benthic invertebrate and fish communities was determined at five stations to assess environmental conditions in the river. Artificial substrate samplers were deployed for six weeks at each of the five transect locations to collect macroinvertebrate samples. Fish samples were collected from the same transects but the sampling locations consisted of 500 meter river stretches along the near-shore margins of both river banks. Qualitative evaluations of aquatic and riparian habitats were also conducted in conjunction with this investigation.

Also in 1994, macroinvertebrate and fish samples were collected at 12 stations in the vicinity of the GCRL, including five stations in the West Lagoon, three stations in the Middle Lagoon, two stations in the Little West Pond, and two stations in the Little East Pond (Stewart *et al.* 1999; Figure 4.27). Macroinvertebrate samples were obtained by collecting sweep net samples in the littoral zone among the aquatic vegetation. Fish were collected by electroshocking 100 meter zones at each of the stations in the Middle and West Lagoons. Ten foot long minnow seine nets were used to conduct fish sampling at the stations in the Little East and Little West Pond. At each station, fish were inspected for the presence of DELT abnormalities (deformities, eroded fins, lesions and tumors; Simon and Stewart 1998). In addition, several specimens of carp (*Cyprinus carpio*) were retained for PAH analysis on whole tissue samples (Appendix 5.7).

As part of a companion study (also implemented in 1994), the Lake Michigan Ecological Research Station of the United States Geological Survey (USGS) initiated an investigation of sediment quality conditions in the GCRL (Gillespie *et al.* 1998). As part of this study, 12 surficial sediment samples were collected in the vicinity of an industrial landfill and storage area that contains slag waste and coke piles (Figure 4.28). The data from sampling stations located in the East and West Lagoons were reported in Gillespie *et al.* 1998, while the data from the sampling stations located in the Little East and Little West Ponds were acquired from the FIELDS database, which is administered by USEPA (USDOI 1994). The concentrations of sediment-associated metals were measured in all of these sediment samples; while the concentrations of selected PAHs were determined in three of the samples (Appendix 4.6). Sediments from seven of these locations were tested using three aquatic species, including the amphipod, *Hyalella azteca*, the fathead minnow, *Pimephales promelas* and the cladoceran, *Ceriodaphnia dubia*. The toxicity tests for *C. dubia* were seven days in duration, with survival being the endpoint measured. The assays using *H. azteca* were 20-day tests, in which both survival and growth were measured. The toxicity of whole sediments to fathead minnows was evaluated over 10 days and both survival and growth were measured.

In 1996, the USACE conducted an investigation to evaluate water and sediment quality conditions in the GCRL (USACE 1996). In this study, surficial sediment samples were collected from a total of six sampling stations that were located between the western limit of the Lagoon and a site located roughly 1.5 miles to the east (Figure 4.29). The sampling depth varied among the samples collected, ranging from 0 to 1 feet (grab samples) to 0 to 4 feet (core samples). Water samples were also collected at two of these sampling stations. The concentrations of total metals, PAHs, PCBs, pesticides, VOCs, SVOCs and conventional variables were measured in each of the sediment samples (Appendix 2.21).

In response to environmental concerns regarding a former manufactured gas plant in Hammond, Indiana, the Northern Indiana Public Service Company (NIPSCO) commissioned a Phase I Site Investigation on the WBGCR-II in 1997 (RETEC 1997). This study involved the collection of surface water, ground water, sediment, and soil samples from a number of sites located on WBGCR-II near Hohman Avenue. In total, 16 sediment samples were collected at 12 sites in the vicinity of the former manufactured gas plant, from just east of Hohman Avenue to approximately 50 feet west of the Norfolk and Western railroad bridge (Figure 4.30). The concentrations of total metals, PAHs, PCBs, cyanide, benzene, VOCs and SVOCs were measured in each of these samples (Appendix 2.22). Of the 16 sediment samples that were collected, 14 samples were taken from the 0 to 2 foot or 2 to 4 foot sediment horizons. Two of the samples were taken from the 3 to 5 foot sediment horizon.

In September and October 1997, an evaluation of soil, sediment, water and ground water quality conditions was conducted in the vicinity of the USS Lead Refinery Inc. (USS Lead) site on the EBGCR-I (ENTACT, Inc. 1998). The sampling of all media types was targeted on the former tank area and inlet canal of the site. The samples of the different media types were analyzed for VOCs, SVOCs, total petroleum hydrocarbons, lead, PCBs, total suspended solids, and/or alkalinity (Appendix 2.23). A total of 13 sediment samples were collected from eight different stations on the USS Lead Canal, which is in the vicinity of the EBGCR's confluence with the IHC (Figure 4.31). The sediment samples were taken from 0 to 2 foot cores, 2 to 3.5 foot cores, 2 to 4 foot cores, or 2 to 5 foot cores at each location. To evaluate the reliability of the data that were collected in this sampling program, split sediment samples were prepared for all of the samples that were collected in the ENTACT, Inc. (1998) study (Figure 4.31; TechLaw, Inc. 1998). In addition, one soil split sample and one ground water split sample was prepared to support this quality assurance evaluation. The majority of split samples were analyzed for total metals only, but two samples from the 0 to 2 foot interval and two samples from a > 2 foot interval were analyzed for a wider variety of substances (i.e., total metals, VOCs, SVOCs, tentatively identified compounds, PAHs, PCBs and total petroleum hydrocarbons; Appendix 2.24).

In 1997, the USEPA initiated an investigation to evaluate sediment quality conditions in the GCRL (Simon 2000). As part of this study, a total of 214 samples were collected to determine the extent of chemical contamination in surficial sediments (Figure 4.32). A variety of chemical analytes were measured in these samples, including TOC, nutrients, metals, PCBs, pesticides and various volatile and semi-volatile organic contaminants (Appendix 2.25). Subsequently (i.e., in 1998), 30 of the original 214 sampling stations were re-sampled to further characterize sediment quality conditions. The concentrations of many of the same analytes were determined in the sediment samples that were collected in 1998; however, TOC and metals were not measured in the 1998 samples (Appendix 2.26).

In September 1997, the IDEM collected tissue samples from carp in two general areas within the GCRL, including the West Lagoon (27 samples) and the East Lagoons (which includes the Middle and East Lagoons; 27 samples; IDEM 2000b). Each fish was dissected to obtain skin-off fillet, gastrointestinal tract and whole body samples (i.e., the remainder of the fish). Each sample consisted of a composite of the tissue obtained from five fish for each tissue type. Subsequently, the concentrations of metals, PAHs, Total PCBs, pesticides, and several other chemicals were determined in each composite sample.

Based on the results of the Phase I Site Investigation, a more detailed river sediment investigation was conducted on a portion of the WBGCR-II that is adjacent to the NIPSCO site in 1998 (ThermoRetec 1999). The objectives of this investigation were to further characterize surface water and sediment quality conditions in the vicinity of the former manufactured gas plant, including the distribution of sediment-associated contaminants. As part of this study, four surface water samples, 12 shallow sediment cores (0 to 5 feet deep), and two whole sediment surface grab samples were collected during the sampling program (Figure 4.33). The concentrations of various chemical contaminants (i.e., total metals and PAHs) were measured in the portions of the sediment cores representing 0 to 2 foot, 2 to 4 foot, or 2 to 5 foot depths (i.e., a total of 21 samples; Appendix 4.7). The two grab sediment samples and one sub-surface sediment sample (i.e., 0 to 2 foot depths) were used to evaluate sediment contamination (focusing on total metals, PAHs, VOCs and SVOCs), sediment toxicity, and benthic invertebrate community structure. Sediment toxicity was evaluated with 10-day survival and growth tests using the amphipod, *Hyalella azteca*, and the midge, *Chironomus tentans*.

The USEPA also commissioned a study in 1998 to characterize sediments in the vicinity of Roxana Marsh (WBGCR-II; URS Greiner Woodward Clyde 1999). As part of this study, two water samples and nine sediment samples were collected from a total of three sampling stations in the WBGCR. In addition, four water samples and 10 sediment samples were collected at a total of five locations within Roxana Marsh (Figure 4.34). The surface water grab samples were analyzed for conventional variables, nitrogen-based compounds, and sulfides. Conventional variables, nitrogen-ammonia, and total sulfides were measured in pore water samples. Sediment sampling consisted of the collection of both surficial grab samples and sediment cores, with chemical analyses including conventional variables, total metals, PCBs, PAHs, and pesticides (Appendix 4.8). Toxicity testing with the amphipod, *Hyalella azteca*, and the midge, *Chironomus tentans*, was conducted on six surficial grab samples; however, the midge tests failed based on low survival in the negative control. Information on the status of benthic invertebrate community was also collected at one station on the WBGCR and two stations in Roxana Marsh.

In 1998, the USFWS conducted an investigation to determine the status of benthic invertebrate communities, fish communities, and aquatic habitats at 19 locations in the Assessment Area (Figure 4.35; Simon *et al.* 2000). Of these 19 sampling stations, eight were located on the EBGCR-I, one was located on the WBGCR-I, four were located on the IHC, three were located on the LGB, two were located on the USC, and one was located in IH. Samples for evaluating the status of benthic invertebrate communities and fish communities were collected at 17 stations each. Macroinvertebrate samples were obtained using artificial substrate samplers. Fish samples were obtained at each station by electroshocking 500 meter sections of river along the near-shore margins of both river banks. Information for calculating qualitative habitat evaluation index (QHEI) scores was also collected at these sampling stations.

In November 1998, the IDEM carried out a sediment sampling program within the Assessment Area (IDEM 1998). A total of 14 surficial sediment samples were collected in this study, including six samples from the EBGCR-I, six samples from the IHC, and two from the WBGCR-I (Figure 4.36). Total metals, PAHs, PCBs and phenol were measured in each sediment sample to determine the chemical characteristics of sediments (Appendix 2.27).

In the same year (1998), a study was initiated by DuPont to evaluate sediment quality conditions on EBGCR-I (Exponent 1999). Sediment samples were collected from 33 stations on the EBGCR-I and six stations in nearby wetland areas, primarily in the vicinity of DuPont's East Chicago facility (which is adjacent to the EBGCR and IHC confluence; Figure 4.37). Both surficial grab samples (68 samples) and core samples (25 samples, to a maximum depth of 15 feet) were collected from the EBGCR-I during this investigation. All six of the wetland samples collected were surficial grabs. Chemical characterization of the sediment samples included measuring conventional variables, VOCs, total metals, SEM, AVS, PAHs, PCBs and pesticides (Appendix 2.28).

In December 1998, Tetra Tech EM Inc. (1998) prepared a data validation report for the DuPont study for the USEPA. To support this evaluation, three sediment split samples were obtained during the DuPont sediment characterization study. Two of the samples were taken from the EBGCR-II and one was from a wetland in the vicinity of the DuPont site (Figure 4.37). Two of the samples were analyzed for a variety of chemical compounds (i.e., VOCs, PAHs, pesticides, PCBs, total metals, SEM, and AVS), while the other sample was analyzed for total metals only (Appendix 2.29).

In early 1999, the IDEM commissioned the USACE to characterize the chemical composition of surficial and sub-surface sediments throughout the Assessment Area (Maxim Technologies 1999). In total, 103 samples from 43 stations were collected and analyzed from transects established on EBGCR-I (60 samples), IHC (10 samples), LGB (18 samples), WBGCR-I (nine samples), and GCRL (five samples). Another 24 samples were collected from 18 wetland stations that were located in the vicinity of EBGCR-I (10 samples), IHC (one sample), and LGB (13 samples; Figure 4.38). Cores were taken from the right, center and left bank of the river at each of the 14 transects that were established; a single core was taken at another sampling location. Samples from these cores were taken from the surface layer (0 to 5 feet) and from one to three additional horizons (to a maximum of 15 feet). In addition, surficial sediment grabs were collected from another

16 locations. Each sediment sample was analyzed for total metals, SEM, AVS, PAHs, PCBs, VOCs, pesticides and oil/grease (Appendix 4.9). As part of this study, the USGS (1999) conducted toxicity tests on 28 surficial sediment samples and two sub-surface sediment samples (Figure 4.38). To evaluate the toxicity of whole sediments, 10-day toxicity tests, measuring survival and growth, were conducted on each sediment sample with the amphipod, *Hyalella azteca*. This toxicity assessment also included a characterization of metals in sediment pore water.

In a related sampling effort, USFWS (2000) initiated a study in May 1999 to evaluate the levels of contaminants in sediment-dwelling organisms from the Assessment Area. In total, 11 samples of benthic macroinvertebrates (primarily the bivalve, *Corbicula fluminea*) were collected from various locations within the Assessment Area. The tissues from these organisms were subsequently analyzed to determine the concentrations of various chemicals of concern including metals, PAHs, PCBs, and pesticides (Appendix 5.9).

The IDEM conducted a follow-up sampling program in October 1999 (IDEM 1999). In this study, a total of 34 sediment samples were collected from 16 stations, including eight stations on EBGCR-I (17 samples), one station on EBGCR-II (two samples), three stations on WBGCR-I (seven samples), two stations on IHC (four samples), and two stations on the WBGCR-II (four samples; Figure 4.39). At each station, a surficial sample and a sub-surface sample (i.e., 0 to 4 feet) were collected and analyzed for total metals, PAHs, PCBs, pesticides and a suite of organic chemicals (Appendix 2.30).

5.0 Grand Calumet River Lagoons

Historically, the Grand Calumet River flowed in an easterly direction from southeastern Illinois to its mouth in Lake Michigan. However, the construction of water diversions and associated changes in streamflow resulted in the sediment accumulation at the mouth of the river in the latter half of the 19th century (Simon and Stewart 1998). The Grand Calumet River Lagoons (GCRL) were formed when the mouth of the river was dammed by sediment deposition (Simon and Stewart 1998). Since that time, further modifications have occurred in the watershed such that the direction of streamflows has been reversed and the GCRL now represent the headwaters of the EBGCR (Figure 1.1 and 1.2; USEPA 1985).

In the context of this report, the GCRL comprise three lagoons (the East Lagoon, Middle Lagoon, and the West Lagoon) and two ponds (Little East Pond and Little West Pond; Figure 5.1). The East Lagoon covers an area of roughly eight hectares and is located in the City of Gary's Marquette Park. The Middle Lagoon covers an area of nearly 10 hectares and is largely situated within the Indiana Dunes National Lakeshore; however, the eastern portion of the Middle Lagoon is within the limits of the City of Gary. The East and Middle Lagoons are connected by a channel that is located under the Lake Street Bridge. The West Lagoon covers an area of nearly 15 hectares and is connected to the Middle Lagoon by a shallow stream. Ownership of the shoreline of the Middle Lagoon is divided between the National Parks Service and U.S. Steel. The GCRL are connected to the EBGCR by a buried concrete culvert. The Little East Pond and Little West Pond are located just north of the stream that connects the Middle and West Lagoons. These ponds are hydrologically connected to the lagoons via a highly permeable sand aquifer.

There are a variety of land use activities in the vicinity of the GCRL. While the GCRL have not received any permitted wastewater discharges, the West Lagoon and Little West Pond are located adjacent to an industrial landfill, with portions of the West Lagoon filled with slag and other wastes that are associated with steel manufacturing (Simon and Stewart 1998). As much of the Middle Lagoon is located within a national park (Indiana Dunes National Lakeshore), there are no direct point source contaminant discharges to this water body. One combined sewer overflow is located on the East Lagoon and may release wastewater into this water body during periods of high rain and/or snow melt (Figure 1.3).

The present assessment is intended to evaluate injury to surface water and biological resources in the GCRL that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the GCRL includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the GCRL are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the GCRL are sufficiently contaminated to harm fish and wildlife resources. Sediments in the GCRL were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury was determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support any restoration planning that might be undertaken within the Assessment Area.

5.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

5.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic or bioaccumulative substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 202 surficial sediment samples from the GCRL. The locations where these samples were collected are shown in Figure 5.1. The results of chemical analyses of these samples indicate that many of the surficial sediment samples from the GCRL have been contaminated by toxic substances (Table 5.1). For example, the concentrations of sediment-associated metals exceeded the PECs in 1% to 47% of the samples, depending on the metal that is considered (i.e., 2 of 198 samples for nickel; 84 of 178 samples for arsenic). Total PAH concentrations exceeded the PEC in 19% (37 of 194 samples) of the samples in which these contaminants were measured; the frequency of exceedance of the PECs for individual PAHs ranges from 26% to 100%. Total PCB concentrations exceeded the PEC in 35% of the samples in which these contaminants were quantified (14 of 40 samples). The PECs for certain pesticides (chlordane and DDTs) were also exceeded in a number of the surficial sediment samples from the GCRL.

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the GCRL, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments (i.e., relative to cumulative toxic potential of sediment-associated contaminants). The results of the present evaluation indicate that many of the surficial sediment samples from this reach of the river system (28%; 56 of 202 samples) had mean

PEC-Qs $ 0.7 (Table 5.2; Figures 5.5 and 5.6). USEPA (2000a) reported that sediments with these chemical characteristics were likely to be toxic to amphipods in 28-day toxicity tests (Section 3.1). Of these samples, 32% (i.e., 18 of 56 samples) had mean PEC-Qs $ 4.0, which is the acute toxicity threshold for sediment-dwelling organisms (Section 3.1). Most of the samples that were collected in the GCRL had intermediate levels of chemical contamination (i.e., 113 of 202 samples had mean PEC-Qs $ 0.1 to < 0.7).

Information on the chemical characteristics of 13 sub-surface sediment samples from the GCRL is contained in the project database. The sampling sites where these sediments were collected are shown in Figure 5.2. Although the available sediment chemistry data are limited, it appears that sub-surface sediments in the GCRL have not been broadly contaminated by toxic substances (Table 5.1). Relatively few sediment samples (i.e., between 0% and 8%) had metal concentrations that exceeded the PECs (depending on the metal that is considered). Similarly, only one out of four samples (25%) had total PAH concentrations that exceeded the PEC; the frequency of exceedance of the PECs for the individual PAHs ranged from 0% to 100%. Total PCB concentrations were measured at one sub-surface sediment station, but this value was not included in the analyses because the detection limit exceeded the PEC. None of the pesticides that were quantified in sub-surface sediments had concentrations in excess of the PECs.

Although the available sediment chemistry data are limited, it appears that sub-surface sediment samples in the GCRL have not been broadly contaminated by toxic substances. Overall, only 1 of 13 (8%) of the sub-surface sediment samples that are reflected in the project database had mean PEC-Qs $ 0.7. However, this sample had a mean PEC-Q of 2,560 (Table 5.9; Figures 5.7 and 5.8), indicating that it has very high concentrations of oil and/or other hazardous substances. Sixty-nine percent of the samples collected in the GCRL would be classified as relatively uncontaminated (i.e., mean PEC-Qs < 0.1) based on the mean PEC-Qs that were calculated for these sub-surface sediments. Considering the range of contaminant concentrations that have been measured, it is apparent that insufficient data are currently available to fully characterize the chemical composition of sub-surface sediments from the GCRL. Therefore, further sampling and analysis of sub-surface sediments is recommended within this portion of the study area.

In summary, the available data on the concentrations of chemical substances demonstrates that surficial and, to a lesser extent, sub-surface sediments in the GCRL have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants in surficial sediments are sufficient to injure sediment-dwelling organisms. Therefore, it is concluded that sediments in the GCRL have been injured due to discharges of oil and/or releases of other hazardous substances. In addition, it is concluded that the biological resources that depend on these critical aquatic habitats provided by surficial sediments have been injured due to the presence of oil and/or other hazardous substances (i.e., metals, PAHs, and PCBs).

5.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if releases of oil or discharges of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1). In this report, the available pore water chemistry data were compiled on a reach-specific basis to facilitate assessment of sediment injury.

Information on the chemical composition of pore water from the GCRL sediments has been collected at five locations in the GCRL (USGS 1999). The locations of these sampling stations are shown on Figure 5.1. In all of these samples, the molar concentrations of AVS exceeded the molar concentrations of SEM. As such, pore water metal concentrations would be predicted to remain below the levels that are associated with toxicity to sediment-dwelling organisms (Ankley *et al.* 1996). Accordingly, the concentrations of cadmium, chromium, copper, lead, nickel, zinc, and sum toxic units for metals in pore water from GCRL sediments were all below the levels that have been shown to be toxic to aquatic organisms in 10-day acute toxicity tests (Table 5.3). The sum toxic units for metals in pore water ranged from 0.21 to 0.64 units (Table 5.3). The concentrations of NH_3 (to 0.01 mg/L) in pore water samples were also below the acute toxicity thresholds that have been reported for aquatic invertebrates (CCREM 1987; USEPA 1992a). Therefore, it is concluded that the concentrations of metals and NH_3 in pore water from GCRL sediments are not sufficient to cause or substantially contribute to sediment injury. No information was located on the levels of PAHs or PCBs in pore water from GCRL sediments.

5.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediments, pore water, and/or elutriates provide critical information for assessing the effects on contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured.

Two studies have been conducted to determine if sediments or sediment-elutriates from the GCRL are toxic to sediment-dwelling organisms or other aquatic species (Gillespie *et al.* 1998; USGS 1999). The results of these studies have been used to determine if discharges of oil or releases of other hazardous substances have contaminated sediments in the GCRL to such an extent that they have been rendered toxic to aquatic organisms. Whole sediment toxicity tests have been conducted on a total of 12 sediment samples from the GCRL. The sampling sites that were visited in these studies are shown in Figure 5.3. The species and endpoints that were tested in these studies included amphipod (*Hyalella azteca*) survival and growth, cladoceran (*Ceriodaphnia dubia*) survival, and fathead minnow (*Pimephales promelas*) survival and growth. Overall, 6 of the 12 (50%) of the sediment samples that were collected from the GCRL were shown to be toxic to one or more species (Table 5.4; Figure 5.9). Most of the sediment samples (63%; 5 of 8 samples) taken from the West Lagoon were acutely toxic to aquatic organisms. By comparison, the incidence of sediment toxicity tended to be lower in sediment samples from the Middle and East Lagoons (i.e., 25%; 1 of 4 samples). The results of the studies that have been conducted demonstrate that sediments from the GCRL, particularly the West Lagoon, are acutely toxic to a variety of aquatic organisms, including sediment-dwelling species. Therefore, these results demonstrate that the condition of sediments in the GCRL is sufficient to cause sediment injury, including toxicity to sediment-dwelling organisms.

5.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998). For this reason, the available information on the status of benthic invertebrate communities was assembled and used to determine if discharges of toxic or bioaccumulative substances have caused or substantially contributed to sediment injury in the GCRL.

Few data were located on the status of benthic invertebrate communities in the GCRL. In 1994, however, Stewart *et al.* (1999) collected macroinvertebrates at 12 stations in the vicinity of the GCRL, including five stations in the West Lagoon, three stations in the Middle Lagoon, two stations in the Little West Pond, and two stations in the Little East Pond (Figure 4.27). Macroinvertebrates were obtained at each station by collecting sweep net samples in the littoral zone among the aquatic vegetation. The results of this study indicated that the lowest number of taxa and species diversity were observed at the stations located in the West Lagoon closest to the industrial landfill (Stewart *et al.* 1999). However, the atypical sampling methods used in this survey make it difficult to compare these results to those that have been obtained for other reaches in the Assessment Area (i.e., sampling of invertebrates in littoral vegetation may not provide direct information for evaluating the effects of contaminated sediments on benthic invertebrate communities). Therefore, it is concluded that insufficient data are currently available to determine if benthic invertebrate communities have been altered relative to reference conditions in northern Indiana and Lake Michigan.

5.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, and TOC, can also be used to determine the general status of aquatic habitats and their suitability for supporting aquatic life. For this reason, the available information on conventional indicators of environmental quality conditions (i.e., TOC, quantitative habitat evaluation index scores, visual observations) was compiled and used to assess the status of benthic habitats in the GCRL. This information is important because it provides a context for interpreting the information on the other indicators of sediment quality conditions (e.g., sediment and pore water chemistry, sediment toxicity, and benthic invertebrate community status).

Based on a review of the available data, it is apparent that elevated levels of TOC occur in portions of the GCRL. In surficial sediments, the levels of TOC range from 0.02% to 38.1%, with the highest levels observed in the West Lagoon (Table 5.5). The levels of

TOC in the Middle Lagoon, East Lagoon, Little West Pond, and Little East Pond averaged between 0.9 and 1.4%. By comparison, TOC levels in the West Lagoon averaged 4.1%. The highest levels of TOC in sub-surface sediments were also observed in the West Lagoon, with measured concentrations averaging 8.2% and ranging from 0.1% to 34.1%. By comparison, Lake Michigan sediments in the vicinity of IH had an average level of TOC of 0.5% (n=31); the upper 95% CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b). Based on the measured concentrations of total PAHs (i.e., up to 54.2% by weight) in the West Lagoon, it is likely that oil and oil-related compounds comprise much of the TOC that occurs in GCRL sediments. The levels of oil and grease measured in the GCRL are presented in Table 5.6.

No information was located on the other indicators of the status of aquatic habitats in the GCRL, such as QHEI scores, visual observations, DO, or SOD. Therefore, it is difficult to determine the extent to which the current status of aquatic habitats in the GCRL represent baseline conditions.

5.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the GCRL have been injured by discharges of oil or releases of other hazardous substances. More specifically, the available data show that metals, PAHs, and PCBs occur in GCRL sediments at concentrations that are sufficient to injure sediment-dwelling organisms, particularly in the West Lagoon. Calculated mean PEC-Qs demonstrate that surficial sediment from the GCRL have chemical characteristics that are sufficient to cause toxicity to sediment-dwelling organisms. The results of various sediment toxicity tests confirm sediments from the GCRL are toxic to aquatic organisms. Insufficient data were available for benthic invertebrate communities in the GCRL to fully evaluate the status of these indicators of sediment quality conditions.

5.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g., epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey). These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

5.2.1 Toxicity of Sediments to Fish

The results of a study conducted by Gillespie *et al.* (1998) provide information on the toxicity of GCRL sediments to fish. In this study, sediment samples were collected in 1995 at two locations in the Middle Lagoon and five locations in the West Lagoon to support toxicity testing (Table 5.7). The toxicity tests that were conducted consisted of 10-day and 12-day survival and growth assays on fathead minnows (*Pimephales promelas*). Both whole sediment and elutriate toxicity tests were conducted on these sediment samples. The results of this study showed that whole sediments from the western-most location in the West Lagoon were acutely toxic to fathead minnows (i.e., 100% mortality in 12 hours); sediment elutriates were not tested for this station. Neither survival nor growth was significantly affected (relative to control sites) in the fathead minnows that were exposed to whole sediments or elutriates from the other six stations that were sampled. Therefore, it is concluded that sediments from the western portion of the West Lagoon are toxic to fish and, hence, have been injured.

5.2.2 Fish Health

Simon and Stewart (1998) collected information on the health of fish utilizing habitats in the GCRL during 1994. In this study, fish were collected at 12 stations in the vicinity of the GCRL and used to determine the incidence of abnormalities, which included deformities, eroded fins, lesions, and tumors (DELT abnormalities). Three of the sampling stations were located in the Middle Lagoon, five stations were located in the West Lagoon, and two stations were located in each the Little East Pond and the Little West Pond. In total, 17 species of fish were collected during this study. Examination of the fish that were obtained during the sampling program indicated that the frequency of DELT abnormalities was low (i.e., 0%) at all of the sampling locations. Therefore, it is concluded that fish health has not been adversely affected by ambient aquatic environmental quality conditions in the GCRL, based on measurements of DELT abnormalities.

5.2.3 Status of Fish Communities

The results of surveys of the status of fish communities also provide relevant information for evaluating environmental quality in the EBGCR-I. Simon *et al.* (2000) reported the results of fish community surveys that were conducted between 1985 and 1990 (i.e., using the IBI as the primary tool for assessing the integrity of fish communities). Based on the results of one survey, fish communities in this reach would be classified as having "poor" integrity (IBI score = 32; Table 14.9).

In 1994, a survey was conducted to evaluate the status of fish communities in the GCRL (Simon and Stewart 1998; Stewart *et al.* 1999). In this study, fish were collected from a total of 12 locations in the GCRL, including three stations located in the Middle Lagoon, five stations in the West Lagoon, and two stations each in the Little East Pond and Little West Pond (Figure 5.4). The status of fish communities in the GCRL was evaluated using an IBI that was originally developed by Karr (1981) and was subsequently calibrated for use in Indiana (Simon and Stewart 1998). Based on the IBI scores that were calculated for the various reach segments within the GCRL, fish community function was considered to range from "fair" to "poor" (Simon and Stewart 1998). The highest IBI scores were calculated for the Middle Lagoon (42), Little East Pond (43), and Little West Pond (42). By comparison, IBI scores were relatively lower in the West Lagoon, ranging from 31 to 38 (Stewart *et al.* 1999). The total number of fish species, the number of darter and madtom species, and number of sensitive fish species were lower in the West Lagoon compared to the Middle Lagoon. In addition, the number of minnow species and insensitive species were higher in the West Lagoon. Together, these data indicate that fish community function throughout the GCRL has been degraded relative to reference conditions in northwest Indiana, particularly in the West Lagoon. Nevertheless, the IBI scores that were recorded for the GCRL were the highest that have been reported in the Assessment Area. In particular, the status of the fish community in the Middle Lagoons provides a sense of what could be achieved in the Assessment Area in the absence of elevated levels of chemical contamination.

5.2.4 Bioaccumulation of Sediment-Associated Contaminants

In this report, bioaccumulation-based SQGs have been used to assess the significance of sediment-associated contaminants of concern to piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey; NYSDEC 1994). Based on the whole sediment chemistry data that have been collected in the GCRL, it is apparent that a variety of bioaccumulative substances are present in surficial sediments at concentrations that pose potential hazards to wildlife species utilizing the GCRL (Table 5.1). Specifically, the concentrations of total PCBs (29 of 29 samples), chlordane (14 of 14 samples), total DDTs (20 of 33 samples), and endrin (1 of 22 samples) in surficial sediments exceeded the levels that have been established to protect piscivorus wildlife species (Table 3.3). Therefore, it is likely that these substances would occur in fish tissues at concentrations that are sufficient to pose a hazard to piscivorus wildlife species. Insufficient data are available to evaluate the extent to which the concentrations of bioaccumulative substances exceed the bioaccumulation-based SQGs in sub-surface sediments.

Comparison of tissue residue levels to fish flesh criteria for the protection of wildlife provides a means of confirming that bioaccumulation in fish and/or invertebrate tissues represents a hazard to wildlife species. Recently, the IDEM collected carp from two general areas within the GCRL, including the West Lagoon and the East Lagoons (Appendix 5.8; IDEM 2000b). Subsequently, the concentrations of metals, PAHs, total PCBs, pesticides, and several other chemicals were determined in three types of tissues, including fillets (i.e., skin off), whole body (i.e., head, gills, bones and attached flesh, without fillets or gastrointestinal tract), and the gastrointestinal tract (i.e., organs in body cavity, post-gills). In addition to the IDEM data, Stewart *et al.* (1999) measured PAH levels in tissues from carp from the GCRL. The available tissue chemistry data were compared to the TRGs for the protection of piscivorus wildlife (Newell *et al.* 1987; i.e., for PCBs and organochlorine pesticides) to determine if tissue residues in GCRL fish pose a hazard to piscivorus wildlife species.

The available tissue chemistry indicates that a variety of chemicals have accumulated in the tissues of fish from the GCRL (Table 5.8). Among the three tissue types tested, the highest concentrations of metals tended to be observed in the organs of the body cavity (i.e., samples of the gastrointestinal tract). In contrast, the highest levels of PAHs tended to be observed in the whole body samples. Tissues residue guidelines for the protection of piscivorus wildlife were not available for metals or PAHs; therefore, it was not possible to evaluate hazards to piscivorus wildlife associated with exposure to these classes of chemicals due to the consumption of fish tissues. The concentrations of total PCBs in whole carp ranged from 570 to 14,000 µg/kg wet weight (WW; n=18), consistently exceeding the TRG of 110 µg/kg WW (i.e., in 17 of 18 fillet samples, 18 of 18 whole fish samples and 18 of 18 gastrointestinal tract samples). This TRG corresponds to a 1 in 100 cancer risk level for piscivorus wildlife species and is similarly to the TRG that is recommended to protect against reproductive impairment in birds (110 µg/kg WW) and mammals (130 µg/kg WW; Newell *et al.* 1987). While the measured concentrations of chlordane did not exceed the TRGs in carp tissues, the levels of total DDTs exceeded the TRG (200 µg/kg WW) in several of the whole body tissue samples (i.e., 4 of 10 samples), all of which were from the East Lagoon. Therefore, it is concluded that total PCBs and DDTs in fish tissues pose an unacceptable hazard to piscivorus wildlife utilizing habitats in the GCRL.

5.2.5 Summary

Based on the information that was evaluated to support this assessment of sediment injury, it is likely that contaminated sediments pose substantial hazards to wildlife in the GCRL. First, the available data suggest that macroinvertebrate communities may have been altered in the West Lagoon, potentially influencing the abundance of preferred fish food organisms in this river reach. Second, GCRL sediments have been shown to be acutely toxic to fish. Fish populations were also depressed in the West Lagoon relative to the Middle Lagoon, as indicated by lower catch-per-unit-effort and lower IBI scores. Furthermore, the concentrations of several substances in sediments are sufficient to cause hazardous levels of bioaccumulation in the tissues of benthic macroinvertebrates and fish. Measured concentrations of contaminants in the tissues of fish confirm that various sediment-associated contaminants have accumulated to levels that pose hazards to piscivorus wildlife species (e.g., herons, kingfishers, otter, mink or osprey). Therefore, it is concluded that injured sediments in the GCRL are adversely affecting fish and wildlife resources utilizing habitats within this reach of the Assessment Area.

5.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in GCRL sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of this report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially-contributing to effects on sediment-dwelling organisms) were identified from the list of chemicals of concern by comparing measured concentrations in whole sediments to the PECs (Table 5.1). The chemicals that occurred in GCRL sediments at concentrations in excess of these chemical benchmarks were identified as contaminants of concern. The results of this evaluation indicate that metals (i.e., arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), PAHs (i.e., $ 12 individual PAHs and total PAHs), and total PCBs, are present in both surficial and/or sub-surface sediments from the GCRL at concentrations that are sufficient to harm sediment-dwelling organisms. The concentrations of these contaminants tend to be lower in sub-surface sediments than they are in surficial sediments. Importantly, the concentrations of cadmium, chromium, copper, nickel, lead, and zinc also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments. Several pesticides also occurred in the GCRL sediments at levels in excess of the consensus-based PECs. The levels of metals and ammonia in pore water did not exceed toxicity thresholds. Therefore, it is concluded that the toxic contaminants of concern in GCRL sediments are metals, PAHs and PCBs.

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 5.1); and, (2) measured contaminant concentrations in tissues to the TRGs for the protection of piscivorus wildlife. The results of this evaluation indicate that total PCBs occurred in surficial sediments at concentrations that are sufficient to cause or substantially contribute to adverse effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). Various pesticides (chlordane, total DDTs, and endrin) also occurred in surficial sediments at concentrations in excess of the bioaccumulation-based SQGs. Insufficient data were available on the chemical composition of sub-surface sediments to identify bioaccumulative contaminants of concern. Information on contaminant residues in fish tissues confirms that PCBs represent the bioaccumulative contaminant of concern in the GCRL. Tissue residue guidelines were not available for metals or PAHs; therefore, it was not possible to evaluate hazards to piscivorus wildlife associated with exposure to these classes of chemicals due to the consumption of fish tissues.

All of these contaminants of concern frequently exceed the chemical benchmarks in GCRL sediments. Of the contaminants of concern that were identified in the Assessment Area, the frequency of exceedance of the PECs was highest for arsenic, chromium, lead, various individual PAHs, total PAHs, and total PCBs. The highest frequencies of exceedance of the bioaccumulation-based SQGs were observed for total PCBs, chlordane, and total DDTs. The concentrations of the contaminants of concern in GCRL sediments frequently exceeded the chemical benchmarks by substantial margins, in some samples by more than a factor of 100. Therefore, arsenic, chromium, lead, PAHs and PCBs occur in whole sediments at concentrations in excess of the levels that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and/or adversely affect fish and wildlife resources in the GCRL.

5.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury was determined by merging the various data sets that provided information on contaminant concentrations in GCRL sediments. To support an evaluation of the spatial distribution of contaminants of concern, mean PEC-quotients were calculated for each of the sediment samples that were obtained from the GCRL. The extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (each sampling station in the GCRL was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial (Figure 5.6) and sub-surface (Figure 5.8) sediments separately.

Based on the sediment chemistry data that have been collected to date, it is apparent that surficial sediments throughout portions of the GCRL have been contaminated by oil or hazardous substances. Sediment chemistry data were compiled for a total of 202 surficial sediment samples that were collected within the GCRL. Of these samples, 28% (i.e., 56 samples) had mean PEC-Qs $ 0.7 (Table 5.2; Figure 5.5). The mean PEC-Qs for these samples ranged from 0.056 to 23,800 (Table 5.9). Sediments from the West Lagoon, which is located adjacent to the U.S. Steel Gary Works facility, had the highest mean PEC-Qs; more than half (53%) of the sediment samples from this reach segment had mean PEC-Qs $ 0.7 (Table 5.2). By comparison, 18% and 30% of the sediment samples from the Middle Lagoon and East Lagoon, respectively, had mean PEC-Qs $ 0.7 (Table 5.2). The levels of contamination in surficial sediments were generally lower in the Little East Pond and Little West Pond.

Although the available data are limited, sub-surface sediments exhibited a similar pattern of contamination as the surficial sediments (Figure 5.7). That is, sub-surface sediments from the West Lagoon had the highest levels of contamination, with mean PEC-Qs as high as 2,560 reported in this portion of the GCRL. This value is 640 times the level that would result in a 50% probability of observing toxicity in 10-day tests and up to 3,660 times the level that would result in a 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca* (USEPA 2000a). Sub-surface sediments from the Middle Lagoon, Little West Pond, and Little East Pond had much lower levels of contamination, with maximum mean PEC-Qs of 0.17 reported for these reach segments. No data were located on the levels of contaminants in sub-surface sediments from the East Lagoon.

It is concluded that surficial and sub-surface sediments from the West Lagoon and surficial sediments from the Middle and East Lagoon are sufficiently contaminated with oil or other hazardous substances to cause or substantially contribute to sediment injury. The results of sediment toxicity tests conducted using GCRL sediments confirm that sediments from the West Lagoon and, to a lesser extent the Middle Lagoon, are toxic to aquatic organisms (Table 5.4; Figure 5.9). Based on multiple lines of evidence, it is apparent that both surficial and sub-surface sediments from the West Lagoon and surficial sediments from the Middle Lagoon have been injured by discharges of oil or releases of other hazardous substances. Both surficial and sub-surface sediments are sufficiently contaminated to cause or substantially contribute to sediment injury.

5.5 Summary

Information on a variety of indicators of sediment quality conditions was reviewed to assess sediment injury in the GCRL. The results of this assessment indicated that whole sediments and pore water from the GCRL are sufficiently contaminated to adversely affect sediment-dwelling organisms and fish and wildlife resources. In addition, the results of whole sediment and elutriate toxicity tests confirm that GCRL sediments are toxic to sediment-dwelling organisms and fish. While fish communities in the GCRL are among the healthiest in the GCR basin, these communities are impaired relative to reference areas in northwestern Indiana, suggesting that contaminated sediments and related factors are adversely affecting fish in this area. Finally, information on the levels of contaminants in fish tissues confirms that piscivorus wildlife utilizing habitats in the GCRL are at risk. Therefore, it is concluded that both surficial and sub-surface sediments in the GCRL are sufficiently contaminated with oil and/or other hazardous substances to cause or substantially contribute to sediment injury. Surficial and sub-surface sediments in the West Lagoon and surficial sediments in the Middle and East Lagoons pose the greatest hazards to biological resources in the GCRL.

6.0 East Branch of the Grand Calumet River - I

The EBGCR flows some 10 miles from the outlet of the GCRL to the confluence of the WBGCR and IHC in northwest Indiana. For the purposes of conducting this assessment of sediment injury, the EBGCR has been divided into two reaches, including the EBGCR-I and the EBGCR-II (Figure 1.1 and 1.2). The EBGCR-I extends some five miles from the ConRail Bridge (which is the first railway bridge located upstream of Industrial Highway, also known as Highway 12) to the confluence with the WBGCR. The EBGCR-II extends from the GCRL (i.e., the culvert that connects the GCRL to the EBGCR) to the ConRail Bridge, a distance of roughly five miles. This section of the report provides an assessment of sediment injury in the EBGCR-I. The assessment of sediment injury in the EBGCR-II is presented in Section 7.0 of this report.

There are a number of potential sources of contaminants to the EBGCR-I. First, there are a variety of industrial facilities that discharge or have historically discharged wastewater into the river via NPDES permitted outfalls, including AMG Resources Corporation, Citgo Petroleum Corporation-E Chicago, E.I. du Pont de Nemours and Company, USS Lead, Harbison-Walker Refractories, and the 9th Avenue Dump Superfund Site. Shell Oil Company, Equilon Enterprises, East Chicago and Citgo Petroleum Corporation also have facilities nearby but have not reported the locations of their discharge points. In addition, the Gary Sanitary District currently operates four NPDES permitted outfalls through which treated municipal wastewater is discharged into the EBGCR-I; a fifth outfall is no longer being used. The Hammond Municipal STP also has an NPDES permitted outfall (i.e., CSO) at Kennedy Avenue. Furthermore, significant amounts of ammonia are produced from existing (and former) coke ovens, sinter plants and blast furnace operations that are part of the integrated steel manufacturing plants located upstream of the EBGCR-I. Other potential contaminant sources include discharges of contaminated groundwater and/or over-land runoff from various industrial facilities, leachate from a landfill located nearby the river, and leaky pipeline crossings. Downstream transport of contaminated water and/or sediments from upstream areas also represents a potential contaminant source in this reach of the Assessment Area.

The present assessment is intended to evaluate injury to surface water and biological resources in the GCRL that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the EBGCR-I includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the EBGCR-I are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the EBGCR-I are sufficiently contaminated to harm fish and wildlife resources. Sediments in the EBGCR-I were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury was determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support restoration planning within the Assessment Area.

6.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

6.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise, evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 162 surficial sediment samples from the EBGCR-I. The locations where these samples were collected are shown in Figure 6.1. The results of chemical analyses of these samples indicate that a substantial proportion of surficial sediments in the EBGCR-I have been contaminated by toxic substances (Table 6.1). For example, the concentrations of sediment-associated metals exceeded the PECs in up to 88% of the samples, depending on the metal under consideration (e.g., 112 of 128 samples for zinc). Total PAH concentrations exceeded the PEC in 81% of the samples in which these contaminants were measured (i.e., 79 of 98 samples); the frequency of exceedance of the PECs for individual PAHs ranged from 80% to 100%. The concentrations of total PCBs also exceeded the PEC in most of the samples in which these contaminants were quantified (83%; 83 of 100 samples).

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the EBGCR-I, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments. The results of the present evaluation indicate that 91% (148 of 162 samples) of the surficial sediment samples from this reach of the river had mean PEC-Qs ≥ 0.7 (Table 6.2; Figure 6.6 and 6.7). USEPA (2000a) reported that sediments with these chemical characteristics were likely to be toxic to amphipods in 28-day toxicity tests. Of these samples, 59% (i.e., 88 of 148 samples) had mean PEC-Qs ≥ 4.0, which is the acute toxicity threshold for amphipods (USEPA 2000a). A total of 13 samples had mean PEC-Qs ≥ 0.1 to < 0.7 (i.e., 8% of the samples), while only one sample had a mean PEC-Q of < 0.1 (i.e., 0.6% of the samples).

Information on the chemical characteristics of 107 sub-surface sediment samples from the EBGCR-I is contained in the project database. The sampling sites where these sediments were collected are shown in Figure 6.2. Evaluation of the available sediment chemistry data indicates that sub-surface sediments in the EBGCR-I have also been contaminated by toxic substances, but not to the same extent as surficial sediments (Table 6.1). Relatively fewer sediment samples (i.e., up to 65%) had metal concentrations that exceeded the PECs (depending on the metal that is considered). Most of these samples had concentrations of total PAHs (52%; 33 of 63 samples) and total PCBs (56%; 22 of 39 samples) that exceeded the PECs.

Based on the mean PEC-Qs that were calculated, it is apparent that sub-surface sediment samples in the EBGCR-I have been contaminated by toxic substances. Overall, 75 of the 107 (70%) sub-surface sediment samples that are reflected in the project database have mean PEC-Qs ≥ 0.7, thereby classifying them as injured. Of these, 57% of the samples (43 of 75 samples) had mean PEC-Qs ≥ 4.0 (Table 6.2; Figure 6.8 and 6.9). A total of 22 samples (21%) had mean PEC-Qs ≥ 0.1 to < 0.7, while only 10 samples (9%) had mean PEC-Qs < 0.1.

In summary, the available data on the concentrations of chemical substances demonstrates that both surficial and sub-surface sediments in the EBGCR-I have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants, in both surficial and sub-surface sediments, are sufficient to injure sediment-dwelling organisms. Therefore, it is concluded that sediments in the EBGCR-I have been injured due to discharges of oil or releases of other hazardous substances. In addition, it is concluded that the sediment-dwelling organisms that depend on the critical aquatic habitats provided by sediments have been injured due to the presence of toxic substances (i.e., metals, PAHs, and PCBs).

6.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1).

Information from two studies is available to characterize the chemical composition of pore water from the EBGCR-I sediments (Hoke *et al.* 1993; USGS 1999). In the first investigation, Hoke *et al.* (1993) collected sediment samples from four stations on the

EBGCR-I to determine the concentrations of various contaminants in pore water (Figure 4.11). These sampling stations were located near Clark Street, upstream of Cline Avenue, downstream of Cline Avenue, and upstream of the confluence with the WBGCR. Evaluation of the results of this study using the toxic units approach indicated that the concentrations of cadmium, copper, lead, zinc and the sum toxic units for metals in pore water from EBGCR-I sediments equaled or exceeded the concentrations that have been shown to be toxic to aquatic organisms in 10-day acute toxicity tests. The sum toxic units for metals in pore water ranged from 0.59 to 6.91 units among the four samples for which pore water chemistry data are available (Table 6.3). The concentrations of metals were sufficient to cause or substantially contribute to sediment toxicity in three of these samples. The detection limit that was reported for cadmium was too high to be able to interpret the chemistry data relative to the published 10-day LC_{50} for *Hyalella azteca* (USEPA 1994; 2000b). In addition to metals, phenol (27.8 to 257 mg/L) and unionized ammonia (0.5 to 5.3 mg/L) were present in pore water samples at concentrations above the acute toxicity thresholds that have been reported for aquatic invertebrates (Table 6.3).

More recently, USGS (1999) obtained 16 sediment samples from 15 sampling stations in EBGCR-I and associated wetlands to support the preparation of samples of pore water for chemical analysis. The concentrations of metals and unionized ammonia were determined in most of these pore water samples. Based on the results of these analyses, it is apparent that pore water throughout much of the EBGCR-I have been contaminated by oil or other hazardous substances. More specifically, seven of the 16 samples that were collected had levels of metals that are sufficient to cause or substantially contribute to toxicity to amphipods in 10-day toxicity tests (Table 6.3). Cadmium, copper, lead, zinc, and sum toxic units were all reported in pore water at concentrations in excess of acute toxicity thresholds (USEPA 1994; 2000b) in one or more samples. In addition, the concentration of unionized ammonia exceeded the toxicity threshold for aquatic invertebrates in a sample that was collected upstream of Cline Avenue.

Data on the concentrations of SEM and AVS in sediments provides additional information for interpreting the pore water chemistry data. Specifically, Ankley *et al.* (1996) reported that sediments with molar concentrations of AVS in excess of the molar concentrations of SEM had pore water metal levels below the concentration that were predicted to cause toxicity. In sediments from the EBGCR-I and associated wetlands nearly 50% of the samples (i.e., 51 of 105) had SEM > AVS. These data indicate that pore water metal concentrations could be elevated in these sediments (i.e., above toxicity thresholds).

Hence, the available SEM and AVS data confirm that metals are present in pore water at levels that are predicted to be toxic to sediment-dwelling organisms.

The available data on the concentrations of metals, phenols, and ammonia in pore water indicate that EBGCR-I sediments have been contaminated by oil or other hazardous substances. Comparison of these data to acute toxicity thresholds for amphipods and other aquatic invertebrates demonstrates that the concentrations of these contaminants in pore water are sufficient to cause or substantially contribute to toxicity to sediment-dwelling organisms. The results of acute toxicity tests conducted with pore water from EBGCR-I sediments support the conclusion that contaminant concentrations in pore water were sufficiently elevated to cause or substantially contribute to toxicity to crustaceans and bacteria (Hoke *et al.* 1993). Therefore, it is concluded that EBGCR-I sediments have been injured due to the presence of oil or other hazardous substances in pore water. In addition, it is concluded that the sediment-dwelling organisms that depend on habitats provided by surficial sediments have been injured due to the presence of toxic substances in pore water.

6.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediment, pore water, and/or elutriates provide critical information for assessing the effects of contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured by discharges of oil or releases of other hazardous substances.

In the EBGCR-I, four studies have been conducted to determine if sediments or associated pore waters are toxic to sediment-dwelling organisms or other aquatic organisms (Figure 6.3). In total, data are available on the toxicity of 44 sediment samples from the EBGCR-I. The species and endpoints that were tested in these studies included amphipod (*Hyalella azteca*) survival and growth, midge (*Chironomus tentans*) growth, cladoceran (*Daphnia magna* and *Ceriodaphnia dubia*) survival, fathead minnow (*Pimephales promelas*) survival, and bacterial (*Vibrio fisheri*) bioluminescence (i.e., as a surrogate for metabolic rate). Overall, 32 of the 44 (73%) sediment samples that were collected from the EBGCR-I were shown to be toxic to one or more of these species (Table 6.4; Figure 6.10). While sediments from the EBGCR-I would likely have been toxic more frequently had longer term tests (including sublethal endpoints) been employed, the results of the studies that have been conducted demonstrate that sediments from the EBGCR-I are acutely toxic to a variety of aquatic organisms, including sediment-dwelling species. Therefore, these results demonstrate that the condition of sediments and associated pore waters in the EBGCR-I is sufficient to injure sediments and associated organisms, including sediment-dwelling species.

6.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998). For this reason, the available information on the status of benthic invertebrate communities was assembled and used to determine if discharges of oil or releases of other hazardous substances have caused or substantially contributed to sediment injury in the EBGCR-I.

Four surveys have been conducted to evaluate the status of benthic invertebrate communities in the EBGCR-I (Table 6.5; Figure 6.4; Polls *et al.* 1993; Sobiech *et al.* 1994; IDEM 2000a as presented in Simon *et al.* 2000). The results of these surveys generally demonstrate that the benthic invertebrate community in the EBGCR-I has been degraded relative to uncontaminated sites in northern Indiana. For example, (Polls *et al.* 1993) conducted benthic surveys, using grab samplers, at two locations in the EBGCR-I (i.e., one located downstream of Kennedy Avenue and one located upstream of Industrial Highway) in 1982 and again in 1986 to assess temporal trends in benthic invertebrate community status. At the station located upstream of Industrial Highway, the benthic invertebrate community was dominated by pollution-tolerant species in both years. Oligochaetes (worms) represented between 78% and 97% of the community over this period, with leeches, midges, and mollusks also observed (Table 6.6). Similarly, oligochaetes comprised 98% to 99% of the benthic invertebrate community at the station located downstream of Kennedy Avenue (Polls *et al.* 1993). More sensitive species, such as amphipods and caddisflies, were not observed at either of the sampling stations in either year. Polls *et al.* (1993) concluded that benthic community structure in the EBGCR-I remained poor from 1982 to 1986, as compared to other locations sampled in northern Indiana and in Lake Michigan. At both stations, the relative abundance of oligochaetes exceeded the upper limit of the range of normal conditions in this Assessment Area (i.e., 3.0% to 73.6% for oligochaetes).

In 1994, Sobiech *et al.* (1994) deployed artificial substrates at five locations in the EBGCR, with one of these stations located in the EBGCR-I (i.e., upstream of Industrial Highway). The results of the Sobiech *et al.* (1994) investigation indicated that the benthic invertebrate community that colonized artificial substrates in the EBGCR-I was dominated by midges (i.e., representing 89% of the organisms that were collected), with leeches, oligochaetes, and mollusks also present (Table 6.5). None of the EPT taxa (i.e., mayflies, stoneflies, and caddisflies) were observed on the artificial substrates that were deployed at this station, indicating that conditions were sufficient to injure sediment-dwelling organisms (i.e., EPT represented 0.5% of the total abundance of invertebrates, the threshold for altered communities).

More recently (i.e., 1996), the IDEM collected information on the status of benthic invertebrate communities at two locations on the EBGCR-I using artificial substrates, including one station near Cline Avenue and one station near Kennedy Avenue (IDEM 2000a; as presented in Simon *et al.* 2000). The results of this investigation indicated that pollution-tolerant species, such as oligochaetes and chironomids, dominated the benthic invertebrate community at both locations, collectively representing 67% and 68% of the total abundance of macroinvertebrates at the Cline Avenue and Kennedy Avenue stations, respectively (Table 6.5). While gastropod and bivalve mollusks were relatively abundant at both locations, none of the pollution-sensitive EPT taxa were observed at these stations. Macroinvertebrate IBI (mIBI) scores ranged from 2.1 to 2.4 at these sampling stations, indicating that the benthic invertebrate community was degraded relative other locations in Indiana (i.e., # 2.93; the average mIBI score for Indiana is in the order of 3.5 ± 0.29; Simon *et al.* 2000).

In 1998, Simon *et al.* (2000) used artificial substrates to evaluate the status of the benthic macroinvertebrate community at six locations in the EBGCR-I (Figure 6.4). As was the case in previous investigations, the benthic macroinvertebrate community at all six stations was dominated by oligochaetes and chironomids. These pollution-sensitive taxa represent from 75% to 98% of the total number of benthic invertebrates that were collected at these stations (Table 6.5). Mollusks represented up to 21% of the organisms that were collected at these stations, while the EPT taxa represented < 0.5% of the total abundance of benthic macroinvertebrates. The mIBI score for these samples ranged from 0.87 to 1.67. The low mIBI score and low abundance of EPT taxa indicate that the structure of benthic invertebrate communities was significantly altered in all of these stations relative to other locations in Indiana.

Collectively, the data that have been collected on the status of benthic invertebrate communities indicate that conditions in the EBGCR-I have improved somewhat since 1982 (i.e., as indicated by the nominal presence of EPT taxa and the increased abundance of gastropod mollusks). Nevertheless, the results of these four surveys indicate that benthic invertebrate communities have been altered at all 14 stations (Table 6.5) in the EBGCR-I, relative to reference conditions in northern Indiana and Lake Michigan (i.e., the range of normal conditions for the mIBI scores and the abundance of oligochaetes and EPT taxa; Section 3.1.1). Impacts on sediment-dwelling organisms, as indicated by altered benthic invertebrate communities, are particularly important because invertebrates represent important food sources for fish and other wildlife species that utilize habitats in the EBGCR-I. Therefore, the results of these surveys provide confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that the environmental quality conditions in the EBGCR-I are sufficient to injure sediments and associated sediment-dwelling organisms.

6.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, TOC, and NH_3 can be used to determine the general status of aquatic habitats and their suitability for supporting aquatic life. Little information was located on the levels of DO or SOD in the EBGCR-I; therefore, it was not possible to evaluate sediment quality conditions relative to these conventional indicators.

The available information indicates that the levels of TOC are elevated throughout the EBGCR-I. In surficial sediments, the levels of TOC ranged from 0.32% to 15.9%, with the highest levels observed downstream of Kennedy Avenue (i.e., near the confluence with the WBGCR). Wetlands in the vicinity of the EBGCR-I had similar levels of TOC in surficial sediments, ranging from 0.17% to 14% (Table 6.6). Sub-surface sediments generally had lower levels of TOC than did surficial sediments. Overall, TOC levels ranged from 0.14% to 14% in sub-surface sediments. By comparison, Lake Michigan sediments in the vicinity of IH had an average level of TOC of 0.5% (n=31); the upper

95% CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b). Therefore, both surficial and sub-surface sediments in the EBGCR-I have received substantial inputs of organic matter relative to other contaminated sites in the Great Lakes basin.

Information on the concentrations of oil and grease in EBGCR-I sediments indicates that much of the TOC in EBGCR-I sediments is present in the form of oil and oil-related compounds. In surficial sediments, oil and grease concentrations ranged from 500 to 147,000 mg/kg (i.e., 0.05% to 14.7%; Table 6.7), averaging 2.9%. Somewhat lower levels of oil and grease have been reported in sub-surface sediments, ranging as high as 9.4% in the EBGCR-I. As such, oil and grease represent, on average, more than 50% of the TOC that is present in both surficial and sub-surface sediments.

In aquatic ecosystems, ammonia is excreted by aquatic organisms, formed during the decomposition of biological tissues and nitrogen-containing wastes, or released from anthropogenic sources. There are a variety of anthropogenic sources of ammonia, such as municipal and industrial wastewater discharges. Free ammonia can be present either as NH_3 or as NH_4^+ (depending on pH and temperature). Unionized ammonia (NH_3) is very toxic to aquatic life, with lethal thresholds as low as 0.1 mg/L reported in the literature (Thurston and Russo 1983; Thurston and Meyn 1984; Thurston *et al.* 1984). In the EBGCR-I, the concentrations of NH_3 in pore water ranged from < 0.01 to 6.61 mg/L (Table 6.3). Of the 20 pore samples in which NH_3 levels were measured, four had concentrations that exceeded the acute toxicity threshold for aquatic invertebrates (0.53 mg/L; CCREM 1987). Therefore, the concentrations of NH_3 in pore water were sufficient to cause or substantially contribute to injury to sediment-dwelling organisms in the EBGCR-I.

In 1994, Sobeich *et al.* (1994) evaluated the status of aquatic habitats at one station in the EBGCR-I. Simon *et al.* (2000) evaluated an additional nine stations in 1998. In these investigations, data were collected on the characteristics of bottom substrates, instream cover, channel morphology, riparian zone and bank erosion, pool and riffle quality, and gradient at each sampling location. These data were then compiled to support the calculation of QHEI scores for each sampling location. The QHEI score was 4.8 at the one station Sobeich *et al.* (1994) evaluated. The results of the Simon *et al.* (2000) study showed that QHEI scores averaged 44.7 and ranged from 39.5 to 48.8 in the EBGCR-I. By comparison, OEPA (1988) reported that mean (± SD) QHEI scores for rivers and streams in the Eastern corn belt plains (ECBPs) eco-region was 74 (± 13.1), with the lower limit of the normal range of QHEI scores being 48. Eighty percent (8 of 10) of the QHEI scores reported for this reach were outside the normal range of QHEI scores for the ECBPs eco-region (i.e., normal range is 48 to 100; OEPA 1988). Additionally, the IDEM (2000c) has established use support assessment criteria for streams in Indiana. These criteria indicated that use impairment is likely to occur when QHEI scores are < 64. Therefore, aquatic habitats in the EBGCR-I were considered to be degraded relative to unimpacted sites in the ECBPs.

In summary, the available information indicates that aquatic habitats have been degraded in the EBGCR-I. In addition, the levels of TOC and associated oil and oil-related compounds are elevated in EBGCR-I sediments, even compared to other Areas of Concern in the Great Lakes. Furthermore, the levels of NH_3 in pore water from EBGCR-I sediments are sufficient to injure sediment-dwelling organisms. Therefore, the available information on conventional indicators of sediment quality conditions indicates that sediments in the EBGCR-I have been injured due to discharges of oil or releases of other hazardous substances.

6.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the EBGCR-I have been injured by discharges of oil or releases of other hazardous substances. More specifically, the data show that metals, PAHs, and PCBs occur in whole sediments at concentrations that are sufficient to injure sediment-dwelling organisms. Calculated mean PEC-Qs exceed, often by a wide margin, the levels that are sufficient to injure sediment-dwelling organisms. The levels of metals, unionized ammonia, and phenol in pore water are also sufficient to cause toxicity to aquatic organisms. In addition, the results of toxicity tests confirm that whole sediments, pore water, and elutriates are toxic to aquatic organisms. That benthic invertebrate communities in this reach of the river are significantly altered relative to reference sites provides further confirmatory evidence that environmental conditions in the reach of the Assessment Area are sufficient to injure sediments and associated biological resources. Together, these multiple lines of evidence demonstrate that sediments and associated biological resources have been injured as a result of discharges of oil or releases of other hazardous substances.

6.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g., epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey). These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

6.2.1 Toxicity of Sediments to Fish

Lucas and Steinfeld (1972) collected a total of 23 sediment samples to evaluate the toxicity of EBGCR-I sediments to fathead minnows. The results of these toxicity tests, which were 96-hours in duration, indicated that 13 of the 23 sediment samples (i.e., 57%) were acutely toxic to fish, with mortality rates ranging from 10% to 100% in these samples (Table 6.8). It is likely that a higher incidence of toxicity would have been observed had longer term toxicity tests been conducted and/or more sensitive endpoints been measured. Therefore, the available data indicate that sediments from the EBGCR-I are acutely toxic to fish and, hence, the environmental conditions in the EBGCR-I are sufficient to adversely affect fish.

6.2.2 Fish Health

Two studies have been conducted to assess the status of fish health in the EBGCR-I (Table 14.8). Sobiech *et al.* (1994) collected fish from the vicinity of the ConRail Bridge and determined the incidence of DELT abnormalities, including deformations, eroded fins, lesions, and tumors. In total, 2.7% of the fish taken from this location had DELT abnormalities. This frequency of DELT abnormalities is higher than the threshold for impaired fish health (i.e., > 1.3% incidence of DELT abnormalities; Simon 1991). The higher incidence of DELT abnormalities relative to the threshold for impaired fish health indicates that fish health has been compromised in the EBGCR-I

More recently, Simon *et al.* (2000) collected fish at nine stations in the EBGCR-I to support evaluations of the integrity of the fish community. The results of this study indicate that the incidence of DELT abnormalities ranged from 0% to 6.2% at these stations. Fish health was impaired at three of the nine stations that were sampled (i.e., the incidence of DELT abnormalities was > 1.3%). Therefore, the results of these surveys provide confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that the environmental quality conditions in the EBGCR-I are sufficient to injure sediments and associated sediment-dwelling organisms

6.2.3 Status of Fish Communities

The results of surveys of the status of fish communities also provide relevant information for evaluating environmental quality in the EBGCR-I. Simon *et al.* (2000) summarized the available information on the status of fish communities in the EBGCR-I using an IBI that was originally developed by Karr (1981) and was subsequently calibrated for use in Indiana (Simon and Stewart 1998). Data collected between 1985 and 1990 demonstrated that IBI scores ranged from 20 to 32 in the EBGCR-I, which indicates that the integrity of fish communities was "poor" to "very poor" (Table 14.9). Data collected more recently in this reach of the Assessment Area demonstrated that the integrity of fish communities has not improved in the past decade. First, Sobeich *et al.* (1994) reported an IBI score of 22 at a station located near the ConRail Bridge. Subsequently, Simon *et al.* (2000) reported IBI scores of 16 to 26 for the eight stations that were sampled in 1998 and concluded that the integrity of fish communities was "poor" to "very poor" at these stations (Table 14.9). Overall, the results of the various surveys that have been conducted indicate that, while the EBGCR-I has the potential of providing a suitable habitat for relatively healthy and diverse communities of warm-water fish, such communities were not present in the EBGCR-I (Simon *et al.* 2000).

6.2.4 Bioaccumulation of Sediment-Associated Contaminants

In this report, bioaccumulation-based SQGs have been used to assess the significance of sediment-associated chemicals of concern to piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey; NYSDEC 1994). Based on the whole sediment chemistry data that have been collected in the EBGCR-I, it is apparent that a variety of bioaccumulative substances are present in surficial sediments at concentrations that pose potential hazards to wildlife species utilizing the EBGCR-I. Specifically, the concentrations of total PCBs, chlordane, total DDTs, endrin, heptachlor, heptachlor epoxide, and lindane in surficial sediments exceed the levels that have been established to protect piscivorus wildlife species (Table 6.1). In sub-surface sediments, the same substances, except for heptachlor epoxide, were present at concentrations in excess of the bioaccumulation-based SQGs. Therefore, it is apparent that a variety of bioaccumulative substances, including PCBs and various organochlorine pesticides, occur in whole sediments from the EBGCR-I at levels that are sufficient to result in the accumulation of these substances in invertebrate and fish tissues to concentrations that pose a risk to piscivorus wildlife.

Comparison of tissue residue levels to fish flesh criteria for the protection of wildlife provides a means of confirming that bioaccumulation in invertebrate and/or fish tissues represents a hazard to wildlife species. Recently, the United States Fish and Wildlife Service collected samples of invertebrate tissues from a number of locations within the Assessment Area (Appendix 5.9; USFWS 2000). The concentrations of metals, PAHs, PCBs, and various pesticides were measured in each sample. Comparison of the measured concentrations of chemicals of concern with published tissue residue guidelines (TRGs) for the protection of piscivorus wildlife (Newell *et al.* 1987) indicated that bivalve mollusks (i.e., *Corbicula fluminea*) from the Assessment Area had elevated levels of total PCBs in their tissues (Table 6.9). At all three locations that were sampled (Industrial Highway, Cline Avenue, and Kennedy Avenue) and in all six samples, the levels of total PCBs exceeded the TRG for the protection of wildlife by more than a factor of 28 (i.e., concentrations ranged from 9.0 to 1,303 µg/kg WW; TRG = 110 µg/kg WW). None of the pesticides measured in sediments were detected in the tissues of these bivalves, however. Although metals and PAHs were measured in *Corbicula fluminea* tissues from the EBGCR-I, the significance of the measured concentrations relative to hazards to wildlife could not be evaluated due to the lack of corresponding TRGs.

A total of 18 samples of fish tissues have been collected to determine the concentrations of tissue-associated contaminants in the EBGCR-I (Appendix 5.1, 5.2, 5.3, 5.4 and 5.5). In 1982, two fish tissue samples (whole fish) were obtained from carp that were collected at the confluence with the WBGCR. In these samples, the concentrations of total PCBs (4,630 to 12,500 µg/kg WW; Table 6.9; Figure 6.5) exceeded the TRG (10 µg/kg WW) for the protection of piscivorus wildlife; the concentrations of total DDTs were elevated in both samples, and; chlordane levels were also elevated in one sample. During the period 1984 to 1994, eight additional tissue samples were collected in the vicinity of Kennedy Avenue (seven samples of carp and one sample of goldfish; whole fish or skin-on fillets). The concentrations of total PCBs (4,700 to 15,900 µg/kg WW) exceeded the TRG for the protection of piscivorus wildlife in all of these samples (Newell *et al*. 1987); total DDT, dieldrin + aldrin, and endrin levels were also elevated in certain samples. Chemical concentrations could not be evaluated in one of the samples because none of the values were reported for those chemicals which TRGs are available. At Cline Avenue, eight fish tissue samples were collected between 1986 and 1994, including five samples of carp (whole fish or skin-on fillets), one sample of golden shiners (whole fish), one sample of goldfish (whole fish) and one sample of pumpkinseed (whole fish). In these samples, the concentrations of total PCBs (810 to 27,100 µg/kg WW) exceeded the TRG for the protection of piscivorus wildlife in seven of these eight samples; PCB levels were not reported in the pumpkinseed sample. Total DDT levels were also elevated relative to the TRG in several samples. Therefore, it is concluded that total PCBs, chlordane, dieldrin + aldrin, endrin and total DDTs have accumulated in fish tissues to levels that are sufficient to cause or substantially contribute to sediment injury relative to piscivorus wildlife species utilizing habitats in the EBGCR-I.

6.2.5 Summary

Based on the information available from various studies, it is apparent that contaminated sediments pose substantial hazards to wildlife in the EBGCR-I. Contaminated sediments in the EBGCR-I are adversely affecting wildlife species in at least four ways. First, alteration of benthic invertebrate communities has reduced the abundance of preferred fish food organisms in this river reach. Second, sediments from the EBGCR-I have been shown to be acutely toxic to fish. Fish health and the integrity of fish populations (as measured using the IBI) inhabiting the EBGCR-I have also been compromised. Third, the concentrations of sediment-associated contaminants are known to exceed, often by wide margins, the levels that have been established to protect piscivorus wildlife species (e.g., herons, kingfishers, otter, mink or osprey). Finally, the concentrations of certain chemicals of concern in benthic invertebrates and fish exceed the TRGs that have been established to protect piscivorus wildlife species. Therefore, it is concluded that injured sediments in the EBGCR-I are adversely affecting fish and wildlife resources utilizing habitats within this reach of the Assessment Area.

6.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in EBGCR-I sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of this report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially contributing to effects on sediment-dwelling organisms) were identified from the list of chemicals of concern by comparing measured concentrations in whole sediments to the PECs (Table 6.1). The substances which occurred in EBGCR-I sediments at concentrations in excess of these chemical benchmarks were identified as contaminants of concern. The results of this evaluation indicate that metals (i.e., arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), PAHs (i.e., 13 individual PAHs and total PAHs), and PCBs are frequently present in both surficial and sub-surface sediments from the EBGCR-I at concentrations that are sufficient to injure sediment-dwelling organisms. However, the concentrations of these contaminants tend to be lower in sub-surface sediments than they are in surficial sediments. Importantly, the concentrations of cadmium, chromium, copper, nickel, lead, and zinc also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments. Several pesticides also occurred in EBGCR-I sediments at levels in excess of the consensus-based PECs.

The concentrations of several chemicals of concern exceeded published toxicity thresholds in pore water from EBGCR-I sediments. Evaluation of the data reported in various studies using the toxic units approach indicates that concentrations of cadmium, copper, lead, zinc, and the sum toxic units in pore water from EBGCR-I sediments were frequently at or above concentrations that have been shown to be toxic to aquatic organisms. The relative levels of SEM and AVS confirm that sediment-associated metals are likely to be available to sediment-dwelling organisms in many of these samples. In addition, the concentrations of phenol frequently equaled or exceeded the concentrations that are known to be acutely toxic to aquatic organisms. The concentrations of unionized ammonia in pore water were also sufficient to cause acute toxicity in aquatic invertebrates. Therefore, the toxic contaminants of concern in pore water are cadmium, copper, lead, zinc, phenol, and ammonia (Table 6.3).

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 6.1); and, (2) measured contaminant concentrations in tissues to the TRGs for the protection of piscivorus wildlife. The results of this evaluation indicate that total PCBs, chlordane, total DDTs, endrin, heptachlor, heptachlor epoxide, and lindane occurred in EBGCR-I sediments at concentrations that are sufficient to cause or substantially contribute to effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). Surficial and sub-surface sediments have been contaminated by one or more of these substances. The available tissue residue data confirm that PCBs, chlordane, dieldrin + aldrin, endrin, and total DDTs have frequently accumulated in fish tissues to levels that pose risks to piscivorus wildlife (Table 6.9).

All of the contaminants of concern frequently exceed the chemical benchmarks in EBGCR-I sediments. The frequency of exceedance of the PECs was highest for lead, zinc, total PAHs, and total PCBs, while the highest frequencies of exceedance of the bioaccumulation-based SQGs were observed for total PCBs, chlordane, heptachlor, and heptachlor epoxide. The concentrations of these substances in EBGCR-I sediments frequently exceeded the chemical benchmarks by substantial margins, in some samples by more than a factor of 100. Therefore, NH_3, metals, PAHs, and PCBs are present in whole sediments at concentrations in excess of the levels that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and to adversely affect wildlife in the EBGCR-I. In tissues, PCBs, chlordane, and total DDTs occurred most frequently at levels in excess of TRGs.

6.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury was determined by merging the various data sets that provided information on contaminant concentrations in EBGCR-I sediments. To support an evaluation of the spatial distribution of contaminants of concern, mean PEC-Qs were calculated for each of the sediment samples that were obtained from the EBGCR-I. The areal extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (each sample was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial and sub-surface sediments separately.

Based on the sediment chemistry data that have been collected to date, it is apparent that surficial sediments throughout the EBGCR-I have been contaminated by oil or other hazardous substances (Table 6.2; Figures 6.6 and 6.7). Sediment chemistry data were compiled for a total of 29 surficial sediment samples that were collected within the portion of the EBGCR-I from the confluence with the WBGCR to Kennedy Avenue. Of these, 76% of the samples (i.e., 22 samples) had mean PEC-Qs ≥ 0.7 (Table 6.2). Importantly, all of the samples (i.e., 17 of 17 samples) collected in the USS Lead Canal had mean PEC-Qs ≥ 0.7. Evaluation of the available sediment chemistry data demonstrates that surficial sediments collected upstream of Kennedy Avenue have also been contaminated by oil or other hazardous substances. For example, 94%, 93%, and 100% of the samples collected between Kennedy Avenue and Cline Avenue, between Cline Avenue and the Cline/I90 Ramps, and between Cline/I90 Ramps and Industrial Highway, respectively, had mean PEC-Qs ≥ 0.7 (Figure 6.6 and 6.7). Mean PEC-Qs ≥ 0.7 in all the surficial sediment samples (i.e., 12 of 12 samples) collected between Industrial Highway and the ConRail Bridge. The available sediment chemistry data also demonstrate that wetland sediments in this portion of the Assessment Area have been contaminated to the extent that they are likely to be toxic to sediment-dwelling organisms (i.e., 14 of 17 samples had mean PEC-Qs ≥ 0.7). Therefore, surficial sediments throughout the EBGCR-I are sufficiently contaminated with oil or other hazardous substances to cause or substantially contribute to sediment injury.

In general, sub-surface sediments in the EBGCR-I tend to be somewhat less contaminated than surficial sediments (Table 6.2; Figure 6.8 and 6.9). For example, 13 of the 18 (72%) sub-surface sediment samples collected west of Kennedy Avenue had mean PEC-Qs ≥ 0.7. All of the sub-surface sediment samples (i.e., 9 of 9 samples) that were collected in the USS Lead Canal had chemical characteristics that are sufficient to cause sediment injury (i.e., mean PEC-Q of ≥ 0.7). Between Kennedy Avenue and Industrial Highway, 48 of 73 (66%) sub-surface sediment samples that were collected had mean PEC-Qs ≥ 0.7. A higher proportion of the sub-surface sediment samples (i.e., 83%, 5 of 6) from the Industrial Highway to ConRail Bridge reach of the river were classified as having conditions sufficient to injure sediments. A mean PEC-Q of 0.6 was calculated for the single sub-surface wetland sediment that was sampled, suggesting that sub-surface wetland sediments may be somewhat less contaminated than surficial sediments (Table 6.10). Overall, sub-surface sediments throughout the EBGCR-I are sufficiently contaminated with oil or other hazardous substances to cause or substantially contribute to sediment injury.

Based on the available sediment chemistry data, it is apparent that sediments throughout the EBGCR-I are likely to be toxic to sediment-dwelling organisms. To put the mean PEC-Q results into perspective, USEPA (2000a) reported that the probability of observing a 50% incidence of toxicity to amphipods in sediments occurred at a mean PEC-Q of ≥ 4.0 in 10-day acute tests and at a mean PEC-Q of ≥ 0.7 in 28-day chronic tests. Therefore, surficial sediments would be expected to be frequently toxic to sediment-dwelling organisms (i.e., sediment samples from the EBGCR-I had mean PEC-Qs of up to 124 times the level that would result in a 50% probability of observing toxicity in 10-day tests and up to 710 times the level that would result in a 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca*; USEPA 2000a).

The data on other indicators of sediment quality conditions confirm that sediments throughout the EBGCR have been injured as a result of discharges of oil or releases of other hazardous substances. For example, sediments throughout the EBGCR-I are known to be toxic to aquatic organisms (Table 6.4; Figure 6.10). Likewise, the results of benthic invertebrate community assessments conducted at various locations from the ConRail Bridge to the confluence with the WBGCR demonstrate that benthic invertebrate communities have been degraded throughout this reach of the river (Section 6.1.4; Table 6.5; Figure 6.4).

6.5 Summary

Based on nine lines of evidence, it is concluded that both surficial and sub-surface sediments from the EBGCR-I between the ConRail Bridge and the confluence with WBGCR, including USS Lead Canal and various wetland areas, have been injured by discharges of oil or releases of other hazardous substances. While surficial sediments tend to be the most contaminated, sub-surface sediments throughout this portion of the Assessment Area also have conditions that are sufficient to cause or substantially contribute to sediment injury and injury to associated biological resources.

7.0 East Branch of the Grand Calumet River - II

The EBGCR flows some 10 miles from the outlet of the GCRL to the confluence of the WBGCR and IHC in northwest Indiana. For the purposes of conducting this assessment of sediment injury, the EBGCR has been divided into two reaches, including the EBGCR-I and the EBGCR-II (Figure 1.1 and 1.2). The EBGCR-I extends some five miles from the ConRail Bridge [which is the first railway bridge located upstream of Industrial Highway (Highway 12)] to the confluence with the WBGCR. The EBGCR-II extends from the GCRL (i.e., the culvert that connects the GCRL to the EBGCR) to the ConRail Bridge, a distance of roughly five miles. This section of the report provides an assessment of sediment injury in the EBGCR-II. The assessment of sediment injury in the EBGCR-I is presented in Section 6.0 of this report.

There are a number of potential sources of contaminants to the EBGCR-II. First, U.S. Steel currently discharges or has historically discharged wastewater into the river (on average, 8.68 billion gallons per year) via 21 outfalls that have been permitted under the NPDES, three of which have now been decommissioned. Significant amounts of ammonia are produced from existing (and former) coke ovens, sinter plants and blast furnace operations that are part of the integrated steel manufacturing plants adjacent to the EBGCR-II. The Gary Sanitary District has seven NPDES permitted outfalls through which wastewater (on average, 0.754 billion gallons per year) and/or stormwater is discharged into the EBGCR-II. H-V Roll Center, Inc. also has an NPDES permitted outfall on this reach of the EBGCR. Marblehead Lime Company had a permitted outfall on the EBGCR-II; however, this outfall has been decommissioned. Other potential contaminant sources include discharges of contaminated groundwater and/or over-land runoff from various industrial facilities, leachate from landfills located nearby the river, and leaky pipeline crossings. Downstream transport of contaminated water and/or sediments from the GCRL also represents a potential source of contaminants to this reach of the river.

The present assessment is intended to evaluate injury to surface water and biological resources in the EBGCR-II that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the EBGCR-II includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the EBGCR-II are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the EBGCR-II are sufficiently contaminated to harm fish and wildlife resources. Sediments in the EBGCR-II were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury was determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support restoration planning within the Assessment Area.

7.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

7.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 98 surficial sediment samples from the EBGCR-II. The locations where these samples were collected are shown in Figure 7.1. The results of chemical analyses of these samples indicate that a substantial proportion of surficial sediments in the EBGCR-II and nearby wetlands have been contaminated by toxic substances (Table 7.1). For example, the concentrations of sediment-associated metals exceeded the PECs in up to 58% of the samples, depending on the metal considered (i.e., 55 of 95 samples for lead). Total PAH concentrations exceeded the PEC in 50% (49 of 98 samples) of the samples in which these contaminants were measured; the frequency of exceedance of the PECs for individual PAHs ranges from 56% to 100%. Total PCB concentrations exceeded the PEC in 96% of the samples in which these contaminants were quantified (51 of 53 samples). Importantly, when samples from the relatively less contaminated wetland sites are not included in these analyses, concentrations of metals exceed the PECs in up to 90% (37 of 41 samples for lead) of the samples, total PAH concentrations exceed the PECs in 98% (42 of 43) of the samples, and total PCBs exceed the PECs in 100% of the samples (n=36).

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the EBGCR-II, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments. The results of the present evaluation indicate that all of the surficial sediment samples from this reach of the river (43 of 43 samples) had mean PEC-Qs $ 0.7 (Table 7.2). USEPA (2000a) reported that sediments with these chemical characteristics were likely to be toxic to amphipods in 28-day toxicity tests. Of these samples, 81% (i.e., 35 of 43 samples) had mean PEC-Qs $ 4.0, which is the acute toxicity threshold for sediment-dwelling organisms. In the nearby wetlands, 33% (18 of 55) of surficial sediment samples had mean PEC-Qs $ 0.7, of which 11% are $ 4.0.

Information on the chemical characteristics of 33 sub-surface sediment samples from the EBGCR-II is contained in the project database. The sampling sites where these sediments were collected are shown in Figure 7.2. Evaluation of the available sediment chemistry data indicates that sub-surface sediments in the riverine portion of EBGCR-II have also been contaminated by toxic substances, however, not to the same extent as surficial sediments (Table 7.1). Relatively fewer sediment samples (i.e., up to 72%) have metal concentrations that exceeded the PECs (depending on the metal that is considered). However, all of the samples (33 of 33 samples) had total PAH concentrations that exceeded the PEC; the frequency of exceedance of the PECs for the individual PAHs ranged from 94% to 100%. For total PCBs, 94% (15 of 16 samples) of the samples had elevated concentrations relative to the PEC.

Based on the mean PEC-Qs that were calculated, it is apparent that sub-surface sediment samples in the EBGCR-II have also been contaminated by toxic substances. Overall, 33 of the 33 (100%) sub-surface sediment samples reflected in the project database have mean PEC-Qs ≥ 0.7, thereby classifying them as injured. Of these, 76% of the samples (25 of 33 samples) had mean PEC-Qs ≥ 4.0 (Table 7.2). None of the samples collected in the EBGCR-II would be classified as relatively uncontaminated (i.e., mean PEC-Qs < 0.7) based on the mean PEC-Qs that were calculated for these sub-surface sediments.

In summary, the available data on the concentrations of chemical substances demonstrates that both surficial and sub-surface sediments in the EBGCR-II have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants, in both surficial and sub-surface sediments, are sufficient to injure sediment-dwelling organisms. Therefore, it is concluded that sediments in the EBGCR-II have been injured due to discharges of oil or releases of other hazardous substances. In addition, it is concluded that the biological resources that depend on these critical aquatic habitats provided by surficial sediments have been injured due to the presence of toxic substances (i.e., metals, PAHs, and PCBs).

7.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1).

Information on the chemical composition of pore water from the EBGCR-II sediments is summarized in Table 7.3. Sediment samples were collected from two stations on the EBGCR-II to determine the concentrations of various contaminants in pore water (Hoke *et al.* 1993). These two sampling stations were located between Grant Street and Broadway (UG 2) and downstream of the GCRL culvert (UG 1). Evaluation of the results of this study indicates that the concentrations of copper, lead, zinc and the sum toxic units for metals in pore water from UG 2 sediments exceeded concentrations that have been shown to be toxic to aquatic organisms in 10-day acute toxicity tests. The sum toxic units for metals in pore water was 3.2 units. The detection limit for cadmium was too high to be able to interpret the chemistry data relative to the published 10-day LC_{50} for *Hyalella azteca* (USEPA 1994; 2000b). The concentrations of divalent metals exceeded the level of AVS (i.e., on a molar basis) at this station, indicating that elevated levels of metals in pore water are likely to be observed (Ankley *et al.* 1996). Phenol (50.3 to 226 mg/L) and unionized ammonia (8.1 mg/L) were also present in pore water samples from one or both of these stations at concentrations above the acute toxicity thresholds that have been reported for aquatic invertebrates. The results of acute toxicity tests conducted with pore water from EBGCR-II sediments support the conclusion that contaminant concentrations in pore water were sufficiently elevated in EBGCR-II sediments to cause or substantially contribute to toxicity to crustaceans and bacteria (Hoke *et al.* 1993).

The available data on the concentrations of metals, phenols, and ammonia in pore water indicate that EBGCR-II sediments have been contaminated by oil or other hazardous substances. Comparison of these data to acute toxicity thresholds for amphipods and other aquatic invertebrates demonstrates that the concentrations of these contaminants in pore water are sufficient to injure sediment-dwelling organisms. Therefore, it is concluded that EBGCR-II sediments have been injured due to the presence of toxic substances in pore water. In addition, it is concluded that the sediment-dwelling organisms that depend on habitats provided by surficial sediments have been injured due to the presence of toxic substances in pore water.

7.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediment, pore water, and/or elutriates provide critical information for assessing the effects of contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured by discharges of oil or releases of other hazardous substances.

In the EBGCR-II, three studies have been conducted to determine if sediments and associated pore waters are toxic to sediment-dwelling organisms or other aquatic organisms (Lucas and Steinfeld 1972; Hoke *et al.* 1993; Sobiech *et al.* 1994; Figure 7.3). In total, data are available on the toxicity of 52 sediment samples from the EBGCR-II. The species and endpoints tested in these studies included amphipod (*Hyalella azteca*) survival, midge (*Chironomus tentans*) growth, cladoceran (*Daphnia magna* and *Ceriodaphnia dubia*) survival, fathead minnow (*Pimephales promelas*) survival, and bacterial (*Vibrio fisheri*) bioluminescence (i.e., as a surrogate for metabolic rate). Overall, 46 of the 52 (88%) sediment samples collected from the EBGCR-II were shown to be toxic to one or more species (Table 7.4; Figure 7.10). While sediments from the EBGCR-II would likely have been toxic more frequently had longer term tests (including sublethal endpoints) been employed, the results of the studies that have been conducted demonstrate that sediments from the EBGCR-II are acutely toxic to a variety of aquatic organisms, including sediment-dwelling species. Therefore, these results demonstrate that the condition of sediments and associated pore waters in the EBGCR-II is sufficient to injure sediments and associated organisms, including sediment-dwelling species.

7.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998). For this reason, the available information on the status of benthic invertebrate communities was assembled and used to determine if discharges of oil or releases of other hazardous substances have caused or substantially contributed to sediment injury in the EBGCR-II.

In 1994, Sobiech *et al.* (1994) deployed artificial substrates at five locations in the EBGCR, with four of these stations located in the EBGCR-II (Figure 7.4). These stations were located upstream of Tennessee Avenue, downstream of Broadway, downstream of Grant Street, and downstream of Bridge Street. The results of this study indicated that the benthic invertebrate community that colonized artificial substrates in the EBGCR-II was dominated by midges and gastropods (i.e., collectively representing 57% to 99% of the organisms that were collected), with leeches, oligochaetes, and bivalve mollusks also present (Table 7.5). None of the EPT taxa (i.e., mayflies, stoneflies, and caddisflies) were observed on the artificial substrates that were deployed at this station. Based on an evaluation of these data, Sobiech *et al.* (1994) classified the integrity of the benthic invertebrate community as very poor throughout the EBGCR-II. As these samples had < 0.5% EPT taxa, they are classified as having altered benthic invertebrate communities.

More recently (1996), The IDEM (2000a) collected information on the status of benthic macroinvertebrate communities at one location on the EBGCR-II using an artificial substrate sampler. This station was located near Bridge Street. The results of this investigation indicated that pollution-tolerant species, such as oligochaetes and chironomids, dominated the benthic invertebrate community at this location. Collectively, these taxa accounted for about 92% of the total abundance of invertebrates at this site. Limited numbers of gastropod and bivalve mollusks, and other dipteran species were observed at this location. None of the pollution-sensitive EPT taxa were observed. The mIBI score for this sample is 1.3, indicating that the benthic invertebrate community was degraded relative to other locations in Indiana (i.e., # 2.93; the average mIBI score for Indiana is in the order of 3.5 ± 0.29; Simon *et al.* 2000).

Collectively, the data that have been collected indicate that the benthic invertebrate communities in the EBGCR-II have been altered at all sampling stations (Table 7.5), relative to reference conditions in northern Indiana and Lake Michigan. Impacts of sediment-dwelling organisms are particularly important because benthic invertebrates represent important food sources for fish and other wildlife species that utilize habitats in the EBGCR-II. The presence of altered benthic invertebrate communities provides confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that environmental quality conditions in the EBGCR-II are sufficient to injure sediments and sediment-dwelling organisms.

7.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, TOC, and NH_3, provide important information for the general status of aquatic habitats and their suitability for supporting aquatic life. For this reason, the available information on conventional indicators of environmental quality conditions was compiled and used to assess the status of benthic habitats in the EBGCR-II. No information was located on the levels of DO or SOD in the EBGCR-II. Therefore, evaluating sediment quality conditions was not possible relative to these conventional indicators.

The available information indicates that the levels of TOC are elevated throughout the EBGCR-II. In surficial sediments, the levels of TOC ranged from1.2% to 28.1% and averaged 6.1%, with the highest levels of TOC observed between Tennessee Street and the GCRL culvert (average of 10.4%; Table 7.6). Concentrations of TOC as high as 16.7% were observed in the reach segment between Virginia Street and Tennessee Street. Reach segments downstream of Virginia Street generally had lower levels of TOC in surficial sediments, ranging from 1.2% to 11%. The average concentration of TOC in sub-surface sediments was 3.6% (Table 7.6). The highest concentrations of TOC in sub-surface sediments were also observed between Tennessee Street and the GCRL culvert (ranging from 1.2% to 12%). By comparison, Lake Michigan sediments in the vicinity of IH had an average level of TOC of 0.5% (n=31; Table 13.6); the upper 95% CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b). Therefore, both surficial and sub-surface sediments in the EBGCR-II have received substantial inputs of organic matter relative to other contaminated sites in the Great Lakes basin. Based on measured concentrations of total PAHs in the EBGCR-II (i.e., up to 6.7%), it is apparent that much of the TOC in these sediments is present in the form of oil and oil-related compounds.

In aquatic ecosystems, ammonia is excreted by aquatic organisms, formed during the decomposition of biological tissues and nitrogen-containing wastes, and/or released from anthropogenic sources. There are a variety of anthropogenic sources of ammonia, such as municipal and industrial wastewater discharges. Free ammonia can be present either as NH_3 or as NH_4^+ (depending on pH and temperature). Unionized ammonia (NH_3) is very toxic to aquatic life, with lethal thresholds as low as 0.1 mg/L reported in the literature (Thurston and Russo 1983; Thurston and Meyn 1984; Thurston *et al.* 1984). In the EBGCR-II, the concentrations of NH_3 in pore water were measured at two locations, including between Grant Street and Broadway and downstream of the GCRL culvert. Unionized ammonia concentrations at these two sampling stations were 0.2 mg/L and 8.1 mg/L, respectively (Table 7.3). The concentration of ammonia in pore water of sediments from the latter station was high enough to cause or substantially contribute to mortality of aquatic invertebrates.

In 1994, Sobiech *et al.* (1994) evaluated the status of physical habitats in the EBGCR-II. In total, the status of physical habitats was evaluated at four locations in this portion of the Assessment Area, including upstream of Tennessee Avenue, downstream of Broadway, downstream of Grant Street, and downstream of Bridge Street. In this study, information on bottom substrate, instream cover, channel morphology, riparian zone and bank erosion, pool and riffle quality, and gradient was compiled at each sampling location and evaluated using a QHEI (Sobiech *et al.* 1994). The results of this evaluation indicated QHEI scores ranged from 22 to 51 in the EBGCR-II. By comparison, OEPA (1988) reported that mean (± SD) QHEI scores for rivers and streams in the ECBPs eco-region was 74 (± 13.1), with the lower limit of the normal range of QHEI scores being 48. Three of the four QHEI scores reported for this reach were outside the normal range of the ECBPs eco-region (i.e., normal range is 48 to 100; OEPA 1988). Additionally, the IDEM (2000c) has established use support assessment criteria for streams in Indiana. These criteria indicated that use impairment is likely to occur when QHEI scores are < 64. As such, it was concluded that the condition of physical habitats may be one of the factors that are limiting the productivity of benthic and fish communities in this reach of the river (Sobiech *et al.* 1994).

In summary, the available information indicates that aquatic habitats have been degraded in the EBGCR-II. In addition, the levels of TOC and associated oil and oil-related compound are elevated in EBGCR-II sediments compared to other Areas of Concern in the Great Lakes. Furthermore, the levels of ammonia in pore water from EBGCR-II sediments have exceeded the concentrations that are known to cause or substantially contribute to injury to sediment-dwelling organisms. Therefore, the available information on the conventional indicators of sediment quality conditions indicates that sediments in the EBGCR-II have been injured due to discharges of oil or releases of other hazardous substances.

7.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the EBGCR-II have been injured by discharges of oil or releases of other hazardous substances. More specifically, the data show that metals, PAHs, and PCBs occur in whole sediments at concentrations that are sufficient to injure sediment-dwelling organisms. Calculated mean PEC-Qs exceed, often by a wide margin, the levels that are sufficient to injure sediment-dwelling organisms. The levels of metals, unionized ammonia, and phenol in pore water are also sufficient to cause toxicity to aquatic organisms. In addition, the results of toxicity tests confirm that whole sediments, and pore water are toxic to aquatic organisms. That benthic invertebrate communities in this reach of the river are significantly altered relative to reference sites provides further confirmatory evidence that environmental conditions in the reach of the Assessment Area are sufficient to injure sediments and associated biological resources. Together, these multiple lines of evidence demonstrate that sediments and associated biological resources have been injured as a result of discharges of oil or releases of other hazardous substances.

7.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g, epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey). These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

7.2.1 Toxicity of Sediments to Fish

In 1971, Lucas and Steinfeld (1972) conducted an investigation of the toxicity of Grand Calumet River sediments. As part of this investigation, surface and sub-surface sediments were collected from a number of locations between Cline Street and the GCRL culvert. In total, 40 samples from the EBGCR-II were obtained to evaluate the toxicity of sediments to fathead minnows (*Pimephales promelas*). The results of this investigation showed that 85% of the surficial and sub-surface sediments from the EBGCR-II were toxic to fish. Therefore, it is concluded that EBGCR-II sediments are acutely toxic to fish (Table 7.7), confirming that environmental conditions are sufficient to adversely affect fish.

7.2.2 Fish Health

Sobiech *et al.* (1994) collected fish at a total of four locations to assess the health of fish and fish communities in the EBGCR-II. The incidence of DELT abnormalities, which included deformities, eroded fins, lesions, and tumors, was determined to support the assessment of fish health in this study. The sampling stations were located downstream of the upstream of Tennessee Avenue, downstream of Broadway, downstream of Grant Street, and downstream of Bridge Street. At these stations, the incidence of DELT abnormalities ranged from 0% upstream of Tennessee Avenue to 17.4% downstream of Broadway. At three of the four stations, the incidence of DELT abnormalities was greater than the threshold for impaired fish health (i.e., > 1.3%; Sobiech *et al.* 1994). Therefore, it is concluded that fish health has been impaired in the EBGCR-II.

7.2.3 Status of Fish Communities

A number of surveys of the status of fish communities have been conducted on the EBGCR-II over the past 25 years. Simon *et al.* (2000) summarized the results of the studies conducted between 1985 and 1990 using a modified IBI (originally developed by Karr 1981 and subsequently calibrated for use in Indiana; Simon and Stewart 1998). Information on the status of fish populations was available for four locations on the EBGCR-II; these sampling stations were located near Broadway, Bridge Street, Grant

Street and Kennedy Avenue (Table 14.9). Overall, IBI scores ranged from 24 to 32 at these locations, which indicates that the integrity of the fish communities was “poor” to “very poor”.

More recently (1994), Sobiech *et al.* (1994) assessed the status of fish communities at four locations on the EBGCR-II, including upstream of Tennessee Street, downstream of Broadway, upstream of Grant Street, and downstream of Bridge Street. The results of this study indicate that fish populations throughout this reach of the Assessment Area have been degraded. The calculated IBI scores ranged from 12 to 22 at these locations, which are indicative of fish communities with “very poor” integrity. The number of sensitive fish species was low, while the percent tolerant species was high at these stations. In addition, no darter, sculpin, or madtom species were identified at any of these locations. Collectively, the results of these studies indicate that the integrity of fish communities in the EBGCR-II is “poor” to “very poor”. Therefore, environmental conditions in the EBGCR-II are sufficient to adversely affect fish.

7.2.4 Bioaccumulation of Sediment-Associated Contaminants

In this report, bioaccumulation-based SQGs have been used to assess the significance of sediment-associated chemicals of concern to piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey; NYSDEC 1994). Based on the whole sediment chemistry data that have been collected in the EBGCR-II, it is apparent that a variety of bioaccumulative substances are present in surficial sediments at concentrations that pose potential hazards to wildlife species utilizing the EBGCR-II. Specifically, the concentrations of total PCBs, chlordane, total DDTs, heptachlor, and lindane occur in surficial sediments exceed the levels that have been established to protect piscivorus wildlife species (Table 7.1). In sub-surface sediments, total PCBs were present at concentrations in excess of the bioaccumulation-based SQGs. Therefore, it is concluded that concentrations of PCBs and other bioaccumulative substances occur in EBGCR-II sediments at levels sufficient to result in bioaccumulation of these substances in invertebrate and fish tissues to concentrations that pose a risk to piscivorus wildlife.

Comparison of tissue residue levels in fish to fish flesh criteria for the protection of wildlife provides a basis for confirming that bioaccumulation in invertebrate and/or fish tissues represents a hazard to wildlife species. A total of six samples of fish tissues have been collected to determine the concentrations of tissue-associated contaminants in the EBGCR-II (Appendix 5.3, 5.4, and 5.5; Table 7.8). All of these samples were collected in the vicinity of Bridge Street, with one sample obtained in 1986 (carp; whole fish), two samples obtained in 1987 (carp; whole fish and golden shiners; whole fish), and three samples obtained in 1994 (two samples of carp; skin on fillets and one sample of goldfish; whole fish). In one of the samples collected in 1987 (i.e., golden shiners), none of the chemicals for which TRGs are available were analyzed (Appendix 5.4). The results of these investigations indicated that total PCBs occurred in fish tissues at concentrations ranging from 3,300 to 9,700 µg/kg WW. The levels of total DDTs in these samples ranged from 112 to 3,350 µg/kg WW. For PCBs, all of the samples had concentrations in excess of the level that has been established for the protection of piscivorus wildlife (i.e., 110 µg/kg WW; Newell *et al.* 1987). One of these samples had elevated levels of total DDTs relative to the TRGs for the protection of wildlife (200 µg/kg WW). Therefore, it is concluded that total PCBs and total DDTs have accumulated in fish tissues to levels that are sufficient to cause or substantially contribute to sediment injury relative to piscivorus wildlife species utilizing habitats in the EBGCR-II.

7.2.5 Summary

Based on the information available from various studies, it is apparent that contaminated sediments pose substantial hazards to wildlife in the EBGCR-II. Contaminated sediments in the EBGCR-II are adversely affecting wildlife species in several ways. First, alteration of benthic invertebrate communities has reduced the abundance of preferred fish food organisms in this river reach. Second, fish health has been compromised in the EBGCR-II. In addition, these sediments are acutely toxic to fish and fish populations inhabiting the EBGCR-II. The concentrations of sediment-associated contaminants are also known to exceed, often by wide margins, the levels that have been established to protect piscivorus wildlife species (e.g., herons, kingfishers, otter, mink or osprey). Finally, the levels of PCBs and other bioaccumulative substances in fish tissues exceed the levels that have been established to protect piscivorus wildlife. Therefore, it is concluded that the injured sediments in the EBGCR-II are adversely affecting fish and wildlife resources within this reach of the Assessment Area.

7.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in EBGCR-II sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of this report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially-contributing to effects on sediment-dwelling organisms) were identified from the list of chemicals of concern by comparing measured contaminant concentrations in whole sediments to the PECs (Table 7.1). The contaminants that occurred in EBGCR-II sediments at concentrations in excess of these chemical benchmarks were identified as toxic contaminants of concern. The results of this evaluation indicate that metals, PAHs, and PCBs, are frequently present in both surficial and sub-surface sediments from the EBGCR-II at concentrations that are sufficient to injure sediment-dwelling organisms. However, the concentrations of these contaminants tend to be lower in sub-surface sediments than they are in surficial sediments. Importantly, the concentrations of cadmium, chromium, copper, nickel, lead, and zinc also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments. Several pesticides also occurred in EBGCR-II sediments at levels in excess of the consensus-based PECs.

The concentrations of several chemicals of concern exceeded published toxicity thresholds in pore water from EBGCR-II sediments. Evaluation of the available data reported in this study using the toxic units approach indicates that concentrations of copper, lead, zinc, and the sum toxic units in pore water from EBGCR-II sediments exceeded the concentrations that have been shown to be toxic to aquatic organisms. In addition, the concentrations of phenol in two samples equaled or exceeded the concentrations known to be acutely toxic to aquatic organisms. The concentrations of unionized ammonia in pore water were also sufficient to cause acute toxicity in aquatic invertebrates. Therefore, the toxic contaminants of concern in pore water are copper, lead, zinc, phenol, and ammonia (Table 7.3).

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 7.1); and, (2) measured contaminant concentrations in fish tissues to the TRGs for the protection of piscivorus wildlife (Table 7.8). The results of this evaluation indicate that total PCBs, chlordane, total DDTs, heptachlor, and lindane, occurred in EBGCR-II sediments at concentrations that are sufficient to cause or substantially contribute to effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). The available tissue residue data confirm that PCBs have accumulated in fish tissues to levels that pose risks to piscivorus wildlife.

All of the contaminants of concern frequently exceeded the chemical benchmarks in EBGCR-II sediments. The frequency of exceedance of the PECs was highest for lead, zinc, total PAHs, and total PCBs, while the highest frequency of exceedance of the bioaccumulation-based SQGs was observed for total PCBs. The concentrations of these substances in EBGCR-II sediments frequently exceeded the chemical benchmarks by substantial margins, in some samples by more than a factor of 100. Therefore, NH_3, phenol, metals, PAHs, and PCBs are present in whole sediments at concentrations in excess of the levels that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and to adversely affect wildlife in the EBGCR-II.

7.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury was determined by merging the various data sets that provided information on contaminant concentrations in EBGCR-II sediments. To support an evaluation of the spatial distribution of contaminants of concern, mean PEC-Qs were calculated for each of the sediment samples that were obtained from the EBGCR-II. The extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (each sample was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial and sub-surface sediments separately.

Based on the sediment chemistry data that have been collected to date, it is apparent that surficial sediments throughout the EBGCR-II have been contaminated by oil or other hazardous substances. Sediment chemistry data were compiled for a total of 98 surficial sediment samples that were collected within the portion of the EBGCR-II from the GCRL culvert to the ConRail Bridge. Of these, 62% of the samples (i.e., 61 samples) had mean PEC-Qs ≥ 0.7 (Table 7.2; Figures 7.6 and 7.7). The mean PEC-Qs for these samples ranged up to 987 (Table 7.9). Generally, the surficial sediment samples that were collected immediately to the west of the GCRL culvert had relatively lower levels of chemical contamination (i.e., mean PEC-Qs ≤ 10). In contrast, surficial sediments collected in the vicinity of Tennessee Street were highly contaminated, with mean PEC-Qs of over 900 calculated for this segment of the stream reach. From Virginia Street to the ConRail Bridge, the level of contamination tended to be lower. Mean PEC-Qs rarely exceeded 100 within this portion of the Assessment Area.

All of the sub-surface sediment samples that have been collected in the EBGCR-II had mean PEC-Qs ≥ 0.7 (Table 7.2; Figures 7.8 and 7.9). As was the case for surficial sediments, the sub-surface sediments in the vicinity of Tennessee Street were the most contaminated. Mean PEC-Qs ranged as high as 937 in this segment of the stream reach (Table 7.9). By comparison, sub-surface sediments from Broadway to the ConRail Bridge were generally less contaminated, with mean PEC-Qs ranging from roughly 2.1 to 116 in these sediments (Table 7.9). Therefore, both surficial and sub-surface sediments throughout the EBGCR-II are sufficiently contaminated with oil or other hazardous substances to cause or substantially contribute to sediment injury.

Based on the available sediment chemistry data, it is apparent that EBGCR-II sediments are likely to be toxic to sediment-dwelling organisms. To put the mean PEC-Q results into perspective, USEPA (2000a) reported that the probability of observing a 50% incidence of toxicity to amphipods in sediments occurred at a mean PEC-Q of ≥ 4.0 in 10-day acute tests and at a mean PEC-Q of ≥ 0.7 in 28-day chronic tests. Therefore, surficial sediments are expected to be frequently toxic to sediment-dwelling organisms (i.e., sediment samples from the EBGCR-II had mean PEC-Qs of up to 247 times the level that would result in a 50% probability of observing toxicity in 10-day tests and up to 1410 times the level that would result in 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca*; USEPA 2000a).

The data on other indicators of sediment quality conditions confirm that sediments throughout the EBGCR have been injured as a result of discharges of oil or releases of other hazardous substances. For example, sediments throughout the EBGCR-II are known to be toxic to aquatic organisms (Table 7.4; Figure 7.10). In addition, the results of benthic invertebrate community assessments demonstrate that benthic invertebrate communities have been degraded throughout this stream reach (Sobiech *et al.* 1994; Table 7.5).

7.5 Summary

Based on nine lines of evidence, it is concluded that both surficial and sub-surface sediments from the EBGCR-II between the GCRL culvert and the ConRail Bridge, have been injured by discharges of oil or releases of other hazardous substances. Both surficial and sub-surface sediments throughout this stream reach are sufficiently contaminated to cause or substantially contribute to sediment injury and injury to associated biological resources.

8.0 West Branch of the Grand Calumet River - I

The WBGCR extends some six miles from the confluence with the EBGCR and IHC in northwest Indiana to the confluence with the Little Calumet River in northeastern Illinois. For the purposes of conducting this assessment of sediment, the WBGCR has been divided into two reaches. The eastern portion of the river, which extends about 0.7 miles from Indianapolis Boulevard to the confluence of the EBGCR and IHC, has been designated as WBGCR-I (Figure 1.1 and 1.2). The other reach of the river, which has been designated as WBGCR-II, extends from Indianapolis Boulevard to the confluence with the Little Calumet River. This section of the report provides an assessment of sediment injury in the WBGCR-I. The assessment of sediment injury in the WBGCR-II is presented in Section 9.0.

From a hydrological perspective, the WBGCR-I is complicated. River discharges and flow direction can change significantly on an hourly basis (Bierman 1995). While this portion of the river generally flows in an easterly direction, it can flow in a westerly direction when the water level of Lake Michigan is high (USACE 1995). In general, most of the flow in the river reach is derived from wastewater discharges from the Hammond Sanitary District WWTP and the East Chicago WWTP. However, stormwater runoff and discharges from various CSOs can also contribute significantly to the flow of the river during and following rain and snowmelt events.

There are a number of potential sources of contaminants to the WBGCR-I. First, the Sanitary District of East Chicago operates one NPDES permitted outfall in this reach of the river system. Other potential sources of contaminants to this portion of the Assessment Area include downstream transport of wastewater from the Hammond Sanitary District WWTP, leakage from various pipeline crossings, and the transport of contaminants from other stream reaches (i.e., from IHC and EBGCR during periods of flow reversal). Historical discharges from various industrial facilities, such as National Recovery Systems and National Briquette Corp. (which are located west of Indianapolis Boulevard), could also have contributed to the contamination of sediments. Other potential contaminant sources include discharges of contaminated groundwater and/or over-land runoff from various industrial facilities, and leachate from landfills located nearby the river.

The present assessment is intended to evaluate injury to surface water and biological resources in the WBGCR-I that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the WBGCR-I includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the WBGCR-I are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the WBGCR-I are sufficiently contaminated to harm fish and wildlife resources. Sediments in the WBGCR-I were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury was determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support restoration planning within the Assessment Area.

8.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

8.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise, evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 19 surficial sediment samples from the WBGCR-I. The locations where these samples were collected are shown in Figure 8.1. The results of chemical analyses of these samples indicate that a large proportion of surficial sediments in the WBGCR-I have been contaminated by oil or other hazardous substances, including metals, PAHs, and PCBs (Table 8.1). For example, the concentrations of sediment-associated metals exceeded the PECs in up to 100% of the samples, depending on the metal that is considered. Total PAH concentrations exceeded the PEC in 94% of the samples (16 of 17 samples) in which these contaminants were measured. Total PCB concentrations exceeded the PEC in all of the samples in which these contaminants were quantified (i.e., 11 of 11 samples).

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the WBGCR-I, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments. The results of the present evaluation indicate that all 19 of the surficial sediment samples from this reach of the river have chemical characteristics that would classify them as injured (i.e., mean PEC-Qs ≥ 0.7; which is associated with a high probability of observing adverse effects to sediment-dwelling organisms in long-term toxicity tests). None of the samples that have been collected in this stream reach had mean PEC-Qs < 0.1 or ≥ 0.1 to < 0.7 (Table 8.2). Eighty-nine percent of the samples (i.e., 17 of 19 samples) had mean PEC-Qs ≥ 4.0, which is associated with a high probability of observing adverse effects to sediment-dwelling organisms in acute toxicity tests.

Based on an evaluation of the available data, it appears that surficial sediments collected from the WBGCR-I over a number of years (i.e., 1988 to 1999) generally have similar chemical characteristics (Table 8.2). Five sediment samples were collected in this river reach prior to 1996; all five of these samples had mean PEC-Qs ≥ 0.7. By comparison, all 14 of the sediment samples collected 1996 and later also had mean PEC-Qs ≥ 0.7. However, a somewhat lower proportion of the surficial sediment samples that were collected most recently had mean PEC-Qs ≥ 4.0 (i.e., 86% vs. 100% for the samples collected pre-1996).

Information on the chemical characteristics of 12 sub-surface sediment samples from the WBGCR-I is contained in the project database. The sampling sites where these sediments were collected are shown in Figure 8.2. Evaluation of the available sediment chemistry data indicates that sub-surface sediments in the WBGCR-I have also been contaminated by toxic substances, but not to the same extent as surficial sediments (Table 8.1). For example, relatively fewer sub-surface sediment samples (i.e., up to 70%) had metal concentrations that exceeded the PECs (depending on the metal that is considered). Likewise, only 78% of the nine sub-surface sediment samples that were collected on the WBGCR-I had concentrations of total PAHs that exceeded the PEC. All of the sub-surface sediment samples in which total PCBs were measured had concentrations that exceeded the PEC (i.e., 2 of 2 samples).

Based on the mean PEC-Qs that were calculated, it is likely that sub-surface sediment samples in the WBGCR-I have been contaminated by oil or other hazardous substances. Overall, nine of the 12 sub-surface sediment samples that are reflected in the project database had mean PEC-Qs ≥ 0.7 (Table 8.2). Again, adverse effects on sediment-dwelling organisms are likely to occur at mean PEC-Q of ≥ 0.7. Over half of these samples (i.e., 5 of 9 samples) had mean PEC-Qs ≥ 4.0. Three of the 12 sub-surface sediment samples that were collected in this river reach had mean PEC-Qs < 0.7. The chemical characteristics of sub-surface sediment samples collected before and after 1996 are similar, based on the relative proportions of the samples with mean PEC-Qs ≥ 0.7 to < 4.0. However, fewer of the samples collected in 1996 and later had mean PEC-Qs ≥ 4.0 (i.e., relative to the samples collected prior to 1996). It is difficult to determine if these differences reflect temporal or small-scale spatial variability.

In summary, the available data on the concentrations of chemical substances demonstrates that both surficial and sub-surface sediments in the WBGCR-I have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants are sufficient to injure both surficial and sub-surface sediments. In addition, it is concluded that the sediment-dwelling organisms that depend on the critical aquatic habitats provided by sediments have been injured due to the presence of oil and hazardous substances, including metals, PAHs, and PCBs.

8.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1).

The concentrations of SEM and AVS were measured in nine sediment samples from the WBGCR-I. In four of these samples, the molar concentrations of SEM exceeded the molar concentrations of AVS. Elevated levels of metals in pore water are likely to be observed in sediments with these characteristics (Ankley *et al.* 1996). As such, pore water from WBGCR-I sediments could have levels of metals that exceed toxicity thresholds.

The concentrations of metals, phenols, and unionized ammonia have been measured in two pore water samples from the WBGCR-I (Table 8.3). The results of chemical analyses of these pore water samples indicate that lead, zinc, phenol, unionized ammonia, and sum toxic units were present at concentrations that exceeded either the 10-day LC_{50} for *Hyalella azteca* or the other acute toxicity thresholds reported for aquatic invertebrates (Table 8.3). The results of toxicity tests conducted on pore water from the WBGCR-I support the conclusion that the concentrations of contaminants are sufficiently elevated in pore water to cause or substantially contribute to sediment injury.

The available data on the concentrations of metals, phenols, and ammonia in pore water indicate that WBGCR-I sediments have been contaminated by oil or other hazardous substances. Comparison of these data to acute and estimated chronic toxicity thresholds demonstrates that the concentrations of these contaminants in pore water are sufficient to injure sediment-dwelling organisms. Therefore, it is concluded that WBGCR-I sediments have been injured due to the presence of toxic substances in pore water. In addition, it is concluded that the sediment-dwelling organisms that depend on habitats provided by surficial sediments have been injured due to the presence of toxic substances in pore water.

8.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediment, pore water, and/or elutriates provide critical information for assessing the effects of contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured by discharges of oil or releases of other hazardous substances.

In the WBGCR-I, two studies have been conducted to determine if sediments and associated pore waters are toxic to sediment-dwelling organisms or other aquatic species (Figure 8.3). In total, data are available on the toxicity of two sediment samples from the WBGCR-I (Table 8.4; Figure 8.10). The species and endpoints that were tested in these studies included amphipod (*Hyalella azteca*) survival, midge (*Chironomus tentans*) growth, cladoceran (*Daphnia magna* and *Ceriodaphnia dubia*) survival, and bacterial (*Vibrio fisheri*) bioluminescence (i.e., as a surrogate for metabolic rate). The results of these toxicity tests demonstrate that both sediment samples were toxic to one or more of the organisms that were tested. While sediments from the WBGCR-I would likely have been toxic more frequently had longer term tests (including sublethal endpoints) been employed, the results of the studies that have been conducted demonstrate that sediments from the WBGCR-I are acutely toxic to a variety of aquatic organisms, including sediment-dwelling species. Therefore, these results demonstrate that the condition of sediments and associated pore waters is sufficient to injure biological resources in the WBGCR-I, including sediment-dwelling species.

8.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998). For this reason, the available information on the status of benthic invertebrate communities was assembled and used to determine if discharges of oil or releases of other hazardous substances have caused or substantially contributed to sediment injury in the WBGCR-I.

Information from two studies was used to assess the status of benthic invertebrate communities in the WBGCR-I. In the first study, artificial substrate samplers were deployed at five sites on the WBGCR, including one site located east of Indianapolis Boulevard (Rainbolt 1993). The results of this study indicated that the benthic macroinvertebrate community was characterized by low species richness, gross dominance by a single taxon (chironomids) and an absence of EPT taxa (Table 8.5). As such, the benthic invertebrate community exhibited significant impairment relative to reference sites in Indiana (i.e., EPT represented < 0.5% of total invertebrate abundance).

In the second study, Simon *et al.* (2000) used artificial substrates to collect samples for assessing the status of the benthic invertebrate community at two locations on the WBGCR-I, including immediately east of Indianapolis Boulevard and at the confluence with the EBGCR. The results of this investigation indicated that the benthic invertebrate communities at these locations were dominated by pollution-tolerant species. Collectively, oligochaetes and chironomids represented 86% to 94% of the total abundance of benthic invertebrates at these stations (Table 8.5). Other dipteran species, leeches, gastropod mollusks, and bivalve mollusks comprised the majority of the other benthic invertebrates that were collected. Although EPT taxa were represented at one of these sites, these sensitive species accounted for a minor proportion (i.e., 0.2%) of the total abundance of benthic invertebrates. The mIBI score for these samples ranged from 0.53 to 0.87, indicating that the structure of benthic invertebrate communities was significantly altered (3 of 3 samples; 100%) relative to other locations in Indiana (i.e., # 2.93; the average mIBI score for Indiana is in the order of 3.5 ± 0.29; Simon *et al.* 2000; Table 8.5; Figure 8.4). Impacts on sediment-dwelling organisms are particularly important because invertebrates represent important food sources for fish and other wildlife species that utilize habitats in the WBGCR-I. The presence of altered benthic invertebrate communities provides confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that the environmental quality conditions in the WBGCR-I are sufficient to injure sediments and sediment-dwelling organisms.

8.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, TOC, and NH_3 can be used to determine the general status of aquatic habitats and their suitability for supporting aquatic life. For this reason, the available information on conventional indicators of environmental quality conditions was compiled and used to assess the status of benthic habitats in the WBGCR-I. Little information was located on the levels of DO or SOD in the WBGCR-I. Therefore, it was not possible to evaluate sediment quality conditions relative to these conventional indicators.

The available information indicates that the levels of TOC are elevated throughout the WBGCR-I (Table 8.6). In surficial sediments, the levels of TOC averaged 11% in this portion of the Assessment Area, with a range of 1.3% to 40.0% reported. Sub-surface sediments generally had lower levels of TOC than did surficial sediments. Overall, TOC levels ranged from 0.13% to 8.6% in sub-surface sediments, averaging 4.2%. By comparison, Lake Michigan sediments in the vicinity of IH had an average level of TOC of 0.5% (n=31; Table 13.6); the upper 95% CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b). Therefore, both surficial and sub-surface sediments in the WBGCR-I have received substantial inputs of organic matter relative to other contaminated sites in the Great Lakes basin.

Information on the levels of oil and grease in WBGCR-I sediments indicates that much of the TOC in these sediments are present in the form of oil and oil-related compounds. In surficial sediments, oil and grease levels ranged from 15,900 to 404,000 mg/kg (i.e., 1.6% to 40.4%; Table 8.7), averaging 18.1%. Oil and grease levels were lower in sub-surface sediments, ranging as high as 2.3% and averaging 0.69%.

In aquatic ecosystems, ammonia is excreted by aquatic organisms, formed during the decomposition of biological tissues and nitrogen-containing wastes, and/or released from anthropogenic sources. There are a variety of anthropogenic sources of ammonia, such as municipal and industrial wastewater discharges. Free ammonia can be present either as NH_3 or as NH_4^+ (depending on pH and temperature). Unionized ammonia is very toxic to aquatic life, with lethal thresholds as low as 0.1 mg/L reported in the literature (Thurston and Russo 1983; Thurston and Meyn 1984; Thurston *et al.* 1984). In the WBGCR-I, the concentrations of unionized ammonia have been measured in pore water samples (Hoke *et al.* 1993; USGS 1999). The concentrations of unionized ammonia were 0.07 mg/L and 6.4 mg/L (Table 8.3), the higher of which exceeded the acute toxicity threshold for aquatic invertebrates (0.53 mg/L; CCREM 1987). As such, the concentrations of unionized ammonia in pore water were sufficient to injure sediment-dwelling organisms in the WBGCR-I.

In 1992, Simon (1993) evaluated the status of aquatic habitats at one station located east of Indianapolis Boulevard. Subsequently (1998), Simon *et al.* (2000) evaluated the status of aquatic habitats at two stations in the WBGCR-I. In these investigations, data were collected on the characteristics of bottom substrates, instream cover, channel morphology, riparian zone and bank erosion, pool and riffle quality, and gradient at each sampling location. These data were then compiled to support the calculation of QHEI scores for each sampling location. The QHEI score calculated at the one station sampled in Simon (1993) was 65.5. The results of the Simon *et al.* (2000) study showed that QHEI scores were similar at the two sites (i.e., 49.7 near Indianapolis Boulevard and 48.6 at the confluence with the EBGCR). By comparison, OEPA (1988) reported that the mean (± SD) QHEI score for the ECBPs eco-region was 74 (± 13.1; the normal range of QHEI scores is 48 to 100). As such, aquatic habitats in the WBGCR-I were considered to be within the normal range of conditions at unimpacted sites in the ECBPs.

In summary, the available information indicates that aquatic habitats have been degraded in the WBGCR-I. In addition, the levels of TOC and associated oil and oil-related compounds are elevated in WBGCR-I sediments, even compared to other Areas of Concern in the Great Lakes. Furthermore, the levels of unionized ammonia in pore water from WBGCR-I sediments are sufficient to injure sediment-dwelling organisms. Therefore, the available information on conventional indicators of sediment quality conditions indicates that sediments in the WBGCR-I have been injured due to discharges of oil or releases of other hazardous substances.

8.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the WBGCR-I have been injured by discharges of oil or releases of other hazardous substances. More specifically, the data show that metals, PAHs, and total PCBs occur in whole sediments at concentrations that are sufficient to injure sediment-dwelling organisms. Calculated mean PEC-Qs exceed, often by a wide margin, the levels that are sufficient to injure sediment-dwelling organisms. The levels of metals, unionized ammonia, and phenol in pore water are also sufficient to cause toxicity to aquatic organisms. In addition, the results of toxicity tests confirm that whole sediments, and pore water are toxic to aquatic organisms. That benthic invertebrate communities in this reach of the river are significantly altered relative to reference sites provides further confirmatory evidence that environmental conditions in this reach of the Assessment Area are sufficient to injure sediments and associated biological resources. Together, these multiple lines of evidence demonstrate that sediments and associated biological resources have been injured as a result of discharges of oil or releases of other hazardous substances.

8.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g., epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey). These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

8.2.1 Toxicity of Sediments to Fish

No information was located on the toxicity of WBGCR-I sediments to fish. Therefore, it was not possible to directly evaluate environmental quality conditions in the WBGCR-I using this indicator.

8.2.2 Fish Health

In 1992, the USEPA conducted a study to evaluate the integrity of fish communities in the WBGCR (Simon 1993). In total, sampling was conducted at seven stations, with one of these stations located in the WBGCR-I (i.e., east of Indianapolis Boulevard). The results of this study showed that fish from this sampling station had a high incidence of DELT abnormalities (10.8%; Table 14.8), which included deformities, fin erosion, lesions, and tumors. The disfigurements that were observed included blindness and morphological alteration.

More recently, Simon *et al.* (2000) collected fish at two stations in the WBGCR-I. These stations were located east of Indianapolis Boulevard and at the confluence with the EBGCR and IHC. The results of this study indicated that the incidence of DELT abnormalities was elevated at both of these stations, with 2.8% and 6.2% of the fish showing signs of impaired health at the Indianapolis Boulevard and confluence stations, respectively. Therefore, the results of these surveys provide confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that the environmental quality conditions in the WBGCR-I are sufficient to injure sediments and associated sediment-dwelling organisms

8.2.3 Status of Fish Communities

The results of surveys of the status of fish communities provide relevant information for evaluating environmental quality in the WBGCR-I. Between 1985 and 1990, a number of surveys were conducted to evaluate the status of fish communities in the vicinity of Indianapolis Boulevard and the confluence with the EBGCR (Simon *et al.* 2000). The results of these surveys were interpreted using a modified IBI, which was originally developed by Karr (1981) and was subsequently calibrated for use in Indiana (Simon and Stewart 1998). At the Indianapolis Boulevard station, IBI scores averaged 13.6 and ranged from 0 to 24 (n=8 surveys). An IBI score of 22 was calculated for one sample from the confluence of the WBGCR-I with the EBGCR. In 1992, Simon (1993) calculated an IBI score of 29 for one station located in the WBGCR-I, east of Indianapolis Boulevard. The results of these investigations indicated that, while the WBGCR-I had the potential of providing a suitable habitat for healthy and diverse communities of warm-water fish, such communities were not present (Simon 1993). Rather, fish communities in this reach of the river were rated as "poor" to "very poor" or as having no fish, based on the calculated IBI scores (Table 14.9). Catches of indicator species groups were typically low, and benthic fish or sunfish were generally not present in the WBGCR-I.

The results of a more recent investigation confirm that fish communities have been impacted in the WBGCR-I. In 1998, Simon *et al.* (2000) conducted a follow-up survey of fish populations at the two stations that had been sampled previously (i.e., east of Indianapolis Boulevard and at the confluence with the EBGCR). Index of biotic integrity scores of 22 and 16, respectively, were reported for these two stations (Table 14.9). As such, the integrity of fish communities is still classified as "very poor" in this reach of the Assessment Area. Therefore, it is concluded that environmental conditions in the WBGCR-I are sufficient to adversely affect fish.

8.2.4 Bioaccumulation of Sediment-Associated Contaminants

In this report, the sediment quality criteria for the protection of wildlife (NYSDEC 1994) were used to assess the significance of sediment-associated chemicals of concern to piscivorus wildlife. Considering the sediment chemistry data that has been collected in the WBGCR-I, it is apparent that a variety of bioaccumulative substances are present in sediments at concentrations that pose potential hazards to wildlife species utilizing habitats within this reach of the river system. Specifically, the concentrations of total PCBs, chlordane, total DDTs, heptachlor and lindane that were measured in surficial sediments exceeded the levels that have been established to protect piscivorus wildlife species (Table 8.1). Therefore, it is apparent that a variety of bioaccumulative substances, including PCBs and various organochlorine pesticides, occur in whole surficial sediments at levels that are sufficient to result in the accumulation of these substances in invertebrate and fish tissues to concentrations that pose a risk to piscivorus wildlife.

Tissue residue guidelines provide another means of assessing the significance of bioaccumulative chemicals of concern to piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey; Newell *et al.* 1987). Comparison of tissue residue levels to fish flesh criteria for the protection of wildlife provides a basis for confirming if bioaccumulation represents a hazard to wildlife species. A total of seven fish tissues samples have been collected to determine the concentrations of tissue-associated contaminants in the WBGCR-I (Appendix 5.1, 5.3, and 5.5; Table 8.8). Two of these samples were collected at the confluence of the east and west branches of the GCR (i.e., the Junction) in 1982 (carp; whole fish), one sample was collected near Indianapolis Boulevard in 1986 (carp; whole fish), and four samples were collected near Indianapolis Boulevard in 1994 (three samples of carp; skin-on fillets, one sample of goldfish; whole fish). The results of these investigations indicated that total PCBs occurred in fish tissues at concentrations ranging from 3,600 to18,500 µg/kg WW. The levels of total chlordane and total DDTs ranged from 23 to 442 µg/kg WW and from 102 to 1,490 µg/kg WW. For PCBs, all seven samples had concentrations in excess of the level that has been established for the protection of piscivorus wildlife (i.e., 110 µg/kg WW; Newell *et al.* 1987). One of these samples had elevated levels of total chlordane and four of the samples had elevated levels of total DDTs (i.e., relative to the TRGs for the protection of wildlife; 370 µg/kg WW and 200 µg/kg WW, respectively). The levels of dieldrin + aldrin were also elevated in one sample. Therefore, it is concluded that total PCBs, and several organochlorine pesticides have accumulated in fish tissues to levels that are sufficient to cause or substantially contribute to sediment injury relative to piscivorus wildlife species utilizing habitats in the WBGCR-I.

8.2.5 Summary

Based on the information available from various studies, it is apparent that contaminated sediments pose substantial hazards to wildlife in the WBGCR-I. Contaminated sediments in the WBGCR-I are adversely affecting wildlife species in several ways. First, the results of sediment toxicity tests and benthic invertebrate community assessments suggest that surficial sediments in this reach of the river are unlikely to support healthy and diverse benthic invertebrate communities. Therefore, it is likely that the abundance of preferred fish food organisms has been reduced in the WBGCR-I. Second, the health of fish utilizing habitats in the WBGCR-I has been impaired. Fish populations inhabiting the WBGCR-I are also depressed relative to those that occur in uncontaminated areas of northern Indiana. Finally, the concentrations of sediment-associated and tissue-associated contaminants are known to exceed, often by wide margins, the levels that have been established to protect piscivorus wildlife species (e.g., herons, kingfishers, otter, mink or osprey). Therefore, it is concluded that injured sediments in the WBGCR-I are adversely affecting fish and wildlife resources utilizing habitats with the Assessment Area.

8.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in WBGCR-I sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of the report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially-contributing to effects on sediment-dwelling organisms) were identified from the list of chemicals of concern by comparing measured contaminant concentrations in whole sediments to the PECs (Table 8.1). The substances which occurred in WBGCR-I sediments at concentrations in excess of these chemical benchmarks were identified as contaminants of concern. The results of this evaluation indicate that metals (i.e., arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), PAHs (i.e., 13 individual PAHs and total PAHs), and PCBs occur in surficial sediments from the WBGCR-I at concentrations that are sufficient to injure sediment-dwelling organisms. While the concentrations of these substances tend to be lower in sub-surface sediments, most of the metals (i.e., arsenic, cadmium, copper, lead, mercury, and zinc), PAHs (i.e., 12 individual PAHs and total PAHs), and total PCBs are present in sub-surface sediments at concentrations that are sufficient to cause or substantially contribute to sediment injury. Importantly, the concentrations of cadmium, chromium, copper, nickel, lead, and zinc also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments. Several pesticides also occurred in WBGCR-I sediments at levels in excess of the PECs.

The concentrations of several chemicals of concern exceeded published toxicity thresholds, in pore water from WBGCR-I sediments (Table 8.3). Evaluation of the data reported in this study using the toxic units approach indicates that concentrations of lead, zinc, phenol, and unionized ammonia in pore water from WBGCR-I sediments were frequently at or above concentrations that have been shown to be toxic to aquatic organisms in standardized toxicity tests. The high detection limits achieved for many substances in the Hoke *et al.* (1993) study and the lack of published toxicity thresholds precluded the identification of other chemicals as contaminants of concern. The relative molar concentrations of SEM and AVS confirm that sediment-associated metals are likely to be available to sediment-dwelling organisms in many of these samples. Therefore, the toxic contaminants of concern in pore water are lead, zinc, and phenol, and unionized ammonia (Table 8.3).

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 8.1); and, (2) measured contaminant concentrations in tissues to the TRGs for the protection of piscivorus wildlife. The results of this evaluation indicate that total PCBs and several organochlorine pesticides (i.e., chlordane, total DDTs, heptachlor, and lindane) occurred in surficial sediments from the WBGCR-I at concentrations that are sufficient to cause or substantially contribute to effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). The available tissue residue data confirm that total PCBs, chlordane, total DDTs, and dieldrin + aldrin have accumulated in fish tissues to levels that pose risks to piscivorus wildlife (Table 8.8).

All of the contaminants of concern frequently exceeded the chemical benchmarks in WBGCR-I sediments. In addition, the concentrations of these substances in WBGCR-I sediments often exceeded the chemical benchmarks by substantial margins, frequently by more than a factor of 100. Therefore, NH_3, phenol, metals, PAHs, and PCBs are present in whole sediments from the WBGCR-I at concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and to adversely affect wildlife.

8.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury was determined by merging the various data sets that provided information on contaminant concentrations in WBGCR-I sediments. To support an evaluation of the spatial distribution of contaminants of concern, mean PEC-Qs were calculated for each of the sediment samples that were obtained from the WBGCR-I. The extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (i.e., each sample was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial and sub-surface sediments separately.

Based on the sediment chemistry data collected to date, it is apparent that surficial sediments throughout the WBGCR-I have been contaminated by oil or other hazardous substances. All 19 of the surficial sediment samples that have been collected between Indianapolis Boulevard and the confluence with the EBGCR, a distance of some 0.65 miles, had mean PEC-Qs $\geq$ 0.7 (Table 8.2; Figure 8.6 and 8.7). Mean PEC-Qs averaged 29.5 and ranged as high as 231 in the surficial sediment samples that were collected in this reach of the Assessment Area (Table 8.9).

Sub-surface sediments throughout the WBGCR-I have also been contaminated by oil or other hazardous substances. Of the 12 sub-surface sediment samples reflected in the project database, most of the samples (i.e., 75%; 9 of 12 samples) had chemical characteristics that were sufficient to cause or substantially contribute to sediment injury (i.e., mean PEC-Qs $\geq$ 0.7; Table 8.2). Such levels of contamination were evident in sub-surface sediments from throughout the stream reach (Figure 8.8 and 8.9). Mean PEC-Qs averaged 4.8 and ranged as high as 13.7 in this reach of the Assessment Area.

Based on the available sediment chemistry data, it is apparent that sediments throughout the WBGCR-I are likely to be toxic to sediment-dwelling organisms (Figure 8.10). To put the mean PEC-Q results into perspective, USEPA (2000a) reported that the probability of observing a 50% incidence of toxicity to amphipods in sediments occurred at a mean PEC-Q of $\geq$ 4.0 in 10-day acute tests and at a mean PEC-Q of $\geq$ 0.7 in 28-day chronic tests. Therefore, surficial sediments are expected to be frequently toxic to sediment-dwelling organisms (i.e., sediment samples from the WBGCR-I had mean PEC-Qs of up to 58 times the level that would result in a 50% probability of observing toxicity in 10-day tests, and up to 330 times the level that would result in a 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca*; Table 8.9; Figure 8.10; USEPA 2000a).

8.5 Summary

Based on eight lines of evidence, it is concluded that both surficial and sub-surface sediments from the WBGCR-I between Indianapolis Boulevard and the confluence with EBGCR have been injured by discharges of oil or releases of other hazardous substances. While surficial sediments tend to be the most contaminated, sub-surface sediments throughout this portion of the Assessment Area also have conditions that are sufficient to cause or substantially-contribute to sediment injury and injury to associated biological resources.

9.0 West Branch of the Grand Calumet River - II

The WBGCR extends some six miles from the confluence of the EBGCR and IHC in northwest Indiana to the confluence with the Little Calumet River in northeastern Illinois (Figure 1.1 and 1.2). Section 8.0 of the report provides an assessment of sediment injury in the WBGCR-I. This section of the report provides an assessment of sediment injury in the WBGCR-II. This reach extends some 5.4 miles from Indianapolis Boulevard to the confluence with the Little Calumet River.

From a hydrological perspective, this portion of the WBGCR is complicated. The river usually flows in a westerly direction from Columbia Avenue to the confluence of the Little Calumet River. However, the river can flow in either an easterly or a westerly direction between Columbia Avenue and Indianapolis Boulevard, depending on the water level in Lake Michigan (USACE 1995). Most of the flow in the river reach is derived from wastewater discharges from the Hammond Sanitary District WWTP; however, stormwater runoff and discharges from various CSOs also contribute significantly to the flow of the river during and following rain and snowmelt events.

There are a number of potential sources of contaminants to the WBGCR-II. First, there is one publically-owned treatment works that releases treated wastewater into the river system (i.e., Hammond Sanitary District WWTP; on average, 0.536 billion gallons per year). Both municipal (i.e., sewage and greywater) and industrial wastewaters are treated at this facility. In addition, there are a number of CSOs that are known to release oil and other hazardous substances into the river system (HNTB 1995), including the Columbia Avenue, Johnson Avenue, and Sohl Avenue CSOs. Calumet Flexicore Corporation and the Explorer Pipeline Company also have permits under the NPDES to discharge wastewater into this reach of the Assessment Area. There are also several historical discharges that have likely released oil or other hazardous substances into the WBGCR-II, such as the NIPSCO gasification plant (which is located near State Line Avenue), the National Briquette Corp. and Natural Recovery Systems facilities (which are located north of Roxana Marsh), the American Steel plant (which is located west of Columbia Avenue), and the Clark Oil and Refining plant (which is located east of Calumet Avenue). Other potential contaminant sources include discharges of contaminated groundwater and/or over-land runoff from various industrial facilities, and leaky pipeline crossings.

The present assessment is intended to evaluate injury to surface water and biological resources in the WBGCR-II that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the WBGCR-II includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the WBGCR-II are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the WBGCR-II are sufficiently contaminated to harm fish and wildlife resources. Sediments in the WBGCR-II were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury were determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support restoration planning within the Assessment Area.

9.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

9.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 84 surficial sediment samples from the WBGCR-II. The locations where these samples were collected are shown in Figure 9.1. The results of chemical analyses of these samples indicate that a large proportion of surficial sediments in the WBGCR-II have been contaminated by toxic substances (Table 9.1). For example, the concentrations of sediment-associated metals exceed the PECs in up to 88% of the samples (depending on the metal considered). Total PAH concentrations exceed the PEC in 82% (67 of 82 samples) of the samples in which these contaminants were measured. Total PCB concentrations also exceed the PEC in most (83%; 25 of 30 samples) of the samples in which these contaminants were quantified.

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the WBGCR-II, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments. The results of this evaluation indicate that 86% (72 of 84 samples) of the surficial sediment samples from this reach of the river have chemical characteristics that would classify them as injured (i.e., mean PEC-Qs $ 0.7; which is the chronic toxicity threshold for sediment-dwelling organisms). Most of the surficial sediment samples (i.e., 67%) that have been collected in this stream reach had mean PEC-Qs $ 4.0, which is the threshold for acute toxicity in sediment-dwelling organisms (Table 9.2). A total of 11 samples (13%) had mean PEC-Qs $0.1 to < 0.7, while only one sample had a mean PEC-Q of < 0.1.

Information on the chemical characteristics of 88 sub-surface sediment samples from the WBGCR-II is contained in the project database. The sampling sites where these sediments were collected are shown in Figure 9.2. Evaluation of the available sediment chemistry data indicates that sub-surface sediments in the WBGCR-II have also been contaminated by toxic substances, but not to the same extent as surficial sediments (Table 9.1). Relatively fewer sediment samples (i.e., up to 43%) have metal concentrations that exceeded the PECs (depending on the metal considered). However, most of these samples had total PAH (75%; 50 of 67 samples) concentrations exceed the PECs. Roughly 43% (i.e., 6 of 14) of the samples in which PCBs were measured had concentrations in excess of the PEC for total PCBs.

Based on the mean PEC-Qs that were calculated, it is apparent that sub-surface sediment samples in the WBGCR-II have been contaminated by toxic substances. Overall, 59 of the 88 (67%) sub-surface sediment samples that are reflected in the project database have mean PEC-Qs $ 0.7, thereby classifying them as injured (Table 9.2). Nearly half of the samples (49%; 43 of 88 samples) had mean PEC-Qs $ 4.0, which indicates that the concentrations of contaminants are sufficient to cause or substantially contribute to acute toxicity to sediment-dwelling organisms. A total of 22 samples (25%) had mean PEC-Qs $ 0.1 to < 0.7, while seven samples (8%) had mean PEC-Qs < 0.1. Overall, these data indicate that sub-surface sediments in the WBGCR-II are somewhat less contaminated than the surficial samples that have been collected in this stream reach.

In summary, the available data on the concentrations of chemical substances demonstrates that both surficial and sub-surface sediments in the WBGCR have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants are sufficient to injure sediments. In addition, it is concluded that the sediment-dwelling organisms that depend on the critical aquatic habitats provided by sediments have been injured due to the presence of toxic substances, including metals, PAHs, and PCBs.

9.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1).

Information from two studies is available to characterize the chemical composition of pore water from the WBGCR-II sediments. In one of these studies, the concentrations of divalent metals and AVS were measured in two sediment samples from the WBGCR-II (Hoke *et al.* 1993). In both of these samples the molar concentrations of divalent metals were lower than the molar concentrations of AVS. Sediments with these characteristics would not be predicted to have elevated levels of metals in pore water (Ankley *et al.* 1996). However, evaluation of the results of this study using this toxic units approach indicates that concentrations of zinc and the sum toxic units for metals in pore water from one sample exceeded the concentrations that have been shown to be toxic to aquatic organisms in 10-day acute toxicity tests (Table 9.3). The sum toxic units for metals in pore water ranged from 0.38 to 2.3 units in the two pore water samples that were collected from the WBGCR-II (Table 9.3). The detection limit for cadmium was too high to be able to interpret toxicity data relative to the published 10-day LC_{50} for *Hyalella azteca* (USEPA 1994; 2000b). In addition, phenol (256 to 326 mg/L) and unionized ammonia (0.38 to 8.02 mg/L) were present in one or more pore water samples at concentrations above the acute toxicity thresholds that have been reported for aquatic invertebrates (CCREM 1987; USEPA 1992a). The results of acute toxicity tests conducted with pore water from WBGCR-II sediments support the conclusion that contaminant concentrations in pore water were sufficiently elevated in WBGCR-II sediments to cause or substantially contribute to toxicity to sediment-dwelling organisms (i.e., crustaceans and bacteria; Hoke *et al.* 1993).

The available data on the concentrations of metals, phenols, and ammonia in pore water indicate that WBGCR-II sediments have been contaminated by oil or other hazardous substances. Comparison of these data to acute and estimated chronic toxicity thresholds demonstrates that the concentrations of these contaminants in pore water are sufficient to injure sediment-dwelling organisms. Therefore, it is concluded that WBGCR-II sediments have been injured due to the presence of toxic substances in pore water. In addition, it is concluded that the sediment-dwelling organisms that depend on habitats provided by surficial sediments have been injured due to the presence of toxic substances in pore water.

9.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediment, pore water, and/or elutriates provide critical information for assessing the effects of contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured by discharges of oil or releases of other hazardous substances.

In the WBGCR-II, four studies have been conducted to determine if sediments and associated pore waters are toxic to sediment-dwelling organisms or other aquatic organisms. In total, data are available on the toxicity of 18 sediment samples from the WBGCR-II (Figure 9.3). The species and endpoints tested in these four studies included amphipod (*Hyalella azteca*) survival and growth, midge (*Chironomus tentans*) survival and growth, cladoceran (*Daphnia magna* and *Ceriodaphnia dubia*) survival, fathead minnow (*Pimephales promelas*) survival, and bacterial (*Vibrio fisheri*) bioluminescence (i.e., as a surrogate for metabolic rate). Overall, 15 of the 18 (83%) sediment samples that were collected from the WBGCR-II were shown to be toxic to one or more species (Table 9.4; Figure 9.10). The incidence of sediment toxicity was 100% in every reach segment except Roxana Marsh (in which 25% of the samples were toxic). While sediments from the WBGCR-II would likely have been toxic more frequently had longer term tests (including sublethal endpoints) been employed, the results of the studies that have been conducted demonstrate that sediments and/or associated pore water from the WBGCR-II are acutely toxic to a variety of aquatic organisms, including sediment-dwelling species. Therefore, these results demonstrate that the condition of sediments and associated pore waters in the WBGCR-II is sufficient to injure sediments and associated organisms, including sediment-dwelling species.

9.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998). For this reason, the available information on the status of benthic invertebrate communities was assembled and used to determine if discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have caused or substantially contributed to sediment injury in the WBGCR-II.

Several surveys have been conducted to evaluate the status of benthic invertebrate communities in the WBGCR-II. The results of these surveys generally demonstrate that the benthic invertebrate community in the WBGCR-II has been degraded relative to uncontaminated sites in northern Indiana (Figure 9.4). Overall, 71% of the benthic invertebrate samples (10 of 14) that have been collected in the WBGCR-II have been altered relative to reference conditions in northern Indiana and Lake Michigan. The results of the various surveys that have been conducted are described below.

Benthic surveys were conducted in the WBGCR-II near Hohman Avenue in 1982 and again in 1986, using grab samplers, to assess temporal trends in benthic invertebrate community status (Polls *et al.* 1993). The results of both of these surveys demonstrate that this segment of the WBGCR-II (i.e., Hohman Avenue to State Line Avenue) was dominated by pollution-tolerant species, primarily oligochaete worms (97.9% to 99.8%), which exceeds the upper limit of the range of normal conditions for the Assessment Area (i.e., 3.0% to 73.6% for oligochaetes). Midges (chironomids) and leeches were also observed in the WBGCR-II sediments collected from this location in 1986. However, more sensitive organisms, such as amphipods and EPT taxa, were absent in WBGCR-II sediments in both years (Table 9.5). Polls *et al.* (1993) concluded that benthic community structure in the WBGCR-II remained poor from 1982 to 1986, as compared to other locations sampled in northern Indiana and in Lake Michigan.

In 1992, the USFWS collected benthic macroinvertebrate samples at four locations on the WBGCR-II using artificial substrate samplers (Table 9.5; Rainbolt 1993). These stations were located near Columbia Avenue, Calumet Avenue, Hohman Avenue, and Burnham

Avenue. The results of this study indicated that the benthic community was characterized by low species richness, lack of EPT taxa, and moderately high Family Biotic Index (FBI) scores (i.e., 6.0 to 6.09). Samples with FBI scores in this range are expected at sites with substantial levels of pollution, and the integrity of the invertebrate community at such sites would be rated as fairly poor (Hilsenhoff 1988).

In 1996, the IDEM collected samples of benthic invertebrates using artificial substrates at two locations on the WBGCR-II, including Indianapolis Boulevard and Sohl Avenue (IDEM 2000a, as presented in Simon *et al.* 2000). At the Indianapolis Boulevard site, pollution-tolerant species, such as oligochaetes and chironomids, were the most abundant taxa, collectively accounting for 77% of the total abundance of benthic invertebrates. Similar results were observed at the Sohl Avenue station (i.e., oligochaetes and chironomids collectively represented 80% of the total abundance). While gastropod mollusks and other dipterans were recorded at these stations, no mayflies, stoneflies, or caddisflies (i.e., EPT taxa) were reported at either of these stations. At these locations, mIBI scores averaged 1.1 to 1.7, which indicates that the benthic community has been degraded relative to other locations in Indiana (i.e., the average mIBI score for Indiana is in the order of 3.5 ± 0.29; Simon *et al.* 2000).

More recently (October 1998), ThermoRetec (1999) conducted a benthic survey in the vicinity of the NIPSCO coal gasification plant, which is located near Hohman Avenue. The results of this survey confirm that benthic invertebrate communities in this reach of the WBGCR-II have been degraded (Table 9.5). In total, three sites were sampled using grab samplers in this investigation. At two of the three locations that were sampled, oligochaetes and chironomids dominated the benthic invertebrate community (i.e., representing 80% to 95% of the benthic organisms that were collected). No mayflies, stoneflies, or caddisflies (i.e., EPT taxa) were reported at these stations. No sediment-dwelling organisms were present at the third site that was sampled (i.e., 0.2 miles west of Hohman Avenue). Based on the results of the Polls *et al.* (1993) and ThermoRetec (1999) studies, benthic invertebrate densities in the EBGCR-I portion of the river were much lower in 1998 than they were in either 1982 or 1986.

The portion of the WBGCR-II in the vicinity of Roxana Marsh was also sampled in 1998 to evaluate the status of benthic invertebrate communities (URS Greiner Woodward Clyde 1999). Two stations in Roxana Marsh and one station in the WBGCR-II were sampled using grab samplers as part of this investigation (Table 9.5). The results of this study showed that the densities of benthic invertebrates were generally lower in this portion of the WBGCR-II relative to the reference site (which was located in the Grant Street Marsh on the Little Calumet River). The samples that were collected in the WBGCR-II and Roxana Marsh were dominated by oligochaetes, representing 63% to 98% of the total abundance of benthic invertebrates. In two of the samples, the relative abundance of oligochaetes was outside the normal range for the Assessment Area. While some dipterans (including various chironomid species; representing 3% to 37% of the total abundance) were present in these samples, more sensitive species such as ostracods, amphipods, caddisflies, dragonflies and damselflies were absent.

The available information from the benthic surveys indicates benthic invertebrate communities have been altered in the WBGCR-II relative to reference conditions in northern Indiana and Lake Michigan. Impacts on sediment-dwelling organisms are particularly important because invertebrates represent important food sources for fish and other wildlife species that might inhabit the WBGCR-II. The presence of altered benthic invertebrate communities provides confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that the condition of sediments in the WBGCR-II is sufficient to injure sediments and sediment-dwelling organisms.

9.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, TOC, and NH_3 can be used to determine the general status of aquatic habitats and their suitability for supporting aquatic life. For this reason, the available information on conventional indicators of environmental quality conditions was compiled and used to assess the status of benthic habitats in the WBGCR-II. Little information was located on the levels of DO or SOD in the WBGCR-II. Therefore, it was not possible to evaluate sediment quality conditions relative to these conventional indicators.

Sediment oxygen demand of 3 to 5 g/m^2/day have been reported for sediments in the WBGCR-II (HydroQual, Inc. 1984; Brannon *et al.* 1989). The data collected more recently demonstrate that SOD in WBGCR-II sediments ranged from 1.5 to 11.3 g/m^2/day (Unger 1992). To put these measurements in perspective, sediments with SOD in excess of 10 g/m^2/day are classified as "sewage-sludge like," while sediments with SOD ranging from 5 to 10 g/m^2/day are classified as "grossly polluted" (Butts 1987). By comparison, sediments with SOD of less than 0.5 $g/m^2/day$ are classified as "clean" (Butts 1987). Using this classification system, sediments from the WBGCR-II are of variable quality, with some of the sediments having sewage-sludge like properties. Therefore, sediments of the WBGCR-II can have a very high demand for oxygen (Polls *et al.* 1993).

Considering the high SODs that have been reported, it is not surprising that low concentrations of DO have been observed in the WBGCR-II (Brannon *et al.* 1989). For example, data reported in Simmers *et al.* (1991) indicate that low DO levels were observed in the water column at numerous sites in the WBGCR-II (ranging from 0.6 to 4 mg/L). More recently, Simon (1993) reported concentrations of DO in the river ranging from 0.4 to 4.4 mg/L. By comparison, the water quality standard for DO is 4.0 mg/L for the protection of aquatic life (USEPA 1988).

The levels of TOC are elevated throughout the WBGCR II. In surficial sediments, the levels of TOC ranged from 5.8% to 27.4% between Indianapolis Boulevard and the I-90 toll road, with Roxana Marsh sediments having the highest levels of TOC (Table 9.6). The levels of TOC in surficial sediments tended to be lower in the western portion of this stream reach (i.e., from I-90 to the confluence with the Little Calumet River; ranging from 1.3% to 19.2%). In sub-surface sediments, the highest concentrations of TOC were observed between Columbia Avenue and Hohman Avenue, ranging from 0.4% to 25.3%. Sub-surface sediments in the vicinity of Roxana Marsh tended to have the lowest levels of TOC, with levels of 2.4% to 5.3% reported (Table 9.6). By comparison, the nearshore areas of Lake Michigan in the vicinity of IH had an average level of sediment-associated TOC of 0.5% (n=31; Table 13.6); the upper 95% CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b). Therefore, both surficial and sub-surface sediments in the WBGCR-II have received substantial inputs of organic matter relative to other contaminated sites in the Great Lakes basin. Although oil and grease measurements were not available for this reach of the Assessment Area, the measured levels of PAHs suggest that oil and oil-related compounds likely comprise at least a portion of the TOC in WBGCR-II sediments. For example, the maximum level of total PAHs that was measured in the Hohman Avenue to State Line Avenue reach segment was 13,800 mg/kg (or roughly 1.4%). By comparison, the maximum TOC level in this reach segment was 15% (Table 9.6). Therefore, oil and oil-related compounds represent 9.3% or more of the TOC in these sediments.

In aquatic ecosystems, ammonia is excreted by aquatic organisms, formed during the decomposition of biological tissues and nitrogen-containing wastes, and/or released from anthropogenic sources. There are a variety of anthropogenic sources of ammonia, such as municipal and industrial wastewater discharges. Free ammonia can be present either as NH_3 or as NH_4^+ (depending on pH and temperature). Unionized ammonia (NH_3) is very toxic to fish and other aquatic life, with lethal thresholds as low as 0.1 mg/L reported in the literature (Thurston and Russo 1983; Thurston and Meyn 1984; Thurston *et al.* 1984). CCREM (1987) reported an acute toxicity threshold of 0.53 mg/L for aquatic invertebrates. The concentrations of NH_3 in pore waters of sediments in the WBGCR ranged from 0.38 mg/L to 8.02 mg/L (Hoke *et al.* 1993; URS Greiner Woodward Clyde 1999; Table 9.3). Concentrations of NH_3 in overlying water ranged from 0.35 to 0.82 mg/L in samples from Roxana Marsh (Dorkin 1994). Water samples from Columbia Avenue and Torrence Avenue had 1.6 mg/L and 3.9 mg/L of NH_3, respectively (Dorkin 1994). These concentrations of ammonia in overlying water and in pore water of sediments in the WBGCR-II are high enough to cause mortality in cladoceran (*Daphnia magna*, *Ceriodaphnia dubia*) in amphipods (*Hyalella azteca*), and in fish (fathead minnows, *Pimephales promelas*; Hoke *et al.* 1993; Dorkin 1994; Besser *et al.* 1998).

Two surveys have been conducted to evaluate the status of physical habitats in the WBGCR-II. In 1992, a survey of aquatic habitat quality and fish community structure at six stations in the WBGCR-II was conducted by Simon (1993). The results of this study demonstrate that aquatic habitats have been lost or degraded due to inputs of sewage sludge into the WBGCR-II. Layers of sludge were observed blanketing submerged vegetation and inhibiting plant growth along the margins of the WBGCR-II. This layer of sludge blanketed macrophytes in the immediate vicinity of the Hammond Sanitary District WWTP and diminished further downstream from this location. Sections of the WBGCR-II from Columbia Avenue to Sohl Avenue contained islands of sludge, sanitary napkins, toilet paper, and cigarette butts. Simon (1993) reported that all the stations evaluated on the WBGCR-II have the potential for sustaining a diverse community of warm-water fish (i.e., QHEI scores ranged from 46 to 57.9, with all but one measurement falling within the normal range for the ECBPs eco-region; 48 to 100). In 1998, Simon *et al.* (2000) evaluated aquatic habitat quality at one station that produced similar results (i.e., QHEI score of 49.7). However, fish communities were virtually non-existent in the river (see Section 8.0). Simon (1993) concluded a limiting factor for habitat in the WBGCR-II was deposition of sludge that blanketed physical habitats that were otherwise capable of supporting communities of fish and aquatic invertebrates. In addition, high biochemical oxygen demand and SOD depleted oxygen from the sediment and the overlying water in the WBGCR-II. Low oxygen concentrations would also severely impact aquatic organisms, including fish. Overall, the results of this physical habitat survey (i.e., Simon 1993) demonstrate that aquatic habitats have been severely degraded in the WBGCR-II. Therefore, it is apparent that sediments and associated biological resources have been injured as a result of discharges of oil and other hazardous substances, including sewage sludge and municipal wastewaters, into the WBGCR-II.

In summary, the available information indicates that aquatic habitats have been degraded in the WBGCR-II. The levels of DO and SOD are indicative of a system that has been impacted by releases of organic matter. In addition, the levels of TOC are elevated in WBGCR-II sediments compared to other Areas of Concern in the Great Lakes. Furthermore, the levels of NH_3 in pore water from WBGCR-II sediments are sufficient to injure sediment-dwelling organisms. Therefore, the available information on conventional indicators of sediment quality conditions indicates that sediments in the WBGCR-II have been injured due to discharges of oil or releases of other hazardous substances.

9.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the WBGCR-II have been injured by discharges of oil or releases of other hazardous substances. More specifically, the data show that metals, PAHs, and PCBs occur in whole sediments at concentrations that are sufficient to injure sediment-dwelling organisms. Calculated mean PEC-Qs exceed, often by a wide margin, the levels that are sufficient to injure sediment-dwelling organisms. The levels of metals (zinc and sum toxic units), unionized ammonia, and phenol in pore water are also sufficient to cause toxicity to aquatic organisms. In addition, the results of toxicity tests confirm that whole sediments, pore water, and/or elutriates are toxic to aquatic organisms. That benthic invertebrate communities in this reach of the river are significantly altered relative to reference sites provides further confirmatory evidence that environmental conditions in the reach of the Assessment Area are sufficient to injure sediments and associated biological resources. Together, these multiple lines of evidence demonstrate that sediments and associated biological resources have been injured as a result of discharges of oil or releases of other hazardous substances.

9.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g., epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey). These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

9.2.1 Toxicity of Sediments to Fish

The effects of contaminated sediments on fish were evaluated by testing sediment elutriates from seven locations in the WBGCR using larval fathead minnows, *Pimephales promelas* (Table 9.7; Burton 1994). The results of these 10-day acute toxicity tests demonstrated that fathead minnows exposed to elutriates from WBGCR sediments had lower survival rates (survival ranged from 0% to 73.3% in the treatment groups from the seven locations) than those in the control treatment. These data indicate contaminant concentrations in sediments are sufficient to injure fish utilizing habitats within the WBGCR-II. Therefore, the results of these surveys provide confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that the environmental quality conditions in the WBGCR-II are sufficient to injure sediments and associated sediment-dwelling organisms

9.2.2 Fish Health

In 1992, the USEPA conducted a study to evaluate the integrity of fish communities in the WBGCR (Simon 1993). In total, sampling was conducted at seven stations in the WBGCR. The results of this study showed that the incidence of DELT abnormalities was 10.8% at the station located near Indianapolis Boulevard. In contrast, the fish collected between Indianapolis Boulevard and Columbia Avenue had a low incidence of DELT abnormalities (i.e., < 1.3% of the fish had deformities, fin erosion, lesions, or tumors). Simon (1993) indicated that most of these fish were young-of-the-year and, as such, had not been exposed to ambient conditions long enough to develop lesions or eroded fins. Likewise, the age structure and near absence of fish in the Illinois stations were the primary factors influencing the low incidence of DELT abnormalities. Simon (1993) indicated that the incidence of DELT abnormalities would likely increase as environmental conditions in the river improve because fish will be able to reach older ages and, as such, increase their exposure time to contaminated sediments.

More recently, Simon *et al.* (2000) collected fish at one station in the WBGCR-II. This station was located near Indianapolis Boulevard. The results of this study indicated that the incidence of DELT abnormalities was elevated at this station, with 2.8% of the fish showing signs of impaired health. Therefore, the results of these surveys provide confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that the environmental quality conditions in the WBGCR-II are sufficient to injure sediments and associated sediment-dwelling organisms

9.2.3 Status of Fish Communities

The results of surveys on the status of fish communities also provide relevant information for evaluating environmental quality in the WBGCR-II. Between 1985 and 1990, a number of surveys were conducted to evaluate the status of fish communities in the WBGCR-II (Simon 2000). The results of these surveys were interpreted using a modified IBI, which was originally developed by Karr 1981 and was subsequently calibrated for use in Indiana (Simon and Stewart 1998). During this period, a total of 11 surveys were conducted at various locations in the WBGCR-II, including near Indianapolis Boulevard, near the I-90 Bridge, and Columbia Avenue. At the Indianapolis Boulevard site, IBI scores ranged from 0 to 24 (n=8). At the I-90 Bridge, IBI scores of 24 were reported for two sampling dates. An IBI score of 0 (n=1) was reported for the Columbia Avenue sampling station. As such, fish communities in the WBGCR-II were largely classified as having “poor” to “very poor” integrity, or as having no fish.

In 1992, Simon (1993) collected fish from seven locations in the WBGCR to evaluate the status of fish communities. The results of this survey indicated that the integrity of the fish community was “poor” to “very poor” between near Indianapolis Boulevard and Torrence Avenue (IBI scores ranged from 12 to 24; n=4). No fish were observed at the Hohman Avenue site (n=1). The integrity of the fish community was rated as “very poor” at the station located in the Illinois segment of the river (the IBI score was 12 at Burnham Avenue).

In 1998, Simon *et al.* (2000) conducted a follow-up survey to evaluate the status of fish populations at Indianapolis Boulevard. Based on the results of this survey, an IBI score of 22 was calculated for this station. As such, it was concluded that the integrity of the fish community was “very poor” at this location. In addition, there is no evidence that the integrity of fish communities in the WBGCR-II have improved since the original surveys were conducted. Therefore, it is concluded that environmental conditions in the WBGCR-II are sufficient to adversely affect fish.

9.2.4 Bioaccumulation of Sediment-Associated Contaminants

In this report, the sediment quality criteria for the protection of wildlife (NYSDEC 1994) were used as chemical benchmarks for evaluating the ecological significance of sediment-associated contaminants in the WBGCR-II. Considering the sediment chemistry data that has been collected in the WBGCR-II, it is apparent that a variety of bioaccumulative substances are present in sediments at concentrations that pose potential hazards to wildlife species utilizing the WBGCR-II. Specifically, the concentrations of total PCBs, chlordane, total DDTs, heptachlor, and lindane in surficial sediments from the WBGCR-II exceed the levels that have been established to protect piscivorus wildlife species (Table 9.1). None of the chemicals of concern were elevated relative to the SQGs, in sub-surface sediments. Therefore, it is apparent that a variety of bioaccumulative substances, including PCBs and various organochlorine pesticides, occur in whole surficial sediments at levels that are sufficient to result in the bioaccumulation of these substances in invertebrates and fish tissues to concentrations that pose a risk to piscivorus wildlife.

Tissue residue guidelines provide another means of assessing the significance of bioaccumulative chemicals of concern to piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey; Newell *et al.* 1987). Comparison of tissue residue levels to fish flesh criteria for the protection of wildlife provides a basis for confirming if bioaccumulation represents a hazard to wildlife species. A total of five fish tissue samples have been collected in the vicinity of Indianapolis Boulevard on the WBGCR. In 1986, one sample of carp tissue (whole fish) was collected at this location. Another four tissue samples were collected in 1994, including three samples of carp tissues (skin-on fillets) and one sample of goldfish (whole fish). The results of chemical analyses of these tissue samples indicated that total PCBs exceeded the TRGs for the protection of piscivorus wildlife in all five samples, with concentrations ranging from 3,610 to 18,500 µg/kg WW. The levels of dieldrin + aldrin and of total DDTs were also elevated (i.e., relative to the TRGs) in one of the samples. Therefore, it is concluded that total PCBs and two organochlorine pesticides have accumulated in fish tissues to levels that are sufficient to cause or substantially contribute to injury to piscivorus wildlife species utilizing habitats in the WBGCR-II.

9.2.5 Summary

Based on the information available from various studies, it is apparent that contaminated sediments pose substantial hazards to wildlife in the WBGCR-II. Contaminated sediments in the WBGCR-II are adversely affecting wildlife species in several ways. First, alteration of benthic invertebrate communities has reduced the abundance of preferred fish food organisms. Second, elutriates from WBGCR-II sediments have been demonstrated to be severely toxic to fish. Third, fish health has also been impaired within this reach of the Assessment Area. Fish populations inhabiting the WBGCR-II are also severely depressed or absent. The concentrations of sediment-associated contaminants are known to exceed, often by wide margins, the levels that have been established to protect piscivorus wildlife species (e.g., herons, kingfishers, otter, mink or osprey). That PCBs and other substances have accumulated in fish tissues to levels that are hazardous to piscivorus wildlife has been confirmed by the available tissue residue data. Therefore, it is concluded that injured sediments in the WBGCR-II are adversely affecting fish and wildlife resources utilizing habitats with this reach of the Assessment Area.

9.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in WBGCR-II sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of this report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially-contributing to effects on sediment-dwelling organisms) in whole sediments were identified from the list of chemicals of concern by comparing measured contaminant concentrations in whole sediments to the PECs (Table 9.1). The substances which occurred in WBGCR-II sediments at concentrations in excess of these chemical benchmarks were identified as contaminants of concern. The results of this evaluation indicate that metals (arsenic, cadmium, copper, lead, mercury, nickel, and zinc), PAHs (i.e., 13 individual PAHs and total PAHs), and PCBs are present in both surficial and sub-surface sediments from the WBGCR-II at concentrations that are sufficient to injure sediment-dwelling organisms. However, the concentrations of metals tend to be lower in sub-surface sediments than they are in surficial sediments. Importantly, the concentrations of cadmium, chromium, copper, nickel, lead, and zinc also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments. Several pesticides also occurred in WBGCR-II sediments at levels in excess of the PECs.

The concentrations of several contaminants of concern exceeded published toxicity thresholds in pore water from WBGCR-II sediments (Table 9.3). Evaluation of the available data indicates that the concentrations of zinc, phenol, and unionized ammonia were frequently at or above concentrations that have been shown to be toxic to aquatic organisms. The high detection limits achieved for several substances and the lack of published toxicity thresholds precluded the identification of other chemicals as the toxic contaminants of concern in pore water.

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 9.1); and, (2) measured contaminant concentrations in tissues to the TRGs for the protection of piscivorus wildlife. The results of this evaluation indicate that total PCBs, chlordane, total DDTs, heptachlor, and lindane occurred in surficial sediments from the WBGCR-II at concentrations that are sufficient to cause or substantially contribute to effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). The available tissue residue data confirm that total PCBs and various organochlorine pesticides have accumulated in fish tissues to levels that pose risks to piscivorus wildlife.

All of these contaminants of concern frequently exceed the chemical benchmarks in WBGCR-II sediments. In addition, the concentrations of these substances in WBGCR-II sediments exceed the chemical benchmarks by substantial margins, frequently by more than a factor of 100. Therefore, NH_3, phenol, metals, PAHs and PCBs are present in whole sediments from the WBGCR-II at concentrations that are in excess of concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and/or to adversely affect wildlife.

9.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury was determined by merging the various data sets that provided information on contaminant concentrations in WBGCR-II sediments. To support an evaluation of the spatial distribution of contaminants of concern, mean PEC-Qs were calculated for each of the sediment samples obtained from the WBGCR-II. The extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (each sample was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial and sub-surface sediments separately.

Based on the sediment chemistry data that have been collected to date, it is apparent that surficial sediments throughout the WBGCR-II have been contaminated by oil or other hazardous substances (Figures 9.6 and 9.7). A total of 19 surficial sediment samples have been collected between Indianapolis Boulevard and the I-90 toll road including Roxana Marsh; 11 of these samples (58%) had mean PEC-Qs $ 0.7 (Table 9.2). The least contaminated samples were obtained from Roxana Marsh; none of the five samples from this reach segment had mean PEC-Qs $ 0.7. Surficial sediments from the eastern portions of this stream reach (i.e., east of the I-90 toll road) tend to be more contaminated than those from the western portion of the WBGCR-II. For example, most of the samples collected between the I-90 toll road and Hohman Avenue (i.e., 88%; 29 of 33 samples) had chemical concentrations that were sufficient to cause or substantially-contribute to sediment injury (i.e., mean PEC-Q of $ 0.7; Table 9.2). All of the samples (i.e., 100%; 21 of 21) collected in the vicinity of and downstream of the NIPSCO coal gasification plant (i.e., between Hohman Avenue and State Line Avenue) had mean PEC-Qs $ 0.7. The Illinois portion of the WBGCR-II was also found to contain contaminated sediments, with mean PEC-Qs $ 0.7 in all 11 sediment samples that were collected in this area. Therefore, surficial sediments throughout the WBGCR-II, excluding Roxana Marsh, are sufficiently contaminated with oil or other hazardous substances to cause or substantially contribute to sediment injury.

In general, sub-surface sediments in the WBGCR-II tend to be less contaminated than surficial sediments (Figure 9.8 and 9.9). For example, none of the 15 sub-surface sediment samples that were collected east of the I-90 toll road had mean PEC-Qs $ 0.7 (Table 9.2). In contrast, 31 of the 41 (i.e., 76%) sediment samples that were collected between the I-90 toll road and Hohman Avenue had chemical characteristics that were sufficient to injure sediment-dwelling organisms (i.e., mean PEC-Qs $ 0.7). A higher proportion of sub-surface sediment samples (i.e., 92%; 23 of 25 samples) from the Hohman Avenue to State Line Avenue portion of the river had mean PEC-Qs $ 0.7. Mean PEC-Qs in the Illinois portion of the river were $ 0.7 in 5 of the 7 sub-surface sediment samples (71%) that have been collected. Therefore, sub-surface sediments from the I-90 toll road to the confluence with the Little Calumet River are sufficiently contaminated with oil or other hazardous substances to cause or substantially contribute to sediment injury.

Based on the available sediment chemistry data, it is apparent that WBGCR-II sediments are likely to be toxic to sediment-dwelling organisms. To put the mean PEC-Q results into perspective, USEPA (2000a) reported that the probability of observing a 50% incidence of toxicity to amphipods in sediments occurred at a mean PEC-Q of $ 4.0 in 10-day acute tests and at a mean PEC-Q of $ 0.7 in 28-day chronic tests. Therefore, surficial sediments would be expected to be frequently toxic to sediment-dwelling organisms (i.e., sediment samples from the WBGCR-II had mean PEC-Qs of up to 76 times the level that would result in a 50% probability of observing toxicity in 10-day tests and up to 434 times the level that would result in a 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca*; USEPA 2000a).

The data on other indicators of sediment quality conditions support the results of the evaluation of the areal extent of injury that was conducted using the mean PEC-Qs. For example, sediments and/or elutriates from Roxana Marsh, Molsberger Place, Columbia Avenue, Sohl Avenue, State Line Avenue, and Torrence Avenue are known to be toxic to fish and invertebrates (Section 9.1.3), with sediments from the Torrence Avenue and Roxana Marsh locations being the least toxic of the samples tested (Table 9.7; Figure 9.10). In addition, the results of benthic invertebrate community assessments conducted between Indianapolis Boulevard and Hohman Avenue (including Roxana Marsh) demonstrate that benthic communities have been degraded (Polls *et al.* 1993; URS Greiner Woodward Clyde 1999; ThermoRetec 1999; IDEM 2000; Rainbolt 1993). Furthermore, benthic habitats from Columbia Avenue to Sohl Avenue have been severely degraded by discharges of sewage sludge (Simon 1993). Taken together, these ancillary data confirm that sediments located from the western portion of Roxana Marsh to the confluence with the Little Calumet River have been injured.

9.5 Summary

Based on eight lines of evidence, it is concluded that both surficial and sub-surface sediments from the WBGCR-II have been injured. With the exception of portions of Roxana Marsh, sediments from Indianapolis Boulevard to the confluence with the Little Calumet River have been injured as a result of discharges of oil and releases of other hazardous substances. While surficial sediments tend to be the most contaminated, sub-surface sediments throughout the majority of this sub-area have conditions that are sufficient to cause or substantially contribute to sediment injury and injury to associated biological resources.

10.0 Indiana Harbor Canal

The IHC reach extends approximately 1.5 miles from the confluence of the WBGCR and EBGCR reaches (i.e., the Junction) north to Columbus Drive. The IHC has been divided into four reach segments to facilitate this assessment, including three segments within the main channel. These segments extend from the Junction to 151st Street, from 151st Street to Chicago Avenue, and from Chicago Avenue to Columbus Drive. The IHC reach also includes the IHC wetlands east of the main channel (Figure 1.1 and 1.2).

There are a number of potential sources of contaminants to the IHC. First, there are a variety of industrial facilities that discharge or have historically discharged wastewater to the canal via NPDES permitted outfalls, including Buckeye Pipeline Company, Union Tank Car Company, Blaw-Knox Foundry and Mill, Energy Cooperative, Praxair, Inc., Phillips Pipeline Company, and Mobile Oil Corp. While some of these outfalls discharge directly to IHC, others are located off channel. Other potential contaminant sources include discharges of contaminated groundwater and/or over-land runoff from various industrial facilities, leaky pipeline crossings, and downstream transport of contaminated water and/or sediments from upstream areas.

The present assessment is intended to evaluate injury to surface water and biological resources in the IHC that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the IHC includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the IHC are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the IHC are sufficiently contaminated to harm fish and wildlife resources. Sediments in the IHC were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury were determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support restoration planning within the Assessment Area.

10.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

10.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 30 surficial sediment samples from the IHC (Table 10.1). The locations where these samples were collected are shown in Figure 10.1. The results of chemical analyses of these samples indicate that a large proportion of surficial sediments in the IHC have been contaminated by oil or other hazardous substances (Table 10.1). For example, the concentrations of sediment-associated metals exceed the PECs in up to 77% of the samples (depending on the metal that is considered). Total PAH concentrations exceed the PEC in 74% (20 of 27 samples) of the samples in which these contaminants were measured. Total PCB concentrations also exceed the PEC in most (84%; 21 of 25 samples) of the surface samples in which these contaminants were quantified.

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the IHC, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments (Table 10.2, Figures 10.6 and 10.7). The results of this evaluation indicate that 90% (27 of 30 samples) of the surficial sediments equaled or exceeded the chronic PEC-Q of 0.7 and 50% (15 of 30 samples) of the surficial sediments equaled or exceeded the acute PEC-Q of 4.0. These data indicate that most of the surficial sediments from this reach of the river are likely to be toxic to sediment-dwelling organisms. A total of 40% of the sediment samples from the IHC had chemical characteristics that were between the chronic mean PEC-Q of ≥ 0.7 and acute mean PEC-Q of < 4.0. In the IHC reach, none of the surface samples had a mean PEC-Q of < 0.1 and only 10% of the surface samples had a mean PEC-Q of ≥ 0.1 to < 0.7. The chemistry of the samples collected prior to 1996 were consistent with the chemistry of the samples that were collected in 1996 and later (Table 10.2). Concentrations of contaminants were lower in the IHC wetlands compared to samples collected from the main canal of the IHC reach. Samples with mean PEC-Q of ≥ 0.7 or a mean PEC-Q of ≥ 4.0 were distributed throughout the main canal of the IHC reach.

Information on the chemical characteristics of sub-surface sediments has been reported for only six samples from the IHC (Figure 10.2). Evaluation of the available sediment chemistry data indicate that sub-surface sediments in the IHC have also been contaminated by oil or other hazardous substances (Table 10.1). The concentrations of sediment-associated metals exceed the PECs in up to 75% of the samples (depending on the metal considered). Total PAH concentrations exceed the PEC in 83% (5 of 6 samples) of the samples in which these contaminants were measured. Total PCB concentrations also exceed the PEC all three of the sub-surface samples in which these contaminants were quantified. Pesticides were reported in only two sub-surface samples from the IHC.

Based on the mean PEC-Qs that were calculated, it is apparent that sub-surface sediment samples in the IHC have been contaminated by oil or other hazardous substances (Table 10.2; Figures 10.8 and 10.9). Overall, 83% (5 of 6 samples) of the sub-surface sediments equaled or exceeded the chronic PEC-Q of 0.7 and 50% (3 of 6 samples) of the sub-surface sediments equaled or exceeded the acute mean PEC-Q of 4.0. Hence, most of the sub-surface sediments from this reach of the river have chemical characteristics that are sufficient to cause or substantially contribute to sediment injury. A total of 33% of the sediment samples from the IHC had chemical characteristics that were between the chronic mean PEC-Q of ≥ 0.7 and acute mean PEC-Q of < 4.0. In the IHC reach, none of the sub-surface samples had a mean PEC-Q of < 0.1, and only 17% of the sub-surface samples had a mean PEC-Q of ≥ 0.1 to < 0.7.

In summary, the available data on the concentrations of chemicals in sediment demonstrates that both surficial and sub-surface sediments in the IHC have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants are sufficient to injure sediments. In addition, it is concluded that the biological resources that depend on the critical aquatic habitats provided by surficial sediments have been injured due to the presence of oil or other hazardous substances, including metals, PAHs, and PCBs.

10.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1). The concentrations of SEM and AVS were measured in 10 sediment samples from the IHC. In 90% of these samples, the molar concentrations of SEM exceeded the molar concentrations of AVS. The concentrations of divalent metals exceeded the concentrations of SEM, on a molar basis, in one additional sample from this reach (Hoke *et al.* 1993). Elevated levels of metals in pore water are likely to be observed in sediments with SEM>AVS (Ankley *et al.* 1996). As such, pore water from IHC sediments could have levels of metals that exceed toxicity thresholds.

Concentrations of metals and/or unionized ammonia (NH_3) in pore water from IHC sediments were reported from five sampling locations (Table 10.3). The concentrations of metals were elevated in two of these five samples (i.e., copper, lead, or zinc levels exceed the thresholds that have been shown to be toxic to the amphipod *Hyalella azteca* in 10-day acute tests). The sum toxic units for metals in these two samples were 1.73 and 3.2, which indicated that there were sufficient concentrations of metals in these samples to cause or contribute to toxicity. The detection limit for cadmium was too high in two of the samples to be able to interpret the pore water concentrations relative to the published 10-day LC_{50} for *H. azteca* (Table 10.3). The concentration of NH_3 in pore waters of sediments in the IHC was reported for four samples. The concentrations of NH_3 in two of these samples were 1.0 and 1.6 mg/L, which both exceed the acute lethal effect concentration reported for freshwater invertebrates (CCREM 1987).

The results of this evaluation indicate that concentrations of contaminants in pore water samples from the IHC are sufficiently elevated to cause or substantially contribute to acute and chronic toxicity to sediment-dwelling organisms. The results of toxicity tests conducted with pore water samples support the conclusion that concentrations of contaminants were sufficiently elevated in IHC sediments to cause or substantially contribute to sediment injury (Section 10.1.3).

10.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediment, pore water, and/or elutriates provide critical information for assessing the effects of contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured by discharges of oil or releases of other hazardous substances.

In the IHC, four studies have been conducted with sediment samples to determine if sediments and associated pore water are toxic to sediment-dwelling organisms or other aquatic species (Table 10.4; Figure 10.3). In total, data are available on the toxicity of five sediment samples from the IHC. The species and endpoints that were tested in these studies included cladoceran (*Daphnia magna* and *Ceriodaphnia dubia*) survival, midge *(Chironomus tentans*) growth, amphipod (*Hyalella azteca*) survival and growth, and bacterial bioluminescence (*Vibrio fisheri;* i.e., as a surrogate for bacterial metabolic rate). Overall, 80% of the five samples that were collected from the IHC were shown to be toxic to one or more species (Figure 10.10). All of the samples tested from the main canal of the IHC reach were identified as toxic. One sample from the IHC wetlands was not toxic to amphipods in a 10-day test. While sediments from the IHC would likely have been toxic more frequently had longer term tests (including sublethal endpoints) been employed, the results of the studies that have been conducted demonstrate that sediments and/or associated pore water from the main canal of the IHC are acutely toxic to a variety of aquatic organisms, including sediment-dwelling species. Therefore, the results of these toxicity tests demonstrate that conditions of sediments and associated pore waters in the IHC are sufficient to injure sediments and associated biological resources, including sediment-dwelling species.

10.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998). For this reason, the available information on the status of benthic invertebrate communities was assembled and used to determine if discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have caused or substantially contributed to sediment injury in the IHC.

Two grab samples have been collected for assessing the status of benthic invertebrate communities inhabiting sediments in the IHC reach (Table 10.5; Figure 10.4; Polls *et al.* 1993). The results of this survey indicate that benthic invertebrate communities in the IHC are dominated by pollution-tolerant species. Over 99% of the major benthic taxa in these samples were oligochaetes, with leeches or mollusks occasionally observed. The oligochaetes were predominantly pollution-tolerant tubificids. More sensitive organisms, such as mayflies, stoneflies, caddisflies (i.e., EPT taxa), and amphipods were absent from these IHC sampling stations. For both grab samples, the relative abundance of oligochaetes exceeded the upper limit of the range of normal conditions in this Assessment Area (i.e., 3.0% to 73.6% for oligochaetes). Therefore, both grab samples from the IHC were considered to have conditions that were sufficient to cause or substantially contribute to injury to sediment-dwelling organisms (i.e., an altered benthic invertebrate community).

Simon *et al.* (2000) evaluated benthic invertebrate samples collected from four stations in the IHC reach using multi-plate artificial substrate samplers. The mIBI score for these samples ranged from 0.53 to 1.13, indicating that the structure of benthic invertebrate communities was significantly altered relative to other locations in Indiana (i.e., # 2.93; the average mIBI score for Indiana is in the order of 3.5 $\pm$ 0.29; Simon *et al.* 2000). The benthic invertebrate community was dominated by pollution-tolerant oligochaetes and chironomids, with pollution-sensitive EPT taxa representing # 0.15% of the total abundance. Artificial substrate samples containing < 0.5% EPT taxa were considered to be indicative of conditions that are sufficient to injure sediment-dwelling organisms (Simon *et al.* 2000). A higher percentage of midges were reported in samples collected from the artificial substrates compared to the grab samples that were collected previously. Swift *et al.* (1996) also observed that artificial substrates tended to be colonized by a higher proportion of non-oligochaete taxa compared to grab samples collected from sediments. Simon *et al.* (2000) concluded that the samples collected from the IHC showed extremely poor benthic invertebrate communities, with a lack of sensitive taxa. Simon *et al.* (2000) also concluded that the lack of sensitive benthic invertebrate species is directly the result of contaminated sediments and the highly toxic conditions that limit colonization.

The available information indicates that benthic invertebrate communities have been altered in the IHC relative to reference conditions in northern Indiana and Lake Michigan (i.e., in 6 of 6 samples; Table 10.5). Impacts on sediment-dwelling organisms are particularly important because invertebrates represent important food sources for fish and other wildlife species that might inhabit the IHC. Therefore, the results of these benthic community surveys provide confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that conditions of sediments in the IHC are sufficient to injure sediments and sediment-dwelling organisms.

10.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, TOC, and NH_3, provide important information for the general status of aquatic habitats and their suitability for supporting aquatic life. For this reason, the available information on conventional indicators of environmental quality conditions was compiled and used to assess sediment injury in the IHC. No information was located on the levels of DO or SOD in the IHC.

Therefore, it was not possible to evaluate sediment quality conditions relative to these conventional indicators.

The available data indicate that the levels of TOC are elevated in the IHC (Table 10.6). In surficial sediments, the concentration of TOC averaged 3.5% and ranged from 0.51% to 14.7% (excluding the IHC wetland). The TOC in one sediment sample from the IHC wetland was 13%. In sub-surface sediments, the levels of TOC ranged from 0.95% to 11.5%, with a mean of 4.1% reported. By comparison, Lake Michigan sediments in the vicinity of the IH had an average level of TOC of 0.5% (n=31); the upper 95% CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b). Therefore, both surficial and sub-surface sediments in the IHC have received substantial inputs of organic matter relative to other contaminated sites in the Great Lakes basin. Based on measurements of oil and grease, it is apparent that oil and oil-related compounds likely comprise much of the TOC in IHC sediments. The maximum concentration of oil and grease in surficial sediments was 54,800 mg/kg (or 5.48%; Table 10.7). As such, oil and grease could account for a substantial proportion of the TOC in these sediments.

In aquatic ecosystems, ammonia is excreted by aquatic organisms, formed during the decomposition of biological tissues and nitrogen-containing wastes, and/or released from anthropogenic sources. There are a variety of anthropogenic sources of ammonia, such as municipal and industrial wastewater discharges. Free ammonia can be present either as NH_3 or as NH_4^+ (depending on pH and temperature). Unionized ammonia (NH_3) is very toxic to aquatic life, with lethal thresholds as low as 0.1 mg/L reported in the literature (Thurston and Russo 1983; Thurston and Meyn 1984; Thurston *et al.* 1984). The concentration of NH_3 in pore waters of sediments in the IHC was reported for four samples (Section 10.1.2; Table 10.3). The concentrations of NH_3 in two of these samples were 1.0 and 1.6 mg/L.

In 1998, Simon *et al.* (2000) evaluated the status of aquatic habitats at three stations in the IHC reach. In this investigation, data was collected on the characteristics of bottom substrates, instream cover, channel morphology, riparian zone and bank erosion, pool and riffle quality, and gradient at each sampling location. These data were then compiled to support the calculation of QHEI scores for each sampling location. The results of this study showed that QHEI scores ranged from 24 to 48.6 at these three stations in the IHC.

By comparison, OEPA (1988) reported that the mean (± SD) QHEI score for the ECBPs was 74 (± 13.1; normal range is 48 to 100). Additionally, the IDEM (2000c) has established use support assessment criteria for streams in Indiana. These criteria indicated that use impairment is likely to occur when QHEI scores are < 64. As such, aquatic habitats in the IHC reach were considered to be degraded relative to unimpacted sites in the ECBPs.

In summary, the available information indicates that aquatic habitats have been degraded in the IHC. In addition, high levels of TOC (and associated oil and grease) and elevated concentrations of ammonia would exacerbate the effects of lost habitat for fish and invertebrates in the river. Therefore, the available information on conventional indicators of sediment quality conditions indicates that sediments in the IHC reach have been injured due to discharges of oil or other hazardous substances.

10.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the IHC have been injured by discharges of oil or releases of other hazardous substances. More specifically, the data show that metals, PAHs, and total PCBs occur in whole sediments at concentrations that are sufficient to injure sediment-dwelling organisms. Calculated mean PEC-Qs exceed, often by a wide margin, the levels that are sufficient to injure sediment-dwelling organisms. The levels of metals, unionized ammonia, and/or phenol in pore water are also sufficient to cause toxicity to aquatic organisms. In addition, the results of toxicity tests confirm that whole sediments and/or pore water are toxic to aquatic organisms. That benthic invertebrate communities in this reach of the river are significantly altered relative to reference sites provides further confirmatory evidence that environmental conditions in the reach of the Assessment Area are sufficient to injure sediments and associated biological resources. Together, these multiple lines of evidence demonstrate that sediments and associated biological resources have been injured as a result of discharges of oil or releases of other hazardous substances.

10.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g., epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey). These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

10.2.1 Toxicity of Sediments to Fish

No information was located on the toxicity to fish of whole sediments, pore water, or elutriates from the IHC. Therefore, it was not possible to directly evaluate environmental quality conditions in the IHC using this indicator.

10.2.2 Fish Health

In 1998, Simon *et al.* (2000) conducted an investigation to evaluate the status of fish communities, including fish health, in the IHC. Fish were collected at three stations in the IHC (including the confluence with the east and west branches of the GCR, 151st Street, and Columbus Drive) and examined for the presence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). The results of this study indicated that the incidence of DELT abnormalities was 6.15%, 0%, and 0.36% at these three stations, respectively. As such, these data show that fish health has been adversely affected by ambient environmental conditions at one station in the IHC. Therefore, the results of these surveys provide confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that the environmental quality conditions in the IHC are sufficient to injure sediments and associated sediment-dwelling organisms

10.2.3 Status of Fish Communities

The results of surveys of the status of fish communities can provide relevant information for evaluating environmental quality in the IHC. Simon *et al.* (2000) reported the results of fish community surveys that were conducted between 1985 and 1990 (i.e., using the IBI as the primary tool for assessing the integrity of fish communities; Karr 1981; Simon and Stewart 1998). Based on the results of one survey, conducted in 1987, fish communities in this reach would be classified as having "very poor" integrity (and an IBI score of 22 was calculated; Table 14.9). In 1998, Simon *et al.* (2000) conducted a follow-up survey that included three stations in the IHC reach. The results of this survey indicated the fish communities in the Assessment Area generally reflected "very poor" biological integrity relative to fish communities expected for northwestern Indiana and the Central Corn Belt Plains (CCBPs) eco-region. The IBI scores for the three stations in the IHC reach ranged from 12 to 20.

10.2.4 Bioaccumulation of Sediment-Associated Contaminants

In this report, the sediment quality criteria for the protection of wildlife (NYSDEC 1994) were used as chemical benchmarks for evaluating the ecological significance of sediment-associated contaminants in the IHC. Considering the sediment chemistry data that has been collected in the IHC, it is likely that a variety of bioaccumulative substances are present in sediments at concentrations that pose potential hazards to wildlife species utilizing the IHC. Specifically, the concentrations of total PCBs, chlordane, total DDTs, heptachlor, and lindane in surficial sediments and concentrations of total PCBs in sub-surface sediments exceeded the levels that have been established to protect piscivorus wildlife species (Table 10.1). Therefore, it is concluded that concentrations of PCBs and other bioaccumulative substances occur in the IHC sediments at levels that are sufficient to result in bioaccumulation of these substances in fish and invertebrate tissues to concentrations that pose a risk to piscivorus wildlife.

Comparison of tissue residue levels to fish flesh criteria for the protection of wildlife provides a means of confirming that bioaccumulation of sediment-associated contaminants in the tissues of fish and/or invertebrates represents a hazard to wildlife species. Recently, USFWS (2000) collected bivalve mollusks (*Corbicula fluminea*) at several locations in the IHC. The results of chemical analyses of these samples indicated that the concentrations of PCBs exceeded the TRG for the protection of piscivorus wildlife in all five samples from this reach (Table 10.8; Figure 10.5). None of the pesticides were detected in bivalve tissues at levels in excess of the TRGs, however (Newell *et al.* 1987). The significance of measured levels of metals and PAHs in these tissues could not be evaluated due to the absence of applicable TRGs.

Information on the levels of bioaccumulative substances was available for two fish tissue samples from the IHC. These samples of carp tissues (whole fish) had elevated levels of total PCBs (4,630 to 12,500 µg/kg), total chlordane (273 to 442 µg/kg), and total DDTs (494 to 1,490 µg/kg). These results show that total PCBs, total DDTs, and chlordane were present in whole fish at levels that posed a risk to piscivorus wildlife (i.e., in excess of the TRGs presented in Table 3.4). Therefore, it is concluded that total PCBs, total DDTs, and chlordane have accumulated in the tissues of fish and/or invertebrates to levels that are sufficient to cause or substantially contribute to sediment injury relative to piscivorus wildlife species.

10.2.5 Summary

Based on the information available from various studies, it is likely that contaminated sediments pose substantial hazards to wildlife in the IHC. There were insufficient data to determine if sediments were directly toxic to fish in the IHC reach. Nevertheless, contaminated sediments in the IHC are likely to be adversely affecting wildlife species in several ways. First, alteration of benthic invertebrate communities has reduced the abundance of preferred fish food organisms. Second, fish health and fish communities have been shown to be impaired relative to uncontaminated reference sites. Third, the concentrations of sediment-associated contaminants are known to exceed, often by wide margins, the levels that have been established to protect piscivorus wildlife species (e.g., herons, kingfishers, otter, mink or osprey). Fourth, the available tissue residue data confirm that PCBs and several other substances pose a risk to piscivorus wildlife.

Therefore, it is concluded that injured sediments in the IHC are adversely affecting fish and wildlife resources in this reach of the Assessment Area.

10.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in IHC sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of the report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially contributing to effects on sediment-dwelling organisms) were identified from the list of chemicals of concern by comparing measured contaminant concentrations in whole sediments to the PECs (Table 10.1). The contaminants which occurred in IHC sediments at concentrations in excess of these chemical benchmarks were identified as toxic contaminants of concern. The results of this evaluation indicate that metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), PAHs (i.e., 13 individual PAHs and total PAHs), and total PCBs, are present in surficial and/or sub-surface sediments from the IHC at concentrations that are sufficient to injure sediment-dwelling organisms (Table 10.1). Importantly, the concentrations of cadmium, chromium, copper, nickel, lead, and zinc also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments.

The concentrations of several chemicals of concern were measured in pore water from five sediment samples from the IHC reach (Table 10.3). These data, in conjunction with published toxicity thresholds, were used to identify toxic contaminants of concern in pore water from IHC sediments. Evaluation of the data reported in this study using the toxic units approach indicates that the concentration of metals (copper lead, zinc, and sum toxic units), ammonia, and phenol were above concentrations that have been shown to be toxic to aquatic organisms. Therefore, the toxic contaminants of concern in pore water included ammonia, phenols, and metals.

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 10.1); and, (2) measured contaminant concentrations in tissues to the TRGs for the protection of piscivorus wildlife. The results of this evaluation indicate that total PCBs, chlordane, total DDTs, heptachlor, and lindane occurred in IHC sediments at concentrations that are sufficient to cause or substantially contribute to effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). That total PCBs, chlordane, and total DDTs have accumulated in invertebrate and/or fish tissues to levels that pose risks to piscivorus wildlife confirms that these substances are bioaccumulative contaminants of concern.

All of the contaminants of concern frequently exceed the chemical benchmarks in IHC sediments. The concentrations of these substances in IHC sediments equal or exceed both the acute (mean PEC-Q of 4.0) and chronic (mean PEC-Q of 0.7) benchmarks by substantial margins (up to 6.5 times the acute threshold and 37 times the chronic threshold; Table 10.9). Therefore, NH_3, phenol, metals, PAHs, and PCBs are present in whole sediments at concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and to adversely affect wildlife in the IHC.

10.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury and associated biological resources was determined by merging the various data sets that provided information on contaminants of concern in IHC sediments. To support an evaluation of the spatial distribution of chemical contaminants, mean PEC-Qs were calculated for each of the sediment samples that were obtained from the IHC. The extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (each sample was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial and sub-surface sediments separately.

Based on the sediment chemistry data that have been collected to date, it is likely that surficial sediments throughout the IHC have been contaminated by oil or other hazardous substances. Mean PEC-Qs for surficial sediments from the confluence with the east and west branches of the GCR to Columbus Drive were frequently at or above the acute mean

PEC-Q of 4.0 and the chronic mean quotient of 0.7 (ranging up to 25.9; Table 10.9; Figures 10.6 and 10.7). The mean PEC-Q for the one sample from the IHC wetlands was 0.7. While contaminant concentrations tended to be somewhat lower in sub-surface sediments (i.e., relative to surficial sediments), the available data show that these sediments have been contaminated by oil and other hazardous substances. Mean PEC-Qs ranged from 0.4 to 9.6 in sub-surface sediments from this reach fo the Assessment Area (Table 10.9; Figures 10.8 and 10.9).

Based on the available sediment chemistry data, it is apparent that IHC sediments are likely to be toxic to sediment-dwelling organisms (Table 10.4; Figure10.10). To put the mean PEC-Q results into perspective, USEPA (2000a) reported that the probability of observing a 50% incidence of toxicity to amphipods in sediments occurred at a mean PEC-Q of \$ 4.0 in 10-day acute tests and at a mean PEC-Q of \$ 0.7 in 28-day chronic tests. Therefore, surficial sediments would be expected to be frequently toxic to sediment-dwelling organisms (i.e., sediment samples from the IHC had mean PEC-Qs of up to 6.5 times the level that would result in a 50% probability of observing toxicity in 10-day tests and up to 37 times the level that would result in a 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca*; USEPA 2000a).

The data on other indicators of sediment quality conditions support the results of the evaluation of the areal extent of sediment injury that was conducted using mean PEC-Qs. Specifically, toxic effects of sediments in laboratory tests with aquatic organisms (Section 10.1.3) and adverse effects on benthic community structure (Section 10.1.4) also support the conclusion that sediments throughout the IHC have been injured by discharges of oil or releases of other hazardous substances.

10.5 Summary

Based on seven lines of evidence, it is concluded that both surficial and sub-surface sediments from the IHC have been injured by discharges of oil or releases of other hazardous substances. While surficial sediments tend to be the most contaminated, sub-surface sediments throughout this portion of the Assessment Area also have conditions that are sufficient to cause or substantially-contribute to sediment injury and injury to associated biological resources.

11.0 Lake George Branch

The LGB reach extends approximately two miles from the Lake George wetlands east to Indianapolis Boulevard (Figure 1.1 and 1.2). The LGB consists of two separate waterbodies, including the Lake George wetlands and the Lake George Canal. A fill area that extends roughly 0.1 miles separates the wetlands from the canal. However, these water bodies are connected by a gated pipe, which discharges water from the wetlands into the Canal, but does not permit flow in the westerly direction. In this report, the wetlands are considered to consist of the western portion of the original canal, associated wetland areas, and Lake St. Mary's. The canal includes the two reach segments between the headwaters (i.e., east of the fill area) to Indianapolis Boulevard.

There are several historic and ongoing sources of contaminants in the LGB. First, Clark Refining (Hammond Terminal), Marathon Oil (Hammond Terminal), and the American Oil Company (AMOCO), have current or historical NPDES permitted outfalls on the Lake George Canal. As the Energy Cooperative (formerly ARCO) site is located on the Lake George Canal, spills of petroleum hydrocarbons and other substances have resulted in discharges of oil or releases of other hazardous substances into surface waters. Other potential contaminant sources include over-land runoff from various industrial facilities, leaky pipeline crossings, and discharge of contaminated ground water though the sheet pile bulkheads.

The present assessment is intended to evaluate injury to surface water and biological resources in the LGB that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the LGB includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the LGB are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the LGB are sufficiently contaminated to harm fish and wildlife resources. Sediments in the LGB were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury was determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support restoration planning within the Assessment Area.

11.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

11.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 23 surficial sediment samples from the LGB. The locations where these samples were collected are shown in Figure 11.1. The results of chemical analyses of these samples indicate that a large proportion of surficial sediments in the LGB have been contaminated by oil or other hazardous substances (Table 11.1). For example, the concentrations of sediment-associated metals exceed the PECs in up to 91% of the samples (depending on the metal that is considered). Total PAH concentrations exceed the PEC in 41% (9 of 22 samples) of the samples in which these contaminants were measured. Total PCB concentrations also exceed the PEC in most (81%; 13 of 16 samples) of the surface samples in which these contaminants were quantified. For pesticides and PAHs, the detection limits that were achieved were frequently above the PECs in samples collected from the LGB reach, which limited the number of samples available to make comparisons to individual PECs (samples with high detection limits were not included in the analyses presented in Table 11.1). For example, the detection limits for acenaphthylene exceeded the PEC in all of the surficial sediment samples in which this substance was quantified. These high detection limits resulted from matrix interferences due to the elevated levels of organic contaminants in these samples. Therefore, a relatively low incidence of exceedance of the PECs should not be interpreted to mean that a substance is actually present in sediments only infrequently at hazardous concentrations.

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the LGB, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments (Table 11.2; Figures 11.5 and 11.6). The results of this evaluation indicate that 83% (19 of 23 samples) of the surficial sediments equaled or exceeded the chronic mean PEC-Q of 0.7; 32% of these samples (6 of 19) equaled or exceeded the acute mean PEC-Q of 4.0. These data indicate that a high percentage of the surficial sediments from this reach of the river are likely to be toxic to sediment-dwelling organisms. A total of 57% of the sediment samples (13 of 23) from the LGB had chemical characteristics that were between the chronic mean PEC-Q of ≥ 0.7 and the acute mean PEC-Q of < 4.0. In the LGB reach, two of the surficial samples had a mean PEC-Q of < 0.1 (9% of the samples), and two of the surficial samples had a mean PEC-Q of ≥ 0.1 to < 0.7 (9% of the samples). Therefore, it is concluded that surficial sediments in the LGB reach of the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances.

Only two of the 23 samples for surficial sediment chemistry in the LGB reach were collected prior to 1996. Therefore, it is not possible to make a thorough comparison of recent sediment chemistry to historic sediment chemistry in the LGB reach. However, the chemistry of the two samples collected prior to 1996 was consistent with the chemistry of the remainder of the samples collected in 1996 and later (Table 11.2). The LGB reach exhibited a substantial degree of spatial variation in chemical contamination levels. For example, the lowest mean PEC-Qs were observed in the wetlands located west of the fill area (i.e., up to 1.7). In contrast, the portion of the LGB located east of the fill area generally had higher PEC-Qs (i.e., 1.8 to 31.5). As such, there are distinct patterns of sediment injury in the LGB, with conditions sufficient to injure sediment-dwelling organisms generally restricted to the surficial and sub-surface sediments located in the main channel of the canal (i.e., both upstream and downstream of the fill area).

Information on the chemical characteristics of 10 sub-surface sediment samples from the LGB is contained in the project database. The sampling sites where these sediments were collected are shown in Figure 11.2. Evaluation of the available sediment chemistry data indicates that sub-surface sediments in the LGB have also been contaminated by oil or other hazardous substances to a similar extent as surficial sediments (Table 11.1). For example, the concentrations of sediment-associated metals exceed the PECs in up to 80% of the samples (depending on the metal that is considered). Total PAH concentrations exceed the PEC in 70% (7 of 10 samples) of the samples in which these contaminants were measured. Total PCB concentrations also exceed the PEC in most (71%; 5 of 7 samples) of the sub-surface samples in which these contaminants were quantified.

Based on the mean PEC-Qs that were calculated, it is apparent that sub-surface sediment samples in the LGB have also been contaminated by oil or other hazardous substances (Table 11.2; Figures 11.7 and 11.8). Overall, 80% (8 of 10 samples) of the sub-surface sediments equaled or exceeded the chronic mean PEC-Q of 0.7, and half of these samples (4 of 8 samples) equaled or exceeded the acute mean PEC-Q of 4.0. Hence, a high percentage of the sub-surface sediments from this reach of the river have chemical characteristics that are sufficient to cause or substantially contribute to sediment injury. A total of 40% of the sediment samples from the LGB had chemical characteristics that were between the chronic mean PEC-Q of ≥ 0.7 and acute mean PEC-Q of < 4.0. In the LGB reach, only one of the sub-surface samples had a mean PEC-Q of < 0.1 (i.e., in the eastern portion of the old canal), and only 10% of the sub-surface samples had a mean PEC-Q of ≥ 0.1 to < 0.7. Concentrations of contaminants were generally lower in the Lake George wetlands compared to the eastern most portions of the LGB reach (Table 11.7; Figure 11.8).

In summary, the available data on the concentrations of chemicals in sediment demonstrates that both surficial and sub-surface sediments in the LGB have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants are sufficient to injure sediments. In addition, it is concluded that the biological resources that depend on the critical aquatic habitats provided by surficial sediments have been injured due to the presence of oil or other hazardous substances (i.e., metals, PAHs, and PCBs). Sediments in the true wetlands portion of the wetlands segment and in Lake St. Mary's have not been injured, based on the analysis of existing sediment chemistry data.

11.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1).

The concentration of SEM and AVS were measured in 30 sediment samples from the LGB. In four of these samples, the molar concentrations of SEM exceeded the molar concentrations of AVS. Sediments with these characteristics are likely to have elevated concentrations of pore water metals (i.e., relative to toxicity thresholds; Ankley *et al.*, 1996). As such, pore water from some of the LGB sediments could have metal concentrations that exceed toxicity thresholds.

Concentrations of metals or ammonia in pore water from LGB sediments were reported from six sampling locations (Table 11.3). Concentrations of metals were elevated in five of these six samples relative to thresholds for lead or zinc that have been shown to be toxic to the amphipod *Hyalella azteca* in 10-day acute tests. The sum toxic units for metals in these samples ranged from 0.31 to 2.24, which indicated that there were sufficient concentrations of metals in some of these samples to cause or substantially contribute to toxicity. The concentrations of unionized ammonia in pore waters of sediments in six samples from the LGB range from < 0.01 to 0.03 mg/L (Section 11.1.3). These concentrations of NH_3 are well below the lethal effect concentrations that have been reported for freshwater invertebrates (Section 11.1.3).

The results of this evaluation indicate that concentrations of metals in pore water samples from the LGB are sufficiently elevated to cause or substantially contribute to acute and chronic toxicity to sediment-dwelling organisms. The results of toxicity tests conducted with whole sediment samples support the conclusion that concentrations of contaminants were sufficiently elevated in LGB sediments to cause or substantially contribute to sediment injury (Section 11.1.3).

11.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediment, pore water, and/or elutriates provide critical information for assessing the effects of contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured by discharges of oil or releases of other hazardous substances.

In the LGB, two studies have been conducted to determine if whole sediment or elutriate samples are toxic to sediment-dwelling organisms or other aquatic species (Table 11.4; Figure 11.3). In total, data are available on the toxicity of seven sediment samples from the LGB (Table 11.4). The species and endpoints that were tested in these studies included amphipod (*Hyalella azteca*) survival and growth, and bacterial (*Vibrio fisheri*) bioluminescence (i.e., as a surrogate for bacterial metabolic rate). Overall, four of the seven samples (i.e., 57%) that were collected from the LGB were shown to be toxic one or both species (Figure 11.9). Sediment samples from all of the individual segments within the LGB reach were identified as toxic in at least one of the tests (25% to 100% of the samples for each reach segment were toxic). With exception of Catalyst Pond, the samples collected in the wetlands west of the fill area and in Lake St. Mary's were not acutely toxic to amphipods. Overall, the results of the studies that have been conducted demonstrate that sediments from the LGB are acutely toxic to aquatic organisms, including sediment-dwelling species. Therefore, the results of these toxicity tests demonstrate that conditions of sediments and associated pore waters in the LGB are sufficient to injure biological resources, including sediment-dwelling species.

11.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998).

One grab sample has been collected for assessing benthic invertebrates inhabiting sediments in the LGB reach (Table 11.5, Figure 11.4; Risatti and Ross 1989). Oligochaetes represented the dominant taxa in this sample, accounting for 78% of the total abundance observed. By comparison, the normal range of oligochaete relative abundance in Lake Michigan reference sites is 3.0% to 73.6%. As such, this sample indicates that the benthic community in the LGB has been altered relative to reference sites in Lake Michigan.

Simon *et al.* (2000) collected benthic invertebrate samples using artificial substrate samplers at three locations on the LGB. The calculated mIBI scores for each of these locations (one in the Lake George Canal and two in the Lake George wetlands) ranged from 0.4 to 0.87, indicating that the structure of benthic invertebrate communities was significantly degraded relative to other locations in Indiana (i.e., #2.93; the average mIBI score for Indiana is in the order of 3.5 $\pm$ 0.29; Simon *et al.* 2000). At each of these stations, the proportion of mayflies, caddisflies, and stoneflies (i.e., EPT taxa) was relatively low, averaging 0.87% of the total abundance. No EPT taxa were observed in the sample from the Lake George Canal. In contrast, the samples from the Lake George wetlands had 0.9% to 1.7% EPT taxa. Artificial substrate samples that contained < 0.5% EPT taxa were considered to be indicative of conditions that were sufficient to injure sediment-dwelling organisms. Pollution-tolerant oligochaetes and chironomids were the dominant taxa in two of the three samples. Although the benthic community was altered in all three samples relative to reference sites (i.e., based on mIBI scores), these results suggest that the wetlands are likely to have healthier benthic invertebrate communities than the Canal.

The available information indicates that benthic invertebrate communities have been altered (i.e., 4 of 4 samples; Table 11.5) in the LGB relative to reference conditions in northern Indiana. Impacts on sediment-dwelling organisms are particularly important because invertebrates represent important food sources for fish and other wildlife species that might inhabit the LGB. The presence of altered benthic invertebrate communities provides confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that conditions of sediments in the LGB are sufficient to injure sediments and sediment-dwelling organisms.

11.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, TOC, and NH_3, provide important information for the general status of aquatic habitats and their suitability for supporting aquatic life. For this reason, the available information on conventional indicators of environmental quality conditions was compiled and used to assess sediment injury in the LGB reach. No information was located on the levels of DO or SOD in the LGB reach. Therefore, it was not possible to evaluate sediment quality conditions relative to these conventional indicators.

The levels of TOC in the LGB are elevated relative to the levels that occur in southern Lake Michigan and at other areas of concern in the Great Lakes. Overall, the mean concentrations of TOC in surficial sediments collected from the LGB reach averaged 7.5% (Table 11.6). Among the three reach segments (see Table 11.6 for definitions), the highest levels of TOC were observed in surficial sediments between the Fill area and the B&O Railroad Bridge (i.e., mean TOC of 18.3%; range 14% to 22%; n=4). Lower levels of TOC were observed in the Lake George wetlands (mean of 5.3%; n=12) and downstream of the B&O Railroad Bridge (mean of 5.2%; n=7). Sub-surface sediment in this reach of the Assessment Area had, on average, 7.9% TOC (n=10). By comparison, Lake Michigan sediment in the vicinity of IH had an average level of TOC of 0.5% (n=31); the upper CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b). These data indicate that the sediments in the LGB have received substantial inputs of organic matter relative to other contaminated sites in the Great Lakes basin.

The available data on the levels of oil and grease in LGB sediments provide important information for interpreting the TOC data. In the LGB surficial sediments, oil and grease concentrations range from 1,100 to 227,000 mg/kg, averaging 43,700 mg/kg or 4.4%

(Table 11.7). The average level of oil and grease represents nearly 60% of the average TOC concentration in the reach. In the B&O Railroad Bridge to headwaters segment, oil and grease represents, on average, 77% of the TOC. Oil and grease levels are also elevated in sub-surface sediments, averaging 5.1% and ranging as high as 15.4%. Therefore, it is likely that oil and oil-related compounds comprise most of the TOC that is present in LGB sediments.

In aquatic ecosystems, ammonia is excreted by aquatic organisms, formed during the decomposition of biological tissues and nitrogen-containing wastes, and/or released from anthropogenic sources. There are a variety of anthropogenic sources of ammonia, such as municipal and industrial wastewater discharges. Free ammonia can be present either as NH_3 or as NH_4^+ (depending on pH and temperature). Unionized ammonia (NH_3) is very toxic to aquatic life, with lethal thresholds as low as 0.1 mg/L reported in the literature (Thurston and Russo 1983; Thurston and Meyn 1984; Thurston *et al.* 1984). The concentrations of NH_3 in pore waters of sediments in six samples from the LGB ranged from < 0.01 to 0.03 mg/L (Table 11.3). These concentrations of NH_3 are well below the lethal effect concentration reported for freshwater invertebrates (Section 11.1.2).

In 1998, Simon *et al.* (2000) evaluated the status of aquatic habitats at two stations in the LGB. In this investigation, data was collected on the characteristics of bottom substrates, instream cover, channel morphology, riparian zone and bank erosion, pool and riffle quality, and gradient at each sampling location. These data were then compiled to support the calculation of QHEI scores for each sampling location. The results of this study showed that QHEI scores ranged from 16 to 45 in the LGB. By comparison, OEPA (1988) reported that the mean ($\pm$SD) QHEI score for the ECBPs eco-region was 74 ($\pm$13.1), with the lower limit of the normal range of QHEI scores being 48. Additionally, the IDEM (2000c) has established use support assessment criteria for streams in Indiana. These criteria indicated that use impairment is likely to occur when QHEI scores are < 64. As such, aquatic habitats downstream of the fill area in the LGB were considered to be degraded relative to unimpacted sites in the ECBPs.

In summary, the available information indicates that aquatic habitats have been degraded in the LGB. In addition, high levels of TOC and associated oil and grease in the LGB would exacerbate the effects of lost habitat for fish and invertebrates in the river. Therefore, it is concluded that sediments in the LGB reach of the Assessment Area have been injured due to discharges of oil or other hazardous substances that have resulted in high levels of TOC.

II.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the LGB have been injured by discharges of oil or releases of other hazardous substances. More specifically, the data show that metals, PAHs, and total PCBs occur in whole sediments (both surface and sub-surface) at concentrations that are sufficient to injure sediment-dwelling organisms. Calculated mean PEC-Qs exceed, often by a wide margin, the levels that are sufficient to injure sediment-dwelling organisms. The levels of metals (lead, zinc and sum toxic units) in pore water are also sufficient to cause toxicity to aquatic organisms. In addition, the results of toxicity tests confirm that whole sediments and elutriates are toxic to aquatic organisms. That benthic invertebrate communities in this reach of the river are significantly altered relative to reference sites provides further confirmatory evidence that environmental conditions in the reach of the Assessment Area are sufficient to injure sediments and associated biological resources. Together, these multiple lines of evidence demonstrate that sediments and associated biological resources have been injured as a result of discharges of oil or releases of other hazardous substances.

II.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g., epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey).

These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

II.2.1 Toxicity of Sediments to Fish

No information was located on the toxicity to fish of whole sediments, pore water, or elutriates from the LGB. Therefore, it was not possible to directly evaluate environmental quality conditions in the LGB using this indicator.

II.2.2 Fish Health

In 1998, Simon *et al.* (2000) conducted an investigation to evaluate the status of fish communities, including fish health, in the LGB. Fish were collected at two stations in the LGB (including west of Indianapolis Boulevard and east of Calumet Avenue) and examined for the presence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). The results of this study indicated that the incidence of DELT abnormalities was 1.68% and 0% at these stations, respectively. As such, these data show that fish health has been adversely affected by ambient environmental conditions at one station in the LGB.

II.2.3 Status of Fish Communities

In 1998, Simon *et al.* (2000) conducted a fish community survey of the Assessment Area and used a modified IBI (originally developed by Karr 1981 and subsequently calibrated for use in Indiana; Simon and Stewart 1998) to describe the results. This fish survey included two stations in the LGB reach. The IBI score for the station that was located in the Lake George Canal was 14 (Table 14.9), which indicates that the fish community has "very poor" integrity. In contrast, the station that was located in the Lake George Wetlands had an IBI score of 38. Importantly, these data indicate that the integrity of fish communities differs substantially within this reach of the Assessment Area. Although an IBI score of 38 is rated as "fair-poor", the fish community in this area is substantially healthier than communities elsewhere in the Assessment Area. The status of the fish community in the Lake George wetlands reflects what can likely be expected at sites with moderately good physical habitats and relatively low levels of chemical contamination.

II.2.4 Bioaccumulation of Sediment-Associated Contaminants

In this report, the sediment quality criteria for the protection of wildlife (NYSDEC 1994) were used as chemical benchmarks for evaluating the ecological significance of sediment-associated contaminants in the LGB. Considering the sediment chemistry data that has been collected in the LGB, it is likely that a variety of bioaccumulative substances are present in sediments at concentrations that pose potential hazards to wildlife species utilizing the LGB. Specifically, the concentrations of total PCBs and total DDTs exceed the bioaccumulation-based SQGs in both surficial and sub-surface LGB sediments exceeded the levels that have been established to protect piscivorus wildlife species (Table 11.1). The absence of applicable TRGs for metals and PAHs precluded an evaluation of the risked posed by these substances to wildlife. Therefore, it is concluded that concentrations of PCBs and other bioaccumulative substances occur in LGB sediments at levels that are sufficient to result in the bioaccumulation of these substances in invertebrate and fish tissues to concentrations that pose a risk to piscivorus wildlife.

Tissue residue guidelines provide another means of assessing the significance of bioaccumulative chemicals of concern to piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey; Newell *et al.* 1987). Comparison of tissue residue levels to fish flesh criteria for the protection of wildlife provides a basis for confirming if bioaccumulation represents a hazard to wildlife species. No data were located on concentrations of tissue-associated contaminants for organisms from the LGB. Therefore, it was not possible to assess the risks posed by tissue-associated contaminants to piscivorus wildlife in the LGB.

II.2.5 Summary

Based on the information available from various studies, it is likely that contaminated sediments pose substantial hazards to wildlife in the LGB. There were insufficient data to determine if sediments were directly toxic to fish in the LGB reach. Nevertheless, contaminated sediments in the LGB are likely to be adversely affecting wildlife species in several ways. First, alteration of benthic invertebrate communities has reduced the abundance of preferred fish food organisms. Second, fish health and fish communities have been shown to be impaired relative to uncontaminated reference sites. Third, the concentrations of sediment-associated contaminants are known to exceed, often by wide margins, the levels that have been established to protect piscivorus wildlife species (e.g., herons, kingfishers, otter, mink or osprey). Therefore, it is concluded that injured sediments in the LGB are adversely affecting fish and wildlife resources in this reach of the Assessment Area.

11.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in LGB sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of the report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially contributing to effects on sediment-dwelling organisms) were identified from the list of chemicals of concern by comparing measured contaminant concentrations in whole sediments to the PECs (Table 11.1). The substances which occurred in LGB sediments at concentrations in excess of these chemical benchmarks were identified as toxic contaminants of concern. The results of this evaluation indicate that metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), PAHs (12 individual PAHs and total PAHs) and total PCBs are present in both surficial and sub-surface sediments from the LGB at concentrations that are sufficient to injure sediment-dwelling organisms (Table 11.1). Importantly, the concentrations of cadmium, chromium, copper, nickel, lead, and zinc also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments.

The concentrations of several chemicals of concern were measured in pore water from five sediment samples from the LGB reach (Table 11.3). These data, in conjunction with published toxicity thresholds, were used to identify toxic contaminants of concern in pore water from LGB sediments. Evaluation of the data reported in this study using the toxic units approach indicates that the concentrations of metals (lead, zinc, and sum toxic units) were elevated relative to concentrations that have been shown to be toxic to aquatic organisms in standardized 10-day acute toxicity tests. Therefore, the toxic contaminants of concern in pore water included metals.

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 11.1); and, (2) measured contaminant concentrations in tissues to the TRGs for the protection of piscivorus wildlife. The results of this evaluation indicate that total PCBs and total DDTs occurred in LGB sediments at concentrations that are sufficient to cause or substantially contribute to effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). No data were located on the levels of bioaccumulative chemicals in fish or invertebrate tissues form the LGB.

All of the contaminants of concern frequently exceed the chemical benchmarks in LGB sediments. The concentrations of these substances in LGB sediments frequently equaled or exceeded the chemical acute (mean PEC-Q of 4.0) and chronic (mean PEC-Q of 0.7) benchmarks by substantial margins (up to eight times the acute threshold and 45 times the chronic threshold; Table 11.8). Therefore, metals, PAHs and PCBs are present in whole sediments at concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and to adversely affect wildlife in the LGB.

11.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury and associated biological resources was determined by merging the various data sets that provided information on contaminant concentrations in LGB sediments. To support an evaluation of the spatial distribution of contaminants of concern, mean PEC-Qs were calculated for each of the sediment samples that were obtained from the LGB. The extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (each sample was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial and sub-surface sediments separately.

Based on the sediment chemistry data that have been collected to date, it is likely that surficial sediments throughout much of the LGB have been contaminated by oil or other hazardous substances. Mean PEC-Qs for surficial sediments in the Lake George Canal segment of the LGB reach always equaled or exceeded 0.7 and frequently equaled or exceeded 4.0 (i.e., the chronic and acute toxicity thresholds, respectively; Table 11.8; Figures 11.5 and 11.6). In contrast, surficial sediments from the Lake George wetlands and Lake St. Mary's tended to have lower levels of contamination, with mean PEC-Qs ranging from 0.08 to 1.67. The concentrations of chemical contaminants in sub-surface samples were similar to surficial sediments in the LGB (Table 11.8; Figures 11.7 and 11.8).

Based on the available sediment chemistry data, it is apparent that LGB sediments are likely to be frequently toxic to sediment-dwelling organisms. To put the mean PEC-Q results into perspective, USEPA (2000a) reported that the probability of observing a 50% incidence of toxicity to amphipods in sediments occurred at a mean PEC-Q of $ 4.0 in 10-day acute tests and at a mean PEC-Q of $ 0.7 in 28-day chronic tests. Therefore, surficial and sub-surface sediments would be expected to be frequently toxic to sediment-dwelling organisms (i.e., sediment samples from the Lake George Canal had mean PEC-Qs of up to eight times the level that would result in a 50% probability of observing toxicity in 10-day tests and up to 45 times the level that would result in a 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca*; Figure 11.9; USEPA 2000a).

11.5 Summary

Based on a review of six lines of evidence, sediments from areas located east of the fill area in the LGB reach have been injured by discharges of oil or releases of other hazardous substances. Sediments in the old canal area west of the fill area have also been injured. It is also concluded that the biological resources that depend on the critical aquatic habitats provided by surficial sediments have been injured in the segments of the LGB east of the fill area due to the presence of oil or other hazardous substances (i.e., metals, PAHs, and PCBs). However, sediments in the wetlands portion and in Lake St. Mary's, except Catalyst Pond, have not been injured.

12.0 US Canal

The USC reach of the Assessment Area (i.e., the Federal Project Area) is comprised of three main components (Figure 1.1 and 1.2). First, the USC reach includes the portion of IHC from Columbus Drive to the Forks. In addition, the portion of the LGB from Indianapolis Boulevard to the Forks is also included within this reach. The USC from the Forks to IH represents the third portion of the USC reach. In total, the USC reach, as defined in this report, is approximately 3.2 miles in length.

There a number of potential sources of contaminants to the USC reach of the Assessment Area. First, LTV Steel Company, Inland Steel Company, and American Steel Foundries currently discharge or have historically discharged wastewater into the canal via permitted outfalls under the NPDES. Five of Inland Steel Company's outfalls are now inactive. Significant amounts of ammonia are produced from existing (and former) coke ovens, sinter plants and blast furnace operations that are part of the integrated steel manufacturing plants adjacent to the USC. In addition, Phillips Pipeline Company, Praxair, Inc., and Mobile Oil Corporation have outfalls off the channel that may discharge indirectly into the USC. Other potential contaminant sources include downstream transport of contaminated water and/or sediments from upstream areas, discharges of contaminated ground water through sheet pile bulkheads, and leaky pipeline crossings.

The present assessment is intended to evaluate injury to surface water and biological resources in the USC that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the USC includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the USC are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the USC are sufficiently contaminated to harm fish and wildlife resources. Sediments in the USC were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury was determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support restoration planning within the Assessment Area.

12.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

12.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 114 surficial sediment samples from the USC. The locations where these samples were collected are shown in Figure 12.1. The results of chemical analyses of these samples indicate that a large proportion of surficial sediments in the USC have been contaminated by oil or other hazardous substances (Table 12.1). For example, the concentrations of sediment-associated metals exceed the PECs in up to 93% of the samples (depending on the metal considered). Total PAH concentrations exceed the PEC in 89% of the samples (54 of 61) in which these contaminants were measured. Total PCB concentrations also exceed the PEC in most of the surface samples (79%; 30 of 38) in which these contaminants were quantified.

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the USC, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments (Table 12.2, Figures 12.6 a-c and 12.7). The results of this evaluation indicate that 92% (105 of 114 samples) of the surficial sediments equaled or exceeded the chronic mean PEC-Q of 0.7 and 61% (70 of 114 samples) of the sediments equaled or exceeded the acute mean PEC-Q of 4.0. These data indicate that most of the surficial sediments from this reach of the river are likely to be toxic to sediment-dwelling organisms. A total of 31% of the sediment samples from the USC had chemical characteristics that were between the chronic mean PEC-Q of ≥ 0.7 and acute mean PEC-Q of < 4.0. In the USC reach, only 2% the surface samples had a mean PEC-Q of < 0.1, and only 6% of the surface samples had a mean PEC-Q of ≥ 0.1 to < 0.7. Therefore, it is concluded that surficial sediments in the USC reach of the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances. All of the data for sediment chemistry in the USC reach were collected prior to 1996. The natural resource trustees and the nine cooperating potentially responsible parties agreed that additional sampling of this well-characterized area was unwarranted. This is why there are no recent sediment chemistry data for this reach of the Assessment Area.

Information on the chemical characteristics of 101 sub-surface sediment samples from the USC is contained in the project database. The sampling sites where these sediments were collected are shown in Figure 12.2. Evaluation of the available sediment chemistry data indicate that sub-surface sediments in the USC have been contaminated by oil or other hazardous substances to a similar extent as surficial sediments (Table 12.1). For example, the concentrations of sediment-associated metals exceed the PECs in up to 88% of the samples (depending on the metal that is considered). Total PAH concentrations exceed the PEC in 100% (18 of 18 samples) of the samples in which these contaminants were measured. Total PCB concentrations also exceed the PEC in most (82%; 42 of 51 samples) of the sub-surface samples in which these contaminants were quantified.

Based on the mean PEC-Qs that were calculated, it is apparent that sub-surface sediment samples in the USC have been contaminated by oil or other hazardous substances (Table 12.2; Figures 12.8a-c and 12.9). Overall, 85% (86 of 101 samples) of the sub-surface sediments equaled or exceeded the chronic mean PEC-Q of 0.7 and 73% (74 of 101 samples) of the sub-surface sediments equaled or exceeded the acute mean PEC-Q of 4.0. Hence, most of the sub-surface sediments from this reach of the river have chemical characteristics that are likely to have been injured. A total of 12% of the sediment samples from the USC had chemical characteristics that were between the chronic mean PEC-Q of ≥ 0.7 and acute mean PEC-Q of < 4.0. In the USC reach, only 3% the sub-surface samples had a mean PEC-Q of < 0.1, and only 12% of the sub-surface samples had a mean PEC-Q of ≥ 0.1 to < 0.7.

In summary, the available data on the concentrations of chemicals in sediment demonstrate that both surficial and sub-surface sediments in the USC have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants are sufficient to cause or substantially contribute to injury of sediments. Therefore, it is concluded that sediments of the USC reach have been injured due to discharges of oil or releases of other hazardous substances. In addition, it is concluded that the sediment-dwelling organisms that depend on the critical aquatic habitats provided by sediments have been injured due to the presence of oil or other hazardous substances (i.e., metals, PAHs, and PCBs).

12.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1).

The concentrations of SEM and AVS were measured in five sediment samples from the USC reach. In all of these samples, the molar concentrations of AVS exceeded the molar concentrations of SEM. Sediments in which AVS is greater than SEM are predicted to have pore water metal concentrations below those that are expected to cause toxicity (Ankley *et al.* 1996). As such, pore water from USC reach sediments is predicted to have levels of metals that are below toxicity thresholds.

Concentrations of metals or ammonia in pore water from USC sediments were reported for three sampling locations (Table 12.3). Concentrations of metals were elevated in one of these three samples above thresholds for cadmium, copper, lead and zinc that have been shown to be toxic to the amphipod *Hyalella azteca* in 10-day acute tests. The sum toxic unit for metals in this sample was 23.6, which indicated that there were sufficient concentrations of metals in this sample to cause or substantially contribute to sediment toxicity. The detection limits for cadmium and lead were too high in one of the samples to be able to interpret the pore water concentrations relative to the published 10-day LC_{50} for *H. azteca*. The concentration of unionized ammonia (NH_3) was measured in one of these three pore water samples. The concentration of NH_3 of 6.2 mg/L in this sample is about 10 times the acute lethal effect concentration reported for freshwater invertebrates and would be high enough to cause mortality in aquatic organisms (CCREM 1987).

Results of this evaluation indicate that concentrations of contaminants in pore water samples from the USC are sufficiently elevated to cause or substantially contribute to acute and chronic toxicity to sediment-dwelling organisms. Importantly, the results of toxicity tests conducted with pore water and elutriate samples support the conclusion that concentrations of contaminants were sufficiently elevated in USC sediments to cause or substantially contribute to the observed toxicity to crustaceans and bacteria (Section 12.1.3). Therefore, it is concluded that the concentrations of contaminants in pore water are sufficiently elevated to cause or substantially contribute to sediment injury in the USC.

12.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediment, pore water, and/or elutriates provide critical information for assessing the effects of contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured by discharges of oil or releases of other hazardous substances.

In the USC, four studies have been conducted with sediment samples to determine if sediments and associated pore water or elutriate samples are toxic to sediment-dwelling organisms or other aquatic species (Table 12.4; Figure 12.3). In total, data are available on the toxicity of 90 sediment samples from the USC. The species and endpoints that were tested in these studies included cladoceran (*Daphnia magna* and *Ceriodaphnia dubia*) survival, midge (*Chironomus tentans* or *C. riparius*) survival and growth, amphipod (*Hyalella azteca*) survival, growth, number of antennal segments and percent mature; and bacterial (*Vibrio fisheri*) bioluminescence (i.e., as a surrogate for bacterial metabolic rate). Overall, 80% of the samples that were collected from the USC were shown to be toxic to one or more species (Table 12.4; Figure 12.10). Sediment samples from all of the individual segments within the USC reach were identified as toxic to one or more species (58% to 95% of the samples collected from the various reach segments were shown to be toxic). While sediments from the USC would likely have been toxic more frequently had longer term tests (including sublethal endpoints) been employed, the results of the studies that have been conducted demonstrate that sediments from the USC are acutely toxic to a variety of aquatic organisms, including sediment-dwelling species. Therefore, the results of these toxicity tests demonstrate that conditions of sediments and associated pore waters in the USC are sufficient to injure biological resources, including sediment-dwelling species.

12.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998). For this reason, the available information on the status of benthic invertebrate communities was assembled and used to determine if discharges of oil or releases of other hazardous substances have caused or substantially contributed to sediment injury in the USC.

Information from 20 grab samples of benthic invertebrates inhabiting sediments in the USC was used to assess injury to sediments and biological resources in this river system (Table 12.5; Figure 12.4; Polls and Dennison 1984; Risatti and Ross 1989; Polls *et al.* 1993; USEPA 1996a). The results of these surveys demonstrate that benthic invertebrate communities in the USC are dominated by pollution-tolerant species. The normal range (i.e., 95% CI) of oligochaete relative abundance in the Assessment Area is 3.0% to 73.6%. Oligochaetes comprised > 73.6% of the organisms in 19 of these 20 samples, with leeches, chironomids, other diptera, or mollusks observed only occasionally. In the other sample, the percent abundance of chironomids was outside the normal range for nearshore reference stations in Lake Michigan. The oligochaetes were predominantly pollution-tolerant tubificids (Polls *et al.* 1993). More sensitive organisms, such as mayflies, stoneflies, caddisflies (i.e., EPT taxa) were absent from these USC sampling stations. Therefore, all of the sediments sampled from the USC were considered to have conditions that were sufficient to cause or substantially contribute to injury of sediment-dwelling organisms.

Simon *et al.* (2000) reported the results of analyses of five benthic invertebrate samples collected from two stations in the USC reach (i.e., the Forks and Dickey Road) using multi-plate artificial substrate samplers (IDEM 2000a, as presented in Simon *et al.* 2000). The results of these surveys are consistent with the historical data obtained from sediment grab samples. The mIBI score for these samples ranged from 0.2 to 2.8, indicating that the structure of benthic invertebrate communities is degraded relative to other locations in Indiana (i.e., the average mIBI score for Indiana is in the order of 3.5 ± 0.29; Simon *et al.* 2000). The benthic invertebrates were primarily pollution-tolerant oligochaetes, with < 0.5% pollution-sensitive EPT taxa observed in four of the five samples. Artificial substrate samples containing < 0.5% EPT taxa were considered to be indicative of conditions that are sufficient to injure sediment-dwelling organisms (Section 3.1.1; Simon *et al.* 2000). Simon et al. (2000) concluded that the lack of sensitive benthic invertebrate species is directly the result of contaminated sediments and the highly toxic conditions that prohibit colonization.

The available information indicates that benthic invertebrate communities have been altered in the USC relative to reference conditions in northern Indiana (i.e., 24 of 25 samples altered). Impacts on sediment-dwelling organisms are particularly important because invertebrates represent important food sources for fish and other wildlife species that utilize habitats within the USC. Therefore, the results of these benthic community surveys provide confirmatory evidence (i.e., in addition to the sediment chemistry and toxicity data) that environmental quality conditions in the USC are sufficient to injure sediments and sediment-dwelling organisms.

12.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, TOC, and NH_3, provide important information for the general status of aquatic habitats and their suitability for supporting aquatic life. For this reason, the available information on conventional indicators of environmental quality conditions was compiled and used to assess sediment injury in the USC reach. No information was located on the levels of DO or SOD in the USC reach. Therefore, it was not possible to evaluate sediment quality conditions relative to these conventional indicators.

The levels of TOC in the USC reach are elevated relative to the levels in sediments from the nearshore areas of Lake Michigan. Mean concentrations of TOC within the various segments of the USC reach ranged from 10.4% to 14.6% in surficial sediments and from 4.3% to 12.6% in sub-surface sediments (Table 12.6). These data indicate that the sediments in the USC have received substantial inputs of organic matter relative to other contaminated sites in the Great Lakes basin. By comparison, Lake Michigan sediments in the vicinity of IH had an average level of TOC of 0.5% (n=31); the upper 95% CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b). As TOC are outside the normal range for the nearshore areas of Lake Michigan and in excess of the levels that have been observed at other areas of concern, it is apparent that the USC reach has received substantial inputs of organic matter.

Information on the levels of oil and grease in sediments provide important data for interpreting the data on TOC. In surficial sediments, average oil and grease concentrations in the various segments ranged from 25,100 to 136,000 mg/kg or 0.86% to 17.5% (Table 12.7). By comparison, average oil and grease levels in the various segments ranged from 14,300 to 101,000 mg/kg in sub-surface sediments (i.e., 1.4% to 10.1%). For the whole reach, oil and grease levels averaged 7.4% and 6.1% in surficial and sub-surface sediments, respectively. These data indicate that, on average, oil and grease represents more than 55% of the TOC that is present in USC sediments. Therefore, discharges of oil and other petroleum hydrocarbons have contaminated sediments and account for most of the TOC in USC sediments.

In aquatic ecosystems, ammonia is excreted by aquatic organisms, formed during the decomposition of biological tissues and nitrogen-containing wastes, and/or released from anthropogenic sources. There are a variety of anthropogenic sources of ammonia, such as municipal and industrial wastewater discharges (i.e., from steel coke making, sintering, and blast furnace). Free ammonia can be present either as NH_3 or as NH_4^+ (depending on pH and temperature). Unionized ammonia (NH_3)is very toxic to aquatic life, with lethal thresholds as low as 0.1 mg/L reported in the literature (Thurston and Russo 1983; Thurston and Meyn 1984; Thurston *et al.* 1984). The concentration of NH_3 in pore waters of sediments in the USC was reported for one sample (6.2 mg/L; Table 12.3). This concentration of NH_3 is about 10 times the acute lethal concentration reported for freshwater invertebrates and would be high enough to cause mortality in aquatic organisms (CCREM 1987).

A survey of aquatic habitat quality and fish community structure in the USC was conducted by Risatti and Ross (1989). The results of this study demonstrate that aquatic habitats have been lost or degraded due to the presence of contaminated sediment in the USC. Layers of oily sludge and tar balls were observed on the sediment surface at six stations along the USC reach. In 1998, Simon *et al.* (2000) evaluated the status of aquatic habitats at two stations in the USC. In this investigation, data was collected on the characteristics of bottom substrates, instream cover, channel morphology, riparian zone and bank erosion, pool and riffle quality, and gradient at each sampling location. These data were then compiled to support the calculation of QHEI scores for each sampling location. The results of this study showed that QHEI scores ranged from 18 to 21 in the USC. By comparison, OEPA (1988) reported that the mean (± SD) QHEI score for the ECBPs eco-region was 74 (± 13.1), with the lower limit of the normal range of QHEI scores being 48. Additionally, the IDEM (2000c) has established use support assessment criteria for streams in Indiana. These criteria indicated that use impairment is likely to occur when QHEI scores are < 64. As such, aquatic habitats in the USC were considered to be degraded relative to unimpacted sites in the ECBPs.

In summary, the available information indicates that aquatic habitats have been degraded in the USC. In addition, high levels of TOC (largely in the form of oil and oil-related compounds) and elevated concentrations of ammonia in the USC would exacerbate the effects of lost habitat for fish and invertebrates in the river. Therefore, it is concluded that sediments in the USC reach of the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances.

12.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the USC have been injured by discharges of oil or releases of other hazardous substances. More specifically, the data show that metals, PAHs, and PCBs occur in whole sediments at concentrations that are sufficient to injure sediment-dwelling organisms. Calculated mean PEC-Qs exceed, often by a wide margin, the levels that are sufficient to injure sediment-dwelling organisms. The levels of metals and unionized ammonia in pore water are also sufficient to cause toxicity to aquatic organisms. In addition, the results of toxicity tests confirm that whole sediments, pore water, and elutriates are toxic to aquatic organisms. That benthic invertebrate communities in this reach of the river are significantly altered relative to reference sites provides further confirmatory evidence that environmental conditions in the reach of the Assessment Area are sufficient to injure sediments and associated biological resources. Together, these multiple lines of evidence demonstrate that sediments and associated biological resources have been injured as a result of discharges of oil or releases of other hazardous substances.

12.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g., epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey). These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

12.2.1 Toxicity of Sediments to Fish

No information was located on the toxicity to fish of whole sediments, pore water, or elutriates from the USC. Therefore, it was not possible to directly evaluate environmental quality conditions in the USC reach using this indicator.

12.2.2 Fish Health

In 1998, Simon *et al.* (2000) conducted an investigation to evaluate the status of fish communities, including fish health, in the USC. Fish were collected at two stations in the USC (including the Forks and Dickey Road and examined for the presence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). The results of this study indicated that the incidence of DELT abnormalities was 0% and 3.3% at these stations, respectively (note: only one fish was captured in the sample for which 0% DELT abnormalities were observed). As such, these data show that fish health has been adversely affected by ambient environmental conditions at one station in the USC.

12.2.3 Status of Fish Communities

The results of surveys of the status of fish communities can provide relevant information for evaluating environmental quality in the USC. Risatti and Ross (1989) summarized data from the fish surveys that were conducted in the USC Assessment Area during 1983 (USEPA 1985; 15 species of fish), 1984 (USACE 1986; 23 species of fish), and 1988 (Risatti and Ross 1989; 10 species of fish). However, there were insufficient data presented in these studies to fully assess the structure of fish communities in the various reaches of the IH Assessment Area. Nevertheless, the results of fish sampling conducted in 1988 indicated that the IH and USC reaches were dominated by pollution-tolerant carp, goldfish, shad, and shiners.

Simon *et al.* (2000) summarized the results of the studies that were conducted between 1985 and 1990 at one station in the USC reach (Dickey Road) using a modified IBI (originally developed by Karr 1981 and subsequently calibrated for use in Indiana; Simon and Stewart 1998). During that period, IBI scores averaged 25 (range 16 to 34) at this location (Table 14.9), which indicates that the integrity of the fish communities was "poor" to "very poor". More recently (1998), Simon *et al.* (2000) conducted a follow-up fish community survey in the Assessment Area, including two stations in the USC. The IBI scores for the two stations sampled in 1998 in the USC (i.e., the Forks and Dickey Road) were 12 and 18, which indicate that the integrity of the fish community is "very poor" relative to fish communities elsewhere in northwestern Indiana and the CCBPs eco-region. Therefore, it is concluded that fish communities have been degraded in the USC reach.

12.2.4 Bioaccumulation of Sediment-Associated Contaminants

In addition to direct effects on aquatic organisms, sediment-associated contaminants can have harmful effects on those wildlife species that feed on fish and other aquatic species. Bioaccumulation-based SQGs provide a basis for assessing the significance of chemicals of concern to piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey; NYSDEC 1994). Considering the sediment chemistry data that has been collected in the USC, it is likely that a variety of bioaccumulative substances are present in sediments at concentrations that pose risks to wildlife species utilizing habitats in the USC (Table 12.1). Specifically, the concentrations of total PCBs, chlordane, total DDTs, heptachlor, and heptachlor epoxide in surface USC sediments and of total PCBs, total DDTs, and heptachlor epoxide in sub-surface USC sediments exceed the levels that have been established to protect piscivorus wildlife species (Table 3.3). The concentrations of 2,3,7,8-TCDD also exceeded the SQG in surficial sediments.

Comparison of tissue residue levels to fish flesh criteria for the protection of wildlife provides means of confirming that bioaccumulation of sediment-associated contaminants in fish and invertebrate tissues represents a hazard to wildlife species. Risatti and Ross (1989) and the IDEM (1994) sampled fish and crayfish from the USC to determine the concentrations of tissue-associated contaminants (Figure 12.5). A total of three samples were collected from near Dickey Road (IDEM 1994; skin-on fillets of carp wet weight; Appendix 5.5) and 15 samples were collected from the Forks (Risatti and Ross 1989; whole body of alewife, carp, golden shiners, crayfish, gizzard shad, sunfish, wet weight; Appendix 5.6). The results of these investigations indicated that the concentrations of total PCBs in crayfish ranged from 125 to 382 µg/kg WW. Forage fish, such as gizzard shad, golden shiner, and alewifes had higher levels of total PCBs, ranging from 126 to 1,130 µg/kg WW. The highest levels of total PCBs were observed in whole carp samples

(200 to 7,860 µg/kg WW) and skin-on carp fillets (3,040 to 22,900 µg/kg WW). All of the tissue samples that have been collected to date have levels of total PCBs that exceed the TRGs for the protection of piscivorus wildlife. Total DDTs and dieldrin + aldrin also occurred at elevated concentrations in one or more samples of carp tissues (skin-on fillets). Therefore, it is concluded that total PCBs, dieldrin + aldrin, and total DDTs have accumulated in tissues to levels that are sufficient to cause or substantially contribute to sediment injury relative to piscivorus wildlife species utilizing habitats in the USC.

12.2.5 Summary

Based on the information available from various studies, it is likely that contaminated sediments pose substantial hazards to wildlife in the USC. There were insufficient data to determine if sediments were directly toxic to fish in the USC reach. However, contaminated sediments in the USC are likely to be adversely affecting wildlife species in several ways. First, alteration of benthic invertebrate communities has reduced the abundance of preferred fish food organisms. Second, the fish community in the portion of the USC reach has been impaired relative to uncontaminated reference sites. Third, the concentrations of sediment-associated contaminants are known to exceed, often by wide margins, the levels that have been established to protect piscivorus wildlife species (e.g., herons, kingfishers, otter, mink or osprey). Finally, concentrations of total PCBs, total DDTs, and dieldrin + aldrin in aquatic organisms from the USC reach exceeded levels that are associated with adverse effects on piscivorus wildlife species (based on TRG for the protection of wildlife species). Therefore, it is concluded that injured sediments in the USC reach are adversely affecting fish and wildlife resources utilizing this reach of the Assessment Area.

12.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in USC sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of the report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially contributing to effects on sediment-dwelling organisms) were identified from the list of chemicals of concern by comparing measured contaminant concentrations in whole sediments to the PECs (Table 12.1). The substances which occurred in USC sediments at concentrations in excess of these chemical benchmarks were identified as toxic contaminants of concern. The results of this evaluation indicate that metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), PAHs ($ 11 individual PAHs and total PAHs), and total PCBs are present in both surficial and sub-surface sediments from the USC at concentrations that are sufficient to injure sediment-dwelling organisms (Table 12.1). Importantly, the concentrations of cadmium, chromium, copper, nickel, lead, and zinc also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments.

The concentrations of chemicals of concern in pore water were measured in three sediment samples from the USC reach. These data, in conjunction with published toxicity thresholds, were used to identify contaminants of concern in pore water from USC sediments. Evaluation of the data reported in this study using the toxic units approach indicates that the concentrations of metals (cadmium, copper, lead, zinc, and sum toxic units) and unionized ammonia were above concentrations that have been shown to be toxic to aquatic organisms. Therefore, the toxic contaminants of concern in pore water included unionized ammonia and metals.

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 12.1); and, (2) measured contaminant concentrations in the tissues to the TRGs for the protection of piscivorus wildlife (Table 3.4). The results of this evaluation indicate that total PCBs, chlordane, total DDTs, heptachlor, heptachlor epoxide, and 2,3,7,8-TCDD occurred in USC sediments at concentrations that are sufficient to cause or substantially contribute to effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). Surficial and sub-surface sediments have been contaminated by one or more of these substances. The available tissue residue data confirm that total PCBs, dieldrin + aldrin, and total DDTs have accumulated in fish and/or invertebrate tissues to levels that post risks to piscivorus wildlife.

All of these contaminants of concern frequently exceed the chemical benchmarks in USC sediments. In addition, the concentrations of these substances in USC sediments equaled or exceeded the chemical acute (mean PEC-Q of 4.0) and chronic (mean PEC-Q of 0.7) benchmarks by substantial margins (44 times the acute threshold and 253 times the chronic threshold; Table 12.9). Therefore, NH_3, metals, PAHs, and PCBs are present in whole sediments at concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and to adversely affect wildlife in the USC reach.

12.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury was determined by merging the various data sets that provided information on contaminant concentrations in USC sediments. To support an evaluation of the spatial distribution of contaminants of concern, mean PEC-Qs were calculated for each of the sediment samples that were obtained from the USC. The extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (each sample was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial and sub-surface sediments separately.

Based on the sediment chemistry data that have been collected to date, it is likely that surficial sediments throughout the USC have been contaminated by a variety of toxic substances. Mean PEC-Qs for surficial sediments in the segment of the USC reach from Columbus Drive to the Forks were routinely at or above a mean PEC-Q of 4.0 (range from 2.3 to 22, 10^{th} percentile 2.3; Table 12.9; Figures 12.6a and 12.7). Similarly, mean PEC-Qs in surficial sediments in the segment of the USC reach from Indianapolis Boulevard to the Forks ranged from 3.5 to 35 (10^{th} percentile 4.1; Figures 12.6b and 12.7). Mean PEC-Qs in surficial sediments in the segment of the USC from the Forks to the entrance to IH were as high as 177 and frequently exceeded 4.0. However, there were only a limited number of samples with quotients < 4.0 or < 0.7 in the segment of the USC from the Forks to the entrance to IH (Figures 12.6a and 12.7).

Data from several studies indicate that the concentrations of chemical contaminants tend to be higher in sub-surface samples in the segment of the USC from Columbus Drive to the Forks (Figures 12.8a and 12.9). In contrast, mean PEC-Qs in sub-surface sediments were similar to or lower than the mean PEC-Qs in surficial sediment in the segment of the USC from Indianapolis Boulevard to the Forks (Figures 12.8b and 12.9). Sub-surface and surficial sediments exhibited a similar pattern of contamination in the segment of the USC from the Forks to the entrance to IH (Figure 12.6c, 12.8c, 12.7, and 12.9).

Based on the available sediment chemistry data, it is apparent that sediments throughout the USC are likely to be toxic to sediment-dwelling organisms. To put these results into perspective, USEPA (2000a) reported that the probability of observing a 50% incidence of toxicity to amphipods in sediments occurred at a mean PEC-Q of $ 4.0 in 10-day acute tests and at a mean PEC-Q of $ 0.7 in 28-day chronic tests. Therefore, surficial sediments would be expected to be frequently toxic to sediment-dwelling organisms (i.e., sediment samples from the USC had mean PEC-Qs of up to 44 times the level that would result in a 50% probability of observing toxicity in 10-day tests and up to 253 times the level that would result in a 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca*; Figure 12.10; USEPA 2000a).

12.5 Summary

Based on seven lines of evidence, it is concluded that both surficial and sub-surface sediments from the USC have been injured. While surficial sediments tend to be the most contaminated, sub-surface sediments throughout the majority of this sub-area have conditions that are sufficient to cause or substantially contribute to sediment injury and injury to associated biological resources.

13.0 Indiana Harbor

The Indiana Harbor/Lake Michigan (IH/LM) reach of the Assessment Area includes Indiana Harbor and the nearshore areas of Lake Michigan. Indiana Harbor is approximately 1.2 miles in length and 0.4 miles in width, extending from the USC reach to the harbor mouth. For this report, the outer limits of the Assessment Area were established by the geographic scope of the data that are available from studies on the Indiana Harbor Area of Concern. Generally, these studies provide data on conditions in southern LM within approximately seven miles of the harbor mouth, including the Whiting and Gary lakeshore areas.

There a number of potential sources of contaminant sources within the IH/LM reach of the Assessment Area. First, downstream transport of contaminated water and sediment from elsewhere in the Assessment Area represents a potential and, probably, an important source of contaminants to IH and southern LM. In addition, there are a variety of NPDES permitted outfalls that are currently or have historically discharged wastewaters into IH, including those operated by Inland Steel Company and LTV Steel Company. Significant amounts of ammonia are produced from existing (and former) coke ovens, sinter plants and blast furnace operations that are part of the integrated steel manufacturing plants adjacent to the IH/LM reach. Various companies also discharge wastewaters directly into LM (i.e., between the Illinois border to the Indiana Dunes National Lakeshore).

Other potential contaminant sources include over-land runoff from industrial facilities, stormwater runoff, contaminant spills, and contaminated ground water leaking through sheet pile bulkheads.

The present assessment is intended to evaluate injury to surface water and biological resources in the IH/LM that are associated with contaminated sediments (i.e., assessment of sediment injury due to discharges of oil and releases of other hazardous substances). In this assessment, oil and other hazardous substances are considered to include a variety of toxic and bioaccumulative substances, including but not limited to PAHs, PCBs, and metals. In addition, a number of other indicators of environmental quality conditions, such as pesticides, DO, SOD, TOC, and NH_3, have been considered in this assessment of sediment injury.

This assessment of sediment injury in the IH/LM includes two main components. The first component consists of an assessment to determine if chemical characteristics of sediments in the IH/LM are sufficient to have injured surface water resources and/or the biological resources that are associated with sediments (i.e., sediment-dwelling organisms). The second component of the assessment is focused on determining if sediments in the IH/LM are sufficiently contaminated to harm fish and wildlife resources. Sediments in the IH/LM were considered to have been injured if the available information indicates that surface water or biological resources have been injured by discharges of oil or releases of other hazardous substances.

Two additional evaluations were undertaken if the results of these two assessments demonstrate that sediments have been injured. First, the chemicals of concern that are present at concentrations sufficient to cause or substantially contribute to sediment injury were identified (termed contaminants of concern). Second, the areal extent of sediment injury was determined, primarily using information on the concentrations of contaminants in whole sediments. These latter two evaluations were intended to provide additional information that could be used to support restoration planning within the Assessment Area.

13.1 Assessment of Injury to Sediment and Associated Sediment - Dwelling Organisms

13.1.1 Whole Sediment Chemistry

Whole sediment chemistry data are essential for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to acute or chronic toxicity thresholds provides a basis for determining if individual chemicals occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (see Section 3.1). Likewise evaluation of these data relative to mean PEC-Qs provides a means of determining if chemical mixtures occur at levels that are sufficient to cause or substantially contribute to sediment injury.

The project database contains information on the chemical characteristics of 87 surficial sediment samples from the IH/LM reach (Tables 13.1). The locations where these samples were collected are shown in Figures 13.1a and b). The results of chemical analyses of these samples indicate that a large proportion of surficial sediments in the IH/LM reach have been contaminated by oil or other hazardous substances. For example, the concentrations of sediment-associated metals exceed the PECs in up to 56% of the samples (depending on the metal considered). Total PAH concentrations exceed the PEC in 75% (33 of 44 samples) of the samples in which these contaminants were measured. Total PCB concentrations exceed the PEC in only 15% of the surface samples (6 of 40 samples) in which these contaminants were quantified.

While the data on the concentrations of individual contaminants provide important information for assessing the quality of sediments in the IH/LM reach, the mean PEC-Q represents a more relevant measure of the overall chemical composition of surficial sediments (Tables 13.2; Figures 13.6 a-d and 13.7a-b). The results of this evaluation indicate that 57% (50 to 87 samples) of the surficial sediments equaled or exceeded the chronic PEC-Q of 0.7 and 14% (12 of 87 samples) of the surficial sediments equaled or exceeded the acute PEC-Q of 4.0. These data indicate that most of the surficial sediments from this reach of the Assessment Area are likely to be toxic to sediment-dwelling organisms. A total of 44% of the sediment samples from the IH/LM reach had chemical characteristics that were between the chronic mean PEC-Q of $ 0.7 and acute mean PEC-Q of < 4.0. In the IH/LM reach, 33% of the surface samples had a mean PEC-Q of $ 0.1 to < 0.7 and 9.2% of the surface samples had a mean PEC-Q of < 0.1.

The IH segment of the IH/LM reach had a higher portion of samples that equaled or exceeded mean PEC-Qs of 0.7 compared to the nearshore areas of LM (Tables 13.2 and 13.9). There was no consistent pattern in the distribution of samples that equaled or exceeded mean PEC-Qs of 0.7 in the IH segment of the IH/LM reach (Figure 13.6a) and the median of the mean PEC-Q for this segment was 2.4. In contrast, the median of the mean PEC-Q in the nearshore areas of LM was 0.1. The sediments in these nearshore areas with mean PEC-Qs ranging from $ 0.1 to < 0.7 were generally located west of the IH segment and samples with a mean PEC-Q < 0.1 were generally located east of the IH segment (Figure 13.7b). These data show that surficial sediments in the IH segment of the IH/LM reach of the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances. In contrast, the nearshore areas of LM had relatively low concentrations of contaminants. All of the data for sediment chemistry in the IH/LM reach were collected prior to 1996. The natural resource trustees and the nine cooperating potentially responsible parties agreed that additional sampling of this well-characterized area was unwarranted. This is why there are no recent sediment chemistry data.

Information on the chemical characteristics of 24 sub-surface sediment samples from the IH/LM reach is contained in the project database. The sampling sites where these sediments were collected are shown in Figure 13.2. Only one of these 24 samples was located in the nearshore area of LM. No PAHs or pesticides were reported for these sub-surface sediment samples. Evaluation of the available sediment chemistry data indicates that sub-surface sediments in the IH/LM reach have also been contaminated by metals and total PCBs to a similar extent as surficial sediments (Table 13.1). For example, the concentrations of sediment-associated metals exceed the PECs in up to 75% of the samples (depending on the metal that is considered). Total PCB concentrations exceed the PEC in 29% of the sub-surface samples (2 of 7 samples) in which these contaminants were quantified.

Based on the mean PEC-Qs that were calculated, it is likely that sub-surface sediment samples in the IH/LM reach have also been contaminated by discharges of oil or releases of hazardous substances (Tables 13.2; Figures 13.8 and 13.9). Overall, 75% (18 of 24 samples) of the sub-surface sediments equaled or exceeded the chronic mean PEC-Q of 0.7 and 17% (4 of 24 samples) of the sub-surface sediments equaled or exceeded the acute PEC-Q of 4.0. Hence, most of the sub-surface sediments from this reach of the Assessment Area have chemical characteristics that are indicative of sediment injury. A total of 58% of the sediment samples from the IH/LM reach had chemical characteristics that were between the chronic mean PEC-Q of $ 0.7 and acute mean PEC-Q of < 4.0. Thirteen percent of the sub-surface samples from this reach had mean PEC-Qs $ 0.1 to < 0.7; these samples were taken from the central and western portions of the harbor and outside the mouth of the harbor. In the IH/LM reach, only 13% the sub-surface samples had a mean PEC-Q of < 0.1; these samples were clustered along the western shore of the IH segment of the IH/LM reach.

In summary, the available data on the concentrations of chemicals in sediment demonstrates that both surficial and sub-surface sediments in the IH segment of the IH/LM reach have been contaminated by oil or other hazardous substances. Comparison of these data to the consensus-based PECs demonstrates that the concentrations of sediment-associated contaminants are sufficient to injure sediment-dwelling organisms. Therefore, it is concluded that the sediments and sediment-dwelling organisms that depend on the critical aquatic habitats in the IH segment of the IH/LM reach have been injured due to the discharges of oil or releases of other hazardous substances (i.e., metals, PAHs, and PCBs). In contrast, the available data on whole sediment chemistry indicate that sediments in nearshore areas of LM have not been injured.

13.1.2 Pore Water Chemistry

Data on the concentrations of contaminants in pore water provide important information for determining if discharges of oil or releases of other hazardous substances have caused sediments to be contaminated by toxic substances. Evaluation of these data relative to published toxicity thresholds for aquatic organisms provides a basis for determining if individual chemicals or chemical mixtures (i.e., using a toxic units approach) occur at concentrations that are sufficient to cause or substantially contribute to sediment injury (Section 3.1). In this report, the available pore water chemistry data were compiled on a reach-specific basis to facilitate assessment of sediment injury.

The concentrations of SEM and AVS were measured in two sediment samples from the IH/LM reach of the Assessment Area. In both of these samples, the molar concentrations of AVS exceeded the molar concentrations of SEM. Sediments in which AVS > SEM are predicted to have pore water metal concentrations below those that are expected to cause toxicity (Ankley *et al.* 1996). As such, pore water from IH/LM sediments is predicted to have levels of metals that are below toxicity thresholds.

Concentrations of metals or ammonia in pore water from IH sediments were reported from three sampling locations within the IH segment of the IH/LM reach (Table 13.3). Concentrations of lead and zinc were elevated in these samples relative to the toxicity threshold for the amphipod *Hyalella azteca* in 10-day acute tests. The sum toxic unit for metals in these samples ranged from 1.65 to 1.83, which indicated that there were sufficient concentrations of metals in these samples to have contributed to the observed toxicity in pore water toxicity tests (Section 13.1.3). The detection limit for cadmium was too high in one of the samples to be able to interpret the pore water concentrations relative to the published 10-day LC_{50} for *H. azteca*. The concentration of unionized ammonia (NH_3) in pore waters of sediments was reported for one sample within the IH segment of the IH/LM reach (0.3 mg/L; Table 13.3). This concentration of NH_3 is below the acute lethal effect concentration reported for freshwater invertebrates (CCREM 1987). There were no samples of pore water from the LM segment of the IH/LM reach.

Results of this evaluation indicate that concentrations of contaminants in pore water samples from the IH segment of the IH/LM reach are sufficiently elevated to cause or contribute to acute and chronic toxicity to sediment-dwelling organisms. The results of toxicity tests conducted with pore water and elutriate samples support the conclusion that concentrations of contaminants were sufficiently elevated in IH sediments to cause or substantially contribute to the observed toxicity to sediment-dwelling organisms (Section 13.1.3). Therefore, it is concluded that concentrations of contaminants are sufficiently elevated to cause or substantially contribute to sediment injury in the IH segment of the IH/LM reach (see Section 13.1.4). Insufficient data were available to assess pore water quality in LM.

13.1.3 Sediment Toxicity Tests

The results of toxicity tests conducted using whole sediment, pore water, and/or elutriates provide critical information for assessing the effects of contaminated sediments on aquatic organisms. Importantly, the results of such toxicity tests provide information that can be used directly to determine if sediments have been injured by discharges of oil or releases of other hazardous substances.

In the IH/LM reach, four studies have been conducted with sediment samples to determine if sediments and associated pore water or elutriate samples are toxic to sediment-dwelling organisms or other aquatic species (Table 13.4; Figure 13.3). In total, data are available on the toxicity of 38 sediment samples from the IH/LM reach. The species and endpoints that were tested in these studies included cladoceran (*Daphnia magna* and *Ceriodaphnia dubia*) survival; midge (*Chironomus tentans* or *C. riparius*) survival and growth; amphipod (*Hyalella azteca*) survival, growth, number of antennal segments, and percent mature; and bacterial (*Vibrio fisheri*) bioluminescence (i.e., as a surrogate for bacterial metabolic rate). Overall, 74% of the samples (n=38) that were collected from the IH/LM reach were shown to be toxic to one or more species (Table 13.4; Figure 13.10). A total of 81% of the sediment samples (i.e., 26 of 32) from the IH segment were identified as toxic. By comparison, only 33% of the sediment samples (i.e., 2 of 6) from the nearshore areas of LM were shown to be toxic to aquatic organisms. While sediments from the IH segment of the IH/LM reach would likely have been toxic more frequently had long-term tests (including sublethal endpoints) been employed, the results of the studies that have been conducted demonstrate that sediments from the IH segment of the IH/LM reach are acutely toxic to a variety of aquatic organisms, including sediment-dwelling species. Therefore, it is concluded that the conditions of sediments and associated pore waters in the IH segment of the IH/LM reach are sufficient to injure sediments and associated biological resources, including sediment-dwelling species. There was insufficient toxicity for the nearshore areas of LM to determine if sediments from this area would be consistently toxic to sediment-dwelling organisms.

13.1.4 Status of Benthic Invertebrate Community

Because many aquatic invertebrates utilize benthic habitats, sediment quality conditions have the potential to influence both the abundance and composition of benthic invertebrate communities. Therefore, information on the status of benthic invertebrate communities provides important information for evaluating the effects of contaminated sediments on sediment-dwelling organisms (Canfield *et al.* 1996; 1998).

Information from 16 benthos samples (15 grab samples and one artificial substrate sample) collected from sediments located in the IH segment and 56 benthos samples collected from sediments located in nearshore areas of LM were used to assess injury to sediments and biological resources in the IH/LM reach (Table 13.5; Figures 13.4a and b; LTI 1984; Polls and Dennison 1984; Risatti and Ross 1989; Polls *et al.* 1993; USEPA 1996a; Simon *et al.* 2000). The results of the surveys conducted in the IH segment of the IH/LM reach demonstrate that benthic invertebrate communities are dominated by pollution-tolerant species. The normal range of oligochaete relative abundance in the Assessment Area is 3.0% to 73.6% (Section 3.1.1). Oligochaete abundance exceeded 73.6% in 12 of the 15 grab samples (i.e., 80%) collected from the IH segment of the IH/LM reach, with leeches, chironomids, other diptera, or mollusks only occasionally observed. The oligochaetes were predominantly pollution-tolerant tubificids (Polls *et al.* 1993). More sensitive organisms, such as mayflies, stoneflies, caddisflies (i.e., EPT taxa) were absent from these sampling stations located in the IH segment of the IH/LM reach. Together, these data indicate the benthic community structure in IH is poor compared to other locations sampled in northern Indiana and in LM (Polls and Dennison 1984; Risatti and Ross 1989; Polls *et al.* 1993; USEPA 1996a).

The results of the surveys conducted in the nearshore areas of LM indicated that samples from these areas had a more diverse assemblage of benthic invertebrates compared to the IH segment of the IH/LM reach. The oligochaetes in the nearshore samples were not predominantly pollution-tolerant tubificids (Polls *et al.* 1993). Leeches, dipterans, mollusks, EPT taxa and other taxa frequently made up a higher percentage of the organisms in the nearshore LM samples evaluated by Risatti and Ross (1989) and by Polls *et al.* (1993; Table 13.5; Figures 13.4a and b). Specifically, the non-oligochaete taxa represented 26% to 86% of the taxa in 21 of 23 samples from these two studies. The percentage of oligochaetes in 20 of these 21 samples was below 73.6% (the upper limit of the normal range of oligochaete abundance).

LTI (1984) collected samples from two locations in the nearshore areas of LM ("WS" samples located to the west of the IH segment, offshore of Whiting, and "S8" samples located just east of IH mouth; Figure 4.7). Additionally, Polls and Dennison (1984) collected samples from the eastern ("G" samples) and western ("H" samples) areas of nearshore LM (Figure 4.6). Consistent with the samples evaluated by Risatti and Ross (1989) and by Polls *et al.* (1993), the "W" and "H" samples located at a distance from the IH segment contained a high proportion of dipterans and mollusks and a low proportion of oligochaetes (Table 13.5). In contrast, the "S" and "G" samples were generally similar to samples evaluated from the IH segment of the IH/LM reach (i.e., containing a higher proportion of oligochaetes relative to other taxa).

Simon *et al.* (2000) evaluated benthic invertebrate samples from one station in the IH segment of the IH/LM reach using artificial substrate samplers. Results of this survey are consistent with the historical data obtained from sediment grab samples collected from the IH segment of the IH/LM reach by LTI (1984); Polls and Dennison (1984); Risatti and Ross (1989); Polls *et al.* (1993); and, USEPA (1996a). The mIBI score for this sample was 0.8, indicating that the structure of benthic invertebrate communities is degraded relative to other locations in Indiana (i.e., the average mIBI score for Indiana is in the order of 3.5 $\pm$ 0.29; Simon *et al.* 2000). The benthic invertebrates were primarily pollution-tolerant oligochaetes, with only 0.2% pollution-sensitive EPT taxa observed. Artificial substrate samples containing < 0.5% EPT taxa were considered to be indicative of conditions that are sufficient to injure sediment-dwelling organisms (Simon *et al.* 2000; Section 3.1.1). Simon *et al.* (2000) concluded that the sample collected from the IH segment of the IH/LM reach showed extremely poor benthic invertebrate communities, with a lack of sensitive taxa.

The available information indicates that benthic invertebrate communities in the IH segment of the IH/LM reach and the nearshore samples from LM that surround the IH segment have been altered relative to reference conditions in LM and elsewhere in northern Indiana (i.e., 13 of 16 samples were altered; Table 13.5). In contrast, the remaining nearshore samples from LM generally supported a relatively diverse community of benthic invertebrates (i.e., 24 of 56 samples were altered). Impacts on sediment-dwelling organisms are particularly important because invertebrates represent important food sources for fish and other wildlife species that might inhabit the IH segment of the IH/LM reach. The presence of altered benthic invertebrate communities provides confirmatory evidence (in addition to the sediment toxicity data) that conditions in the IH segment of the IH/LM reach and the nearshore areas of LM surrounding the IH segment are sufficient to injure sediments and sediment-dwelling organisms. The LM segment of this reach does not appear to have conditions sufficient to injure sediment-dwelling organisms beyond roughly a half mile from the mouth of IH or the shoreline of LM.

13.1.5 Other Indicators of Benthic Habitat Quality

Conventional indicators of environmental quality, such as DO, SOD, TOC, and NH_3, provide important information for the general status of aquatic habitats and their suitability for supporting aquatic life. For this reason, the available information on conventional indicators of environmental quality conditions was compiled and used to assess sediment injury in the IH/LM reach. No information was located on the levels of DO or SOD in the IH/LM reach. Therefore, it was not possible to evaluate sediment quality conditions relative to these conventional indicators.

The levels of TOC in the IH segment tend to be higher than those that occur in the nearshore areas of LM. Mean concentrations of TOC in surficial sediments were 11.8% (range 0.1% to 32%) within the IH segment of the IH/LM reach and 0.5% (range 0.002% to 7.6%) in the nearshore areas of LM (Table 13.6). Sub-surface sediments in the IH segment of the IH/LM reach averaged 13.4% (range 0.1% to 60.2%). By comparison, Lake Michigan sediments in the vicinity of the IH had an average level of TOC of 0.5% (n=31); the upper 95% CI for these samples was 3.4%. The upper limit of the normal range of TOC values (3.4%) is similar to the average level of TOC that has been measured at other Areas of Concern in the Great Lakes (mean = 2.7%; 95% CI is 2.0% to 3.4%; USEPA 1996b).

Data on oil and grease concentrations provide useful information for interpreting the data on TOC. These data show that oil and grease levels averaged 42,600 mg/kg (or 4.3%) in surficial sediments from IH (Table 13.7). Similar levels of oil and grease (mean of 4.4%) were reported for sub-surface sediments from IH. As such, it is likely that oil and oil-related compounds comprise a substantial proportion of the TOC in IH sediments.

In aquatic ecosystems, ammonia is excreted by aquatic organisms, formed during the decomposition of biological tissues and nitrogen-containing wastes, and/or released from anthropogenic sources. There are a variety of anthropogenic sources of ammonia, such as municipal and industrial wastewater discharges. Free ammonia can be present either as NH_3 or as NH_4^+ (depending on pH and temperature). Unionized ammonia (NH_3) is very toxic to aquatic life, with lethal thresholds as low as 0.1 mg/L reported in the literature (Thurston and Russo 1983; Thurston and Meyn 1984; Thurston *et al.* 1984). The concentration of NH_3 in pore waters of sediments was reported for one sample within the IH segment of the IH/LM reach (0.3 mg/L; Section 13.1.2). This concentration of NH_3 is below the acute lethal effect concentration reported for freshwater invertebrates (CCREM 1987).

A survey of aquatic habitat quality and fish community structure in IH and the USC reach was conducted by Risatti and Ross (1989). The results of this study demonstrated that aquatic habitats in the USC reach have been lost or degraded due to the presence of contaminated sediments. Layers of oily sludge and tar balls were observed on the surface of six stations along the USC reach. In contrast, oily sludge was not observed by LTI (1984) or by Risatti and Ross (1989) in sediments located in the IH segment of the IH/LM reach or in the nearshore areas of LM. Instead, there was fine sand or gravel located at all of the stations sampled in the IH/LM reach. LTI (1984) classified the physical habitats of the nearshore sediments in LM as generally "fair" to "poor" for fish spawning potential (Figure 4.7).

In 1998, Simon *et al.* (2000) evaluated the status of aquatic habitats at one station in the IH/LM reach. In this investigation, data was collected on the characteristics of bottom substrates, instream cover, channel morphology, riparian zone and bank erosion, pool and riffle quality, and gradient at each sampling location. These data were then compiled to support the calculation of QHEI scores for each sampling location. The results of this study showed that this station had a QHEI score of 17. By comparison, OEPA (1988) reported that the mean (± SD) QHEI score for the ECBPs eco-region was 74 (± 13.1), with the lower limit of the normal range of QHEI scores being 48. Additionally, the IDEM (2000c) has established use support assessment criteria for streams in Indiana. These criteria indicated that use impairment is likely to occur when QHEI scores are < 64. As such, aquatic habitats in the IH/LM reach were considered to be degraded relative to unimpacted sites in ECBPs.

In summary, the available information indicates that aquatic habitats have been degraded in the IH segment of the IH/LM reach. In addition, high levels of TOC and associated oil and oil-related compounds in the IH segment of the IH/LM reach would exacerbate the effects of lost habitat for fish and invertebrates in the Assessment Area. Therefore, it is concluded that sediments in the IH segment of the IH/LM reach of the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances.

13.1.6 Summary

Based on a review of the available data, it is concluded that sediments in the IH segment and nearby areas of LM have been injured by discharges of oil or releases of hazardous substances. More specifically, the data show that metals, PAHs, and PCBs occur in whole sediments at concentrations that are sufficient to injure sediment-dwelling organisms. Calculated mean PEC-Qs exceed, often by a wide margin, the levels that are sufficient to injure sediment-dwelling organisms. The levels of metals in pore water are also sufficient to cause toxicity to aquatic organisms. In addition, the results of toxicity tests confirm that whole sediments, pore water, and elutriates are toxic to aquatic organisms. That benthic invertebrate communities are significantly altered relative to reference sites provides further confirmatory evidence that environmental conditions in this reach of the Assessment Area are sufficient to injure sediments and associated biological resources. Together, these multiple lines of evidence demonstrate that sediments and associated biological resources in the IH segment and nearby areas of LM have been injured as a result of discharges of oil or releases of other hazardous substances. However, the available data indicate sediments and associated biological resources beyond 0.5 miles of IH and the LM shoreline have not been injured.

13.2 Assessment of Effects on Fish and Wildlife Resources

In addition to effects on sediment-dwelling organisms, contaminated sediments have the potential to adversely affect a variety of fish and wildlife resources, including fish, amphibians, reptiles, birds, and mammals (i.e., aquatic-dependent wildlife), in a number of ways (Ingersoll *et al.* 1997). First, exposure to contaminated sediments can compromise fish health, as evidenced by an increased incidence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). In addition, direct toxicity (i.e., due to exposure to contaminated sediments) or reductions in the availability of preferred fish food organisms can result in reduced populations of fish species (e.g., epibenthic species) and/or altered community characteristics (e.g., reduced diversity). Furthermore, accumulation of contaminants in fish tissues can adversely affect the fish themselves or result in adverse effects on piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey). These types of ecological effects can be evaluated using information on the toxicity of sediments to fish, fish health, fish community structure, whole sediment chemistry (i.e., relative bioaccumulation-based SQGs), and tissue chemistry (i.e., relative to TRGs).

13.2.1 Toxicity of Sediments to Fish

No information was located on the toxicity of IH/LM to fish. Therefore it is not possible to assess the toxicity of whole sediments, elutriates, or pore water to fish in this reach of the Assessment Area.

13.2.2 Fish Health

In 1998, Simon *et al.* (2000) conducted an investigation to evaluate the status of fish communities, including fish health, in the IH/LM area. Fish were collected at one station in Indiana Harbor and examined for the presence of deformities, eroded fins, lesions, and tumors (i.e., DELT abnormalities). The results of this study indicated that the incidence of DELT abnormalities was 12.8% at this station. As such, these data show that fish health has been adversely affected by ambient environmental conditions in the IH/LM area.

13.2.3 Status of Fish Communities

The results of surveys of the status of fish communities can provide relevant information for evaluating environmental quality in the IH/LM reach. Risatti and Ross (1989) summarized data from the fish surveys that were conducted in the IH Assessment Area during 1983 (USEPA 1985; 15 species of fish), 1984 (USACE 1986; 23 species of fish), and 1988 (Risatti and Ross 1989; 10 species of fish). The data presented in these studies do not support a comprehensive evaluation of the structure of fish communities in the various reaches of the IH Assessment Area. Nevertheless, the results of fish sampling conducted in 1988 indicated that IH and the USC reach were dominated by pollution-tolerant carp, goldfish, shad, and shiners.

Simon *et al.* (2000) conducted a survey of fish communities in the Assessment Area in 1998 (Table 14.9). Fish communities were evaluated using an IBI that was originally developed by Karr (1981) and was subsequently calibrated for use in Indiana (Simon and Stewart 1998). This survey included one station in the IH segment of the IH/LM reach. Based on the results of this survey, an IBI score of 14 was calculated for this reach of the Assessment Area. As such, fish communities in the harbor were considered to have “very poor” biological integrity relative to fish communities elsewhere in northwestern Indiana and the CCBPs eco-region. Together, the data from these studies indicate that fish communities in IH are impaired relative to reference conditions.

13.2.4 Bioaccumulation of Sediment-Associated Contaminants

In addition to direct effects on aquatic organisms, sediment-associated contaminants can have harmful effects on those wildlife species that feed on fish and other aquatic species. In this report, the sediment quality criteria for the protection of wildlife (NYSDEC 1994) were used as chemical benchmarks for evaluating the ecological significance of sediment-associated contaminants in the IH/LM reach. Considering the sediment chemistry data that has been collected in the IH/LM reach, the concentrations of total PCBs frequently (88% of samples; 29 of 33 samples) exceed the chemical benchmark that has been established for the protection of piscivorus wildlife in surficial sediments (Table 13.1). The levels of chlordane and 2,3,7,8-TCDD also exceeded these bioaccumulation-based SQGs in one or more surficial sediment samples. Insufficient data were located to evaluate the risks posed to wildlife by bioaccumulative substances in sub-surface sediments.

Tissue residue guidelines provide another means of assessing the significance of bioaccumulative chemicals of concern to piscivorus wildlife species (e.g., herons, kingfisher, otter, mink or osprey; Newell *et al.* 1987). Comparison of tissue residue levels to fish flesh criteria for the protection of wildlife provides a basis for confirming if bioaccumulation represents a hazard to wildlife species.

Risatti and Ross (1989) sampled fish and crayfish from the IH segment or from nearshore areas of LM to determine the concentrations of tissue-associated contaminants. A total of 18 samples were collected from the IH segment and four samples were collected from nearshore LM (whole body of alewife, carp, crayfish, gizzard shad, perch, sunfish; Appendix 5.6). The results of this investigation indicated that the levels of total PCBs ranged from 121 to 149 µg/kg WW in crayfish from the IH segment. Forage fish, such as alewifes, gizzard shad, and sunfish, from this segment had somewhat higher levels of total PCBs in their tissues, ranging from 15 to 986 µg/kg WW. The levels of total PCBs ranged from 634 to 4,340 µg/kg in the carp from IH. Crayfish and forage fish from Southern Lake Michigan had similar levels of total PCBs in their tissues as those in IH. Sixteen of 17 samples from the IH segment and two of four samples from nearshore LM had concentrations of total PCBs that exceeded the level that has been established for the protection of wildlife (i.e., 110 µg/kg). Therefore, it is concluded that total PCBs have accumulated in tissues to levels that are sufficient to cause or substantially contribute to injury to piscivorus wildlife species utilizing habitats in the IH/LM reach.

13.2.5 Summary

Based on the information that is available from various studies, it is apparent that contaminated sediments pose substantial hazards to wildlife in the IH/LM reach of the Assessment Area. Contaminated sediments in the IH/LM reach are likely to be adversely affecting wildlife species in several ways. First, alteration of benthic invertebrate communities has reduced the abundance of preferred fish food organisms in the IH segment of the IH/LM reach (Section 13.1.4). Second, fish health has been compromised within the IH segment of the IH/LM reach. Third, fish populations are impaired within IH, potentially reducing the abundance of prey species to piscivorus wildlife. Finally, the concentrations of total PCBs in sediments exceed the levels that have been established for the protection of piscivorus wildlife. The risks posed to wildlife by tissue associated PCBs were confirmed by the presence of elevated levels of PCBs in invertebrate and fish tissues (i.e., in excess of the TRGs for the protection of wildlife species). Therefore, it is concluded that the injured sediments in the IH/LM reach are adversely affecting fish and wildlife resources within this reach of the Assessment Area.

13.3 Determination of Contaminants of Concern

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to adverse effects on sediment-dwelling organisms and fish and wildlife resources. In this report, the toxic or bioaccumulative chemicals that occur in IH/LM sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed contaminants of concern. The contaminants of concern in whole sediments and pore water are identified in this section of the report.

The toxic contaminants of concern (i.e., those with a high potential for causing or substantially contributing to effects on sediment-dwelling organisms) were identified from the list of chemicals of concern by comparing measured contaminant concentrations in whole sediments to the PECs (Table 13.1). The contaminants which occurred in IH sediments at concentrations in excess of these chemical benchmarks were identified as toxic contaminants of concern. The results of this evaluation indicate that metals (arsenic, cadmium, chromium, copper, lead, nickel, and zinc), PAHs (13 individual PAHs and total PAHs), and total PCBs are present in surficial sediments from the IH/LM reach at concentrations that are sufficient to cause or substantially contribute to injury to sediment-dwelling organisms. The levels of metals and total PCBs were also elevated in sub-surface sediments. Importantly, metal concentrations in IH, (i.e., cadmium, chromium, copper, nickel, lead, and zinc) and metal concentrations in LM (i.e., chromium, copper, nickel, lead, and zinc) also exceeded the upper limit of background levels in Indiana (Table 3.5), confirming that they are present at elevated levels in Assessment Area sediments.

The concentrations of several chemicals of concern exceeded the published toxicity thresholds in pore water from IH sediments. Evaluation of the data using the toxic units approach indicates that the concentration of metals (lead and zinc) was above concentrations that have been shown to be toxic to aquatic organisms in standardized 10-day acute toxicity tests (Table 13.3). Therefore, the metals represent the toxic contaminants of concern in pore water.

The bioaccumulative contaminants of concern were identified from the list of chemicals of concern by comparing: (1) measured contaminant concentrations in whole sediments to the bioaccumulation-based SQGs (Table 13.1); and, (2) measured contaminant concentrations in tissues to the TRGs for the protection of piscivorus wildlife. Exceedances of the TRGs in fish or invertebrate tissues were also used to identify bioaccumulation contaminants of concern. The results of this evaluation indicate that total PCBs, chlordane, and 2,3,7,8-TCDD occurred in IH surficial sediments at concentrations that are sufficient to cause or substantially contribute to effects on wildlife (i.e., due to the accumulation of these substances in aquatic food webs). The available tissue residue data confirm that total PCBs have accumulated in the tissues of aquatic organisms to levels that pose risks to piscivorus wildlife. Insufficient data were available for sub-surface sediments to adequately evaluate these sub-surface sediments or pesticides.

All of the contaminants of concern frequently exceed the chemical benchmarks in sediments from the IH segment of the IH/LM reach. The concentrations of these substances in sediments from the IH segment of the IH/LM reach equaled or exceeded the chemical acute (mean PEC-Q of 4.0) and chronic (mean PEC-Q of 0.7) benchmarks by substantial margins (23 times the acute threshold and 129 times the chronic threshold; Table 13.9). The highest number of exceedances of the bioaccumulation-based SQGs was observed for total PCBs. Therefore, metals, PAHs, and PCBs are present in whole sediments at concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling organisms and to adversely affect wildlife in the IH segment of the IH/LM reach. In contrast, sediments in the nearshore areas of LM generally had lower levels of contamination and, hence, pose fewer risks to sediment-dwelling organisms and fish and wildlife resources.

13.4 Evaluation of the Areal Extent of Sediment Injury

The areal extent of sediment injury was determined by merging the various data sets that provided information on contaminant concentrations in IH sediments. To support an evaluation of the spatial distribution of contaminants of concern, mean PEC-Qs were calculated for each of the sediment samples that were obtained from the IH/LM reach. The extent of sediment injury was subsequently determined by mapping these data (i.e., mean PEC-Qs) using ArcView/Spatial Analyst software (each sample was georeferenced based on the latitude and longitude of the collection site). This evaluation considered surficial and sub-surface sediments separately.

Based on the sediment chemistry data that have been collected to date, it is likely that both surficial and sub-surface sediments throughout the IH segment of the IH/LM reach have been contaminated by oil or other hazardous substances. Mean PEC-Qs for surficial sediments in the IH segment of the IH/LM reach were frequently at or above a mean PEC-Q of 0.7 (range from 0.07 to 90.1, median 2.4; Table 13.9; Figures 13.6a and 13.7a) and were similar to the mean PEC-Qs in the upstream USC reach (Figures 12.6c and 12.7). In contrast, mean PEC-Qs in samples from the nearshore areas of LM were routinely < 0.7 (90th percentile 0.4, Table 13.9; Figure 13.7b). Mean PEC-Qs in nearshore sediments generally decreased in an easterly (Figure 13.6b) and northerly (Figure 13.6c) direction from the IH segment of the IH/LM reach. Whereas, there was no consistent pattern in sediment contamination in western nearshore sediments from LM (Figures 13.6d). Concentrations of contaminants in sub-surface sediments (Figures 13.8 and 13.9) tended to be similar to or lower than surficial sediments in the IH segment of the IH/LM reach. There was not sufficient data from sub-surface sediments to evaluate conditions in the nearshore areas of LM.

Based on the available sediment chemistry data, it is apparent that sediments in IH and in LM in the immediate vicinity of IH are likely to be toxic to sediment-dwelling organisms (Figure 13.10). To put these results into perspective, USEPA (2000a) reported that the probability of observing a 50% incidence of toxicity to amphipods in sediments occurred at a mean PEC-Q of ≥ 4.0 in 10-day acute tests and at a mean PEC-Q of ≥ 0.7 in 28-day chronic tests. Therefore, sediments in the IH segment of the IH/LM reach would be expected to be frequently toxic to sediment-dwelling organisms (i.e., sediment samples from the IH segment had mean PEC-Qs of up to 23 times the level that would result in a 50% probability of observing toxicity in 10-day tests and up to 129 times the level that would result in a 50% probability of observing toxicity in 28-day tests with the amphipod *Hyalella azteca*; USEPA 2000a).

13.5 Summary

Based on a review of seven lines of evidence, it is concluded that both surficial and sub-surface sediments in the IH/LM reach of the Assessment Area have been injured by discharges of oil or releases of other hazardous substances. Information on whole sediment and pore water chemistry indicates that metals, PAHs, and PCBs occur in sediments from the IH/LM reach at levels that are sufficient to injure sediment-dwelling organisms and/or wildlife. Sediments from IH and LM near the mouth of the IH have been shown to be toxic to sediment-dwelling organisms and to have altered benthic invertebrate communities. Fish communities and fish health in this area were also impaired relative to reference sites elsewhere in Indiana. The IH segment of this reach has conditions sufficient to injure sediments, sediment-dwelling organisms, and wildlife. By comparison, most of the LM segment of this reach have conditions that are not indicative of sediment injury.

14.0 Summary and Conclusions

This investigation was conducted to determine if sediments within the Grand Calumet River, Indiana Harbor Canal, Indiana Harbor, or the nearshore areas of Lake Michigan (i.e., the Assessment Area) have been injured due to discharges of oil or releases of other hazardous substances. If the results of this assessment indicated that sediment injury has occurred within the Assessment Area, then the subsequent objectives of this investigation were to identify contaminants of concern in the Assessment Area and to evaluate the areal extent of sediment injury.

In this report, sediment injury was defined as the presence of conditions that have injured or are sufficient to injure sediment-dwelling organisms, and/or fish and wildlife resources. As such, this assessment of sediment injury was intended to provide the information needed to evaluate injury to surface water resources and biological resources within the Assessment Area. Contaminants of concern were defined as those toxic or bioaccumulative substances that occur in sediments at concentrations that are sufficient to cause or substantially contribute to sediment injury, including injury to sediment-dwelling organisms, and/or fish and wildlife resources.

In accordance with the Assessment Plan (Natural Resources Trustees 1997), this assessment of sediment injury was focused on evaluating the effects on natural resources that have occurred due to discharges of oil or releases of other hazardous substances. The chemicals of concern in the Assessment Area include polychlorinated biphenyls (PCBs), oil and oil-related compounds (including alkanes, alkenes, naphthalenes, and polycyclic aromatic hydrocarbons; PAHs), and metals (Natural Resources Trustees 1997). The other substances that were considered in this study include various pesticides, phenols, and conventional variables [such as total organic carbon (TOC), sediment oxygen demand (SOD), and unionized ammonia (NH_3)]. As many of these substances tend to become associated with sediments upon release into aquatic ecosystems, sediment contamination represents a concern with respect to the restoration of beneficial uses in the Assessment Area (IDEM 1991).

To facilitate this evaluation, the Assessment Area was divided into nine separate reaches, including the Grand Calumet River Lagoons (GCRL), East Branch Grand Calumet River-I (EBGCR-I), East Branch Grand Calumet River-II (EBGCR-II), West Branch Grand Calumet River-I (WBGCR-I), West Branch Grand Calumet River-II (WBGCR-II), Indiana

Harbor Canal (IHC), Lake George Branch (LGB), US Canal (USC) and Indiana Harbor/Lake Michigan (IH/LM). In each of these reaches, the available sediment quality and related information was collected, evaluated, compiled, and used to assess injury to sediments and associated biological resources. The results of these assessments are presented in Sections 5 to 13 of this report. A summary of these results is presented below to provide an overview of sediment quality and related conditions within the Assessment Area.

14.1 Injury to Sediment-Dwelling Organisms

In total, four primary indicators were used to assess injury to sediment-dwelling organisms within the Assessment Area. These indicators included whole sediment chemistry, pore water chemistry, sediment toxicity (including whole sediment, pore water, and/or elutriates), and benthic invertebrate community structure. The status of physical habitats in each reach of the Assessment Area was also described.

Information on the concentrations of sediment-associated contaminants has been gathered for the entire Assessment Area. Collectively, these sediment chemistry data indicate that both surficial and sub-surface sediments in all of the reaches have been injured as a result of discharges of oil or releases of other hazardous substances (Figure 14.1 and 14.2). The highest frequencies of exceedance of the chronic toxicity threshold for amphipods (i.e., mean probable effect concentration-quotients; PEC-Q of $ 0.7; USEPA 2000a) were observed in the WBGCR-I (90%; n=31 samples), IHC (89%; n=36 samples) and, USC (89%; n=215 samples; Table 14.1). The frequency of exceedance of the chronic toxicity threshold ranged from 72% to 86% in the EBGCR-I, EBGCR-II, WBGCR-II, LGB, and the IH segment of the IH/LM reach (Table 14.1). By comparison, only one of 33 samples (3%) from the nearshore areas of the LM segment of the IH/LM reach, had chemical characteristics sufficient to cause or substantially contribute to injury to sediment-dwelling organisms. Relatively lower levels of sediment contamination were also observed in the Lake George wetlands and in the Roxana Marsh portion of the WBGCR-II (Table 14.2 and 14.3). The contaminants of concern in whole sediments from the Assessment Area included metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), PAHs (13 individual PAHs and total PAHs), and total PCBs.

The available information on pore water chemistry confirms that sediments within the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances. In particular, the levels of metals, phenol, and unionized ammonia (NH_3) frequently exceeded published toxicity thresholds for sediment-dwelling organisms. The levels of simultaneously extracted metals (SEM) frequently exceeded the concentrations of acid volatile sulfides (AVS) in sediments, indicating that elevated levels of metals are likely to occur in pore water (in 70 of 169 sediment samples in which these variables were measured; Table 14.4). The concentrations of contaminants in pore water were sufficient to cause or substantially contribute to sediment toxicity in sediments from the EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, LGB, and IH (i.e., two or more samples had contaminant concentrations in excess of the published toxicity thresholds; Table 14.1). Insufficient data were available to characterize contaminant concentrations in pore water from GCRL, USC, and LM sediments.

Information on the toxicity of whole sediments, pore water, or elutriates was available for all of the reaches in the Assessment Area. The results of the laboratory toxicity tests demonstrate that whole sediments, pore water, and elutriates were frequently toxic to aquatic organisms throughout the Assessment Area (Table 14.1; Figure 14.3). Among the various reaches that were investigated, the frequency of sediment toxicity ranged from 33% in LM to 100% in the WBGCR-I. The frequency of sediment toxicity equaled or exceeded 50% in all nine of the reaches, including GCRL (50%; n=12), EBGCR-I (73%; n=44), EBGCR-II (88% n=52), WBGCR-I (100%; n=2), WBGCR-II (83%; n=18), IHC (80%; n=5), LGB (57%; n=7), USC (80%; n=90) and IH/LM (74%; n=38; Table 14.1). The frequency of sediment toxicity tended to be lowest in the Middle and East Lagoons (GCRL), Roxana Marsh (WBGCR-II), Lake George wetlands (LGB), the wetlands associated with the IHC, and the nearshore areas of Lake Michigan. Collectively, the sediment toxicity data demonstrate that sediments and sediment-dwelling organisms have been injured throughout the Assessment Area.

Information on the structure of benthic invertebrate communities is available for all of the reaches within the Assessment Area. Evaluation of these data relative to conditions in the nearshore areas of LM indicates that the structure of benthic invertebrate communities has been altered throughout the Assessment Area (Table 14.1; Figure 14.4). In the EBGCR-I (n=14), EBGCR-II (n=5), WBGCR-I (n=3), IHC (n=6), and LGB (n=4), 100% of the samples that have been collected had characteristics that were indicative of altered benthic invertebrate communities (Table 14.1). A somewhat lower frequency of benthic community alteration was observed in the WBGCR-II (71% of samples; n=14), USC (96%; n=25 samples), IH (81%; n=16 samples), and LM (43%; n=56). Overall, average macroinvertebrate index of biotic integrity (mIBI) scores for the various reaches ranged from 0.7 to 1.4 (Table 14.5). Benthic invertebrate communities were typically dominated by pollution-tolerant species, primarily oligochaetes, throughout much of the Assessment Area. Pollution-sensitive species, such as the EPT taxa (mayflies, stoneflies, and caddisflies) were rarely present in any of the reaches within the Assessment Area. Collectively, these data confirm that environmental conditions in the Assessment Area are sufficient to injure sediments and sediment-dwelling organisms.

Most of the reaches in the Assessment Area were characterized as having altered habitats. Qualitative habitat evaluation index (QHEI) scores ranged from 16 to 65.5 within the Assessment Area, with the lowest scores reported for IHC, LGB, USC, and IH (Simon *et al.* 2000; Table 14.6). Elevated levels of TOC were observed throughout the Assessment Area; the upper limit of the 95% confidence interval of TOC for reference sites (i.e., 3.4% TOC) was frequently exceeded in the EBGCR-II, WBGCR-I, WBGCR-II, LGB, USC, and IH. The lowest levels of TOC were observed in the sediments collected from the nearshore areas of LM (Table 13.6). Based on the levels of oil and grease and the levels of PAHs that have been measured in sediments, oil and oil-related compounds comprise much of the TOC that occurs within the Assessment Area. Together, these data confirm that sediments within the Assessment Area have been contaminated due to discharges of oil or releases of other hazardous substances.

Overall, there was a high level of concordance among the four primary indicators of sediment injury (i.e., whole sediment chemistry, pore water chemistry, sediment toxicity, and benthic invertebrate community structure; Table 14.1). All four lines of evidence indicated that conditions sufficient to injure sediment-dwelling organisms occurred within the EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, LGB, USC, and IH/LM. In the GCRL, two lines of evidence – sediment chemistry and sediment toxicity – indicated the presence of conditions sufficient to injure sediments and sediment-dwelling organisms. These conditions were most prevalent in the West Lagoon. Evaluation of the available data indicates that sediment injury is less likely to occur in the nearshore areas of LM (i.e., two lines of evidence indicate that sediment injury has occurred). Within the LM segment of the IH/LM reach, sediment toxicity and alteration of the benthic invertebrate community occurred most frequently within 0.5 miles from the entrance to IH. Collectively, this information indicates that benthic habitats throughout the Assessment Area, with a few exceptions, have been degraded due to discharges of oil or releases of other hazardous substances. Benthic habitats located in areas farther removed from the harbor entrance tended to reflect uninjured conditions.

14.2 Effects on Fish and Wildlife Resources

A total of five lines of evidence were used to assess effects on fish and wildlife resources that are associated with sediment contamination (i.e., related to the sediment injury that was demonstrated within the various reaches of the Assessment Area). The primary indicators that were used in this report to assess sediment injury relative to fish and wildlife resources included toxicity to fish, fish health, fish community structure, whole sediment chemistry, and tissue chemistry (Table 14.7).

Information of the toxicity of whole sediments, pore water, and/or elutriates to fish (i.e., fathead minnows; *Pimephales promelas*) are available for four reaches within the Assessment Area, including the GCRL, EBGCR-I, EBGCR-II, and WBGCR-II. The results of such laboratory toxicity tests demonstrate that sediments from the EBGCR-I, EBGCR-II, and WBGCR-II are frequently acutely toxic to fish. The incidence of sediment toxicity ranged from 57% (n=23) in the EBGCR-I to 100% (n=7) in the WBGCR-II (Table 14.7). In contrast, only one sample from the GCRL was toxic to fish, which indicates that conditions sufficient to cause acute toxicity to fish were observed only in the western portion of the West Lagoon.

In this report, information on incidence of deformities, fin erosion, lesions, and tumors (i.e., DELT abnormalities) in fish was used to assess fish health in the Assessment Area (Table 14.8). Based on the information that was collated for this area, fish health has been compromised (i.e., incidence of DELT abnormalities > 1.3%) in several of the reaches including the EBGCR-I, EBGCR-II and the WBGCR-I. The average incidence of DELT abnormalities ranged from 0% in the GCRL to 12.8% in IH/LM. The highest incidence of DELT abnormalities (17.4%) was observed in the EBGCR-I.

A number of field surveys have been conducted over the past 15 years to evaluate the status of fish communities in the Assessment Area. The results of these surveys demonstrate that the integrity of fish communities has been impaired (i.e., relative to reference sites in Indiana) in all of the reaches that have been examined (Table 14.9). Overall, index of biotic integrity (IBI) scores ranged from 0 to 43 in the various stream reaches, which classifies fish communities as “fair”, “poor”, “very poor”, or as having no fish (Table 14.9). The lowest average IBI scores were reported for IH/LM (14; n=1); WBGCR-II (15.9 ± 9.8; n=17); WBGCR-I (16.5 ± 10.4; n=12); IHC (17.5 ± 4.4; n=4). Based on these IBI scores, the integrity of fish communities in these four reaches would be classified as “very poor”. Somewhat higher average IBI scores were reported for the EBGCR-I, EBGCR-II, LGB, and USC; average IBI scores in these reaches ranged from 23 to 26. As such, fish communities in these four reaches would be classified as having “poor” to “very poor” integrity. Within the LGB, the wetland areas that are located to the west of the Lake George Canal had the highest IBI score (38; Simon *et al.* 2000). Relatively higher IBI scores were also reported for the GCRL, with IBI scores ranging from 31 to 43 (mean IBI score of 38.1 ± 5.0; n=13). In the GCRL, the lowest IBI scores (i.e., 31 to 38) were reported for the West Lagoon (which is located closest to an iron and steel manufacturer’s slag landfill; Simon and Stewart 1998). In contrast, IBI scores for the Middle Lagoon averaged 42 (Simon and Stewart 1998).

In this report, the sediment injury relative to wildlife was also evaluated using sediment chemistry data. More specifically, the measured concentrations of bioaccumulative substances in whole sediments were compared to bioaccumulation-based sediment quality guidelines (SQGs) for the protection of wildlife (NYSDEC 1994). The results of this evaluation demonstrated that the concentrations of various sediment-associated contaminants were sufficient to adversely affect wildlife species that utilize habitats within the Grand Calumet River watershed (i.e., through bioaccumulation of contaminants in sediment-dwelling organisms and subsequent food web transfer to wildlife species, such as green herons). Among the various reaches, the frequency of exceedance of one or more of the bioaccumulation-based SQGs ranged from 18% to 93% of the sediment samples (Table 14.7), indicating that all of the reaches have levels of bioaccumulative substances in sediments that are sufficient to cause or substantially contribute to adverse effects on wildlife. The highest incidences of exceedance of the bioaccumulation-based SQGs were observed in the GCRL (84%; n=58), IHC (93%; n=15) LGB (83%; n=29), USC (84%; n=37) and IH/LM (88%; n=33). Total PCBs represented the only bioaccumulative contaminants of concern in the Assessment Area; however, chlordane, total DDTs, endrin, heptachlor, heptachlor epoxide, lindane, and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) also exceeded the bioaccumulation-based SQGs in many sediment samples.

Bioaccumulation-based SQGs were not available for metals or PAHs, which precluded an evaluation of the potential for bioaccumulation of these chemical classes.

Tissue chemistry data provide important information for determining if bioaccumulative substances pose unacceptable hazards to wildlife species. In this report, the measured concentrations of bioaccumulative substances in the tissues of fish and other aquatic organisms were compared to the tissue residue guidelines (TRGs) that have been established for the protection of piscivorus wildlife species (Newell *et al.* 1987). The results of this evaluation indicate that tissue residue levels in fish and invertebrates from the Assessment Area frequently exceeded the TRGs for piscivorus wildlife. The concentrations of one or more bioaccumulative substances exceeded the TRGs in 50% to 100% of the tissue samples, depending on which reach of the Assessment Area was considered. The highest frequencies of exceedance of the TRGs (i.e., 100%) were reported for the GCRL, EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, and USC. Eighty-six percent (n=21) of the tissue samples from IH/LM had tissue residue levels in excess of the TRGs. Total PCBs represented the bioaccumulative contaminants of concern in the tissues of aquatic organisms; however, chlordane, total DDTs, dieldrin + aldrin, and endrin were also measured at elevated levels in fish and invertebrate tissues.

In this report, five separate lines of evidence were used to assess sediment injury relative to wildlife species. Overall, the results of this assessment indicate that conditions within the GCRL, EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, LGB, USC, and IH/LM are sufficient to adversely affect wildlife species (i.e., one or more lines of evidence demonstrate effects on wildlife, including, amphibians, reptiles, fish, birds, and mammals; Table 14.7). More specifically, sediments have been demonstrated to be toxic to fish in three reaches of the Assessment Area. In addition, fish health has been compromised in three reaches of the Assessment Area. As would be expected in areas that have impaired fish health and toxic conditions, the integrity of fish communities was "poor" to "very poor" (as measured using IBI scores) throughout most of the Assessment Area (i.e., in seven of nine reaches). Finally, the available sediment chemistry data indicate that the concentrations of bioaccumulative substances are high enough to pose hazards to wildlife (i.e., as a result of bioaccumulation in the sediment-dwelling organisms and subsequent food web transport to piscivorus wildlife species) in all nine reaches. The available data on tissue chemistry confirm that bioaccumulation is occurring throughout the Assessment Area and that the concentrations of bioaccumulative substances in the tissues of aquatic organisms are sufficient to adversely affect piscivorus wildlife species (i.e., in eight of nine reaches). Therefore, sediment injury relative to wildlife resources has been demonstrated throughout the Assessment Area.

14.3 Overall Assessment of Injury to Sediments

An evaluation of the harmful effects of sediment-associated contaminants in the Assessment Area was conducted. To support this assessment, the study area was divided into nine separate reaches, including GCRL, EBGCR-I, EBGCR-II, WBGCR-I, WBGCR-II, IHC, LGB, USC, and IH/LM. The results of this evaluation demonstrate that sediments throughout the Assessment Area have been injured due to discharges of oil or releases of other hazardous substances. This conclusion is supported by up to nine of the following separate lines of evidence:

- Concentrations of metals, PAHs, and/or PCBs, in whole sediments frequently exceeded the consensus-based probable effect concentrations (PECs) throughout the Assessment Area;
- Concentrations of metals, phenol, and/or ammonia in pore water from Assessment Area sediments exceeded published toxicity thresholds at various locations;
- Whole sediments, pore water, and/or elutriates from the Assessment Area were frequently toxic to aquatic organisms, including sediment-dwelling species;
- The structure of benthic invertebrate communities throughout the Assessment Area has been severely altered relative to communities in the nearshore areas of LM or elsewhere in Indiana;
- The health of fish in the Assessment Area has been compromised, as indicated by a high incidence of deformities, fin erosion, lesions, and tumors;
- Whole sediments, pore water, and/or elutriates from the Assessment Area were frequently toxic to fish;

- C The integrity of fish communities in the Assessment Area has been frequently degraded relative to reference sites in Indiana;
- C Concentrations of total PCBs in sediments frequently exceeded the bioaccumulation-based SQGs for the protection of wildlife; and,
- C Concentrations of total PCBs in the tissues of aquatic organisms frequently exceeded the TRGs for the protection of wildlife.

Any one of these independent lines of evidence could be used alone to support the conclusion that sediment injury has occurred in the Assessment Area. When taken together, however, these nine separate lines of evidence provide an indisputable weight-of-evidence for concluding that discharges of oil or releases of other hazardous substances have created conditions that are sufficient to severely injure sediments and the organisms that depend on these critical habitats. The levels of metals, PAHs, PCBs, unionized ammonia and phenols in whole sediments, pore water, and/or fish tissues were sufficient to cause or substantially contribute to the injury of sediments, sediment-dwelling organisms, and/or fish and wildlife resources.

Various metals (arsenic, cadmium, chromium, copper, lead, nickel, and zinc), PAHs (anthracene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, benz(a)anthracene, dibenz(a,h)anthracene, benzo(a)pyrene, chrysene, fluoranthene, pyrene, and total PAHs), PCBs (total PCBs), phenols (phenol) and unionized ammonia are considered to be the toxic and/or bioaccumulative contaminants of concern in the Assessment Area. All of these substances frequently exceeded the chemical benchmarks in surficial and sub-surface sediments throughout the Assessment Area. In addition, the concentrations of these substances in sediments often exceeded the chemical benchmarks by substantial margins, frequently by more than a factor of 100. Therefore, all of these substances were present in whole sediment and/or pore water at concentrations that are sufficient to cause or substantially contribute to injury to sediment-dwelling organisms, and/or adversely affect fish and wildlife resources. It is important to note, however, that this assessment was restricted by the availability of PECs, published bioaccumulation-based SQGs, and other benchmarks that are relevant for assessing sediment quality conditions. In certain reaches of the Assessment Area, this assessment was also restricted by limitations on the availability of data on the concentrations of chemical analytes in whole sediments and/or pore waters. Therefore, substances not included on the list of contaminants of concern cannot necessarily be considered to be of low priority with respect to sediment injury.

The levels of sediment-associated contaminants are sufficient to cause or substantially contribute to injury to surficial sediments throughout most of the Assessment Area (Table 14.2). In surficial sediments, the highest levels of sediment contamination occur in the GCRL, with mean PEC-Qs of up to 23,800 calculated for this reach; the average mean PEC-Q for this reach was approximately 160. These chemical characteristics make these sediments the most contaminated and toxic surficial sediment samples that we have ever evaluated. The average mean PEC-Q in the EBGCR-II was similar (i.e., 126; range of 1.4 to 987). Lower average mean PEC-Qs were calculated for the WBGCR-I and the WBGCR-II (i.e., 29.5 and 22.6, respectively). The EBGCR-I and USC had average mean PEC-Qs of 14.0 and 11.7, respectively. Lower levels of contamination were reported in the IHC (average mean PEC-Q of 5.2), LGB (average mean PEC-Q of 4.3), and IH/LM (average mean PEC-Q of 4.4). The lowest levels of contamination in surficial sediments were observed in Roxana Marsh (in the WBGCR-II; average mean PEC-Q of 0.4), Lake George wetlands (in the LGB; average mean PEC-Q of 0.9), East Lagoon (in the GCRL; average mean PEC-Q of 0.6), Little West Pond (in the GCRL; average mean PEC-Q of 0.3), Little East Pond (in the GCRL; average mean PEC-Q of 0.1), IHC wetlands (in the IHC; average mean PEC-Q of 0.7) and the nearshore areas of LM (in the IH/LM; average mean PEC-Q of 0.2). By comparison USEPA (2000a) reported that acute and chronic toxicity to sediment-dwelling organisms is likely to be observed when mean PEC-Qs are $ 4.0 and $ 0.7 respectively.

The levels of chemical contamination in sub-surface sediments were similar to those that were observed in surficial sediments (Table 14.3). The highest mean PEC-Qs in sub-surface sediments occurred in the EBGCR-II and the GCRL, with mean PEC-Qs of up to 937 and 2,560, respectively, calculated for these reaches (with average mean PEC-Qs of approximately 98 and 197, respectively). Based on these chemical characteristics, these sub-surface sediment samples are among the most contaminated and toxic that we have ever evaluated. Lower average mean PEC-Qs were calculated for the EBGCR-I (12.7), WBGCR-II (19.3), and USC (17.0). Indiana Harbor and the nearshore areas of LM had the lowest average mean PEC-Qs (2.4). While most of the sub-surface sediments in the Assessment Area had levels of contaminants that were sufficient to cause or substantially contribute to sediment injury, relatively low levels of contamination were observed in Roxana Marsh (in WBGCR-II; average mean PEC-Q of 0.05), Lake George wetlands

(LGB; average mean PEC-Q of 0.1), Middle Lagoon (in GCRL; average mean PEC-Q of 0.03), and the nearshore areas of LM (IH/LM average mean PEC-Q of 0.1).

The results of this investigation indicated that sediments and associated sediment-dwelling organisms throughout the Assessment Area have been injured by discharges of oil or releases of other hazardous substances. Similarly, fish and wildlife resources have been adversely affected by ambient conditions within the Assessment Area. Restoration of natural resources in the Assessment will necessitate the development and implementation of a restoration plan that will improve the quality of bed and bank sediments (Natural Resource Trustees 1997).

Restoration planning is likely to involve, among other activities, the development of target clean-up levels for the various contaminants of concern. While this task was beyond the scope of this investigation, the sediment effect concentrations that were employed in this assessment represent relevant tools for deriving such target clean-up levels. More specifically, the PECs and associated mean PEC-Qs were used to identify the concentrations of sediment-associated contaminants that are likely to cause or substantially contribute to sediment toxicity. Therefore, target clean-up levels would need to be lower than the PECs to ensure that bed sediments would once again support healthy and diverse populations of sediment-dwelling organisms and associated fish and wildlife communities. USEPA (2000a) reported that the incidence of toxicity to freshwater amphipods is generally less than 20% at mean PEC-Qs of < 0.1 and increases with increasing levels of sediment contamination. If virtual elimination of sediment toxicity and restoration of the benthic invertebrate community were primary restoration goals, then target clean-up levels for sediments might be in the order of 0.25 for mean PEC-Qs. Such a level of sediment contamination would be predicted to be associated with roughly a 20% incidence of toxicity to freshwater amphipods (USEPA 2000a).

As certain contaminants of concern have the potential to bioaccumulate in the food web, target clean-up levels should be established to facilitate the restoration of fish and wildlife resources. New York State Department of Environmental Conservation (NYSDEC 1994) derived numerical sediment quality criteria for the protection of wildlife. Such criteria could be used to establish target clean-up levels for bioaccumulative substances within the Assessment Area.

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