An Assessment of Sediment Injury in the West Branch of the Grand Calumet River

Volume I

Prepared for:

Environmental Enforcement Section
Environment and Natural Resources Division
U.S. Department of Justice
POB 7611
Washington, District of Columbia
20044-7611

Prepared -- January 1999 -- by:

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ENVIRONMENTAL SCIENCES LTD.

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Sediment Injury in the West Branch of the Grand Calumet River: Assessment of the Significance of Contaminated Sediments

Prepared for:

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U.S. Department of Justice
POB 7611
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Dr. Christopher G. Ingersoll and Donald D. MacDonald have been retained by the U.S. Department of Justice (DOJ) to provide both factual and opinion evidence in the matter of United States v. Sanitary District of Hammond. Dr. Ingersoll has not been deposed and has not testified as an expert in any other matters on behalf of DOJ or any other party. Mr. MacDonald has been deposed and has testified as an expert on other matters related to the discharge of toxic and/or bioaccumulative substances into the environment (i.e., United States, *ET AL*. v. Montrose Chemical Corporation of California *ET AL*.; Regina v. Harrison Hot Springs Hotel).

This report, which was prepared jointly by Dr. C.G. Ingersoll and Mr. D.D. MacDonald, provides an assessment of injury to sediments, sediment-dwelling organisms, wildlife, or human health that has occurred as a result of releases of toxic or bioaccumulative substances into the West Branch of the Grand Calumet River. Dr. Ingersoll and Mr. MacDonald collectively spent roughly 540 hours in the preparation of this report. Dr. Ingersoll's and Mr. MacDonald's time was billed at the rate of $90.00 per hour. Tadd Berger, Diana Tao, Mary Lou Haines, and Sue McDonald assisted the authors in the preparation of the report by participating in the collection and compilation of various types of data and information. Collectively, these individuals spent roughly 480 hours during course of the study. These individuals were billed at a rate of $30.00 per hour. MacDonald Environmental Sciences Ltd. and the U.S. Geological Survey collectively received roughly $60,000.00 for preparing this report. The costs associated with conducting additional activities (e.g., testifying) in connection with this matter have not yet been fully determined.

United States, *ET AL.* v.
The Sanitary District of Hammond, Indiana *ET AL.*

Witness Statement of Christopher G. Ingersoll
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Background Information Relevant to the Preparation of this Witness Statement

Nature of the Evidence Given

The evidence provided in the following witness statement consists of both factual and opinion evidence.

Professional Qualifications

The professional experience and educational qualifications which qualify Dr. Ingersoll and Mr. MacDonald to give the opinions that included in this witness statement are set out in the curricula vitae, which are attached as Appendix 4 of this witness statement. 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 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 (1999) standard method for measuring the chronic toxicity of sediment-associated contaminants with freshwater invertebrates (EPA series number pending);
- 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,

- P 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:

- P Development of an approach to the derivation of Canadian sediment quality guidelines;
- P Development of numerical sediment quality assessment guidelines for 34 chemical substances in Florida coastal waters;
- P Development of Canadian sediment quality guidelines for freshwater ecosystems;
- P Development of Canadian sediment quality guidelines for marine and estuarine ecosystems;
- P Participation in the development of numerical sediment quality guidelines for NOAA's National Status and Trends Program;
- P Development of procedures for deriving site-specific sediment quality remediation objectives;
- P Development of a sediment toxicity database for evaluating matching sediment chemistry and biological effects data;
- P Development of Canadian sediment quality guidelines for toxaphene, DDTs, and PCBs;
- P Development of sediment effect concentrations for assessing sediment injury in the Southern California Bight; and
- P 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 case other than as paid consultants to the Respondent. Our prior involvement with U.S. government litigation has been as a paid consultants on specific projects related to hazard and environmental assessments. We have had no prior involvement with the matter involving the Sanitary District of Hammond. 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 Evidence

In preparing this evidence, 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 (Section 10.0). 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.

Abstract

The Grand Calumet River system, which flows through northwestern Indiana and southeastern Illinois, has been subject to intensive industrial development throughout much of this century. Over this period, releases of contaminants from both point and non-point sources have resulted in widespread contamination of surface waters and sediments within the Grand Calumet River-Indiana Harbor Area of Concern. In this report, we evaluated sediment quality conditions in the West Branch of the Grand Calumet River (WBGCR) to determine if such releases of toxic or bioaccumulative substances have injured sediments or injured sediment-dwelling organisms, wildlife, or human health. Sediment injury is demonstrated by the presence of conditions sufficient to injure sediment-dwelling organisms (i.e., the invertebrates that live in or near sediment that represent critical elements of aquatic ecosystems, including fish food organisms), wildlife (i.e., amphibians, reptiles, fish, birds, and mammals), or human health exist in the WBGCR. A number of indicators of environmental quality conditions were used to determine if sediment injury has occurred in the WBGCR. Specifically, sediment injury is indicated by degraded water quality conditions, degraded sediment quality conditions, loss of physical habitats, toxicity to sediment-dwelling organisms or fish, altered benthic invertebrate or fish community structure, or accumulation of contaminants in the tissues of aquatic organisms to levels that can adversely affect wildlife or human health.

This evaluation of injury to sediments, sediment-dwelling organisms, wildlife, or human health in the WBGCR consisted of seven main steps. First, we collected, reviewed, and collated the available data on sediment quality conditions, sediment toxicity, benthic invertebrate community structure, fish community structure, physical habitat condition, and related information on the WBGCR. Next, contaminants of concern in the WBGCR were identified. Then, chemical benchmarks for assessing the quality of freshwater sediments were established, including consensus-based sediment effect concentrations (including threshold effect concentrations and probable effect concentrations), published bioaccumulation-based sediment quality guidelines, and published toxicity thresholds for pore water. Subsequently, the probable effect concentrations were critically evaluated determine their ability to correctly predict toxicity in sediments from locations throughout the United States. Then, the reliable probable effect concentrations and the other chemical benchmarks of environmental quality were used to determine if contaminated sediments in the WBGCR were likely to injure sediments, sediment-dwelling organisms, wildlife, or human health (i.e., to assess sediment injury). Next, the probable effect concentrations and other chemical benchmarks of environmental quality conditions were used to identify priority toxic or bioaccumulative substances. Finally, the spatial extent of sediment injury was determined in the WBGCR.

Comparison of measured contaminant concentrations to the chemical benchmarks that were established in this report demonstrate that discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have created conditions in the WBGCR that are sufficient to cause or substantially contribute to sediment injury. The concentrations of contaminants (as quantified using mean probable effect concentration quotients) are up to 490 times higher than the levels that have been demonstrated to be highly toxic to sediment-dwelling organisms (i.e., mean PEC-quotients of 1.5 or greater), making these sediments some of the most contaminated and toxic sediment samples we have ever evaluated. The measured concentrations of contaminants in sediments also exceed the levels that have been established to protect wildlife and human health.

In addition to being highly contaminated, these sediments are known to have injured aquatic organisms in the WBGCR. Specifically, the results of toxicity tests on bulk sediments and pore water demonstrate that WBGCR sediments are toxic to both invertebrates and fish. In addition, degraded physical habitats, altered benthic invertebrate communities, and depressed fish populations have been documented in the WBGCR. When taken together, these multiple separate lines of evidence provide a weight-of-evidence for concluding that the levels of chemical contaminants and other substances in WBGCR sediments are sufficient to severely injure sediments, sediment-dwelling organisms, wildlife, or human health.

The priority toxic or bioaccumulative substances in bulk sediments and pore waters (i.e., the substances that are causing or substantially contributing to sediment injury) include arsenic, cadmium, chromium, copper, lead, nickel, zinc, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, pyrene, total PAHs, total PCBs, and chlordane, dieldrin, Sum DDE, total DDT, heptachlor, lindane, toxaphene, phenol, and unionized ammonia. Additional priority substances include dissolved oxygen, sediment oxygen demand, and total organic carbon. Chemical benchmarks were not available for many other substances, which limited our ability to develop a complete list of priority substances in the WBGCR. Sediments throughout the WBGCR have been injured; however, the sediments located from the western portion of Roxanna Marsh to State Line Avenue are the most contaminated and have the highest probability of causing continued injury to sediment-dwelling organisms. The highest concentrations of chemical contaminants occur in the vicinity of State Line Avenue, Sohl Avenue, and Molsberger Place.

The probable effect concentrations represent 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 probable effect concentrations to ensure that bed sediments would once again support healthy and diverse populations of sediment-dwelling organisms and associated fish and wildlife communities.

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Glossary 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.

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

Aquatic organisms – All of the species that utilize habitats within aquatic ecosystems (e.g., aquatic plants, invertebrates, fish, amphibians, reptiles, birds, and mammals).

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.

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

Bulk sediment – Sediment and associated pore water.

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 – 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.

Glossary of Terms (continued)

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 PECs – The probable effect concentrations that were developed in this study from published sediment quality guidelines. A subset of the SECs.

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

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

Contaminant of Concern – The substances that occur in sediments at levels that could harm sediment-dwelling organisms, wildlife, or human health.

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

Demersal fish species – fish that are associated with bottom sediments, such as carp or sculpins.

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.

Glossary of Terms (continued)

Endpoint – The response measured in a toxicity test.

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).

Infaunal organisms – The organisms that live in bottom sediments.

Injury – The presence of documented or predicted harmful effects on sediment-dwelling organisms, wildlife, or human health.

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.

Priority Substances – The chemicals that occur in sediments at concentrations sufficient to injure sediment-dwelling organisms, wildlife, or human health.

Sediment – Particulate material that usually lies below water.

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

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

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

Glossary of Terms (continued)

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

Sediment quality guideline – Chemical benchmark that is intended to define the concentration of sediment-associated contaminants 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.

Toxic substances – The chemicals that have the potential to harm sediment-dwelling organisms, wildlife, or human health.

Wildlife – The fish, reptiles, amphibians, birds, and mammals that are associated with aquatic ecosystems.

List of Acronyms

10-d	10 day
AETA	Apparent Effects Threshold Approach
ASTM	American Society for Testing and Materials
CCME	Canadian Council of Ministers of the Environment
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
DO	dissolved oxygen
DOJ	United States Department of Justice
EC_{50}	median effective concentration
ELA	Effects Level Approach
EqPA	Equilibrium Partitioning Approach
ERA	Effects Range Approach
ERLs	effect range low values
ERMs	effect range median values
$g/m^2/day$	grams per meter squared per day
GCR/IH	Grand Calumet River/Indiana Harbor
HSD	Hammond Sanitary District
IBI	index of biotic integrity
LC_{50}	median lethal concentration
LELs	lowest effect levels
METs	minimal effect thresholds
mg/kg	milligrams per kilogram; parts per million
mg/L	milligrams per liter
NH_3	un-ionized ammonia
NH_4^+	ionized ammonia
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observed effect concentration
NYSDEC	New York State Department of Environmental Conservation
PAHs	polycyclic aromatic hydrocarbons

List of Acronyms (continued)

PCBs	polychlorinated biphenyls
PECs	probable effect concentrations (consensus-based)
PELs	probable effects levels
SAB	Science Advisory Board
SBA	Sediment Background Approach
SECs	sediment effect concentrations (consensus-based)
SEM-AVS	simultaneously extracted metals-acid volatile sulfide
SEM-AVSA	Simultaneously Extracted Metals-Acid Volatile Sulfides Approach
SETAC	Society of Environmental Toxicology and Chemistry
SLCA	Screening Level Concentration Approach
SOD	sediment oxygen demand
SQALs	sediment quality advisory levels
SQC	sediment quality criteria
SQGs	sediment quality guidelines
SSTA	Spiked Sediment Toxicity Test Approach
Sum DDD	*p,p*'-DDD + *o,p*'-DDD
Sum DDE	*p,p*'-DDE + *o,p*'-DDE
Sum DDT	*p,p*'-DDT + *o,p*'-DDT
TECs	threshold effect concentrations (consensus-based)
TELs	threshold effect levels
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
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
WBGCR	West Branch of the Grand Calumet River
WWTPs	wastewater treatment plants

Executive Summary

Introduction

The Grand Calumet River system is an important drainage basin that flows through northwestern Indiana and southeastern Illinois. Throughout much of this century, the Grand Calumet River system has been subject to intensive industrial development (USEPA 1996b) and it currently represents one of the most highly industrialized areas in the United States (Bright 1988). Over this time period, discharges from both point and non-point sources have released a variety of toxic, bioaccumulative, and other substances into the river system, including total organic carbon, nutrients, oil and grease, metals, phenolics, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), phthalates, and certain pesticides (Bright 1988; Polls *et al.* 1993; Hoke *et al.* 1993; Dorkin 1994). While some of these substances remain primarily in the water column, other substances have accumulated to high concentrations in bottom sediments. Due to concerns regarding widespread contamination of surface waters and sediments, the Grand Calumet River-Indiana Harbor ecosystem has been designated as one of 43 Great Lakes Areas of Concern by the International Joint Commission (IJC 1988).

This report was prepared to determine if sediments in the West Branch of the Grand Calumet River (WBGCR) have been injured as a result of discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances. In addition, priority toxic or bioaccumulative substances (i.e., those that are causing or substantially contributing to sediment injury) were identified. The areal extent of sediment injury in the WBGCR was also determined. Supporting documentation on discharges of sewage sludge, municipal wastewaters, and storm water by the Hammond Sanitary District and on the transport and fate of materials discharged by the Hammond Sanitary District is provided by Bell (1995) and Bierman (1995), respectively.

Study Objectives

The goal of this study is to determine if discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have injured sediments in the WBGCR. More specifically, the primary objectives of this study are:

- To identify contaminants of concern in the WBGCR;
- To establish chemical benchmarks for evaluating the harmful effects of sediment-associated contaminants on sediment-dwelling organisms (i.e., the invertebrates living in or near sediment that represent critical elements of aquatic ecosystems, including fish food organisms), wildlife (i.e., amphibians, reptiles, fish, birds, and mammals), or human health;
- To determine if the levels of the contaminants of concern (either alone or in chemical mixtures) in WBGCR sediments are sufficient to cause or substantially contribute to injury to sediments, sediment-dwelling organisms, wildlife, or human health;
- To identify priority toxic or bioaccumulative substances in WBGCR sediments (i.e., the substances that occur at concentrations, either individually or in combination), sufficient to cause or substantially contribute to sediment injury; and,
- To determine the areal extent of sediment injury in the WBGCR.

Study Approach

A step-wise approach was used to assess the harmful effects of sediment-associated contaminants on sediment-dwelling organisms, wildlife, or human health in the WBGCR. This process included seven main steps:

1. Compilation of the existing information on sediment quality conditions in the WBGCR (see Section 2.0 of the report);

2. Identification of contaminants of concern in the WBGCR (see Section 3.0 of the report);

3. Development of chemical benchmarks for assessing sediment quality conditions in the WBGCR (including consensus-based sediment effect concentrations, published bioaccumulation-based sediment quality guidelines, and published toxicity thresholds in pore water; see Section 4.0 and Appendix 2.0 of the report);

4. Critical evaluation of the consensus-based sediment effect concentrations to determine their reliability (see Section 5.0 of the report);

5. Assessment of injury to sediments, sediment-dwelling organisms, wildlife, or human health in the WBGCR (see Section 6.0 of the report);

6. Identification of priority toxic or bioaccumulative substances in the WBGCR (see Section 7.0 of the report); and,

7. Determination of the areal extent of sediment injury in the WBGCR (see Section 8.0 of the report).

The approach that was used in this study is described in more detail below.

As a first step, we compiled the existing sediment quality data and related information on the WBGCR. This information was used in conjunction with published sediment quality guidelines (e.g., Smith *et al.* 1996; Ingersoll *et al.* 1996) and other environmental quality guidelines to identify contaminants of concern in the WBGCR. Subsequently, we reviewed and compiled the published effects-based and the bioaccumulation-based sediment quality guidelines for the contaminants of concern in the WBGCR. The effects-based sediment quality guidelines provide a basis for assessing the harmful effects of sediment-associated contaminants on sediment-dwelling organisms, whereas the bioaccumulation-based guidelines provide chemical benchmarks for assessing the harmful effects on wildlife and human health that could occur as a result of the accumulation of sediment-associated contaminants in fish and other aquatic organisms.

We used the existing effects-based sediment quality guidelines to develop consensus-based sediment effect concentrations for the contaminants of concern in the WBGCR. The consensus-based sediment effect concentrations were derived in this report by calculating the geometric mean of the existing sediment quality guidelines with similar narrative intents. Two sediment effect concentrations were derived for each contaminant of concern, including a threshold effect concentration (below which harmful effects on sediment-dwelling organisms are unlikely to occur) and a probable effect concentration (above which sediment-dwelling organisms are likely to be injured as a result of toxicity). Consensus-based sediment effect concentrations were derived in this report because they provide a unifying synthesis of the existing guidelines, reflect causal rather than correlative effects, and account for the effects of contaminant mixtures in sediments (Swartz 1999).

Because consensus-based probable effect concentrations represent unique environmental assessment tools, they were critically evaluated in this report to determine their ability to correctly classify sediment samples as toxic. To support this evaluation, matching sediment chemistry and sediment toxicity data were assembled from numerous locations throughout the United States, including four data sets specific to the Grand Calumet River-Indiana Harbor Area of Concern (Hoke *et al.* 1993; Burton 1994; Dorkin 1994; USEPA 1996a; 1996b). The results of this evaluation indicated harmful effects on sediment-dwelling organisms are routinely observed when contaminant concentrations exceed the probable effect concentrations derived in this report. As such, the consensus-based probable effect concentrations provide a reliable basis for assessing sediment injury in the WBGCR.

In addition to the sediment effect concentrations, several other chemical benchmarks were established to support the assessment of sediment quality conditions in the WBGCR. Specifically, the existing bioaccumulation-based sediment quality guidelines were used to assess the harmful effects of contaminated sediments on wildlife or human health (NYSDEC 1993). In addition, published toxicity thresholds were used to assess the effects on contaminants in pore water (USEPA 1992b; 1994).

We used the probable effect concentrations derived in this report, as well as the other chemical benchmarks, to determine if the concentrations of sediment-associated contaminants in the WBGCR were sufficient to cause or substantially contribute to sediment injury. Other indicators of sediment quality conditions, such as the results of sediment toxicity tests, pore water quality and pore water toxicity (pore water is the water that fills the spaces between the sediment particles), the status of benthic invertebrate and fish communities, and general physical habitat condition, were also used to document sediment injury in this river system.

The chemical benchmarks were also used to identify the priority toxic or bioaccumulative substances in the WBGCR (i.e., those substances that are present at concentrations sufficient to harm sediment-dwelling organisms). Finally, the severity and extent of sediment injury in the WBGCR was evaluated using the chemical benchmarks (i.e., to identify hot spots with respect to sediment contamination).

Identification of Contaminants of Concern

The identification of contaminants of concern represented a critical first step in the assessment of sediment injury in the WBGCR. In this report, contaminants of concern are defined as those substances which occur in WBGCR sediments at levels that could pose harmful effects on sediment-dwelling organisms, wildlife, or humans. Based on a review of the available information on the WBGCR, we conclude that there are a number of substances present at levels in sediments that warranted further analysis in this report. These contaminants of concern include total organic carbon, sediment oxygen demand, oil and grease, metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), certain pesticides, phenolics, and phthalates. In addition, loss of physical habitat and the levels of ammonia, dissolved oxygen, metals, and phenols in pore water and/or overlying water are considered to have the potential to injure sediment-dwelling organisms, wildlife, or humans.

Development of Chemical Benchmarks

In this report, we used data on the concentrations of chemical contaminants in sediments as a primary basis for assessing sediment injury in the WBGCR. Sediment chemistry data were used as the primary indicator of sediment quality conditions because such data provide a direct link to contaminant sources, because the WBGCR has been well characterized in terms of sediment chemistry, and because sediment-associated contaminants are known to be toxic to aquatic organisms, including sediment-dwelling organisms and fish. Three types of chemical benchmarks were developed to support this assessment, including consensus-based sediment effects concentrations (calculated in this report), published bioaccumulation-based sediment quality guidelines, and published toxicity thresholds for pore water.

We developed consensus-based sediment effect concentrations in this report for a variety of contaminants of concern that have accumulated in WBGCR sediments, including metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and pesticides. For each contaminant of concern, two sediment effect concentrations were developed, provided at least three published sediment quality guidelines were available. The effects-based sediment quality guidelines that met the selection criteria established for this study were sorted into two categories according to their original narrative intent. Threshold effect concentrations were developed using the sediment quality guidelines that were intended to identify contaminant concentrations below which harmful effects on sediment-dwelling organisms were unlikely to be observed. Probable effect concentrations were developed using the guidelines that were intended to identify contaminant concentrations above which sediment-dwelling organisms are likely to be injured. The two types of sediment effect concentrations were calculated as the geometric mean of the various sediment quality guidelines that fell within each category, provided that three or more guidelines were available for that chemical substance.

In total, we derived sediment effect concentrations for 28 contaminants of concern that represented contaminants of concern in the WBGCR. We then evaluated these chemical benchmarks and used the reliable consensus-based probable effect concentrations to assess the harmful effects of contaminated sediments on sediment-dwelling organisms. The published bioaccumulation-based sediment quality guidelines were used directly to assess the effects of sediment-associated contaminants on wildlife or human health. Benchmarks for evaluating other indicators of sediment quality conditions, including pore water chemistry, benthic invertebrate community structure, and the status of fish communities, were obtained from the published scientific literature. While the threshold effect concentrations were not used in this assessment, we developed these values to provide companion tools that could be used to support the establishment of sediment quality remediation targets, should remedial actions be undertaken in the WBGCR.

Evaluation of the Consensus-Based Probable Effect Concentrations

Historically, a wide range of approaches have been used to develop chemical benchmarks (e.g., sediment quality guidelines) for assessing the harmful effects of contaminated sediments. In this report, we have provided a unifying synthesis of the existing guidelines by deriving consensus-based sediment effect concentrations for the contaminants of concern in the WBGCR. To address uncertainty regarding their reliability, these consensus-based sediment effect concentrations were critically evaluated to determine if they can be used to accurately predict toxicity in field-collected sediments. To this end, matching sediment chemistry and toxicity data from various locations in the United States were assembled and evaluated. Subsequently, the concentrations of sediment-associated contaminants were compared to the probable effect concentrations that were developed in this report. Sediment samples with chemical concentrations in excess of the probable effect concentrations were predicted to be toxic. The results of the toxicity tests that were conducted on each of these samples were used to determine if individual samples were toxic or non-toxic. This information was used to determine the predictive ability of each probable effects concentration by calculating the proportion of the sediment samples that were correctly classified as toxic. We expressed the predictive ability of the probable effect concentrations as a percentage.

The results of this evaluation indicated that most of the probable effect concentrations derived in this report (i.e., 16 of 28) provide an accurate basis for predicting sediment toxicity. For example, the predictive ability of the probable effect concentrations for metals ranged from 81% for arsenic to 92% for chromium and copper. The probable effect concentrations for six individual PAHs and total PAHs were also demonstrated to be reliable, with predictive ability ranging from 95 to 100%. The predictive ability of the probable effect concentration for total PCBs was 84%. The probable effect concentration for Sum DDE was also found to be an accurate predictor of sediment toxicity (i.e., predictive ability of 97%); however, the predictive ability of the probable effect concentration for chlordane was somewhat lower (i.e., 74%). Insufficient data were available to evaluate the predictive ability of the probable effect concentrations for 11 substances mercury, anthracene, fluorene, fluoranthene, dieldrin, Sum DDD, Sum DDT, total DDT, endrin, heptachlor epoxide, and lindane. We used the reliable probable effect concentrations, in conjunction with the other assessment tools, to determine if the concentrations of sediment-associated contaminants are sufficient to cause or substantially contribute to sediment injury in the WBGCR.

Assessment of Injury to Sediment-Dwelling Organisms

In this report, we used a number of indicators of sediment quality conditions to determine if sediments in the WBGCR have been injured by releases of sewage sludge, municipal wastewaters, or other toxic or bioaccumulative substances. The existing sediment chemistry data from the WBGCR were used as primary indicators of sediment quality conditions in this assessment. However, information on pore water chemistry, sediment toxicity, the status of benthic invertebrate and fish communities, and general physical habitat conditions was also used to determine in WBGCR sediments have been injured.

The existing information on sediment quality conditions provides overwhelming evidence that sediments have been injured by releases of contaminants into the WBGCR. Comparison of the available sediment chemistry data from the WBGCR to the reliable probable effect concentrations derived in this report demonstrates that all of the chemical substances considered are present at concentrations that are likely to be toxic to sediment-dwelling organisms. For example, the concentrations of metals frequently exceed the probable effect concentrations in surficial sediments, with maximum concentrations consistently more than ten times the probable effect concentrations. Similarly, the concentrations of individual PAHs and total PAHs routinely exceed the probable effect concentrations, with maximum concentrations consistently more that a hundred times the probable effect concentrations. Elevated levels of PCBs and Sum DDE have also been detected in WBGCR sediments. Data on the concentrations of organic carbon in WBGCR sediments demonstrates that high levels of organic matter, which are indicative of discharges of sewage sludge, are frequently present in sediments with elevated chemical concentrations.

To facilitate comparisons of contaminant concentrations in sediments that contain complex chemical mixtures, mean probable effect concentration quotients were calculated for each of the sediment samples in the database. Mean probable effect concentration quotients are calculated by dividing the concentration of each substance by its respective probable effect concentration. The sum of these quotients is then divided by the number of substances for which probable effect concentration quotients were calculated. The mean probable effect concentration quotient provides an estimate of the total level of chemical contamination in individual sediment samples. There is a high probability (i.e., > 75%) that sediment samples with a mean probable effect concentration quotient of > 1.5 will be toxic to sediment-dwelling organisms (Long and MacDonald 1998; Ingersoll *et al.* 1998).

The available sediment chemistry data provides the necessary and sufficient information to conclude that sediments throughout the WBGCR have been injured by discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances. To increase the degree of confidence that can be placed in the results of this assessment, the available information on several other indicators of sediment quality conditions in the WBGCR was also examined. The results of this additional evaluation confirm that sediments and sediment-dwelling organisms have been injured in this river system. More specifically, physical habitats have been lost or degraded due to inputs of sewage sludge into the WBGCR. In addition, the structure of benthic invertebrate communities has been altered, with a shift towards pollution-tolerant species being observed. This represents an impairment of river system due to the loss of diversity of sediment-dwelling organisms, the loss of species that represent preferred fish food organisms, and an increase in the abundance of species that tend to accumulate chemicals substances in their tissues (i.e., due to their high tolerance of chemical contaminants). Fish populations are also depressed in the WBGCR, primarily as a result of the deposition of sewage sludge and associated habitat loss and degradation (Simon 1993). The available data on sediment oxygen demand confirm that sediments in the WBGCR can be classified as "sewage sludge-like materials".

The results of whole sediment and pore water toxicity tests confirm that WBGCR sediments are harmful to sediment-dwelling organisms and fish. Specifically, Hoke *et al.* (1993) and Burton (1994) demonstrated that WBGCR sediments are acutely toxic to amphipods, midges, or fish (fathead minnows). In addition, pore water from WBGCR sediments is acutely toxic to water fleas and bacteria (Hoke *et al.* 1993). All of these standard toxicity testing organisms have been found to provide a reliable basis for establishing injury associated with sediment contamination (ASTM 1998a).

Assessment of Injury to Wildlife and Human Health

In addition to being harmful to sediment-dwelling organisms, bed sediments have the potential to impair the uses of the WBGCR by wildlife and humans. Specifically, total PCBs, chlordane, total DDT, heptachlor, and lindane are present in WBGCR sediments at concentrations sufficient to cause harmful effects in wildlife species (i.e., due to bioaccumulation in the food web). Similarly, benzo(a)pyrene, total PCBs, chlordane, dieldrin, total DDT, heptachlor, lindane, and toxaphene are present at concentrations in WBGCR sediments sufficient to pose a hazard to human health (i.e., through the consumption of contaminated fish tissues). The sediments that represent the greatest concern with respect to bioaccumulation and subsequent food web effects are located between the western portion of Roxanna Marsh and State Line Avenue. The actual hazards posed to human health by bioaccumulative substances have, at least in part, been mitigated by a directive from the Indiana State Board of Health, which states that no fish from the Grand Calumet River-Indiana Harbor ecosystem should be eaten.

Priority Toxic or Bioaccumulative Substances

The priority toxic or bioaccumulative substances in the WBGCR were identified by comparing the existing sediment chemistry data to the chemical benchmarks that were established to support the assessment of sediment injury. With respect to injury to sediment-dwelling organisms, the priority toxic or bioaccumulative substances in WBGCR sediments include arsenic, cadmium, chromium, copper, lead, nickel, zinc, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, pyrene, total PAHs, total PCBs, Sum DDE, phenol, and unionized ammonia. Dissolved oxygen pore water, sediment oxygen demand, and total organic carbon also represent priority substances with respect to injury to sediment-dwelling organisms. The substances that are present at concentrations sufficient to injure wildlife species include total PCBs, chlordane, total DDT, heptachlor, and lindane. The substances that pose the greatest risk to human health include benzo(a)pyrene, total PCBs, chlordane, dieldrin, total DDT, heptachlor, lindane, and toxaphene. It is difficult to assign a relative priority to these substances in WBGCR sediments. All of these substances frequently exceed the chemical benchmarks in surficial sediments from the WBGCR. In addition, the concentrations of these substances in WBGCR sediment exceed the chemical benchmarks by substantial margins, frequently by more than a factor of 100. Therefore, virtually all of these substances are present in whole sediment at concentrations that are in excess of concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling species in the WBGCR. It is important to note, however, that this assessment was restricted by the availability of reliable PECs, published bioaccumulation-based SQGs, and other benchmarks of sediment quality conditions. The availability of sediment and pore water chemistry data also restricted this assessment. Therefore, substances not included on the lists of priority substances can not necessarily be considered to be of low priority with respect to sediment injury.

Areal Extent of Sediment Injury

Examination of the existing sediment chemistry data indicates that the concentrations of chemical contaminants in surficial sediments throughout the WBGCR are in excess of the levels that are likely to injure sediment-dwelling organisms. The highest mean probable effect concentration quotients in surficial sediments were observed in the vicinity of State Line Avenue (up to 742), Sohl Avenue (up to 541), and Molsberger Place (up to 224). Mean probable effect concentration quotients tended to decrease to the east of Molsberger Place into Roxanna Marsh (up to 15.5 at the more easterly site and up to 76 at the more westerly location), indicating that the sediment-associated contaminants likely originated from sources located west of Roxanna Marsh. Therefore, the sediments located from the western portion of Roxanna Marsh to State Line Avenue are the most contaminated and have the highest probability of causing continued injury to sediment-dwelling organisms. Among the sediment horizons (i.e., depths) tested, surficial sediments (0 to 3 feet) tended to have the highest concentrations of chemical contaminants at most locations. Nevertheless, highly elevated mean probable effect concentration quotients were observed to sediment depths of up to 9 feet. Deeper sediments (i.e., 10 to 15 feet) appear to be less contaminated than shallower sediments (0 to 9 feet).

Conclusions

A variety of indicators of sediment quality conditions were used to assess sediment injury in the WBGCR, including bulk sediment chemistry (in conjunction with consensus-based PECs and bioaccumulation-based SQGs), pore water chemistry, bulk sediment toxicity, pore water toxicity, benthic invertebrate community structure, fish population structure, and physical habitat condition. Evaluation of the available information on each of these distinct indicators demonstrates that bed sediments and associated physical habitats have been injured in the WBGCR. When taken together, these multiple separate lines of evidence provide a weight-of-evidence for concluding that discharges of sewage sludge, municipal wastewaters, and other discharges of toxic or bioaccumulative substances have created conditions that are sufficient to severely injure sediments in the WBGCR. Therefore, it is concluded that the levels of chemical contaminants and other indicators of environmental quality conditions in the WBGCR are sufficient to injure sediments, sediment-dwelling organisms, wildlife, or human health. To put the severity of sediment contamination in the WBGCR into perspective, mean probable effect concentration quotients in excess of 1.5 are frequently associated with sediment toxicity (i.e., the incidence of effects is roughly 75% above this level). Sediment samples from the WBGCR had mean probable effect concentration quotients of up to 495 times this level, making these sediments among the most contaminated and toxic sediment samples that we have ever evaluated.

The priority toxic or bioaccumulative substances in bulk sediments and/or pore waters (i.e., the substances that are causing or substantially contributing to sediment injury) include arsenic, cadmium, chromium, copper, lead, nickel, zinc, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, pyrene, total PAHs, total PCBs, and chlordane, dieldrin, Sum DDE, total DDT, heptachlor, lindane, toxaphene, phenol, and unionized ammonia. Additional priority substances include dissolved oxygen, sediment oxygen demand, and total organic carbon. Sediments throughout the WBGCR have been injured; however, the sediments located in the areas from the western portion of Roxanna Marsh and to State Line Avenue are the most contaminated and have the highest probability of continuing to injury aquatic resources in the river. The highest concentrations of chemical contaminants were located in the vicinity of State Line Avenue, Sohl Avenue, and Molsberger Place.

The consensus-based probable effect concentrations represent 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 probable effect concentrations to ensure that bed sediments would once again support healthy and diverse populations of sediment-dwelling organisms and associated fish communities.

1.0 Introduction

The Grand Calumet River system is an important drainage basin that flows through northwestern Indiana and southeastern Illinois. The headwaters of the Grand Calumet River are located near the Marquette Park Lagoons in Gary, Indiana. From the headwaters, the river flows roughly 20 km before joining the Indiana Harbor Canal and the West Branch of the Grand Calumet River (WBGCR; Brannon *et al.* 1989). The Indiana Harbor Canal, which is about 6.5 km in length, connects the Grand Calumet River with Indiana Harbor Canal and Lake Michigan to the north. The WBGCR extends some 9.5 km from the Indiana Harbor Canal to the confluence with the Little Calumet River, in southeastern 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. However, the river can flow in either an eastern or westerly direction between Columbia Avenue and the Indiana Harbor Canal, depending on the water level in Lake Michigan (USACE 1995).

The Grand Calumet River drainage basin is one of the most highly industrialized areas in the United States (Bright 1988) . 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, milling and machining companies, and many others (Ryder 1993). Permitted discharges from such industrial sources, municipal wastewater treatment plants (WWTPs), and other sources contribute substantial quantities of wastewater to the river system. Such wastewater discharges comprise most of the flow and are important sources of contamination to the river (Bright 1988; Brannon *et al.* 1989). Non-point sources of contaminants to the system include urban and industrial run-off, combined sewer overflows, leachate or overflow from a number of wastefills or ponds, and spills of pollutants in and around industrial operations (Brannon *et al.* 1989). Due to widespread contamination of surface waters and sediments, the Grand Calumet River-Indiana Harbor ecosystem has been designated as a Great Lakes Area of Concern by the International Joint Commission (IJC 1988).

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. 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 liverwarts), and aquatic macrophytes (e.g., sedges, reeds, and pond weed), are the main autotrophic organisms in aquatic 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 fast-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, and slower-flowing sections of rivers and are comprised largely of sand, silt, and clay, provide substrates in which aquatic macrophytes can root and grow. The nutrients that are present in the 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 communities. 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, in so doing, release nutrients to the water column and increase bacterial biomass.

Bacteria represent the primary heterotrophic producers in aquatic ecosystems. 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 benthic-dwelling invertebrates and 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. For example, virtually all fish species consume aquatic invertebrates during all or a portion of their life cycle. In addition, many birds consume aquatic invertebrates during either their aquatic (e.g., dippers and sand pipers) or emergent (e.g., swallows) portions of their life cycle. Similarly, aquatic invertebrates represent important food sources for both amphibian (e.g., frogs and salamanders) and reptile (e.g., turtles and snakes) species. 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 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 process 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 contaminants on aquatic organisms (including plants, invertebrates, amphibians, and reptiles), wildlife (amphibians, reptiles, fish, birds, and mammals), or human health has become more apparent in recent years (Long and Morgan 1991). Specifically, sediment quality is important because many toxic contaminants (such as metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, 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 contaminants to the water column. In addition, sediment-associated contaminants 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., determining if sediments, sediment-dwelling organisms, wildlife, or human health have been injured by releases of toxic or bioaccumulative substances into the environment).

Historic and ongoing contaminant sources have discharged a variety of toxic or bioaccumulative substances into the WBGCR system, including total organic carbon, nutrients, metals, oil and grease, phenolics, polycyclic aromatic hydrocarbons (PAHs), phthalates, pesticides, and polychlorinated biphenyls (PCBs; Bright 1988; Polls *et al.* 1993; Hoke *et al.* 1993; Dorkin 1994). While some of these substances remain primarily in the water column, others tend to accumulate in sediments. Elevated levels of many of these substances have been observed in WBGCR sediments (Hoke *et al.* 1993; Dorkin 1994). The presence of elevated concentrations of contaminants in aquatic sediments represents a 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 (tricopterans), dragonflies, 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 be harmful to sediment-dwelling organisms; 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 sediment-dwelling organisms, wildlife, or human health have been injured due to the presence of sediment-associated contaminants in the WBGCR and, if so, to evaluate the severity and spatial extent of sediment injury. The primary objectives of this study are:

- to develop a list of contaminants of concern in the WBGCR;
- to establish chemical benchmarks for evaluating the harmful effects of sediment-associated contaminants on sediment-dwelling organisms (i.e., epi-benthic and infaunal invertebrates that represent critical elements of aquatic ecosystems, including fish

food organisms), wildlife (i.e., amphibians, reptiles, fish, birds, and mammals), or human health;

- to determine if the levels of the contaminants of concern (either alone or in chemical mixtures) in WBGCR sediments are sufficient to cause or substantially contribute to injury to sediments, sediment-dwelling organisms, wildlife, or human health;
- to identify priority toxic or bioaccumulative substances in WBGCR sediments (i.e., the substances that occur at concentrations, either individually or in combination, sufficient to cause or substantially contribute to sediment injury); and,
- to determine the areal extent of sediment injury in the WBGCR.

In this report, two general terms are used to describe the tools that are used to evaluate the biological importance of contaminants in bulk sediments. The term sediment quality guidelines (SQGs) is used to describe previously published sediment quality assessment values (e.g., threshold and probable effect levels - Smith *et al.* 1996; no effect concentrations - Ingersoll *et al.* 1996). By comparison, consensus-based sediment effect concentrations (SECs) have been calculated in this report from published SQGs and are used 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., the species that live in the sediments) and epibenthic (i.e., the species that live on the sediments) organisms. These tools are termed consensus-based SECs because they provide a unifying synthesis of the existing SQGs (Swartz 1999; i.e., by providing an indicator of central tendency of the available SQGs).

Bioaccumulation is the process whereby environmental contaminants accumulate in the tissues of organisms through various exposure routes (e.g., oral, dermal, and respiratory). The chemical benchmarks that define the concentrations of sediment-associated contaminants that would be sufficient to cause bioaccumulation in aquatic organisms to levels that are sufficient to harm wildlife species (including fish, amphibians, reptiles, birds, and mammals) or humans that consume fish or shellfish are termed bioaccumulation-based SQGs.

The main purpose of this report is to determine if sediments in the WBGCR have been injured as a result of contaminant discharges to the system (i.e., to evaluate sediment injury). An injury to sediments has resulted from discharges of hazardous substances if the measured concentrations of one of more contaminants in bed sediments are sufficient to injure biological resources, including sediment-dwelling organisms, wildlife, or human health. Specifically, sediment injury is demonstrated by:

- degraded pore water quality conditions (i.e., as indicated by exceedances of published toxicity thresholds for aquatic organisms);
- degraded sediment quality conditions (i.e., as indicated by exceedances of the consensus-based PECs);
- degradation or loss of physical habitats (as indicated by the results of field surveys);
- acute or chronic mortality, reduced growth, impaired reproduction, or abnormal development of sediment-dwelling organisms (as indicated by the results of toxicity tests);
- altered, depressed, or 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 toxicity tests);
- altered organ morphology, increased incidence of tumors/lesions, or degraded health of fish (as indicated by the results of field surveys);
- degraded or depressed fish populations (as indicated by the results of field surveys);

- fish tissue tainting (as indicated by changes in the taste, odor, or consistency of fish tissues); or,

- accumulation of contaminants in the tissues of aquatic organisms to levels that could harm wildlife species or result in imposition of fish consumption restrictions (as indicated by exceedances of tissue residue guidelines).

Definitions of many of the other terms that have been used in this report are provided in the Glossary of Terms that appears at the beginning of this report.

2.0 Study Approach

A step-wise approach was used to assess the toxic effects of sediment-associated contaminants on sediment-dwelling organisms, wildlife, or human health in the WBGCR. The seven main steps in this process included:

5. compilation of the existing information on sediment quality conditions in the WBGCR (see Section 2.0 of the report);
6. identification of contaminants of concern in the WBGCR (see Section 3.0 of the report);
7. development of chemical benchmarks for assessing sediment quality conditions in the WBGCR (including consensus-based sediment effect concentrations, published bioaccumulation-based SQGs, and published toxicity thresholds in pore water; see Section 4.0 and Appendix 2.0 of the report);
8. critical evaluation of the consensus-based sediment effect concentrations to determine their reliability (see Section 5.0 of the report);
9. assessment of injury to sediments, sediment-dwelling organisms, wildlife, or human health in the WBGCR (see Section 6.0 of the report);
10. identification of priority toxic or bioaccumulative substances in the WBGCR (see Section 7.0 of the report); and,
11. determination of the areal extent of sediment injury in the WBGCR (see Section 8.0 of the report).

Each of these steps is described in the following sections.

2.1 Compilation of Sediment Quality Data and Related Information

Information on the chemical and toxicological characteristics of sediments in the WBGCR were collected in three stages. In the first stage, more than ten 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 effects of sediment-associated contaminants (MacDonald 1994; MacDonald *et al.* 1996; Smith *et al.* 1996).

In the second stage of the process, several additional bibliographic database 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 400 additional data sets were obtained as a result of the second stage of the data acquisition effort (MacDonald *et al.* 1996; USEPA 1996a; Ingersoll *et al.* 1996). The first two stages of the data acquisition process were completed during the period January 1992 to December 1997 (i.e., these data were not collected specifically for this study).

In the final stage of the process, which was conducted specifically to support this assessment of sediment injury, sediment chemistry or biological effects data specific to the WBGCR were obtained. The U.S. Department of Justice provided copies of a number of reports that had been prepared by various investigators (e.g., Bell 1995; Bierman 1995). In addition, staff with the USEPA were contacted to obtain additional sediment chemistry and biological effects data on the WBGCR (e.g., Dorkin 1994).

All of the data sets retrieved during the course of the study were reviewed to determine their applicability to the assessment of sediment injury in the WBGCR. The criteria that were used to evaluate each of the candidate data sets are described in Appendix 1. Data sets on the WBGCR that met the selection criteria were subsequently incorporated into data files (in MS Excel format). Matching sediment chemistry and biological effects data from the WBGCR and from other geographic areas that met the selection criteria were also incorporated into data files (in MS Excel format) and used to critically evaluate the consensus-based SECs developed in this report.

2.2 Identification of Contaminants of Concern

Identification of contaminants of concern represents a critical element of the overall sediment injury assessment in the WBGCR. In this report, contaminants of concern are defined as those substances which occur in WBGCR sediments at levels that could potentially harm sediment-dwelling organisms, wildlife, or humans. The identification of contaminants of concern is important because the process provides a basis for selecting the substances for which chemical benchmarks are needed. Therefore, effective identification of the contaminants of concern helps to focus the subsequent steps in the sediment injury assessment process.

The contaminants of concern in the WBGCR were identified using a three step process. As a first step, a portion of the available data on the concentrations of contaminants in WBGCR sediments was assembled (i.e., Hoke *et al.* 1993; Dorkin 1994). These data were used to identify the substances that are known to occur in WBGCR sediments.

The second step in the identification of contaminants of concern involved identifying informal chemical benchmarks for the substances that are known to occur in WBGCR sediments. The probable effects levels (PELs) promulgated by Smith *et al.* (1996) and Ingersoll *et al.* (1996) were generally used as informal chemical benchmarks in this initial evaluation; however, other SQGs with similar narrative intent were employed for those substances for which freshwater PELs were not available (e.g., Long and Morgan 1991; EC & MENVIQ 1992; Persaud *et al.* 1993; NYSDEC 1993). The freshwater PELs are intended to represent the contaminant concentrations which, if exceeded, are likely to be associated harmful effects on sediment-dwelling organisms. Professional judgement was also used to identify contaminants of concern for those substances and media for which published chemical benchmarks were not readily available.

In the final step of the process, the concentrations of each contaminant were compared to the informal chemical benchmarks that were identified. The substances that occurred in WBGCR sediments at concentrations in excess of the PELs or other SQGs were identified as contaminants of concern. A number of conventional indicators of environmental quality (e.g., sediment oxygen demand, total organic carbon) and chemical contaminants in pore water (e.g., ammonia, metals, and phenolics) were also identified as contaminants of concern in the WBGCR if they occurred at levels above the toxicity thresholds for aquatic organisms that have been reported in the scientific literature (i.e., USEPA 1992b; 1994).

2.3 Development of Chemical Benchmarks for Assessing Sediment Quality Conditions

Numerical sediment quality guidelines (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 1992a; Adams *et al.* 1992; USEPA 1996a; Ingersoll *et al.* 1996; USEPA 1997a). Such SQGs 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., screening tools, remediation objectives).

Currently, there are a variety of SQGs that can be used for assessing the quality of freshwater sediments. In this report, we relied on published effects-based SQGs to calculate consensus-based SECs for assessing sediment quality in the WBGCR. As the term implies, consensus-based SECs reflect the agreement among the various SQGs by providing an estimate of their central tendency. 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).

A step-wise approach was used to evaluate the applicability of existing SQGs for deriving consensus-based SECs. As a first step, the SQGs that have been derived by various investigators for assessing the quality of freshwater sediments were collected and collated. These SQGs were primarily located by conducting focused searches of the MacDonald Environmental Sciences Ltd. and USGS topic libraries on sediment quality assessment. A number of specialists in the field were also contacted to obtain additional SQGs and supporting documentation.

Next, the SQGs obtained from all sources were evaluated to determine their applicability to this study. To facilitate this evaluation, the supporting documentation that was obtained with each of the SQGs was reviewed (Appendix 2). The SQGs from these sources were further considered for use in this report if:

- the methods that were used to derive the SQGs were readily apparent;
- the SQGs were based on empirical data that related contaminant concentrations to harmful effects on sediment-dwelling organisms or were intended to be predictive of effects on sediment-dwelling organisms (i.e., not simply an indicator of contamination). Alternatively, the SQGs were based on the potential for harmful effects on wildlife or humans as a result of bioaccumulation in the tissues of aquatic organisms; and,
- the SQGs had been derived on a *de novo* basis (i.e., not simply adopted from another jurisdiction or source).

The effects-based SQGs that were expressed on an organic carbon-normalized basis were converted to dry weight-normalized values at 1% organic carbon (MacDonald *et al.* 1994; 1996; USEPA 1997a). The dry weight-normalized SQGs were utilized because the results of previous studies have shown that they predicted sediment toxicity as well or better than organic carbon-normalized SQGs (Barrick *et al.* 1988; Ingersoll *et al.* 1996; USEPA 1996a; MacDonald 1997).

The effects-based SQGs that met these selection criteria were then grouped to facilitate the derivation of consensus-based SECs (Swartz 1999). Specifically, the SQGs for the protection of sediment-dwelling organisms were grouped into two categories according to their original narrative intent, including threshold effect concentrations (TECs) and probable effect concentrations (PECs). The TECs were intended to identify contaminant concentrations below which harmful effects on sediment-dwelling organisms were unlikely to be observed. Examples of TECs include threshold effect levels (TELs; Smith *et al.* 1996; USEPA 1996a), effect range low values (ERLs; Long and Morgan 1991; USEPA 1996a), and lowest effect levels (LELs; Persaud *et al.* 1993). The PECs were intended to identify contaminant concentrations above which harmful effects on sediment-dwelling organisms were likely to be frequently or always observed (MacDonald *et al.* 1996; Swartz 1999). Examples of PECs include probable effect levels (PELs; Smith *et al.* 1996; USEPA 1996a), effect range median values (ERMs; Long and Morgan 1991; USEPA 1996a); and severe effect levels (Persaud *et al.* 1993; Table 1).

Following classification of the published SQGs, consensus-based TECs were calculated by determining the geometric mean of the SQGs that were included in this category. Likewise, consensus-based PECs were calculated by determining the geometric mean of the PEC-type values. The geometric mean, rather than the arithmetic mean, was calculated because it provides an estimate of central tendency that is not unduly affected by outliers and because the distributions of the SQGs were not known. Consensus-based TECs or PECs were calculated only if three of more published SQGs were available for a chemical substance or group of substances. The consensus-based PECs were used to assess sediment injury in the WBGCR (i.e., to identify the concentrations of sediment-associated contaminants above which sediment-dwelling organisms are likely to be injured). The consensus-based TECs were developed to provide companion tools that can be used to identify contaminant concentrations below which harmful effects are unlikely to occur. It is anticipated that the TECs could be used during the development of sediment quality remediation objectives (i.e., clean-up targets), should sediment remediation be undertaken in the WBGCR.

Fewer published SQGs were located for evaluating the potential effects of sediment-associated contaminants on wildlife and human health. For this reason, no attempt was made to calculate consensus-based SECs in this report for the protection of wildlife or human health. Rather, the available SQGs were used directly in this assessment to determine if sediment-associated contaminants posed unacceptable hazards to wildlife or human health.

Published SQGs were not located for certain indicators of sediment quality conditions. In these cases, published toxicity thresholds (e.g., median lethal concentrations or median effective concentrations; LC_{50}s or EC_{50}s) were used to support this assessment of sediment injury in the WBGCR (USEPA 1992b; USEPA 1994).

2.4 Critical Evaluation of the Sediment Effect Concentrations

The consensus-based PECs were critically evaluated to determine if they would provide effective tools for assessing sediment injury in the WBGCR. More specifically, the reliability of the consensus-based PECs for assessing sediment quality in the WBGCR was evaluated by determining their predictive ability. To support this evaluation, matching sediment chemistry and biological effects data were compiled for various freshwater locations in the United States, including the Grand Calumet River system (i.e., the independent data set; Appendix 3). The predictive ability of the consensus-based TECs was not evaluated because these chemical benchmarks are more appropriate for determining the remediation objectives than assessing sediment injury; remediation was not the focus of this study.

In this report, predictive ability is defined as the ability of the consensus-based PECs to correctly classify sediment samples as toxic. The predictive ability of the PECs was evaluated using a three step process. First, the measured concentration of each substance in each sediment sample contained in the independent data set was compared to the corresponding PEC. Sediment samples were predicted to be toxic if the measured concentration of a chemical substance exceeded the corresponding PECs.

In the next step of the evaluation, the toxicity of each sediment sample in the independent data set was determined using the results of the toxicity tests that were conducted. Sediment samples that caused significant responses in at least one test endpoint were designated as being toxic to sediment-dwelling organisms. In contrast, sediment samples were designated as non-toxic if they did not cause a significant response in at least one test endpoint.

Finally, the predictive ability of the consensus-based PEC for each chemical substance was determined independently using the information that was compiled in the previous steps of the evaluation. In this report, predictive ability was calculated as the proportion of sediment samples that were correctly classified as being toxic, using the information on chemical concentrations. The predictive ability of the PECs was expressed as a percentage.

The criteria for evaluating the reliability of the consensus-based PECs were adapted from Long *et al.* (1998a). Specifically, the PEC for each substance was considered to be reliable for assessing sediment injury in the WBGCR if greater than 75% of the sediment samples were correctly predicted to be toxic using the PEC. The PECs that were ultimately used in this sediment injury assessment were those that were found to be reliable (i.e., predictive ability $\geq$75%) and for which a minimum of 20 samples were included in the predictive ability evaluation. This latter criterion was established to assure that the results were not unduly influenced by the number of sediment samples that was available to conduct the evaluation of predictive ability (CCME 1995).

2.5 Evaluation of Sediment Injury

In this report, sediment injury is demonstrated by the presence of conditions sufficient to injure sediment-dwelling organisms, wildlife or human health in the WBGCR. A number of indicators of environmental quality conditions were used to determine if sediment injury has occurred in the WBGCR. Specifically sediment injury is demonstrated by:

- degraded pore water quality conditions (i.e., as indicated by exceedances of published toxicity thresholds for aquatic organisms);
- degraded sediment quality conditions (i.e., as indicated by exceedances of the consensus-based PECs);
- degradation or loss of physical habitats (as indicated by the results of field surveys);
- acute or chronic mortality, reduced growth, impaired reproduction, or abnormal development of sediment-dwelling organisms (as indicated by the results of toxicity tests);
- altered, depressed, or 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 toxicity tests);
- altered organ morphology, increased incidence of tumors/lesions, or degraded health of fish (as indicated by the results of field surveys);

- degraded or depressed fish populations (as indicated by the results of field surveys);
- fish tissue tainting (as indicated by changes in the taste, odor, or consistency of fish tissues); or,
- accumulation of contaminants in the tissues of aquatic organisms to levels that could harm wildlife species or result in imposition of fish consumption restrictions (as indicated by exceedances of tissue residue guidelines).

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

2.6 Identification of Priority Toxic or Bioaccumulative Substances

In this report, priority substances are defined as those substances that occur in WBGCR sediments at concentrations or levels that are sufficient to cause or substantially contribute to injury to sediment-dwelling organisms, wildlife, or human health. The priority substances were identified by comparing the concentrations of each substance that have been measured in WBGCR sediments to the corresponding chemical benchmarks that have been established in this report. The chemical benchmarks that were used in this evaluation included the reliable consensus effects-based PECs, the published bioaccumulation-based SQGs, and the published toxicity thresholds for pore water. Existing classification schemes for evaluating the status of conventional indicators of environmental quality (such as ammonia, dissolved oxygen, total organic carbon, and sediment oxygen demand) were also used to identify priority substances in the WBGCR. Those substances that occurred in WBGCR sediments (i.e., in one or more samples) at concentrations in excess of the chemical benchmarks were identified as priority substances. For metals, those substances that exceeded the PECs and were present at concentrations in excess of background levels were identified as priority substances.

2.7 Evaluation of the Spatial Extent of Sediment Injury

The severity and extent of sediment injury in the WBGCR was evaluated using several procedures. First, the existing sediment chemistry data for the WBGCR were used in conjunction with the reliable consensus-based PECs and bioaccumulation-based SQGs to conduct the initial assessment of the potential for harmful effects in WBGCR sediments. This assessment was conducted by comparing the sediment chemistry data to the consensus-based PECs that were developed and evaluated in this report. In this way, the sediment samples with contaminant concentrations in excess of these PECs could be identified. The samples with the potential to harm sediment-dwelling organisms, wildlife, or human health were identified as those with contaminant concentrations in excess of one or more of the PECs. The sediments which had concentrations of multiple chemicals in excess of the PECs were considered to be the most injurious to the various receptors (Canfield *et al.* 1996; Ingersoll *et al.* 1996; MacDonald *et al.* 1996; Long and MacDonald1998).

The severity and extent of sediment injury was also assessed using mean PEC-quotients (Long *et al.* 1998a). In this analysis, the concentration of each priority substance in each sediment sample was divided by its respective consensus-based PEC to calculate a PEC-quotient. PEC-quotients were calculated only for those substances for which reliable PECs were available. Subsequently, the sum of the PEC-quotients was calculated for each sediment sample by adding the PEC-quotients that were determined for the priority substances. The summed PEC-quotients were then normalized to the number of PEC-quotients that were calculated for each sediment sample (i.e., to calculate the mean PEC-quotient for each sample; Canfield *et al.* 1998; Kemble *et al.* 1998a; Long *et al.* 1998a). This normalization step was conducted to provide comparable indices of contamination among samples, for which different numbers of chemical substances were analyzed.

In this evaluation, the mean PEC-quotients for each sample from the WBGCR were compared to the mean PEC-quotients that have been associated with specific types of sediment injury at other locations (Ingersoll *et al.* 1996; Canfield *et al.* 1996; 1998; Kemble *et al.* 1998a; Long *et al.*1998a; Long and MacDonald 1998). For example, Long and MacDonald (1998) evaluated data from many locations in the United States and concluded that the probability of observing highly significant toxicity in acute (10-d) amphipod survival tests was approximately 75% at mean ERM quotients of >1.5. Therefore, sediments with mean PEC-quotients of 1.5 or more are likely to injury sediment-dwelling organisms. The mean PEC-quotients (i.e., exceedances of mean PEC-quotients of 1.5) for the various sediment samples from the WBGCR was used to identify the locations in the WBGCR where the most severe injury to sediment-dwelling organisms are likely to occur.

While sediment chemistry data and PECs provide important tools for assessing sediment quality conditions, other types of information can also be used to determine if sediment-dwelling organisms, wildlife, or human health have been injured by contaminated sediments. For this reason, the available information from physical habitat surveys, sediment toxicity tests, benthic invertebrate community assessments, and fish community surveys were assembled and were also used to determine the severity and extent of sediment injury in the WBGCR. In this report, the sediments that were associated with physical habitat degradation, significant toxicity to sediment-dwelling organisms, or degraded benthic invertebrate community characteristics were considered to be injured. Furthermore, reduction in the abundance of freshwater fish species, alteration of fish community characteristics, impairment of the health of freshwater fish, or elevated levels of chemical contaminants in fish tissues (as compared to tissue residue guidelines) were considered to be sufficient to injure wildlife or human health in the WBGCR. The locations within the WBGCR where one or more of these conditions have been documented were considered to be priority areas with respect to sediment contamination.

3.0 Contaminants of Concern in the West Branch of the Grand Calumet River

Information from a number of sources indicates that sediments in the West Branch of the Grand Calumet River have been contaminated by discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances to the system. For example, Simon (1991) reported that depositional habitats were blanketed by sludge throughout much of the WBGCR, particularly between Indianapolis Boulevard and Columbia Avenue. In addition, sediments in certain locations, such as in the vicinity of Hohman Avenue, contained substantial quantities of oil. Furthermore, "islands" of sludge, sanitary napkins, toilet paper, and cigarette butts were observed between Columbia Avenue and Sohl Avenue, apparently as a result of combined sewer overflow (CSO) events (Simon 1991). Hence, physical loss of habitat and chemical contamination has been demonstrated in the WBGCR.

In this report, contaminants of concern are defined as those substances which occur in sediments of the WBGCR at levels that could harm sediment-dwelling organisms, fish, wildlife, or humans. Based on a review of a portion of the data available on the characteristics of WBGCR sediments (i.e., Hoke *et al.* 1993; Dorkin 1994; Bierman 1995) and of the sediment quality conditions necessary to support the various uses of the river (as indicated by freshwater SQGs and other toxicity thresholds), it is apparent that sediments in the WBGCR contain a number of contaminants of concern. The substances that occur at levels in sediments that warranted further evaluation in this report included total organic carbon (TOC), sediment oxygen demand (SOD), oil and grease, metals, PAHs, PCBs, organochlorine pesticides, phenolics, and phthalates. Physical habitat loss, due to the deposition of sewage-like wastes on benthic habitats, was also identified as a factor that could adversely affect sediment-dwelling organisms and wildlife. Furthermore, the levels of dissolved oxygen (DO), ammonia, metals, and phenols in pore water and/or overlying water were considered to have the potential to harm sediment-dwelling organisms, wildlife, or humans in the WBGCR.

4.0 Development of Chemical Benchmarks for Assessing Sediment Quality Conditions

Sediment chemistry data provide essential information for assessing the nature, severity, and extent of injury to biological resources (including sediment-dwelling organisms, wildlife, or human health) and the sediments upon which they depend. However, effective interpretation of such data is dependent on the availability of reliable chemical benchmarks that define thresholds for harmful effects to biological resources. In this report, three types of chemical benchmarks were established to assess sediment injury in the WBGCR, including consensus-based sediment effects concentrations, published bioaccumulation-based SQGs, and published toxicity thresholds for pore water. Each of these chemical benchmarks are further described in the following sections of the report.

4.1 Consensus-Based Sediment Effect Concentrations

A variety of approaches to the development of effects-based SQGs (i.e., for the protection of sediment-dwelling organisms) have been described in the scientific literature. These approaches to the derivation of SQGs can be classified into two main categories, including those that have an empirical basis and those that have a theoretical basis (for detailed information on the various approaches, including derivation procedures, intended uses, and limitations of the SQGs, see USEPA 1992; MacDonald 1994; Ingersoll *et al.* 1997; see Appendix 2). Both empirical and theoretical approaches were considered for deriving consensus-based SECs in this report, including:

- Screening Level Concentration Approach (SLCA);
- Effects Range Approach (ERA);
- Effects Level Approach (ELA);
- Apparent Effects Threshold Approach (AETA);
- Sediment Background Approach (SBA);

- Equilibrium Partitioning Approach (EqPA);
- Simultaneously Extracted Metals-Acid Volatile Sulfides Approach (SEM-AVSA); and,
- Spiked Sediment Toxicity Test Approach (SSTA)

Brief descriptions of each of these approaches are offered in Appendix 2. In addition, narrative descriptions of the various SQGs that have been derived using these approaches are presented in Table 1. These narrative descriptions were used to classify the SQGs into appropriate categories (i.e., TECs or PECs; see Section 2.3).

To support the calculation of consensus-based SECs for contaminants of concern in the WBGCR, the published SQGs that have been developed using a variety of approaches were assembled. Subsequently, the supporting documentation for each of these SQGs was reviewed to determine their applicability for deriving consensus-based SECs. The results of this evaluation indicated that six sets of SQGs were appropriate for deriving consensus-based threshold effect concentrations (TECs) for the contaminants of concern in the WBGCR, including:

- Threshold effect levels (TELs; Smith *et al.* 1996);
- Lowest effect levels (LELs; Persaud *et al.* 1993);
- Minimal effect thresholds (METs; EC and MENVIQ 1992);
- Effect range low values (ERLs; Long and Morgan 1991);
- Threshold effect levels for *Hyalella azteca* in 28-d toxicity tests (TELs; USEPA 1996a; Ingersoll *et al.*1996); and,
- Sediment quality criteria (SQC) and advisory levels (SQALs; USEPA 1997a).

Several other SQGs were also considered for deriving consensus TECs, but were not included for the following reasons. First, none of the SQGs that have been developed using data on the effects on sediment-associated contaminants in marine sediments only were used to derive TECs. However, the ERLs that were derived using both freshwater and marine data were included (i.e., Long and Morgan 1991).

Second, the ERLs that were developed by USEPA (1996a) were not utilized because they were developed from the same data that were used to derive the TELs (i.e., from several areas of concern in the Great Lakes). In addition, simultaneously extracted metals-acid volatile sulfide (SEM-AVS)-based SQGs were not used because they could not be applied without simultaneous measurements of SEM and AVS concentrations (i.e., no data, generated using acceptable methods, were available for WBGCR sediments; DiToro *et al.* 1990). Furthermore, none of the SQGs that were derived using the sediment background approach were used because they were not effects-based. The published SQGs that corresponded to threshold effect concentrations for metals, PAHs, PCBs and organochlorine pesticides, and phenolics are presented in Tables 2, 3, 4, and 5, respectively.

Based on the results of the initial evaluation, five sets of SQGs were determined to be appropriate for calculating consensus-based PECs for the contaminants of concern in the WBGCR, including:

- Probable effect levels (PELs; Smith *et al.* 1996);
- Severe effect levels (SELs; Persaud *et al.* 1993);
- Toxic effect thresholds (METs; EC and MENVIQ 1992);
- Effect range median values (ERMs; Long and Morgan 1991); and,
- Probable effect levels for Hyalella azteca in 28-d toxicity tests (PELs; USEPA 1996a; Ingersoll *et al.* 1996).

While several other SQGs were considered for deriving the consensus-based PECs, they were not included for the following reasons. To maximize the applicability of the resultant PECs, none of the SQGs that were developed for assessing the quality of marine sediments were used to derive PECs. As was the case for the TECs, the ERMs that were derived using both freshwater and marine data (i.e., Long and Morgan 1991) were included, however. The ERMs that were derived using data from various areas of concern in the Great Lakes (i.e., USEPA 1996a) were not included to avoid duplicate representation of these data in the consensus-based PECs. No data, using acceptable methods (Di Toro *et al.* 1990), have been generated for SEM-AVS in WBGCR sediments; therefore, SEM-AVS-based SQGs were not used in this report. Furthermore, none of the AET or related values (e.g., NECs from Ingersoll *et al.* 1996; PAETs from Cubbage *et al.* 1997) were used because they were not considered to represent toxicity thresholds (rather, they represent contaminant concentrations above which harmful biological effects always occur). The published SQGs that corresponded to PECs for metals, PAHs, PCBs and organochlorine pesticides, and phenolics in the WBGCR are presented in Tables 6, 7, 8, and 9, respectively.

For each substance, consensus-based TECs or PECs were derived if three or more acceptable SQGs were available in the scientific literature. The consensus-based TECs or PECs were determined by calculating the geometric mean of the published SQGs and rounding to three significant digits (Section 2.3). A summary of the consensus-based SECs that were derived for the contaminants of concern in the WBGCR are presented in Table 10.

4.2 Bioaccumulation-Based Sediment Quality Guidelines

In addition to being toxic to aquatic biota, sediment-associated contaminants can accumulate in the tissues of sediment-dwelling organisms. Because many epibenthic and infaunal organisms represent important components of the food web, sediment-associated contaminants can be transferred to higher trophic levels in the food web via sediment-dwelling organisms. In this way, contaminated sediments represent a potential hazard to humans and wildlife that consume aquatic organisms. While assessments of bioaccumulation can be conducted in several ways, bioaccumulation-based SQGs provide relevant tools for evaluating sediment quality relative to the potential for bioaccumulation (Cook *et al.* 1992; Ingersoll *et al.* 1997), particularly when data on the concentrations of contaminants in fish and invertebrate tissues are not available.

Bioaccumulation-based SQGs (which are sometimes termed residue-based SQGs) define the concentrations of individual chemicals or classes of chemicals in sediments that will not result in the accumulation of contaminants to unacceptable levels in the tissues of aquatic organisms. The first step in the development of bioaccumulation-based SQGs involves the derivation or selection of an appropriate tissue residue guideline for the substance or substances under consideration. Tissue residue guidelines identify the maximum concentration of bioaccumulative substances that will not result in harmful effects on those species that accumulate the contaminants in their tissues or on those species that consume aquatic organisms, including wildlife and humans. Tissue residue guidelines have been established for the protection of human health (e.g., Food and Drug Administration action levels - USEPA 1989) and for the protection of wildlife (e.g., New York State Department of Environmental Conservation fish flesh criteria for piscivorus wildlife - Newell *et al.* 1987).

Next, the relationships between the concentrations of contaminants in sediments and contaminant residues in aquatic biota is established. In general, the necessary sediment-to-biota bioaccumulation factors are determined from field studies or estimated using various modeling approaches. The SQGs are then derived by dividing the tissue residue guideline by the sediment-to-biota bioaccumulation factor (Cook *et al.* 1992).

Bioaccumulation-based SQGs are important tools for conducting sediment quality assessments for several reasons. First and foremost, unlike the effects-based SQGs described in Section 4.1, the bioaccumulation-based SQGs explicitly consider the potential for bioaccumulation and effects on higher trophic levels in the food web. That is, the bioaccumulation-based SQGs provide a basis for interpreting sediment chemistry data in terms of the potential for harmful effects on human health and wildlife. The available bioaccumulation-based SQGs for the contaminants of concern in the WBGCR which met the evaluation criteria (Section 2.3) are presented in Table 11. Because there were a limited number of bioaccumulation-based SQGs, they were used directly to assess sediment quality conditions in the WBGCR (i.e., no attempt was made to derive consensus-based SECs using the available bioaccumulation-based SQGs).

4.3 Published Toxicity Thresholds

As indicated previously, appropriate SQGs were not available for certain indicators of sediment quality conditions (e.g., concentrations of contaminants in pore water). For these indicators, toxicity thresholds (including either median lethal concentrations or median effective concentrations; LC_{50}s or EC_{50}s) were identified using the information contained in the USEPA Acquire Database (USEPA 1992) or from information generated subsequently by USEPA (1994). The published toxicity thresholds for metals, phenols, and unionized ammonia are listed in Table 12.

5.0 Evaluation of the Consensus-Based Sediment Effect Concentrations

The predictive ability of the consensus-based PECs for the contaminants of concern in the WBGCR was evaluated using matching sediment chemistry and biological effects from a number of freshwater locations in North America. In this report, the predictive ability of the PECs was examined because they were intended to be the primary tools used in the assessment of sediment injury. The criteria that were used to assess the acceptability of candidate data sets (i.e., for evaluating the predictive ability of the consensus-based PECs) are presented in Appendix 1. Data from the following locations were considered to be of acceptable quality for use in this evaluation:

- West Branch Grand Calumet River, IN (Burton 1994; Dorkin 1994);
- Grand Calumet River and Indiana Harbor Canal, IN (Hoke *et al.* 1993; Giesy *et al.* 1993);
- Indiana Harbor, IN (USEPA 1993a; 1996a; 1996b);
- Lower Fox River and Green Bay, WI (Call *et al.* 1991);
- Waukegan Harbor, IL (USEPA 1996a; Kemble *et al.* 1998a);
- Saginaw River, MI (USEPA 1993b);
- Buffalo River, NY (USEPA 1993c);
- Potomac River, DC (Schlekat *et al.* 1994; Wade *et al.* 1994; Velinsky *et al.* 1994);
- Trinity River, TX (Dickson *et al.* 1989; USEPA 1996a);
- Clark Fork River, MT (USFWS 1993);
- Milltown Reservoir, MT (USFWS 1993);
- Lower Columbia River, WA (Johnson and Norton 1988); and,
- Upper Mississippi River, MN to MO (USEPA 1996a; USEPA 1997c; Kemble 1998b).

These studies provided 17 data sets with which to evaluate the predictive ability of the consensus-based SECs for each of the contaminants of concern in the West

Branch of the Grand Calumet River (Appendix 3-1 to 3-17). Overall, the incidence of toxicity in these studies was roughly 50% (i.e., 172 of the 347 samples evaluated in these studies were found to be toxic to one or more sediment-dwelling organisms). The predictive ability of the consensus-based PECs for each contaminant of concern was evaluated independently. In this assessment, individual sediment samples were predicted to be toxic if the concentration of the contaminant of concern exceeded the PEC for that substance. The accuracy of each prediction was then evaluated by determining if the sediment sample actually was toxic to one or more aquatic organisms. The following responses of aquatic organisms to contaminant challenges (i.e., toxicity test endpoints) were used as indicators of toxicity in this assessment (i.e., sediment samples were designated as toxic if one or more of the following endpoints were significantly different from the responses observed in reference or control sediments):

- amphipod, *Hyalella azteca*, survival;
- amphipod, *Hyalella azteca*, growth;
- amphipod, *Hyalella azteca*, reproduction;
- mayfly, *Hexagenia limbata*, survival;
- mayfly, *Hexagenia limbata*, growth;
- midge, *Chironomus tentans* or *Chironomus riparius*, survival;
- midge, *Chironomus tentans* or *Chironomus riparius*, growth;
- midge deformities;
- oligochaete, *Lumbriculus variegatus*, survival;
- daphnid, *Ceriodaphnia dubia*, survival; and,
- bacterium, *Photobacterium phosphoreum*, luminescence (i.e., Microtox).

The consensus-based PECs that correctly predicted toxicity in at least 75% of the sediments from various locations in North America were considered to provide a reliable basis for evaluating sediment quality in the WBGCR. The results of the predictive ability assessment indicate that most of the consensus-based PECs are reliable (i.e., accurately predict toxicity to sediment-dwelling organisms in freshwater sediments (Tables 13 to 40). For example, the predictive ability of the probable effect concentrations for metals ranged from 81% for arsenic to 92% for chromium and copper. The probable effect concentrations for six individual PAHs and total PAHs were also demonstrated to be reliable, with predictive ability ranging from 95 to 100%. The predictive ability of the probable effect concentration for total PCBs was 84%. The probable effect concentration for Sum DDE was also found to be an accurate predictor of sediment toxicity (i.e., predictive ability of 97%); however, the predictive ability of the probable effect concentration for chlordane was somewhat lower (i.e., 74%). Therefore, the consensus-based PECs for arsenic, cadmium, chromium, copper, lead, nickel, zinc, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, pyrene, total PAHs, total PCBs, and Sum DDE provide an accurate basis for predicting toxicity in freshwater sediments from numerous locations in North America (i.e., predictive ability was > 75% for each of these PECs; range of 81% to 100%). Sediments that contain one or more of these substances at concentrations in excess of the PECs are likely to be toxic to sediment-dwelling organisms. Insufficient data were available (i.e., fewer than 20 samples predicted to be toxic) to evaluate the PECs for mercury, anthracene, fluorene, fluoranthene, dieldrin, Sum DDD, Sum DDT, total DDT, endrin, heptachlor epoxide, and lindane. Only the PECs that were found to accurately predict toxicity to sediment-dwelling organisms and for which the minimum data requirement were met (i.e., a minimum of 20 samples were predicted to be toxic; Section 2.4) were used to assess sediment injury in the West Branch of the Grand Calumet River (Table 41).

In addition to assessing their predictive ability, the relevance of the consensus-based PECs for metals was evaluated by comparing them to background levels in stream and lake sediments in Indiana and Illinois (HNTB 1990; IDEM 1991). The results of this evaluation indicate that the PECs developed in this report are all higher than the maximum background concentrations that have been measured in Indiana and Illinois sediments (Table 42), with the exception of lead. The consensus-based PEC for lead was somewhat lower than the maximum concentration that has been observed in Indiana sediments (i.e., 128 mg/kg vs. 150 mg/kg). For this reason, the available data on the concentrations of lead in deep sediments (i.e., 10 to 15 feet) from the WBGCR were examined to determine background levels of lead in this river system (Dorkin 1994). The results of this evaluation demonstrate that background levels of lead in the WBGCR probably range from < 5.4 to 24 mg/kg (i.e., at Molsberger Place). As the consensus-based PEC for lead is much higher than the site-specific background concentrations that have been measured, it was considered to be relevant for assessing sediment quality in the WBGCR.

6.0 Assessment of Sediment Injury in the West Branch of the Grand Calumet River

This study was conducted 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. Sediment injury is defined as the presence of conditions that have injured or are sufficient to injure sediment-dwelling organisms, wildlife, or human health in the WBGCR. In this report, injury to sediments, sediment-dwelling organisms, wildlife, or human health is indicated by degraded water quality conditions, degraded sediment quality conditions, loss of physical habitats, toxicity to aquatic invertebrates or fish, altered benthic invertebrate or fish communities, or accumulation of contaminants in the tissues of aquatic organisms to levels that can harm wildlife or human health (Section 2.5).

The present evaluation of sediment injury in the WBGCR includes three main components. The first component consists of an evaluation to determine if contaminated sediments in the WBGCR have injured or are sufficient to harm sediment-dwelling organisms. The second component is focused on evaluating the harmful effects of contaminated sediments on wildlife, including fish, birds, and mammals inhabiting the WBGCR basin. The third component of the evaluation is intended to determine if contaminated sediments in the WBGCR pose a significant risk to human health.

6.1 Assessment of 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 (USEPA

1994; ASTM 1998a). 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 (USEPA 1994; ASTM 1998a). Furthermore, information on the physical characteristics of habitats can be used to determine if riverine systems are likely to support health and productive aquatic communities. 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.

In the past 10 years, a number studies have been conducted in the Grand Calumet River system to evaluate environmental concerns associated with contaminated sediments. While some of these studies provide information on sediment chemistry alone, other studies provide data on multiple indicators of sediment quality conditions. In this report, the existing information on sediment quality conditions was compiled and used to determine if discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have caused or substantially contributed to sediments injury in the WBGCR.

6.1.1 Sediment Chemistry in the WBGCR

Sediment chemistry data provide essential information for determining if discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have caused or substantially contributed to sediments injury in the WBGCR. Sediment chemistry data are particularly important in the sediment injury assessment process because these data provide a direct linkage to contaminant sources and because elevated contaminant concentrations are linked to harmful effects on sediment-dwelling organisms and other aquatic species. For these reasons, sediment chemistry data have been used as a primary basis for assessing sediment injury in the WBGCR.

In this report, consensus-based PECs were developed to provide chemical benchmarks for assessing the effects of contaminated sediments on sediment-dwelling organisms. To assure that the consensus-based PECs provided a reliable basis for conducting such assessments, these chemical benchmarks were evaluated to determine their predictive ability (Section 5.0). The results of this evaluation indicated that consensus-based PECs for 16 of 28 substances provided an accurate basis for predicting toxicity in field-collected sediments from various locations in the United States, including the Grand Calumet River-Indiana Harbor Area of Concern (Table 41). These reliable PECs were used in the following analysis to determine if the concentrations of sediment-associated contaminants were sufficient to injure sediments and associated biological resources in the WBGCR.

Data on the chemical composition of whole sediments are available from six studies that have been conducted in the WBGCR (HydroQual, Inc. 1984; HNTB 1989; 1991; Unger 1992; Hoke *et al.* 1993; Dorkin 1994). Each of these studies was reviewed and evaluated to obtain relevant information for assessing sediment quality conditions in this river system (Figures 1 to 29). Collectively, the results of these investigations demonstrate that the concentrations of arsenic, cadmium, chromium, copper, lead, nickel, zinc, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, pyrene, total PAHs, total PCBs, and Sum DDE consistently exceed the consensus-based PECs in WBGCR sediments, typically by wide margins (Figure 1, 2, 3, 4, 5, 7, 8, 12, 13, 14, 15, 16, 18, 19, 20, and 24). In addition, mean PEC quotients (which provides a measure of overall sediment contamination in sediments that contain contaminant mixtures) in WBGCR sediments exceed, often by wide margins, the levels that are associated with a high probability of observing toxicity to sediment-dwelling organisms (Figure 30). The results of these studies also demonstrate that, at several locations, the severity of sediment contamination tends to decrease with increasing sediment depth (Figure 31).

It is difficult to assign a relative priority to these substances in WBGCR sediments. All of these substances frequently exceed the chemical benchmarks in surficial sediments from the WBGCR. In addition, the concentrations of these substances in WBGCR sediment exceed the chemical benchmarks by substantial margins, frequently by more than a factor of 100. Therefore, virtually all of these substances are present in whole sediment at concentrations that are in excess of concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling species in the WBGCR.

In summary, the available data on the concentrations of chemical substances demonstrates that both surficial and deeper sediments in the WBGCR have been contaminated by discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances. Comparison of these data to the consensus-based probable effects concentrations that were derived in this report demonstrates that the concentrations of sediment-associated contaminants are sufficient to harm sediment-dwelling organisms. Therefore, it is concluded that WBGCR sediments, including both surficial and deeper sediments, have been injured due to the presence of toxic substances. In addition, it is concluded that the biological resources that depend on these critical habitats provided by surficial sediments have been injured due to the presence of toxic substances.

6.1.2 Sediment and Pore Water Toxicity in the WBGCR

The results of toxicity tests conducted using whole sediments or pore waters provide critical information for assessing the effects on contaminated sediments on aquatic organisms. In the WBGCR, two studies have been conducted to determine if sediments and associated pore waters are toxic to sediment-dwelling organisms or other aquatic organisms. The results of these studies, which are described below, have been used to determine if discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have caused or substantially contributed to sediments injury in the WBGCR.

Between October 1988 and May 1990, Hoke *et al.* (1993) collected sediment samples from a total of 13 stations with the Grand Calumet River - Indiana Harbor Area of Concern. Three of these stations were on the WBGCR, one located east of Roxanna Marsh (Indianapolis Boulevard), one located near Molsberger Place, and one located near State Line Avenue. The toxicity of sediments and pore water from these locations was evaluated using a battery of standard toxicity tests, including one bulk-sediment test and three pore water tests. The bulk-sediment test 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 water fleas, *Ceriodaphnia dubia* and *Daphnia magna*. The results of these toxicity tests indicated that midge growth was reduced (i.e., by 89 to 98% compared to reference conditions) in all of the sediment samples collected in the WBGCR. In addition, pore water from the sediments that were collected at all of these sites was acutely toxic to the water fleas and to the bacterium, *Photobacterium phosphoreum* (i.e., Microtox). Therefore, the results of this study demonstrate that sediments from the WBGCR are toxic to a variety of aquatic organisms, including sediment-dwelling species.

A second investigation on the toxicity of WBGCR sediments was initiated in 1993 (Burton 1994; Dorkin 1994). In this study, surficial sediments were collected from a number of locations to further evaluate the toxic effects of WBGCR sediments on aquatic organisms. These samples were collected at a total of seven stations, including Roxanna Marsh (2 stations), Molsberger Place, Columbia Avenue, Sohl Avenue, State Line Avenue, and Torrence Avenue. Sediments from these locations were tested using two aquatic species, including amphipods, *Hyalella azteca*, and fathead minnows, *Pimephales promelas*. The toxicity tests on both species were 10-days in duration, with survival and growth measured in fathead minnow test and survival measured in the amphipod test. The results of these toxicity tests indicate that all of the sediments taken from the WBGCR were acutely toxic to amphipods, with very low survival (i.e., 0 to 10%) observed at all but the Torrence Avenue station (72.5% survival). In addition, sediments from all seven of the stations were acutely toxic to fathead minnows. These findings demonstrate that sediments from the WBGCR are toxic to aquatic organisms.

In summary, the available information on the toxicity of bulk sediments and pore water includes data on eight locations in the WBGCR and six species of aquatic organisms, which were tested using standardized tests. The results of these toxicity tests demonstrate that the sediments and pore waters from all locations are toxic to all of the species that have been tested. Importantly, these standardized tests have been demonstrated to be predictive of harmful effects on sediment-dwelling organisms in the field (ASTM 1998a; USEPA 1994). Therefore, these results demonstrate that the condition of sediments and associated pore waters in the WBGCR is sufficient to injure sediments and associated aquatic organisms, including sediment-dwelling organisms.

6.1.3 Status of Benthic Invertebrate Community in the WBGCR

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 sediments injury in the WBGCR.

Information from two surveys of the status of benthic invertebrate communities in the WBGCR were obtained (Polls *et al.* 1993) and were used to assess sediment injury in this river system. These surveys were conducted near Hohman Avenue in 1982 and again in 1986. The survey results were summarized by Polls *et al.* (1993) to assess temporal trends in benthic invertebrate community status over that time period. The results of both of these surveys demonstrate that the benthic invertebrate community in the WBGCR was dominated by pollution-tolerant species, including worms (oligochaetes) and midges (chironomids). Leaches were also observed in the WBGCR sediments collected from this location in 1986. However, more sensitive organisms, such as amphipods and caddisflies, were absent in WBGCR in both years (Table 43). Polls *et al.* (1993) concluded that benthic community structure in the WBGCR remained poor from 1982 to 1986, as compared to other locations sampled in northern Indiana and in Lake Michigan.

The available information from the benthic surveys indicates benthic invertebrate communities have been altered in the WBGCR 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 WBGCR. Therefore, these results demonstrate that the condition of sediments in the WBGCR is sufficient to injure sediments and associated sediment-dwelling organisms in the field.

6.1.4 Pore Water Chemistry in the WBGCR

Pore water is the water that occupies the spaces between sediment particles. Pore water is often isolated from the sediment matrix to conduct toxicity testing or to measure the concentrations of chemical substances (USEPA 1994; ASTM 1998a). Evaluation of the concentrations of contaminants in pore water is important because sediment-dwelling organisms are directly exposed to chemical substances in this sediment phase. Importantly, the toxicity of sediments to aquatic organisms has been directly correlated to 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 (USEPA 1994; ASTM 1998a).

The biological significance of measured concentrations of contaminants in pore water can be evaluated by comparing these chemistry data to toxicity thresholds for aquatic organisms. USEPA (1994) reported toxicity thresholds from 10-d water-only toxicity tests with the amphipod *Hyalella azteca* for several chemical contaminants of concern in the WBGCR. Comparison of the concentration of a chemical in pore water to an LC_{50} or an EC_{50} for that chemical provides a means of determining if the concentration of that compound in the pore water was sufficient to cause direct toxicity to sediment-dwelling organisms. 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 toxic units are likely to be toxic to sediment-dwelling organisms.

The concentrations of metals in pore water from sediments taken from the WBGCR were reported by Hoke *et al.* (1993; Table 44). Evaluation of the results of this study using this toxic units approach indicates that concentrations of copper, lead, and zinc, and the sum toxic units for metals in pore water from WBGCR sediments were at or above concentrations that have been shown to be toxic to aquatic organisms in 10-d acute toxicity tests (Table 44). The sum toxic units for metals in pore water ranged from 0.38 to 3.5 units. The detection limits reported in Hoke *et al.* (1993) were too high to be able to interpret toxicity data for cadmium relative to the published 10-d LC_{50} for *Hyalella azteca* (USEPA 1994).

Data from 10-d toxicity tests provide important information for evaluating the acute toxicity of waterborne contaminants. However, data from longer term tests and on more sensitive endpoints show that harmful effects can occur at contaminant concentrations below the LC_{50} values. For example, recently completed life-cycle toxicity tests with *Hyalella azteca* have demonstrated the no-observable-effect concentration (NOEC), based on growth and reproduction of amphipods, is often about 10% of the acute 10-d LC_{50} (USEPA 1994; C.G. Ingersoll, unpublished data). Therefore, using acute toxicity data (i.e., LC_{50}) from 10-d tests in this evaluation is likely to underestimate the chronic toxicity of metals by roughly a factor of 10 (Table 44). Comparison of the measured concentrations of metals in pore water to the acute and estimated chronic toxicity thresholds indicate that concentrations of certain metals in the sediments of the WBGCR are sufficiently elevated to cause acute and chronic toxicity to sediment-dwelling organisms. The results of acute toxicity tests conducted with pore water from WBGCR sediments support the conclusion that concentrations of metals were sufficiently elevated in WBGCR sediments to cause or substantially contribute to toxicity to crustaceans and bacteria (Hoke *et al.* 1993; Section 6.1.2).

Hoke *et al.* (1993) also reported concentrations of phenolic compounds in pore water from sediments of the WBGCR (Table 45). Data from this study indicate that phenol, chlorophenol, dichlorophenol, dinitrophenol, and cresol were present in the pore water from WBGCR sediments (Table 45). Information on the toxicity thresholds for specific phenolic compounds was obtained from the USEPA Acquire database (USEPA 1992). In the same way that sum toxic units were calculated for metals, it is possible to calculate sum toxic units for phenolic compounds.

Using the data from the Hoke *et al.* (1993) study, it is apparent that the concentrations of individual phenolic compounds and the sum toxic unit fraction equaled or exceeded the concentrations that are known to be acutely toxic to aquatic organisms in all samples (Table 45). The number of sum toxic units of phenolics in pore water from WBGCR sediments ranged from 5.3 to 7.7 units. Therefore, phenolic compounds occur in pore water from WBGCR sediments at concentrations that are sufficient to cause or substantially contribute to acute toxicity to sediment-dwelling organisms. These results also demonstrate that phenol is likely responsible for most of the toxicity to aquatic organisms that is attributable to phenolic compounds.

The evaluation in Table 45 was made primarily using lethality data measured in short-term tests. This evaluation would be enhanced if chronic toxicity data were available for a single species tested with all of the compounds listed in Table 45. However, this information is not available for these phenolic compounds. Therefore, this evaluation probably underestimates the toxicity of phenolic compounds because chronic toxicity data for sensitive organisms were not available. If it is assumed that the chronic toxicity of phenolic compounds is roughly 10% of the acute concentration, then cresol, in addition to phenol, would be present at high enough concentrations in pore water to cause or substantially contribute to acute or chronic toxicity to sediment-dwelling organisms. The results of acute toxicity tests conducted with these WBGCR sediments support the conclusion that concentrations of phenolic compounds were sufficiently elevated in pore water to cause or substantially contribute to toxicity to aquatic organisms, including crustaceans and bacteria (Hoke *et al.* 1993; Section 6.1.2).

The addition of the excessive amounts of organic matter in the WBGCR also results in the production of ammonia in sediment (i.e., due to increased microbial activity). Free ammonia can be presented either unionized ammonia (NH_3) or as ionized ammonia (NH_4^+; depending on pH and temperature). Unionized ammonia is acutely toxic to aquatic life at concentrations as low as 0.1 mg/L (USEPA 1985). Concentrations of unionized ammonia in pore waters of sediments in the WBGCR ranged from 0.8 mg/L to 6.4 mg/L (Giesy *et al.* 1992). Concentrations of unionized ammonia in overlying water of sediments ranged from 0.35 to 0.85 in samples from Roxana Marsh to 1.7 mg/L in samples from Columbia Avenue and 3.9 mg/L in samples from Torrence Avenue (Dorkin 1994). These concentrations of ammonia in overlying water and in pore water of sediments in the WBGCR were high enough to cause mortality in cladocerans (*Daphnia magna*, *Ceriodaphnia dubia*), amphipods (*Hyalella azteca*), and fish (fathead minnows, *Pimephales promelas*; Hoke *et al.* 1993; Dorkin 1994; Besser *et al.* 1998).

The available data on the concentrations of metals, phenols, and ammonia in pore water provide strong indications that WBGCR sediments have been contaminated by discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances. Comparison of these data to acute and estimated chronic toxicity thresholds demonstrates that the concentrations of several contaminants in pore water are sufficient to harm sediment-dwelling organisms. Therefore, it is concluded that WBGCR 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.

6.1.5 Characteristics of Physical Habitats in the WBGCR

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 the current assessment, the available information on the characteristics of aquatic habitats of the WBGCR was assembled and used to determine if discharges of sewage sludge and municipal wastewaters have injured biological resources in the river.

A survey of aquatic habitat quality and fish community structure in the WBGCR 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. Layers of sludge were observed blanketing submerged vegetation and inhibiting plant growth along the margins of the WBGCR. This layer of sludge blanketed macrophytes in the immediate vicinity of the Hammond Sanitary District (HSD) WWTP and diminished further downstream from this location. Sections of the WBGCR from Columbia Avenue to Sohl Avenue contained islands of sludge, sanitary napkins, toilet paper, and cigarette butts. Simon (1993) concluded that these islands of sludge resulted from combined sewer overflow (CSO) events, based on the presence and composition of materials that accumulated on samplers placed on the west side of Columbia Avenue. Additionally, the CSO events at Sohl and Johnson Avenue inhibited plant growth by dislodging plants.

Simon (1993) reported that all the stations evaluated on the WBGCR have the potential for sustaining a diverse community of warm-water fish. 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 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 sediment oxygen demand depleted oxygen from the sediment and the overlying water in the WBGCR. Low oxygen concentrations would also severely impact aquatic organisms, including fish (Section 7.3).

Overall, the results of this physical habitat survey (i.e., Simon 1993) demonstrate that aquatic habitats have been severely degraded in the WBGCR. Therefore, it is apparent that sediments and associated biological resources have been injured as a result of discharges of sewage sludge and municipal wastewaters into the WBGCR.

6.2 Assessment of Injury to Wildlife

Sediment-associated contaminants have the potential to adversely affect wildlife species in several ways. First, certain wildlife species can be exposed directly to contaminated sediments through dermal contact (e.g., demersal 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 may be exposed to sediment-associated contaminated as a result of food web transfers and associated bioaccumulation. The accumulation of toxic substances in the tissues of these 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, result in decreased abundance of food organisms.

The effects of contaminated sediments in the WBGCR on fish were evaluated by Burton (1994) and Dorkin (1994). In this study, the toxicity of whole sediments from seven locations in the WBGCR to larval fathead minnows, *Pimephales promelas*, was evaluated in standardized 10-d acute toxicity tests. The results of these tests demonstrated that fathead minnows exposed to 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. In addition, the growth rates of fathead minnows were reduced following exposure to sediments from six of the seven locations; growth rates were not affected in fish exposed to samples from the Columbia Avenue location). These data indicate contaminant concentrations in sediments are sufficient to harm fish utilizing habitats within the WBGCR.

The results of surveys of the status of fish communities also provide relevant information for evaluating environmental quality in the WBGCR. Simon (1991; 1993) evaluated the status of fish communities in the WBGCR using an Index of Biotic Integrity (IBI) originally developed by Karr (1981). In addition to sampling the WBGCR, Simon (1991; 1993) also evaluated IBI data from uncontaminated reference sites in northern Indiana. The results of this investigation indicated that, while all sampling stations on the WBGCR had the potential of providing suitable habitat for healthy and diverse communities of warm-water fish, such communities were not present in the WBGCR (Simon 1993). The following IBI scores were reported for several stream reaches in the WBGCR: (1) "poor" east of Indianapolis Boulevard, (2) "very poor" west of Indianapolis Boulevard to the Sohl Avenue bridge, and (3) "no fish" west of Hohman Avenue. Reduced IBI scores for the entire WBGCR were attributed to septic conditions and nutrient enrichment. The source of the contamination was most apparent in the immediate vicinity of the HSD Outfall 001 (Simon 1993). Catches of all indicator species groups were low at six of the seven stations sampled. No benthic fish or sunfish were collected at most of the stations. Simon (1993) concluded that the lack of fish was due to a blanket of sludge over the entire bottom of the river.

Aquatic habitats east of Indianapolis Boulevard (Station 1) supported 10 species of fish and rich beds of aquatic macrophytes. This station had the highest IBI score (29, which is rated as "poor"). From the west side of Indianapolis Boulevard to the east side of Columbia Avenue (Stations 2 and 3) progressively worse conditions were observed, with fresh sludge blanketing aquatic vegetation (IBI score 24, "very poor"). Septic conditions and nutrient addition resulted in tremendous plant growth west of Columbia Avenue to Sohl Avenue (IBI scores of 12, "very poor"). Habitats between Hohman Avenue and Torrence Avenue were also impacted by the deposition of the sludge material, with little plant growth evident (IBI scores of 12 to 19, "very poor"). Simon (1991; 1993) summarizes IBI metrics for other locations sampled in northern Indiana. These locations were rated as "very poor", "poor", or "fair", with the WBGCR rated as having the lowest IBI scores of all of the locations sampled in northern Indiana.

No data were located on the health of fish utilizing habitats in the WBGCR; therefore, it was not possible to determine if fish health has been impaired in the WBGCR.

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 contaminants of concern to piscivorus wildlife species (e.g., ospreys, and mink; NYSDEC 1993). Comparison of tissue residue levels in fish to fish flesh criteria for the protection of wildlife provides another means of determining if bioaccumulation represents a hazard to wildlife species. However, no tissue residue data were located for fish or invertebrates in the WBGCR.

In this report, the sediment quality criteria for the protection of wildlife (NYSDEC 1993) were used as chemical benchmarks for evaluating the ecological significance of sediment-associated contaminants in the WBGCR. Considering the sediment chemistry data collected by Hoke *et al.* (1993) and Dorkin (1994), it is apparent that a variety of bioaccumulative substances are present in WBGCR sediments at concentrations that pose potential hazards to wildlife species utilizing the WBGCR. Specifically, the concentrations of total PCBs, chlordane, total DDT, heptachlor, and lindane in WBGCR sediments exceed the levels that have been established to protect piscivorus wildlife species (Table 46).

Based on the information available from various studies, it is apparent that contaminated sediments pose substantial hazards to wildlife in the WBGCR. Contaminated sediments in the WBGCR are adversely affecting wildlife species in at least four ways. First, WBGCR sediments have been demonstrated to be severely toxic to fish. Second, alteration of benthic invertebrate communities has reduced the abundance of preferred fish food organisms. Third, fish populations inhabiting the WBGCR are severely depressed. Finally, 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, etc.). Therefore, the sediments and associated wildlife species in the WBGCR have been injured by discharges of sewage sludge, municipal wastewaters, and toxic or bioaccumulative substances.

6.3 Assessment of Injury to Human Health

While humans may be exposed to sediment-associated contaminants via several routes, consumption of contaminated fish tissues represents the most important exposure route. Evaluation of the actual hazards posed by bioaccumulative substances in the WBGCR requires information on the levels of contaminants that are present in fish tissues, on the weekly consumption of contaminated fish tissues by various sectors of the population, and on the toxicity of each contaminant to mammalian receptors. Alternatively, tissue residue guidelines (e.g., FDA Action Levels; USEPA 1989) can be used, in conjunction with tissue residue data, to determine if existing concentrations of bioaccumulative substances pose a potential hazard to human consumers. However, resident fish populations are so depressed in the WBGCR that it is not possible to obtain sufficient samples for fish tissue analysis (D. Sparks. USFWS. Bloomington, IN. Personal communication).

As the hazards posed by the bioaccumulation of various chemicals in fish tissues can not be evaluated directly in the WBGCR, an alternative approach has been used in this report. The New York State Department of Environmental Conservation (NYSDEC 1993) has developed sediment quality guidelines for the protection of human health. These bioaccumulation-based guidelines are intended to protect humans from unacceptable levels of exposure to bioaccumulative contaminants resulting from the consumption of contaminated fish flesh. Such guidelines have been developed for benzo(a)pyrene, total PCBs, several organochlorine pesticides, and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin.

Comparison of the levels of bioaccumulative substances in the WBGCR to the NYSDEC (1993) sediment quality guidelines indicates that sediment-associated contaminants pose a potential hazard to human health. Specifically, the sediment chemistry data collected by Hoke *et al.* (1993) and Dorkin (1994) indicate that the levels of benzo(a)pyrene, total PCBs, chlordane, dieldrin, total DDTs, heptachlor, lindane, and toxaphene exceed the sediment quality guidelines in WBGCR sediments. Therefore, contaminant concentrations in WBGCR sediments are sufficient to cause or substantially contribute to sediment injury. No information was located on the taste or odor of fish taken from the WBGCR; therefore, it was not possible to determine if fish tissue tainting has occurred in fish from the WBGCR.

To assess the actual risks to human health posed by contaminated fish, Crane (1996) conducted a human health risk assessment in the Grand Calumet River/Indiana Harbor Area of Concern as part of USEPA's Assessment and Remediation of Contaminated Sediments Program. The results of this assessment indicated that fish from the Grand Calumet River/Indiana Harbor Area of Concern were contaminated with a variety of bioaccumulative substances, including aldrin, alpha-HCH, benzene, chlordane, DDTs, dieldrin, heptachlor epoxide, hexachlorobenzene, mirex, PCBs, and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, all of which are known or are probable carcinogens (Crane 1996). The risk of developing cancer over a lifetime as a result of consuming carp and golden shiners from this area ranged from 2 in 1,000 to 3 in 100,000, depending on where the fish were caught and the daily consumption rate of fish. The USEPA recommends that actions be considered to mitigate or minimize exposures to contaminants when estimated cancer risks exceed the range 1 in 100,000 to 1 in 1,000,000 (USEPA 1988). Crane (1996) indicated that the actual risks to human health may be somewhat lower in the Grand Calumet River/Indiana Harbor Area of Concern because fish populations are so severely depressed. In addition, a directive to limit the consumption of fish from the Grand Calumet River/Indiana Harbor Area of Concern was issued by the Indiana State Board of Health in 1985 (ISBH 1986; Weiss *et al.* 1997). As this directive states that no fish from the Grand Calumet River/Indiana Harbor Area of Concern should be eaten and the area has been posted, the actual risks posed to humans have, at least partially, been mitigated. Nevertheless, the imposition of fish consumption limits in the WBGCR represents an impairment of this use of the river. Therefore, the data on sediment chemistry, in conjunction with the bioaccumulation-based SQGs, for the protection of human health, indicate that sediments have been injured in the WBGCR.

6.4 Conclusions

In this report, several indicators of sediment quality conditions have been used to assess injury to sediments and the associated biological resources of the WBGCR. These indicators include sediment chemistry (i.e., relative to consensus-based and bioaccumulation-based chemical benchmarks), sediment toxicity, benthic invertebrate community structure, fish community surveys, pore water chemistry, pore water toxicity, and the status of physical habitats. Evaluation of the information available on each of these indicators demonstrates that sediments in the WBGCR have been injured by discharges of sewage sludge, municipal wastewaters, and toxic or bioaccumulative substances. More specifically, the concentrations of contaminants that have been measured in WBGCR sediments and pore waters are sufficient to harm sediment-dwelling organisms, wildlife, and/or human health. In addition, the results of two studies demonstrate that sediments and pore waters from the WBGCR are toxic to sediment-dwelling organisms and other aquatic species. Furthermore, benthic invertebrate communities in the WBGCR have also been degraded by contaminated sediments, as evidenced by the presence of pollution-tolerant species and the absence of sensitive species. Fish populations in the WBGCR are also severely depressed. Finally, aquatic habitats within the WBGCR have been severely degraded by inputs of sewage sludge into the river.

The available information on any one of these indicators of sediment quality conditions is sufficient to demonstrate that bed sediments and associated habitats have been injured in the WBGCR. Taken together, however, these separate lines of evidence provide a weight-of-evidence for concluding that discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have created conditions in the WBGCR that are sufficient to injure sediments and the organisms that depend on these critical habitats. Therefore, the levels of chemical contaminants and other indicators of sediment quality conditions are sufficient to injure sediments, sediment-dwelling organisms, wildlife, or human health in the WBGCR.

7.0 Identification of Toxic or Bioaccumulative Substances in the West Branch of the Grand Calumet River

The available information on sediment quality conditions indicates that sediments in the WBGCR have been contaminated by a variety of toxic or bioaccumulative substances (see Glossary for definitions of toxic substances and bioaccumulative substances). Moreover, the levels of many contaminants are sufficient to injure sediments, sediment-dwelling organisms, wildlife, or human health in this river system. The existence of injured sediments and biological resources in the WBGCR has been confirmed by the results of toxicity tests, benthic invertebrate assessments and fish population surveys. Therefore, there is no question that sediments and associated biological resources have been severely injured in the WBGCR.

Following the assessment of sediment injury, it is useful to identify the factors that are causing or substantially contributing to harmful effects on sediment-dwelling organisms, wildlife, or human health. In this report, the contaminants of concern that occur in WBGCR sediments at levels that are sufficient to cause or substantially contribute to sediment injury are termed priority toxic or bioaccumulative substances. The priority substances in bulk sediments and pore water are identified in the following sections of this report. In addition, a number of conventional indicators of environmental quality conditions that are contributing to sediment injury are also identified in this section of the report.

7.1 Bulk Sediment Chemistry

Data on the chemical composition of bulk sediments are available from six studies that have been conducted in the WBGCR (HydroQual, Inc. 1984; HNTB 1989; 1991; Unger 1992; Hoke *et al.* 1993; Dorkin 1994). Each of these studies was reviewed and evaluated to obtain relevant information for assessing sediment quality conditions in this river system (i.e., using sediment chemistry data). Data from acceptable studies were compared to the previously established chemical benchmarks (see Section 4.0) to identify the substances that are causing or substantially contributing to sediment toxicity and other harmful effects in the WBGCR.

The priority substances in bulk sediments from the WBGCR were identified from the list of contaminants of concern by comparing measured contaminant concentrations in sediments to the reliable PECs and the bioaccumulation-based SQGs (Tables 41 and 10). The contaminants which occurred in WBGCR sediments at concentrations in excess of these chemical benchmarks were identified as priority toxic or bioaccumulative substances.

In 1984, an investigation of water and sediment quality conditions was conducted within the Grand Calumet River, Indiana Harbor Canal, Indiana Harbor, and nearby areas in Lake Michigan (HydroQual, Inc. 1984). Two of the sampling stations in this study were located on the WBGCR, including one near Indianapolis Boulevard (C7) and another near Hohman Avenue (C9). A variety of toxic or bioaccumulative substances were measured in sediments collected from these sites, including metals, PAHs, PCBs, pesticides, phenols, phthalates, aromatic hydrocarbons, and dioxins and furans (Appendix 4-2). The results of this study demonstrate that the sediments from both locations are contaminated by metals, PAHs, and PCBs; however, the analytical detection limits reported in this study for the pesticides were generally too high to determine if these substances were present at hazardous levels (i.e., above chemical benchmarks). The levels of cadmium, chromium, copper, lead, nickel, zinc, phenanthrene, chrysene, pyrene, total PAHs, and total PCBs exceeded, by wide margins, the consensus-based PECs in sediments from the Indianapolis Boulevard and Hohman Avenue stations. Hence, these substances were present at levels in excess of concentrations that would cause or substantially contribute to sediment toxicity (Appendix 4-2). At the Indianapolis Boulevard station, the levels of arsenic, naphthalene, benz[a]anthracene, and benzo(a)pyrene were also elevated relative to the consensus-based PECs (Appendix

4-2). The concentrations of total PAHs (Figure 19) and total PCBs (Figure 20) exceeded the PECs by roughly one and two orders of magnitude, respectively, at this location.

Between October, 1988 and May, 1990, Hoke *et al.* (1993) collected sediment samples from 13 stations within the Grand Calumet River - Indiana Harbor Area of Concern. Three of these stations were on the WBGCR, one located east of the HSD-WWTP outfall (i.e., east of Roxanna Marsh; UG-8), one located nearby the HSD-WWTP outfall (UG-9), and one located west of the HSD-WWTP outfall (i.e., near State Line Avenue; UG-10). Data on the concentrations of a wide range of chemical substances in sediment and pore water were collected at each of these sites, including metals, PAHs, PCBs, organochlorine pesticides, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, phthalates, chlorophenols, chlorinated benzenes, and a variety of other substances (Appendix 4-3).

The results of the Hoke *et al.* (1993) study indicate that surficial sediments in the WBGCR are contaminated by a variety of toxic or bioaccumulative substances. Several chemical substances occur in WBGCR sediments at concentrations in excess, by a wide margin, of the consensus-based PECs derived in this report and, therefore, are likely to cause or be associated with harmful effects on sediment-dwelling organisms. Specifically, the concentrations of cadmium, copper, lead, nickel, naphthalene, phenanthrene, benzo(a)pyrene, chrysene, pyrene, total PAHs, total PCBs, and Sum DDE were well in excess of their respective PECs in all three samples from the WBGCR (i.e., UG-8, UG-9, and UG-10; Appendix 4-3). In addition, chromium concentrations exceeded the PEC at site UG-8 and UG-9. Therefore, all of these substances occur in the WBGCR sediments at levels sufficient to injure sediment-dwelling organisms.

Using the data from Hoke *et al.* (1993), it is clear that several organic chemicals occur in WBGCR sediments at levels that are sufficient to harm wildlife or human health. Based on comparisons to the bioaccumulation-based SQGs (Table 11), the concentrations of total PCBs, chlordane, total DDTs, heptachlor, and lindane in WBGCR sediments are sufficient to harm piscivorus wildlife species. Similarly, the concentrations of benzo(a)pyrene, total PCBs, chlordane, dieldrin, total DDTs, heptachlor, lindane, and toxaphene in WBGCR sediments are present at concentrations sufficient to harm human health (i.e., due to the consumption of contaminated fish tissues). These results are supported by the data generated by Unger (1992) in a related study (Appendix A-4)

In 1989, The Sanitary District of Hammond, Indiana commissioned a study to evaluate the quality and quantity of sediments in the WBGCR (HNTB 1989). As part of this investigation, sediment chemistry data were collected at six locations from Roxanna Marsh to the Indiana-Illinois state line, including White Oak, Kent Avenue, Columbia Avenue, Sohl Avenue, and State Line Avenue (HNTB 1989). Samples from each location were prepared by compositing samples taken from the top (0 to 3 feet), middle (3 to 6 feet), and bottom (6 to 9 feet) layers of sediment. A variety of contaminants of concern were measured in each sample, including metals, PAHs, PCBs, pesticides, phenols, phthalates, aromatic hydrocarbons, and dioxins and furans (Appendix 4-5). The concentrations of cadmium, chromium, lead, nickel, zinc, naphthalene, phenanthrene, benzo(a)pyrene, pyrene, total PCBs, and Sum DDE exceeded, by a wide margin, the consensus-based PECs at all of the stations in the WBGCR. In addition, the levels of arsenic and copper were elevated at one or more of the sampling stations. In some cases, the concentrations of sediment-associated contaminants exceeded the PECs by up to two orders of magnitude (e.g., cadmium and benzo(a)pyrene).

As part of a follow-up to the HNTB (1989) study, additional sediment samples were collected on behalf of the Hammond Sanitary District in 1989 and 1990 (HNTB 1991). In this investigation, sediment cores were collected at five locations on the WBGCR (Roxanna Marsh, Columbia Avenue east, Columbia Avenue west, Sohl Avenue, and State Line Avenue) and were used to prepare composite samples from the top, middle, and bottom portions of the cores. The results of this study indicate that the concentrations of cadmium, lead and zinc exceed the consensus-based PECs at all five locations (Appendix 4-6). Several of the sites also had elevated levels of copper and nickel, relative to the consensus-based PECs. However, none of the organic substances measured (i.e., benzo(a)pyrene, PCBs) were present at concentrations in excess of the PECs. These two substances were measured at three of the five locations sampled.

In 1993, Dorkin (1994) collected samples from a number of locations in the WBGCR to determine the chemical characteristics of the sediments. These samples were collected at a total of seven stations, including Roxanna Marsh (2 stations), Molsberger Place, Columbia Avenue, Sohl Avenue, State Line Avenue, and Torrence Avenue. In the first phase of the study, one surficial sediment sample was collected at each station (these grab samples were split to support an evaluation of sediment toxicity; Burton 1994). In the second phase, multiple samples were collected at each station to assess cross-sectional and vertical variability in sediment quality conditions. Metals, PAHs, phthalates, phenols, corn oil, and various other semi-volatile substances were included as target analytes by Dorkin (1994).

The sediment chemistry data collected by Dorkin (1994) demonstrate that sediments in the WBGCR have been contaminated by a variety of toxic and/or bioaccumulative substances. In surficial sediments, the levels of copper and lead exceeded, often by a wide margin, the consensus-based PECs at all seven of the stations (Appendix 4-7). The PECs for arsenic and cadmium were also exceeded at six of the seven stations. The highest levels of metals were observed in the vicinity of Molsberger Place, which is located nearby the HSD-WWTP outfall. The concentrations of several PAHs (naphthalene, phenanthrene, and benz[a]anthracene) also exceeded the consensus-based PECs at the Sohl Avenue and State Line Avenue stations. At several of the locations sampled in this study, the concentrations of various metals exceeded the consensus-based PECs by more than an order of magnitude, while the concentrations of certain PAHs were even higher relative to the consensus-based PECs.

In summary, the results of these six sediment quality investigations demonstrate that whole sediments within the WBGCR have been contaminated by a variety of toxic or bioaccumulative substances. Comparison of these data with the consensus-based PECs that were developed in this report indicates that the priority substances with respect sediment-dwelling organisms in WBGCR sediments include arsenic, cadmium, chromium, copper, lead, nickel, zinc, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, pyrene, total PAHs, total PCBs, and Sum DDE (Table 47). The substances that are present at concentrations that are sufficient to harm wildlife species include total PCBs, chlordane, total DDTs, heptachlor, and lindane (Table 47). The substances that pose the greatest risk to human health include benzo(a)pyrene, total PCBs, chlordane, dieldrin, total DDTs, heptachlor, lindane, and toxaphene (Table 47).

It is difficult to assign a relative priority to these substances in WBGCR sediments. All of these substances frequently exceed the chemical benchmarks in surficial sediments from the WBGCR. In addition, the concentrations of these substances in WBGCR sediment exceed the chemical benchmarks by substantial margins, frequently by more than a factor of 100. Therefore, virtually all of these substances are present in whole sediment at concentrations that are in excess of concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling species in the WBGCR.

7.2 Pore Water Chemistry

The concentrations of numerous contaminants of concern in pore water were reported by Hoke *et al.* (1993). These data, in conjunction with published toxicity thresholds (USEPA 1992b; 1994), were used to identify priority substances in pore water from WBGCR sediments. Evaluation of the 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 WBGCR sediments were frequently at or above concentrations that have been shown to be toxic to aquatic organisms in standardized 10-d acute toxicity tests (Table 44). In addition, the concentrations of phenolic compounds (i.e., phenol) and the sum toxic unit fraction frequently equaled or exceeded the concentrations that are known to be acutely toxic to aquatic organisms (Table 45). Phenol accounted for the majority of the toxic units measured in pore water. The concentrations of unionized ammonia in pore water were also sufficient to cause acute toxicity in aquatic invertebrates and fish. Therefore, the priority substances in pore water are copper, lead, zinc, and phenol, and ammonia (Table 47). 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 priority substances.

7.3 Conventional Indicators of Environmental Quality

Conventional indicators of environmental quality, such as biochemical oxygen demand, chemical oxygen demand, sediment oxygen demand, and total organic carbon can also be used to determine the general status of aquatic habitats and their suitability for supporting aquatic life. These indicators of water quality and sediment quality conditions are influenced by inputs of organic matter (Clark *et al.* 1977; Tchobanoglous 1979). Biochemical oxygen demand is the amount of oxygen required to stabilize and decompose organic matter by the aerobic biochemical action of microbial organisms. Chemical oxygen demand is also used to measure the content of organic matter and is often higher than biochemical oxygen demand because more compounds can be chemically oxidized than can be biologically oxidized. Sediment oxygen demand (SOD) can result from both biochemical oxygen demand and chemical oxygen demand. Total organic carbon provides another measure of the organic matter content of water and sediment.

Sediment oxygen demand is an important factor influencing the relationship between sediment quality and the quality of overlying water. Organic matter deposited in sediment can increase microbial activity in sediments and, hence, increased oxygen demand. When the levels of dissolved oxygen are low, the process of decomposition of organic matter is slowed down, which can result in further accumulation of organic matter in sediment (Clark *et al.* 1977). High sediment oxygen demand is a concern because it can result in low dissolved oxygen in sediment pore water and in overlying water. Elevated levels of sediment oxygen demand can also result in the release of contaminants from sediment under reducing anaerobic conditions. For example, microbial degradation of organic matter in sediment can result in the release of reduced metals into the water column (Brannon *et al.* 1989).

Adequate concentrations of dissolved oxygen in both water and sediment are essential for maintaining critical habitats for communities of aquatic organisms in water and sediment. Distributions of aquatic communities are influenced by level of dissolved oxygen in water or sediment. Fish and aquatic invertebrates, such as salmonids and mayflies, require oxygen concentrations above 4 mg/L on a continuous basis (ASTM 1998a; 1998b). Similarly, the USEPA criterion for dissolved oxygen is 5 mg/L on a continuous basis (USEPA 1997). Extremely low concentrations of dissolved oxygen (i.e., 0.4 to 0.6 mg/L) for even short periods of time would be likely to cause mortality in most species of fish and invertebrates inhabiting the WBGCR, with the exception of some pollution-tolerant species of oligochaetes and midges (ASTM 1998a; 1998b). Low concentrations of dissolved oxygen have been reported in the WBGCR by a variety of investigators (Brannon *et al.* 1989). Data reported in the Simmers *et al.* (1991) indicate that low dissolved oxygen levels were observed in the water column at numerous sites in the WBGCR (ranging from 0.6 to 4 mg/L). More recently, Simon (1993) reported concentrations of dissolved oxygen in the river ranging from 0.4 to 4.4 mg/L.

As indicated above, the transport of metals from sediment to overlying water tends to increase under anaerobic conditions (Brannon *et al.* 1989). This is particularly problematic in the WBGCR because the sediments contain extremely high concentrations of metals (Section 7.2.1). In oxygen-rich sediments, a surficial layer of insoluble metal sulfides can reduce diffusion of metals to overlying water. However, under anaerobic conditions, this surface layer is eliminated resulting in the transport of soluble metals from sediment to the overlying water. The high potential for transport of metals into the water column is emphasized by the elevated metals that have been documented in pore water of sediments from the WBGCR (Hoke *et al.* 1993; Section 7.2).

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

Concentrations of total organic carbon in sediments of the WBGCR are reported in HNTB (1989; 1990; 1991). Concentrations of total organic carbon measured in composited samples of sediment ranged from 4 to 20%, with higher concentrations typically observed in surface samples. Similarly, Hoke *et al.* (1993) reported concentrations of total organic carbon ranging from 13 to 22% in surface samples of sediment. By comparison, USEPA (1996a) reported that the mean concentration of total organic carbon in sediments from the Great Lakes areas of concern was 2.7% (95% confidence interval of 0.65%). These data indicate that the WBGCR has received substantial inputs of organic matter resulting from sewage discharges to the river (Simon 1993) relative to other contaminated sites in the Great Lakes basin.

In aquatic ecosystems, ammonia is excreted by aquatic organisms and formed during the decomposition of biological tissues and nitrogen-containing wastes. Free ammonia can be present either un-ionized ammonia (NH_3) or as ionized ammonia (NH_4^+; depending on pH and temperature). Un-ionized 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). The concentrations of un-ionized ammonia in pore waters of sediments in the WBGCR ranged from 0.8 mg/L to 6.4 mg/L (Giesy *et al.* 1993). Concentrations of un-ionized ammonia in overlying water of sediments ranged from 0.35 to 0.85 in samples from Roxana Marsh to 1.7 mg/L in samples from Columbia Avenue and

3.9 mg/L in samples from Torrence Avenue (Dorkin 1994). These concentrations of ammonia in overlying water and in pore water of sediments in the WBGCR are high enough to cause mortality in cladocerans (*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; Section 6.1.2).

In summary, low concentrations of oxygen, high levels of total organic carbon, and elevated concentrations of ammonia resulting from increased microbial activity and associated biochemical oxygen demand and sediment oxygen demand in the WBGCR would exacerbate the effects of lost habitat for fish and invertebrates resulting from deposition of organically-rich sludge in the river. Therefore, sediment oxygen demand, dissolved oxygen, total organic carbon, and ammonia are additional priority substances in the WBGCR.

7.4 Conclusions

Based on the results of this assessment, it is apparent that a variety of toxic or bioaccumulative substances occur in WBGCR sediments at levels that are sufficient to injure sediment-dwelling organisms, wildlife, or human health. With respect to causing harmful effects on sediment-dwelling organisms, the priority toxic substances in sediments and pore water include arsenic, cadmium, chromium, copper, lead, nickel, zinc, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, pyrene, total PAHs, total PCBs, and Sum DDE (Table 47). Other priority substances include dissolved oxygen, sediment oxygen demand, total organic carbon, and unionized ammonia. With respect to harmful effects on wildlife, total PCBs, chlordane, total DDTs, heptachlor, and lindane represent the priority bioaccumulative substances (Table 47). Benzo(a)pyrene, total PCBs, chlordane, dieldrin, total DDTs, heptachlor, lindane, and toxaphene represent the priority bioaccumulative substances with respect to harmful effects on human health (Table 47). It is important to note, however, that this assessment was restricted by the availability of reliable PECs, published bioaccumulation-based SQGs, and other chemical benchmarks of sediment quality conditions. The availability of sediment and pore water chemistry data also restricted this assessment. Therefore, substances not included on the lists of priority substances can not necessarily be considered to be of low priority with respect to sediment injury.

8.0 Determination of the Areal Extent of Sediment Injury in the West Branch of the Grand Calumet River

The areal extent of sediment injury was determined by merging the various data sets that provided information on contaminant concentrations in WBGCR sediments (Section 7.0). As a first step, the data available on the concentrations of the contaminants of concern in surficial sediments were compiled into a single data set. The location of each of the sampling sites was expressed in terms its distance from the confluence of the WBGCR and Indiana Harbor Canal the compiled data set. In this way, it was possible to evaluate the distribution of each sediment-associated contaminant by river kilometer (Figures 1 to 29). While the data on numerous contaminants of concern are plotted on these figures, the extent of sediment injury was determined using only the data on the substances for which reliable PECs or other chemical benchmarks were available.

The available information on the concentrations of contaminants of concern in surficial sediments from the WBGCR is presented in Figures 1 to 29. The highest concentrations of arsenic, copper, lead, zinc, benz[a]anthracene, chrysene, dieldrin, and Sum DDT were observed in the vicinity of the HSD-WWTP discharge near Molsberger Place (which is located approximately 2.6 km west of the confluence with Indiana Harbor Canal). The levels of cadmium, chromium, anthracene, phenanthrene, benzo(a)pyrene, fluoranthene, pyrene, total PAHs, total PCBs, chlordane, Sum DDE, total DDT, and lindane were also elevated in sediments from this location. The concentrations of many contaminants, particularly metals and PCBs, tend to decrease in both directions from the Molsberger Place station (Figure 30), indicating that the HSD-WWTP discharge is likely a primary source of contaminants to the WBGCR (i.e., it is unlikely that the contaminants originated from sources located east of Indianapolis Boulevard due to the lower contaminant concentrations measured in the eastern portion of Roxanna Marsh). The available data on the chemical composition of sewage sludge from the HSD-WWTP, while limited by the very high detection limits that were achieved in the study (e.g., >200 mg/kg DW for toxaphene) and the limited suite of analytes tested, confirm that sludge from this facility had elevated levels of metals, phenanthrene, phthalates, toluene, xylenes, and PCBs (HNTB 1991). The concentrations of many chemical substances are also elevated at and downstream of the Sohl Avenue station, which suggests that the CSOs at Columbia and Sohl Avenue are important sources of contaminants to the WBGCR.

To support an evaluation of the spatial distribution of chemical contaminants, mean PEC-quotients were calculated for each of the sediment samples from the WBGCR. The results of this evaluation confirm that surficial sediments from the Molsberger Place station have been contaminated by a variety of toxic substances. Mean PEC-quotients at this station ranged from 17.2 to 224 (Figure 30). Mean PEC-quotients were lower in surficial sediments from Roxanna Marsh (up to 76.0 in the western portion and up to 15.5 in the eastern portion) and Indianapolis Boulevard (up to 17.8) stations. Surficial sediments from the Sohl Avenue and State Line Avenue stations were the most contaminated, with up to 541 and 742 mean PEC-quotients observed at these stations, respectively. At Torrence Avenue, mean PEC-quotients of up to 21.5 have been calculated. To put these results into perspective, Long *et al.* (1998a) and Ingersoll *et al.* (1998) reported that the probability of observing toxicity to amphipods was in the order of 75% when sediments contained more than 1.5 mean ERM-quotients (which is functionally equivalent to mean PEC-quotients). Therefore, surficial sediments at all of the stations in the WBGCR are highly likely to be toxic to sediment-dwelling organisms (i.e., sediment samples from the WBGCR had mean PEC-quotients of up to 490 times the level that would result in a 75% probability of observing toxicity).

Data from several studies indicate that the concentrations of chemical contaminants tend to be highest in surficial sediments from the WBGCR (i.e., Horizon 1; Figure 31). At the Molsberger Place station, mean PEC-quotients ranged from 17 to 224 in the top sediment horizon (i.e., 0 to 3 feet in depth); deeper sediments (i.e., 4 to 9 feet in depth; i.e., Horizons 2 and 3) were somewhat less contaminated (i.e., up to 29.8 mean PEC-quotients) at this station (Figure 31). This pattern of decreasing sediment contamination with depth is also apparent at the stations near Sohl Avenue, Hohman Avenue, State Line Avenue, Torrence Avenue, and the eastern portion of Roxanna Marsh. However, deeper sediments (i.e., 4 to 9 feet in depth) tended to be more contaminated at Columbia Avenue, Indianapolis Boulevard, and in the western portion of Roxanna Marsh. Therefore, deeper sediments in the WBGCR are also likely to be toxic to sediment-dwelling organisms, based on the elevated mean PEC-quotients that were calculated for WBGCR sediments. It should be noted that the areal extent of sediment injury would be larger if more conservative chemical benchmarks (e.g., the threshold effect concentrations) had been used to establish thresholds for harmful effects on sediment-dwelling organisms. The deepest sediments sampled (10 to 15 feet) are less likely to be toxic as mean PEC-quotients of <1.0 were calculated for these samples.

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-quotients. For example, sediments from Roxanna Marsh, Molsberger Place, Columbia Avenue, Sohl Avenue, State Line Avenue, and Torrence Avenue are known to be toxic to fish and invertebrates (Hoke *et al.* 1993; Burton 1994), with sediments from the Torrence Avenue location being the least toxic of the samples tested. In addition, the results of benthic invertebrate community assessments conducted in the vicinity of Hohman Avenue demonstrate that benthic communities have been degraded. Furthermore, benthic habitats from Columbia Avenue to Sohl Avenue have been severely degraded by discharges of sewage sludge. Taken together, these data confirm that sediments located from the western portion of Roxanna Marsh to State Line Avenue are the most severely injured among the locations sampled in the WBGCR.

9.0 Conclusions

An evaluation of the harmful effects of sediment-associated contaminants in the West Branch of the Grand Calumet River (WBGCR) was conducted. The results of this evaluation demonstrate that sediments throughout most of the WBGCR have been injured due to discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances. This conclusion is supported by nine independent lines of evidence as follows.

1. Concentrations of metals, PAHs, PCBs, and Sum DDE in sediments exceed the consensus-based PECs at many locations;

2. Concentrations of total PCBs, and several organochlorine pesticides in sediments exceed the bioaccumulation-based SQGs for the protection of wildlife at several locations;

3. Concentrations of benzo(a)pyrene, total PCBs, and several organochlorine pesticides in sediments exceed the bioaccumulation-based SQGs for the protection of human health at several locations.

4. Concentrations of metals, phenols, and ammonia in pore water exceed published toxicity thresholds at several locations;

5. Riverine habitats have been severely degraded by releases of sewage sludge;

6. Sediments from the WBGCR are toxic to invertebrates and fish;

7. Pore water from WBGCR sediments are toxic to invertebrates;

8. The structure of benthic invertebrate communities has been severely altered; and,

9. Fish populations are severely depressed.

Any one of these independent lines of evidence could be used alone to support the conclusion that sediment injury has occurred in the WBGCR. When taken together, however, these nine separate lines of evidence provide an indisputable weight-of-evidence for concluding that discharges of sewage sludge, municipal wastewaters, and other toxic or bioaccumulative substances have created conditions in the WBGCR that are sufficient to severely injury sediments and the organisms that dependent on these critical habitats. Therefore, the levels of priority toxic or bioaccumulative substances and other indicators of environmental quality conditions are sufficient to injure sediments, sediment-dwelling organisms, wildlife, or humans utilizing the WBGCR.

Various metals (arsenic, cadmium, chromium, copper, lead, nickel, and zinc), PAHs (naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, pyrene, and total PAHs), PCBs (total PCBs), pesticides (chlordane, dieldrin, Sum DDE, total DDT, heptachlor, lindane, and toxaphene), phenols (phenol), and conventional indicators (dissolved oxygen, sediment oxygen demand, total organic carbon, and unionized ammonia) are considered to be priority substances in the WBGCR. It is difficult to assign a relative priority to these substances in WBGCR sediments. All of these substances frequently exceed the chemical benchmarks in surficial sediments from the WBGCR. In addition, the concentrations of these substances in WBGCR sediment exceed the chemical benchmarks by substantial margins, frequently by more than a factor of 100. Therefore, all of these substances are present in whole sediment and/or pore water at concentrations that are sufficient to cause or substantially contribute to toxicity in sediment-dwelling species in the WBGCR. It is important to note, however, that this assessment was restricted by the availability of reliable PECs, published bioaccumulation-based SQGs, and other chemical benchmarks of sediment quality conditions. The availability of sediment and pore water chemistry data also restricted this assessment. Therefore, substances not included on the lists of priority substances can not necessarily be considered to be of low priority with respect to sediment injury.

The levels of priority substances are sufficient to cause or substantially contribute to sediment injury throughout the WBGCR system. In surficial sediments the highest levels of sediment contamination occur in the vicinity of Molsberger Place (i.e., nearby the HSD-WWTP outfall), Sohl Avenue, and State Line Avenue. At many sampling sites, surficial sediments tend to be the most contaminated.

Nevertheless, contaminant concentrations are sufficient to injury sediments to depths of up to 9 feet throughout much of the river system. The concentrations of contaminants in deeper sediments (i.e., 10 to 15 feet) are much less likely to cause or substantially contribute to sediment injury.

The probable effect concentrations represent 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 probable effect concentrations to ensure that bed sediments would once again support healthy and diverse populations of sediment-dwelling organisms and associated fish and wildlife communities.

____________________________ __________________

Donald D. MacDonald, President Date Signed
MacDonald Environmental Sciences Ltd.

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Tables

Table 1. Descriptions of the published sediment quality guidelines (SQGs) that have been developed using various approaches.

Type of SQG	Acronym	Approach	Description	Reference
Lowest Effect Level	LEL	SLCA	Sediments are considered to be clean to marginally polluted. No effects on the majority of sediment-dwelling organisms are expected below this concentration.	Persaud *et al.* 1993
Severe Effect Level	SEL	SLCA	Sediments are considered to be heavily polluted. Adverse effects on the majority of sediment-dwelling organisms are expected when this concentration is exceeded.	Persaud *et al.* 1993
Threshold Effect Level	TEL	WEA	Represents the concentration below which adverse effects are expected to occur only rarely.	Smith *et al.* 1996
Probable Effects Level	PEL	WEA	Represents the concentration above which adverse effects are expected to occur frequently.	Smith *et al.* 1996
Effects Range - Low	ERL	WEA	Represents the chemical concentration below which adverse effects would be rarely observed.	Long and Morgan 1991
Effects Range - Median	ERM	WEA	Represents the chemical concentration above which adverse effects would frequently occur.	Long and Morgan 1991
Threshold Effect Level for *Hyalella azteca* in 28-day tests	TEL-HA28	WEA	Represents the concentration below which adverse effects on the amphipod, *Hyalella azteca* , are expected to occur only rarely (in 28-day tests).	USEPA 1996a; Ingersoll *et al.* 1996
Probable Effects Level for *Hyalella azteca* in 28-day tests	PEL-HA28	WEA	Represents the concentration above which adverse effects on the amphipod, *Hyalella* azteca, are expected to occur frequently (in 28-day tests).	USEPA 1996a; Ingersoll *et al.* 1996

Table 1. Descriptions of the published sediment quality guidelines (SQGs) that have been developed using various approaches.

Type of SQG	Acronym	Approach	Description	Reference
Minimal Effect Threshold	MET	SLCA	Sediments are considered to be clean to marginally polluted. No effects on the majority of sediment-dwelling organisms are expected below this concentration.	EC and MENVIQ 1992
Toxic Effect Threshold	TET	SLCA	Sediments are considered to be heavily polluted. Adverse effects on sediment-dwelling organisms are expected when this concentration is exceeded.	EC and MENVIQ 1992
Chronic Equilibrium Partitioning Threshold	SQAL/SQC	EqPA	Represents the concentration in sediments that is predicted to be associated with concentrations in the interstitial water below the chronic water quality criterion. Adverse effects on sediment-dwelling organisms are predicted to occur only rarely below this concentration.	Bolton *et al.* 1985; Zarba 1992

Table 2. Sediment quality guidelines for metals in freshwater ecosystems that reflect threshold effect concentrations (i.e. below which harmful effects are unlikely to be observed).

Substance	*Threshold Effect Concentrations (in mg/kg DW)*						
	TEL	**LEL**	**MET**	**ERL**	**TEL-HA28**	**SQAL/SQC**	**Consensus-Based TEC**
Arsenic	5.9	6	7	33	11	NG	9.79
Cadmium	0.596	0.6	0.9	5	0.58	NG	0.99
Chromium	37.3	26	55	80	36	NG	43.4
Copper	35.7	16	28	70	28	NG	31.6
Lead	35	31	42	35	37	NG	35.8
Mercury	0.174	0.2	0.2	0.15	NG	NG	0.18
Nickel	18	16	35	30	20	NG	22.7
Silver	NG	NG	NG	1	NG	NG	NG
Zinc	123	120	150	120	98	NG	121

TEL = Threshold effect level; dry weight (Smith *et al.* 1996).
LEL = Lowest effect level, dry weight (Persaud *et al.* 1993).
MET = Minimal effect threshold; dry weight (EC & MENVIQ 1992).
ERL = Effects range low; dry weight (Long and Morgan 1991).
TEL-HA28 = Threshold effect level for *Hyalella azteca* ; 28 day test; dry weight (USEPA 1996a).
SQAL = Sediment quality advisory levels; SQC = sediment quality criteria; dry weight (USEPA 1997a).
NG = No guideline reported.

Table 3. Sediment quality guidelines for PAHs in freshwater ecosystems that reflect threshold effect concentrations (i.e., below which harmful effects are unlikely to be observed).

Substance	*Threshold Effect Concentrations (in µg/kg DW)*						
	TEL	**LEL**	**MET**	**ERL**	**TEL-HA28**	**SQC/SQAL**	**Consensus-Based TEC**
Low Molecular Weight PAHs							
Acenaphthene	NG	NG	NG	150	NG	1300	**NG**
Acenaphthylene	NG	NG	NG	NG	NG	NG	**NG**
Anthracene	NG	220	NG	85	10	NG	**57.2**
Fluorene	NG	190	NG	35	10	540	**77.4**
Naphthalene	NG	NG	400	340	15	470	**176**
2-Methylnaphthalene	NG	NG	NG	65	NG	NG	**NG**
Phenanthrene	41.9	560	400	225	19	1800	**204**
Total LMW-PAHs	NG	NG	NG	NG	76	NG	**NG**
High Molecular Weight PAHs							
Benz[a]anthracene	31.7	320	400	230	16	NG	**108**
Benzo(a)pyrene	31.9	370	500	400	32	NG	**150**
Chrysene	57.1	340	600	400	27	NG	**166**
Dibenz[a,h]anthracene	NG	60	NG	60	10	NG	**33.0**
Fluoranthene	111	750	600	600	31	6200	**423**
Pyrene	53	490	700	350	44	NG	**195**
Total HMW-PAHs	NG	NG	NG	NG	190	NG	**NG**
Total PAHs	NG	4000	NG	4000	260	NG	**1610**

TEL = Threshold effect level; dry weight (Smith *et al.* 1996).
LEL = Lowest effect level, dry weight (Persaud *et al.* 1993).
MET = Minimal effect threshold; dry weight (EC & MENVIQ 1992).
ERL = Effects range low; dry weight (Long and Morgan 1991).
TEL-HA28 = Threshold effect level for *Hyalella azteca* ; 28 day test; dry weight (USEPA 1996a).
SQAL = Sediment quality advisory levels; SQC = sediment quality criteria; dry weight at 1% OC (USEPA 1997a).
NG = No guideline reported.

Table 4. Sediment quality guidelines for PCBs, organochlorine pesticides, dioxins, and furans in freshwater ecosystems that reflect threshold effect concentrations (i.e., below which harmful effects are unlikely to be observed).

Substance	*Threshold Effect Concentrations (in µg/kg DW)*						
	TEL	**LEL**	**MET**	**ERL**	**TEL-HA28**	**SQC/SQAL**	**Consensus-Based TEC**
PCBs							
Total PCBs	34.1	70	200	50	32	NG	59.8
Aroclor 1016	NG	7	100	NG	NG	NG	NG
Aroclor 1248	NG	30	50	NG	NG	NG	NG
Aroclor 1254	NG	60	60	NG	NG	NG	NG
Aroclor 1260	NG	5	5	NG	NG	NG	NG
Organochlorine Pesticides							
Chlordane	4.5	7	7	0.5	NG	NG	3.24
Dieldrin	2.85	2	2	0.02	NG	110	1.90
Sum DDD	3.54	8	10	2	NG	NG	4.88
Sum DDE	1.42	5	7	2	NG	NG	3.16
Sum DDT	NG	8	9	1	NG	NG	4.16
Total DDTs	7	7	NG	3	NG	NG	5.28
Endrin	2.67	3	8	0.02	NG	42	2.22
Heptachlor epoxide	0.6	5	5	NG	NG	NG	2.47
Lindane (gamma-BHC)	0.94	3	3	NG	NG	3.7	2.37
Mirex	NG	7	11	NG	NG	NG	NG
Dioxins and Furans							
2,3,7,8-TCDD	NG	NG	NG	NG	NG	NG	NG
2,3,7,8-TCDD TEQs	NG	NG	NG	NG	NG	NG	NG

TEL = Threshold effect level; dry weight (Smith et al. 1996).
LEL = Lowest effect level, dry weight (Persaud et al. 1993).
MET = Minimal effect threshold; dry weight (EC & MENVIQ 1992).
ERL = Effects range low; dry weight (Long and Morgan 1991).
TEL-HA28 = Threshold effect level for Hyalella azteca; 28 day test; dry weight (USEPA 1996a).
SQAL = Sediment quality advisory levels; SQC = sediment quality criteria; dry weight at 1% OC (USEPA 1997a).
NG = No guideline reported.

Table 5. Sediment quality guidelines for phenolics in freshwater ecosystems that reflect threshold effect concentrations (i.e., below which harmful effects are unlikely to be observed).

Substance	*Threshold Effect Concentrations (in mg/kg DW)*						
	TEL	**LEL**	**MET**	**ERL**	**TEL-HA28**	**SQC/SQAL**	**Consensus-Based TEC**
Phenol	NG	NG	NG	NG	NG	NG	NG
o-Chlorophenol	NG	NG	NG	NG	NG	NG	NG
o-Cresol	NG	NG	NG	NG	NG	NG	NG
4,6-Dinitro-o-cresol	NG	NG	NG	NG	NG	NG	NG
2,4-Dinitrophenol	NG	NG	NG	NG	NG	NG	NG
Pentachlorophenol	NG	NG	NG	NG	NG	NG	NG

TEL = Threshold effect level; dry weight (Smith *et al.* 1996).
LEL = Lowest effect level, dry weight (Persaud *et al.* 1993).
MET = Minimal effect threshold; dry weight (EC & MENVIQ 1992).
ERL = Effects range low; dry weight (Long and Morgan 1991).
TEL-HA28 = Threshold effect level for *Hyalella azteca* ; 28 day test; dry weight (USEPA 1996a).
SQAL = Sediment quality advisory levels; SQC = sediment quality criteria; dry weight at 1% OC (USEPA 1997a).
NG = No guideline reported.

Table 6. Sediment quality guidelines for metals in freshwater ecosystems that reflect probable effect concentrations (i.e. above which harmful effects are likely to be observed).

Substance	*Probable Effect Concentrations (in mg/kg DW)* PEL	SEL	TET	ERM	PEL-HA28	Consensus-Based PEC
Arsenic	17	33	17	85	48	33.0
Cadmium	3.53	10	3	9	3.2	4.98
Chromium	90	110	100	145	120	111
Copper	197	110	86	390	100	149
Lead	91.3	250	170	110	82	128
Mercury	0.486	2	1	1.3	NG	1.06
Nickel	36	75	61	50	33	48.6
Silver	NG	NG	NG	2.2	NG	NG
Zinc	315	820	540	270	540	459

PEL = Probable effect level; dry weight (Smith *et al.* 1996).
SEL = Severe effect level, dry weight (Persaud *et al.* 1993).
TET = Toxic effect threshold; dry weight (EC & MENVIQ 1992).
ERM = Effects range median; dry weight (Long and Morgan 1991).
PEL-HA28 = Probable effect level for *Hyalella azteca* ; 28 day test; dry weight (USEPA 1996a).
NG = No guideline.

Table 7. Sediment quality guidelines for PAHs in freshwater ecosystems that reflect probable effect concentrations (i.e. above which harmful effects are likely to be observed).

	Probable Effect Concentrations (in ug/kg DW)					
Substance	**PEL**	**SEL**	**TET**	**ERM**	**PEL-HA28**	**Consensus-Based PEC**
Low Molecular Weight PAHs						
Acenaphthene	NG	NG	NG	650	NG	**NG**
Acenaphthylene	NG	NG	NG	NG	NG	**NG**
Anthracene	NG	3700	NG	960	170	**845**
Fluorene	NG	1600	NG	640	150	**536**
Naphthalene	NG	NG	600	2100	140	**561**
2-Methylnaphthalene	NG	NG	NG	670	NG	**NG**
Phenanthrene	515	9500	800	1380	410	**1170**
Total LMW-PAHs	NG	NG	NG	NG	1200	**NG**
High Molecular Weight PAHs						
Benz[a]anthracene	385	14800	500	1600	280	**1050**
Benzo(a)pyrene	782	14400	700	2500	320	**1450**
Chrysene	862	4600	800	2800	410	**1290**
Dibenz[a,h]anthracene	NG	1300	NG	260	NG	**NG**
Fluoranthene	2355	10200	2000	3600	320	**2230**
Pyrene	875	8500	1000	2200	490	**1520**
Total HMW-PAHs	NG	NG	NG	NG	2300	**NG**
Total PAHs	NG	100000	NG	35000	3400	**22800**

PEL = Probable effect level; dry weight (Smith *et al.* 1996).
SEL = Severe effect level, dry weight (Persaud *et al.* 1993).
TET = Toxic effect threshold; dry weight (EC & MENVIQ 1992).
ERM = Effects range median; dry weight (Long and Morgan 1991).
PEL-HA28 = Probable effect level for *Hyalella azteca* ; 28 day test; dry weight (USEPA 1996a).
NG = No guideline.

Table 8. Sediment quality guidelines for PCBs, organochlorine pesticides, dioxins, and furans in freshwater ecosystems that reflect probable effect concentrations (i.e. above which harmful effects are likely to be observed).

	Probable Effect Concentrations (in ug/kg DW)					
Substance	**PEL**	**SEL**	**TET**	**ERM**	**PEL-HA28**	**Consensus-Based PEC**
PCBs						
Total PCBs	277	5300	1000	400	240	676
Aroclor 1016	NG	530	400	NG	NG	NG
Aroclor 1248	NG	1500	600	NG	NG	NG
Aroclor 1254	NG	340	300	NG	NG	NG
Aroclor 1260	NG	240	200	NG	NG	NG
Organochlorine Pesticides						
Chlordane	8.9	60	30	6	NG	17.6
Dieldrin	6.67	910	300	8	NG	61.8
Sum DDD	8.51	60	60	20	NG	28.0
Sum DDE	6.75	190	50	15	NG	31.3
Sum DDT	NG	710	50	7	NG	62.9
Total DDTs	4450	120	NG	350	NG	572
Endrin	62.4	1300	500	45	NG	207
Heptachlor Epoxide	2.74	50	30	NG	NG	16.0
Lindane (gamma-BHC)	1.38	10	9	NG	NG	4.99
Mirex	NG	1300	800	NG	NG	NG
Dioxins and Furans						
2,3,7,8-TCDD	NG	NG	NG	NG	NG	NA
2,3,7,8-TCDD TEQs	NG	NG	NG	NG	NG	NA

PEL = Probable effect level; dry weight (Smith *et al.* 1996).
SEL = Severe effect level, dry weight (Persaud *et al.* 1993).
TET = Toxic effect threshold; dry weight (EC & MENVIQ 1992).
ERM = Effects range median; dry weight (Long and Morgan 1991).
PEL-HA28 = Probable effect level for *Hyalella azteca* ; 28 day test; dry weight (USEPA 1996a).
NG = No guideline.

Table 9. Sediment quality guidelines for phenolics in freshwater ecosystems that reflect probable effect concentrations (i.e., above which harmful effects are likely to be observed).

Substance	*Probable Effect Concentrations (in ug/kg DW)*					
	PEL	**SEL**	**TET**	**ERM**	**PEL-HA28**	**Consensus-Based PEC**
Phenol	NG	NG	NG	NG	NG	NG
o-Chlorophenol	NG	NG	NG	NG	NG	NG
o-Cresol	NG	NG	NG	NG	NG	NG
4,6-Dinitro-o-cresol	NG	NG	NG	NG	NG	NG
2,4-Dinitrophenol	NG	NG	NG	NG	NG	NG
Pentachlorophenol	NG	NG	NG	NG	NG	NG

PEL = Probable effect level; dry weight (Smith *et al.* 1996).
SEL = Severe effect level, dry weight (Persaud *et al.* 1993).
TET = Toxic effect threshold; dry weight (EC & MENVIQ 1992).
ERM = Effects range median; dry weight (Long and Morgan 1991).
PEL-HA28 = Probable effect level for *Hyalella azteca* ; 28 day test; dry weight (USEPA 1996a).
NG = No guideline.

Table 10. Summary of the consensus-based SECs for the contaminants of concern in the West Branch of the Grand Calumet River.

Substance	Consensus-Based TEC	Consensus-Based PEC
Metals (in mg/kg DW)		
Arsenic	9.79	33.0
Cadmium	0.99	4.98
Chromium	43.4	111
Copper	31.6	149
Lead	35.8	128
Mercury	0.18	1.06
Nickel	22.7	48.6
Zinc	121	459
Polycyclic Aromatic Hydrocarbons (in µg/kg DW)		
Anthracene	57.2	845
Fluorene	77.4	536
Naphthalene	176	561
Phenanthrene	204	1170
Benz[a]anthracene	108	1050
Benzo(a)pyrene	150	1450
Chrysene	166	1290
Fluoranthene	423	2230
Pyrene	195	1520
Total PAHs	1610	22800
Polychlorinated Biphenyls (in µg/kg DW)		
Total PCBs	59.8	676
Pesticides (in µg/kg DW)		
Chlordane	3.24	17.6
Dieldrin	1.90	61.8
Sum DDD	4.88	28.0
Sum DDE	3.16	31.3
Sum DDT	4.16	62.9
Total DDT	5.28	572
Endrin	2.22	207
Heptachlor epoxide	2.47	16.0
Lindane (gamma-BHC)	2.37	4.99

Table 11. Bioaccumulation-based SQGs for the contaminants of concern in the West Branch of the Grand Calumet River (from NYSDEC 1993).

Substance	Wildlife-Based SQGs	Human Health-Based SQGs
Polycyclic Aromatic Hydrocarbons (µg/kg OC)		
Benzo(a)pyrene	NG	1300
Polychlorinated Biphenyls (in µg/kg OC)		
Total PCBs	1400	0.8
Pesticides (in µg/kg OC)		
Chlordane	6	1
Dieldrin	NG	100
Total DDT	1000	10
Endrin	800	800
Heptachlor	30	0.8
Heptachlor epoxide	30	0.8
Lindane (gamma-BHC)	1500	60
Mirex	3700	70
Toxaphene	NG	20
Dioxins and Furans (µg/kg OC)		
2,3,7,8-TCDD	0.2	10

NG = no guideline

Table 12. Toxicity thresholds for contaminants of concern in the West Branch of the Grand Calumet River.

Contaminant of Concern	Aquatic Plants		10-d LC_{50} for	Other Aquatic Invertebrates		Fish	
	Acute	Chronic	*Hyalella azteca*	Acute	Chronic	Acute	Chronic
Metals							
Cadmium	30 µg/L (6)	1 µg/L (6)	2.9 µg/L (4)	3.6 µg/L (6)	0.17 µg/L (6)	< 0.5 µg/L (6)	0.47 µg/L (6)
Chromium	2500 µg/L (7)	NR	NR	15 µg/L (2)	2.5 µg/L (2)	265 µg/L (2)	73 µg/L (2)
Copper	NR	1 µg/L (1)	35 µg/L (4)	20 µg/L (1)	8 µg/L (1)	21 µg/L (1)	3.9 µg/L (2)
Lead	4140 µg/L (7)	450 µg/L (7)	< 16 µg/L (4)	124 µg/L (7)	1 µg/L (7)	448 µg/L (2)	3.5 µg/L (7)
Nickel	300 µg/L (5)	50 µg/L (5)	780 µg/L (4)	102 µg/L (5)	15 µg/L (2)	50 µg/L (5)	25 µg/L (5)
Zinc	20 µg/L (7)	2 µg/L (7)	73 µg/L (4)	51 µg/L (7)	10 µg/L (7)	280 µg/L (7)	10 µg/L (7)
Phenolics							
Phenol	NR	NR	NR	45 µg/L (3)	NR	NR	NR
o-chlorophenol	NR	NR	NR	5600 µg/L (3)	NR	NR	NR
p-chlorophenol	NR	NR	NR	5600 µg/L (3)	NR	NR	NR
2,4-dichlorophenol	NR	NR	NR	520 µg/L (3)	NR	NR	NR
2,4-dinitrophenol	NR	NR	NR	NR	NR	NR	NR
o-cresol	NR	NR	NR	100 µg/L (3)	NR	NR	NR
p-cresol	NR	NR	NR	100 µg/L (3)	NR	NR	NR
Other Substances							
Unionized ammonia	NR	NR	NR	0.53 mg/L (2)	NR	0.083 mg/L (2)	0.002 mg/L (2)

Data Sources: (1) Spear and Pierce 1979; (2) CCREM 1987; (3) USEPA 1992a; (4) USEPA 1994; (5) EC and HC 1994; (6) Outridge *et al.* 1994; (7) USGS 1998; NR = not reported.

Table 13. Evaluation of the predictive ability of the consensus-based PEC for arsenic.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	NM	NM	NA	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	3	3	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	3	3	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	1	0	0%	Dickson *et al.* 1989
Trinity River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	4	2	50%	USFWS 1993
Milltown Reservoir, MT	7	5	4	80%	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	NM	NM	NA	USEPA 1997c
Waukegan Harbor, IL	20	5	5	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	3	2	67%	USEPA 1996a
All Locations	**239**	**26**	**21**	**81%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 14. Evaluation of the predictive ability of the consensus-based PEC for cadmium.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
West Branch Grand Calumet River, IN	7	5	5	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Indiana Harbor, IN	108	81	76	94%	USEPA 1996b
Potomac River, DC	15	0	0	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	1	0	0%	Dickson *et al.* 1989
Trinity River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	1	1	100%	USFWS 1993
Milltown Reservoir, MT	7	2	1	50%	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	19	19	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	2	1	50%	USEPA 1996a
All Locations	**337**	**116**	**108**	**93%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 15. Evaluation of the predictive ability of the consensus-based PEC for chromium.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	8	8	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	5	5	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Indiana Harbor, IN	108	80	76	95%	USEPA 1996b
Potomac River, DC	15	5	2	40%	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	1	0	0%	Dickson *et al.* 1989
Trinity River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	1	0	0%	Call *et al.* 1991
Buffalo River, NY	5	2	2	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	NM	NM	NA	USEPA 1997c
Waukegan Harbor, IL	20	1	1	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	1	1	100%	USEPA 1996a
All Locations	**347**	**109**	**100**	**92%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 16. Evaluation of the predictive ability of the consensus-based PEC for copper.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	8	8	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	6	6	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Indiana Harbor, IN	108	78	73	94%	USEPA 1996b
Potomac River, DC	15	0	0	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	1	0	0%	Dickson *et al.* 1989
Trinity River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	4	2	50%	USFWS 1993
Milltown Reservoir, MT	7	6	5	83%	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	2	2	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**347**	**110**	**101**	**92%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 17. Evaluation of the predictive ability of the consensus-based PEC for lead.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	9	9	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	7	7	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Indiana Harbor, IN	108	87	82	94%	USEPA 1996b
Potomac River, DC	15	12	5	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	0	0	NA	Dickson *et al.* 1989
Trinity River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	1	0	0%	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	1	1	100%	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	2	2	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	1	1	100%	USEPA 1996a
All Locations	**347**	**125**	**112**	**90%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 18. Evaluation of the predictive ability of the consensus-based PEC for mercury.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	NM	NM	NA	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	2	2	100%	USEPA 1993a; 1996a
Potomac River, DC	15	0	0	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	1	1	100%	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	NM	NM	NA	USEPA 1997c
Waukegan Harbor, IL	20	0	0	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**4**	**4**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 19. Evaluation of the predictive ability of the consensus-based PEC for nickel.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	7	7	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	4	4	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	3	3	100%	USEPA 1993a; 1996a
Indiana Harbor, IN	108	72	69	96%	USEPA 1996b
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	0	0	NA	Dickson *et al.* 1989
Trinity River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	6	0	0%	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	1	1	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**347**	**95**	**86**	**91%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 20. Evaluation of the predictive ability of the consensus-based PEC for zinc.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	5	5	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	6	6	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Indiana Harbor, IN	108	88	82	93%	USEPA 1996b
Potomac River, DC	15	3	1	33%	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	1	0	0%	Dickson *et al.* 1989
Trinity River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	4	2	50%	USFWS 1993
Milltown Reservoir, MT	7	6	5	83%	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	0	0	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	1	1	NA	USEPA 1996a
All Locations	**347**	**120**	**108**	**90%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 21. Evaluation of the predictive ability of the consensus-based PEC for anthracene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	NM	NM	NA	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	6	6	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	2	2	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	1	1	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**13**	**13**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 22. Evaluation of the predictive ability of the consensus-based PEC for fluorene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	NM	NM	NA	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	6	6	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	1	1	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	1	1	100%	USEPA 1996a
All Locations	**239**	**13**	**13**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 23. Evaluation of the predictive ability of the consensus-based PEC for naphthalene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	4	4	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	2	0	0%	USEPA 1997c
Waukegan Harbor, IL	20	5	5	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**26**	**24**	**92%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 24. Evaluation of the predictive ability of the consensus-based PEC for phenanthrene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	9	9	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	6	6	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	2	2	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	4	4	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**25**	**25**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 25. Evaluation of the predictive ability of the consensus-based PEC for benz[a]anthracene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	7	7	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	7	7	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	1	1	100%	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	NM	NM	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**20**	**20**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 26. Evaluation of the predictive ability of the consensus-based PEC for benzo(a)pyrene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	7	7	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	1	1	100%	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	1	1	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**24**	**24**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 27. Evaluation of the predictive ability of the consensus-based PEC for chrysene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	8	8	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	7	7	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	1	0	0%	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	1	1	100%	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	2	2	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**24**	**23**	**96%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 28. Evaluation of the predictive ability of the consensus-based PEC for fluoranthene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	1	1	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	7	7	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	2	2	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**15**	**15**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 29. Evaluation of the predictive ability of the consensus-based PEC for pyrene.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	7	7	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	1	0	0%	Call *et al.* 1991
Buffalo River, NY	5	2	2	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	1	1	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	2	2	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**28**	**27**	**96%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 30. Evaluation of the predictive ability of the consensus-based PEC for total PAHs.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	7	7	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	7	7	100%	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	4	4	100%	USEPA 1993a; 1996a
Potomac River, DC	15	1	1	100%	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	0	0	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	1	1	100%	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	0	0	NA	USFWS 1993
Milltown Reservoir, MT	7	0	0	NA	USFWS 1993
Lower Columbia River, WA	12	0	0	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	0	0	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	0	0	NA	USEPA 1996a
All Locations	**239**	**20**	**20**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 31. Evaluation of the predictive ability of the consensus-based PEC for total PCBs.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	3	3	100%	USEPA 1993a; 1996a
Potomac River, DC	15	3	3	100%	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinty River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	10	2	20%	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	2	2	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	0	0	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	19	19	19	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	2	2	100%	USEPA 1996a
All Locations	**238**	**49**	**41**	**84%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 32. Evaluation of the predictive ability of the consensus-based PEC for chlordane.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	0	0	NA	USEPA 1993a; 1996a
Potomac River, DC	15	12	5	42%	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	4	2	50%	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	9	9	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**35**	**26**	**74%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 33. Evaluation of the predictive ability of the consensus-based PEC for dieldrin.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	8	8	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	0	0	NA	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	0	0	NA	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	5	5	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**13**	**13**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 34. Evaluation of the predictive ability of the consensus-based PEC for Sum DDD.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	5	5	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	0	0	NA	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	0	0	NA	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	0	0	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**5**	**5**	**100%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 35. Evaluation of the predictive ability of the consensus-based PEC for Sum DDE.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	0	0	NA	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	0	0	NA	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	1	0	0%	USEPA 1997c
Waukegan Harbor, IL	19	18	18	100%	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**238**	**30**	**29**	**97%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 36. Evaluation of the predictive ability of the consensus-based PEC for Sum DDT.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	1	0	0%	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	0	0	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**11**	**10**	**91%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 37. Evaluation of the predictive ability of the consensus-based PEC for total DDT.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	2	1	50%	USEPA 1993a; 1996a
Potomac River, DC	15	0	0	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	NM	NM	NA	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	0	0	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**12**	**11**	**92%**	

NM = Substance was not measured in the study; NA = not applicable.

Table 38. Evaluation of the predictive ability of the consensus-based PEC for endrin.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	NM	NM	NA	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	0	0	NA	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	0	0	NA	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	0	0	NA	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	0	0	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**0**	**0**	**NA**	

NM = Substance was not measured in the study; NA = not applicable.

Table 39. Evaluation of the predictive ability of the consensus-based PEC for heptachlor epoxide.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	NM	NM	NA	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	0	0	NA	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	5	0	0%	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	NM	NM	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	3	3	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	NM	NM	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**8**	**3**	38%	

NM = Substance was not measured in the study; NA = not applicable.

Table 40. Evaluation of the predictive ability of the consensus-based PEC for lindane.

Sampling Location	Number of Samples Collected	Number of Samples Predicted to be Toxic using the PECs	Number of Samples Correctly Predicted to be Toxic	Predictive Ability (%) of the PECs	Reference
Grand Calumet River and Indiana Harbor, IN	10	10	10	100%	Hoke *et al.* 1993; Giesy *et al.* 1993
West Branch Grand Calumet River, IN	7	NM	NM	NA	Burton 1994; Dorkin 1994
Indiana Harbor, IN	4	0	0	NA	USEPA 1993a; 1996a
Potomac River, DC	15	NM	NM	NA	Schlekat *et al.* 1994; Wade *et al.* 1994 Velinsky *et al.* 1994
Trinity River, TX	72	6	3	50%	Dickson *et al.* 1989
Trinity River, TX	4	NM	NM	NA	USEPA 1996a
Lower Fox River and Green Bay, WI	13	0	0	NA	Call *et al.* 1991
Buffalo River, NY	5	0	0	NA	USEPA 1993c; 1996a
Saginaw River, MI	10	1	1	100%	USEPA 1993b; 1996a
Clark Fork River, MT	6	NM	NM	NA	USFWS 1993
Milltown Reservoir, MT	7	NM	NM	NA	USFWS 1993
Lower Columbia River, WA	12	NM	NM	NA	Johnson and Norton 1988
Upper Mississippi River, MN - MO	4	NM	NM	NA	USEPA 1996a
Upper Mississippi River, MN - MO	47	0	0	NA	USEPA 1997c
Waukegan Harbor, IL	20	0	0	NA	Kemble *et al.* 1998a
Waukegan Harbor, IL	3	NM	NM	NA	USEPA 1996a
All Locations	**239**	**17**	**14**	82%	

NM = Substance was not measured in the study; NA = not applicable.

Table 41. Summary of the predictive ability of the consensus-based PECs for the contaminants of concern in the West Branch of the Grand Calumet River.

Substance	Consensus-Based PEC	Number of Samples Predicted to be Toxic	Number of Samples Correctly Predicted to be Toxic	Predictive Ability of PEC
Metals (in mg/kg DW)				
Arsenic	33.0*	26	21	81%
Cadmium	4.98*	126	118	94%
Chromium	111*	109	100	92%
Copper	149*	110	101	92%
Lead	128*	125	112	90%
Mercury	1.06	4	4	100%
Nickel	48.6*	95	86	91%
Zinc	459*	120	108	90%
Polycyclic Aromatic Hydrocarbons (in µg/kg DW)				
Anthracene	845	13	13	100%
Fluorene	536	13	13	100%
Naphthalene	561*	26	24	92%
Phenanthrene	1170*	25	25	100%
Benz[a]anthracene	1050*	20	20	100%
Benzo(a)pyrene	1450*	24	24	100%
Chrysene	1290*	24	23	96%
Fluoranthene	2230	15	15	100%
Pyrene	1520*	29	28	96%
Total PAHs	22800*	20	20	100%
Polychlorinated Biphenyls (in µg/kg DW)				
Total PCBs	676*	49	41	84%
Pesticides (in µg/kg DW)				
Chlordane	17.6	35	26	74%
Dieldrin	61.8	13	13	100%
Sum DDD	28.0	5	5	100%
Sum DDE	31.3*	30	29	97%
Sum DDT	62.9	11	10	91%
Total DDT	572	12	11	92%
Endrin	207	0	0	NA
Heptachlor epoxide	16.0	8	3	38%
Lindane (gamma-BHC)	4.99	17	14	82%

* = Reliable PEC (i.e., ≥ 75% predictability and ≥ 20 samples predicted to be toxic).

Table 42. Maximum background concentration (mg/kg) of metals in Indiana and Illinois stream and lake sediments.

	Illinois [a]	Indiana [b]
Cadmium	1.0	1.0
Chromium	23.0	50.0
Copper	60.0	20.0
Nickel	---	21.0
Lead	38.0	150.0
Zinc	100.0	130.0

[a] Maximum background concentrations of metals in Illinois stream and lake sediment (HNTB 1990). Values reported represent the mean plus four standard deviations.
[b] Maximum background concentrations of metals in Indiana stream and lake sediment (IDEM 1991).

Table 43. Sediment quality and benthic invertebrate distributions in the West Branch of the Grand Calumet River in 1982 and 1986 (near Hohman Avenue; Polls *et al.* 1993).

Measure	1982	1986	Percent Increase (Decrease)
Sediment quality characteristics			
Total solids (%)	26	22	(16)
Total volatile solids (%)	24	83	348
Chemical oxygen demand (mg/kg)	491×10^3	408×10^3	(17)
Fats, oils, grease (mg/kg)	61×10^3	82×10^3	34
Phenol (mg/kg)	5.4	4.6	(15)
Total Iron (mg/kg)	73×10^3	21×10^3	(71)
Benthic invertebrates (numbers/m^2)			
Oligochaetes (worms)	13.0×10^3	25.4×10^3	92
Hirudinea (leaches)	0	25	NA
Chironomidae (midges)	279	25	(91)
Total number of organisms	13.3×10^3	25.4×10^3	90
Total number of groups	2	3	50

Note: Values reported represent a mean of three replicate grab samples of surficial sediments.

Table 44. Concentrations of metals (µg/L) measured in pore water samples evaluated in Hoke *et al.* (1993) compared to 10-d LC_{50} concentrations for the amphipod *Hyalella azteca* for water-only exposures reported in USEPA (1994). Toxic units fractions for individual samples and compounds are listed in parentheses.

Metal	Concentrations of metals measured in pore water (µg/L)			LC_{50}
	UG-8	UG-9	UG-10	
Cadmium	<16	<10	<10	2.8
Chromium	<10	<10	<10	NR[1]
Copper	8 (0.23)	25 (0.71)	<5	35
Lead	37 (2.3)	<20	<20	<16
Nickel	<100	<100	<100	780
Zinc	74 (1.0)	114 (1.6)	28 (0.38)	73
Sum toxic unit[2]	3.5	2.3	0.38	---

[1] Not reported.

[2] Sum toxic unit fraction based on the LC_{50} for copper, lead, and zinc for UG-8, based on the LC_{50} for copper and zinc for UG-9, and based on the LC_{50} for zinc for UG-10.

Table 45. Concentrations of phenolic compounds (µg/L) measured in pore water samples evaluated in Hoke *et al.* (1993) compared acute toxicity concentrations (LC_{50} or EC_{50}) reported in the USEPA AQUIRE database (USEPA 1992a). Toxic units fractions for individual samples and compounds are listed in parenthesis.

Substance	Concentrations of phenolic compounds measured in pore water (µg/L)			LC_{50} or EC_{50}
	UG-8	UG-9	UG-10	
Phenol	225.3 (5.01)	326.2 (7.25)	255.5 (5.68)	45
o-chlorophenol	40.5 (0.008)	100.4 (0.021)	88.6 (0.019)	5600[1]
p-chlorophenol	3.7	15.2	17.5	---
2,4-dichlorophenol	23.7 (0.017)	23.5 (0.017)	24.0 (0.017)	1400
2,4-dinitrophenol	54.1 (0.104)	34.5 (0.066)	30.6 (0.059)	520
4,6-dinitrolphenol	0	1.6	1.5	NR[2]
o-cresol	10.2 (0.193)	23.6 (0.339)	20.9 (0.451)	100[1]
p-cresol	9.1	10.3	24.2	---
Sum toxic unit [3]	5.33	7.65	6.22	---

[1] Pore-water concentrations were summed to calculate toxic unit fractions for ortho- and para-chlorophenol and were also summed to calculate toxic unit fractions for ortho- and para-cresol.

[2] Not reported.

[3] Sum toxic unit fraction based on the LC_{50} or EC_{50} for phenol, chlorophenol, 2,4-dichlorophenol, 2,4-dinitrophenol, and cresol.

Table 46. Levels of select bioaccumulative substances in West Branch Grand Calumet River sediments (Hoke *et al.* 1993).

Substance	Station	Concentration (mg/kg DW)	Organic Carbon (%)	Concentration (µg/kg OC)	Wildlife-Based SQGs	Human Health-Based SQGs	Exceedance of SQGs[1]
PAHs							
Benzo(a)pyrene	UG-8	83.62	22.3	374978	NG	1300	HH
	UG-9	100.21	18.8	533032			HH
	UG-10	32.51	13.4	242612			HH
PCBs							
tPCBs	UG-8	2.8	22.3	12556	1400	0.8	HH, W
	UG-9	4.61	18.8	24521			HH, W
	UG-10	7.93	13.4	59179			HH, W
Pesticides							
Chlordane	UG-8	2.41	22.3	10807	6	1	HH, W
	UG-9	2.18	18.8	11596			HH, W
	UG-10	2.14	13.4	15970			HH, W
Dieldrin	UG-8	0.04	22.3	179	NG	100	HH
	UG-9	3.21	18.8	17074			HH
	UG-10	1.14	13.4	8507			HH
tDDT	UG-8	0.04	22.3	179	1000	10	HH
	UG-9	3.21	18.8	17074			HH, W
	UG-10	1.14	13.4	8507			HH, W
Heptachlor	UG-8	2.56	22.3	11480	30	0.8	HH, W
	UG-9	6.41	18.8	34096			HH, W
	UG-10	2.81	13.4	20970			HH, W
Lindane	UG-8	0.79	22.3	3543	1500	60	HH, W
	UG-9	3.16	18.8	16809			HH, W
	UG-10	0.26	13.4	1940			HH, W
Toxaphene	UG-8	7.38	22.3	33094	NG	20	HH
	UG-9	3.32	18.8	17660			HH
	UG-10	2.05	13.4	15299			HH
Dioxins and Furans							
2,3,7,8-TCDD	UG-8	3.5E-09	22.3	0.000016	0.2	10	
	UG-9	7.3E-09	18.8	0.000039			
	UG-10	7.3E-09	13.4	0.000054			

[1] Indicates whether the measured contaminant concentration exceeds the bioaccumulation-based SQG for wildlife (W) or human health (HH).

Table 47. Priority toxic or bioaccumulative substances identified in sediments of the West Branch of the Grand Calumet River.

	Aquatic Organisms		Wildlife	Human Health
Contaminants of Concern	**Bulk Sediments**	**Pore Water**	**Bulk Sediments**	**Bulk Sediments**
Metals				
Arsenic	U			
Cadmium	U			
Chromium	U			
Copper	U	U		
Lead	U	U		
Mercury				
Nickel	U			
Zinc	U	U		
Polycyclic Aromatic Hydrocarbons				
Acenaphthene				
Anthracene				
Fluorene				
Naphthalene	U			
Phenanthrene	U			
Benz[a]anthracene	U			
Benzo(a)pyrene	U			U
Chrysene	U			
Fluoranthene				
Pyrene	U			
Total PAHs	U			
PCBs				
Total PCBs	U		U	U
Pesticides				
Chlordane			U	U
Dieldrin				U
Sum DDD				
Sum DDE	U			
Sum DDT				
Total DDT			U	U
Endrin				
Heptachlor			U	U
Heptachlor epoxide				
Lindane (gamma-BHC)			U	U
Toxaphene				U

Table 47. Priority toxic or bioaccumulative substances identified in sediments of the West Branch of the Grand Calumet River.

Contaminants of Concern	Aquatic Organisms		Wildlife	Human Health
	Bulk Sediments	Pore Water	Bulk Sediments	Bulk Sediments
Phenols				
Phenol		U		
Chlorophenol				
Dichlorophenol				
Dinitrophenol				
Cresol				
Conventional Indicators				
Dissolved oxygen		U		
Sediment oxygen demand	U			
Total organic carbon	U			
Unionized ammonia		U		

Note: The absence of a chemical substance on the priority substances list does not necessarily mean that the substance does not pose a hazard to sediment dwelling organisms, wildlife, or human health.

Table 48. Summary of mean PEC-quotients for sediments from various locations on the WBGCR.

Location	River Kilometer	Horizon (ft)	HydroQual, Inc. (1984)	Hoke *et al.* (1993)	Unger (1992)	HNTB (1989)	HNTB (1991)	Dorkin (1994)							Overall
								P1-C1	P1-C2	P2-C1	P2-C2	P2-C4	P2-N	P2-S	
Indianapolis Blvd.	1.1	0-3	13.5	14.3	17.8										15.2
Indianapolis Blvd.	1.1	4-6			21.6										21.6
Indianapolis Blvd.	1.1	7-9			39.9										39.9
Roxanna Marsh	1.5	0-3								0.5	0.4		0.5	15.5	0.5
Roxanna Marsh	1.5	4-6								0.3	0.4				0.4
Roxanna Marsh	1.5	7-9								0.3	0.3				0.3
Roxanna Marsh @ White Oak St.	2.0	0-3		20.6	76.0	42.9		7.7	11.5	32.6	13.9		12.4	3.8	29.3
Roxanna Marsh @ White Oak St.	2.0	0-9					3.8								3.8
Roxanna Marsh @ White Oak St.	2.0	4-6			96.6	50.9				33.0	22.1				50.6
Roxanna Marsh @ White Oak St.	2.0	7-9			60.8	28.2				3.4	0.7				23.3
Molsberger Place	2.6	0-3				22.4		17.2		34.2	69.8		91.1	224	46.9
Molsberger Place	2.6	4-6								29.8	4.7				17.2
Molsberger Place	2.6	7-9								4.0	1.4				2.7
Molsberger Place	2.6	10-12								0.6	0.3				0.5
Molsberger Place	2.6	13-15								0.1					0.1
East of Columbia Ave.	2.85	0-9					6.2								6.2
Columbia Ave.	2.9	0-3				34.2		1.8		3.3	9.9		13.4	3.2	12.5
Columbia Ave.	2.9	0-9					3.3								3.3
Columbia Ave.	2.9	4-6								13.9	28.7				21.3
Columbia Ave.	2.9	7-9								60.3	36.9				48.6
Sohl Ave.	4.1	0-3				39.9		8.3		541	217	5.8			162.5
Sohl Ave.	4.1	4-6								263	76.4	45.8			128.5
Sohl Ave.	4.1	7-9								17.1	6.5	13.8			12.5

Table 48. Summary of mean PEC-quotients for sediments from various locations on the WBGCR.

Location	River Kilometer	Horizon (ft)	HydroQual, Inc. (1984)	Hoke *et al.* (1993)	Unger (1992)	HNTB (1989)	HNTB (1991)	Dorkin (1994)							Overall
								P1-C1	P1-C2	P2-C1	P2-C2	P2-C4	P2-N	P2-S	
West of Sohl Ave.	4.2	0-3				38.5									38.5
West of Sohl Ave.	4.2	0-9					2.4								2.4
Hohman Ave.	4.6	0-3	2.0												2.0
State Line Ave.	5.2	0-3		11.5	55.7	29.6		53.9		741	246		47.3	61.4	169
State Line Ave.	5.2	0-9					1.4								1.4
State Line Ave.	5.2	4-6			109	59.7				312	14.0				124
State Line Ave.	5.2	7-9			51.6	37.3									44.4
East of Torrence Ave.	9.3	0-3						15.8	21.5	17.8					18.4
East of Torrence Ave.	9.3	4-6								12.9					12.9
East of Torrence Ave.	9.3	7-9								2.2					2.2

For Dorkin (1994):
P1-C1 = Phase 1; Center 1
P1-C2 = Phase 1; Center 2
P2-C1 = Phase 2; Center 1
P2-C2 = Phase 2; Center 2
P2-C4 = Phase 2; Center 4
P2-N = Phase 2; North
P2-S = Phase 2; South

Figures

Figure 1. Spatial distribution of arsenic in surficial sediments within the WBGCR.

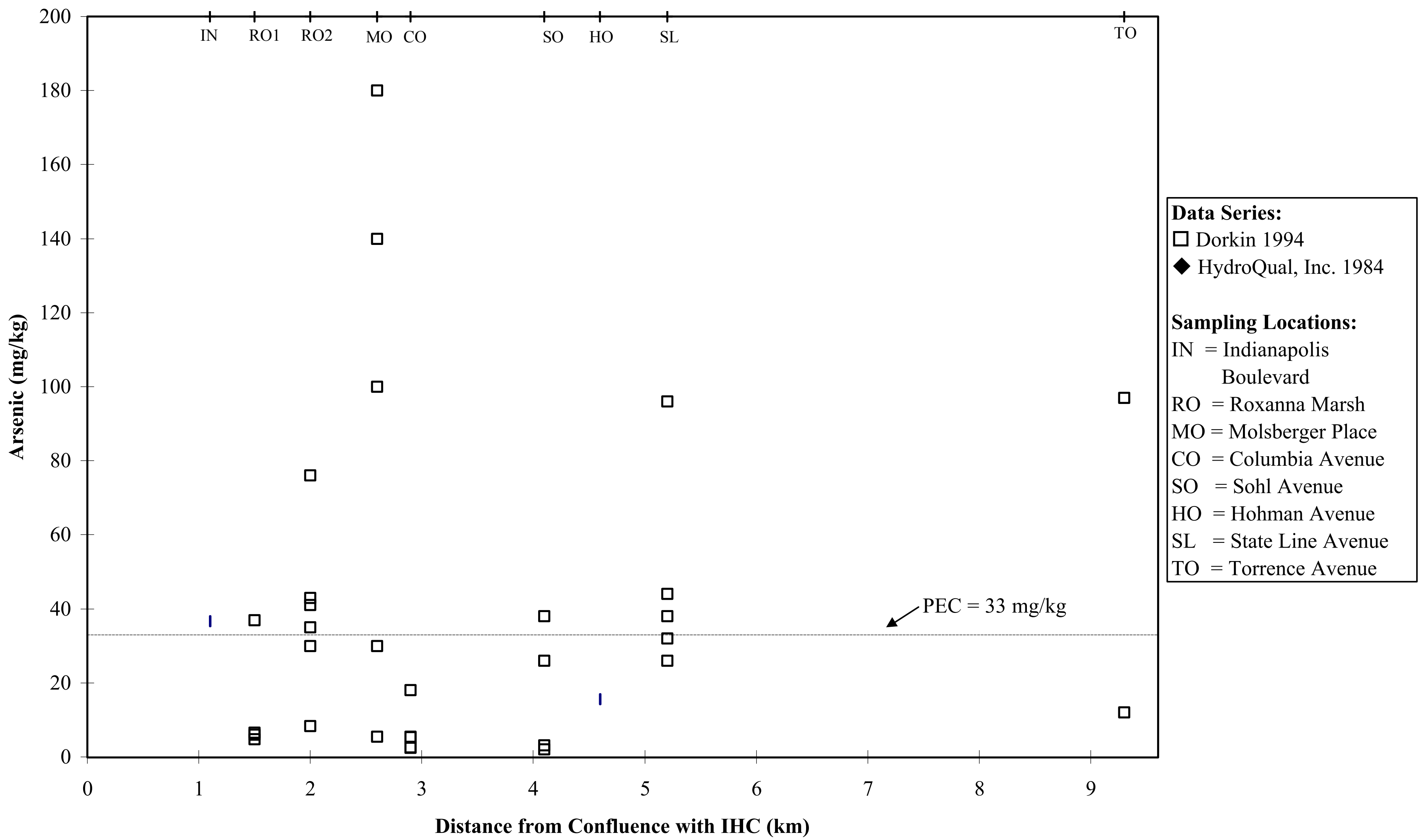

Figure 2. Spatial distribution of cadmium in surficial sediments within the WBGCR.

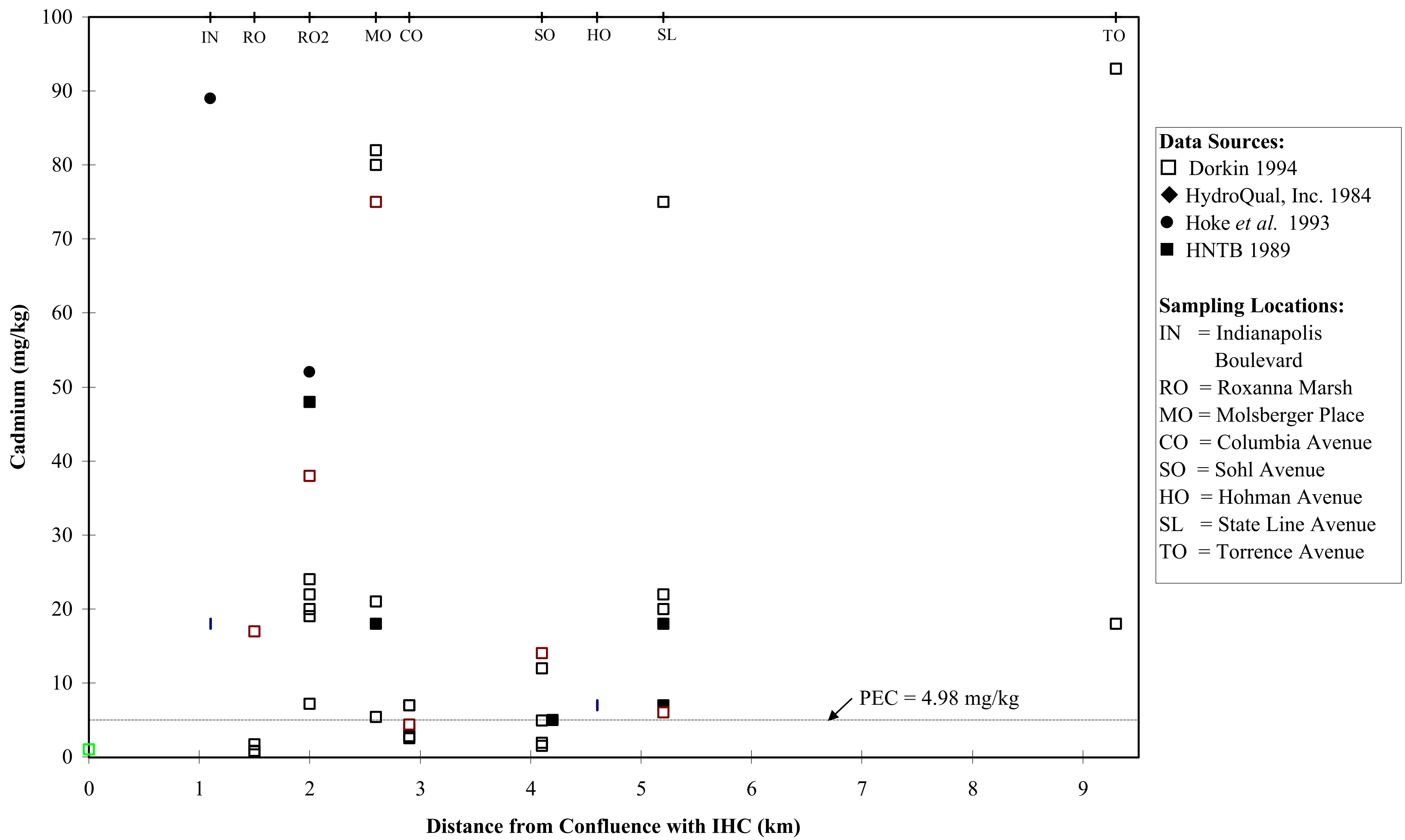

Figure 3. Spatial distribution of chromium in surficial sediments within the WBGCR.

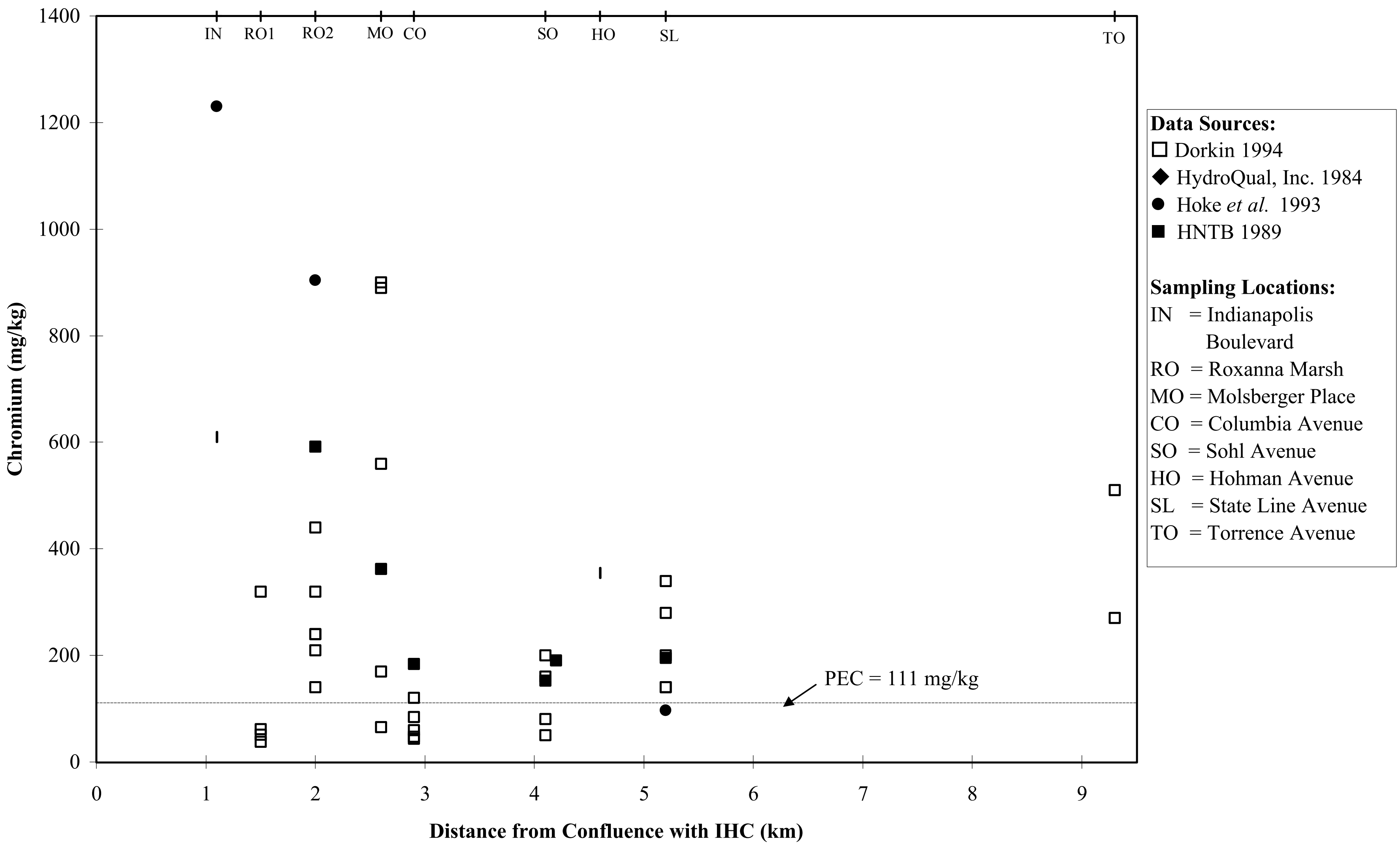

Figure 4. Spatial distribution of copper in surficial sediments within the WBGCR.

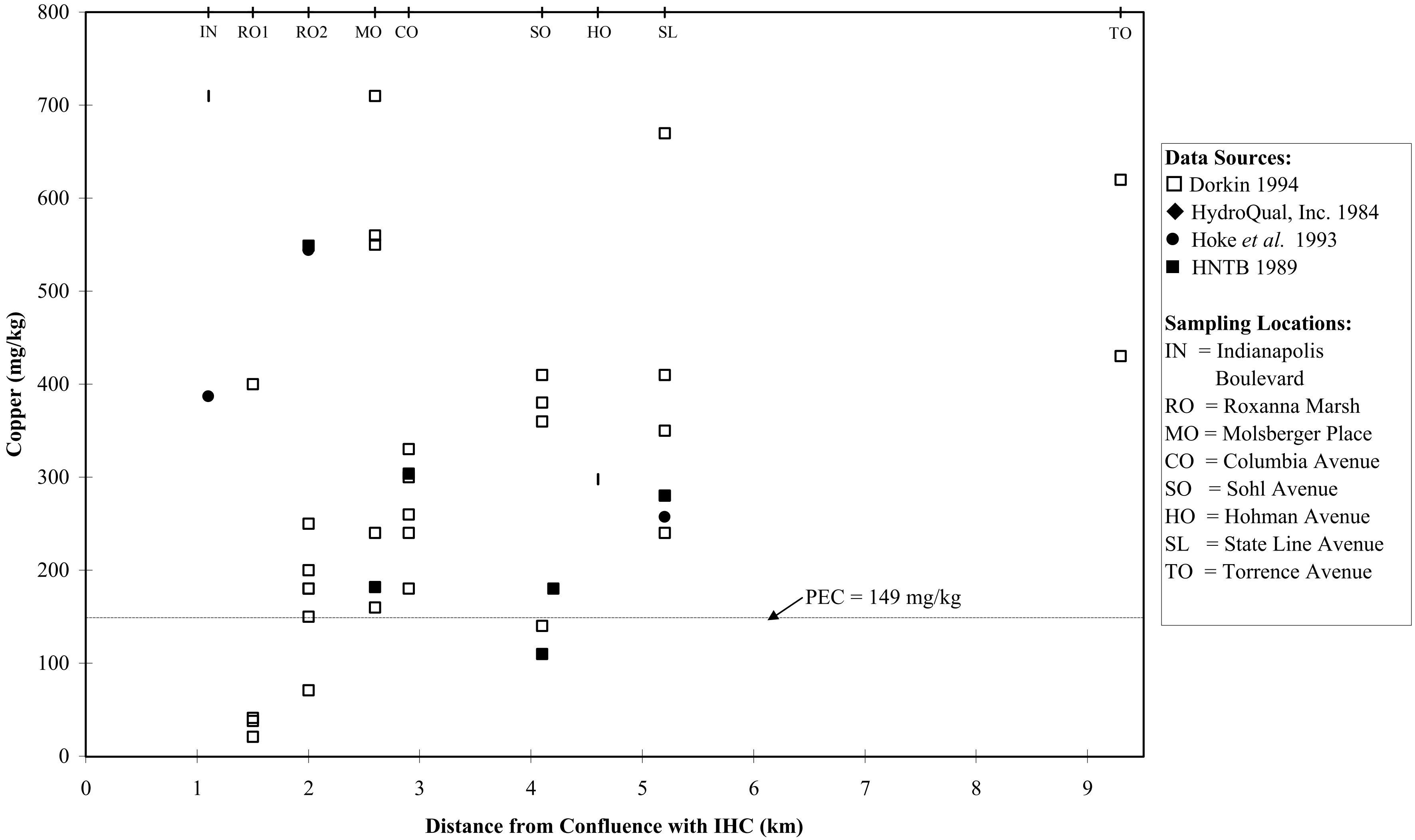

Figure 5. Spatial distribution of lead in surficial sediments within the WBGCR.

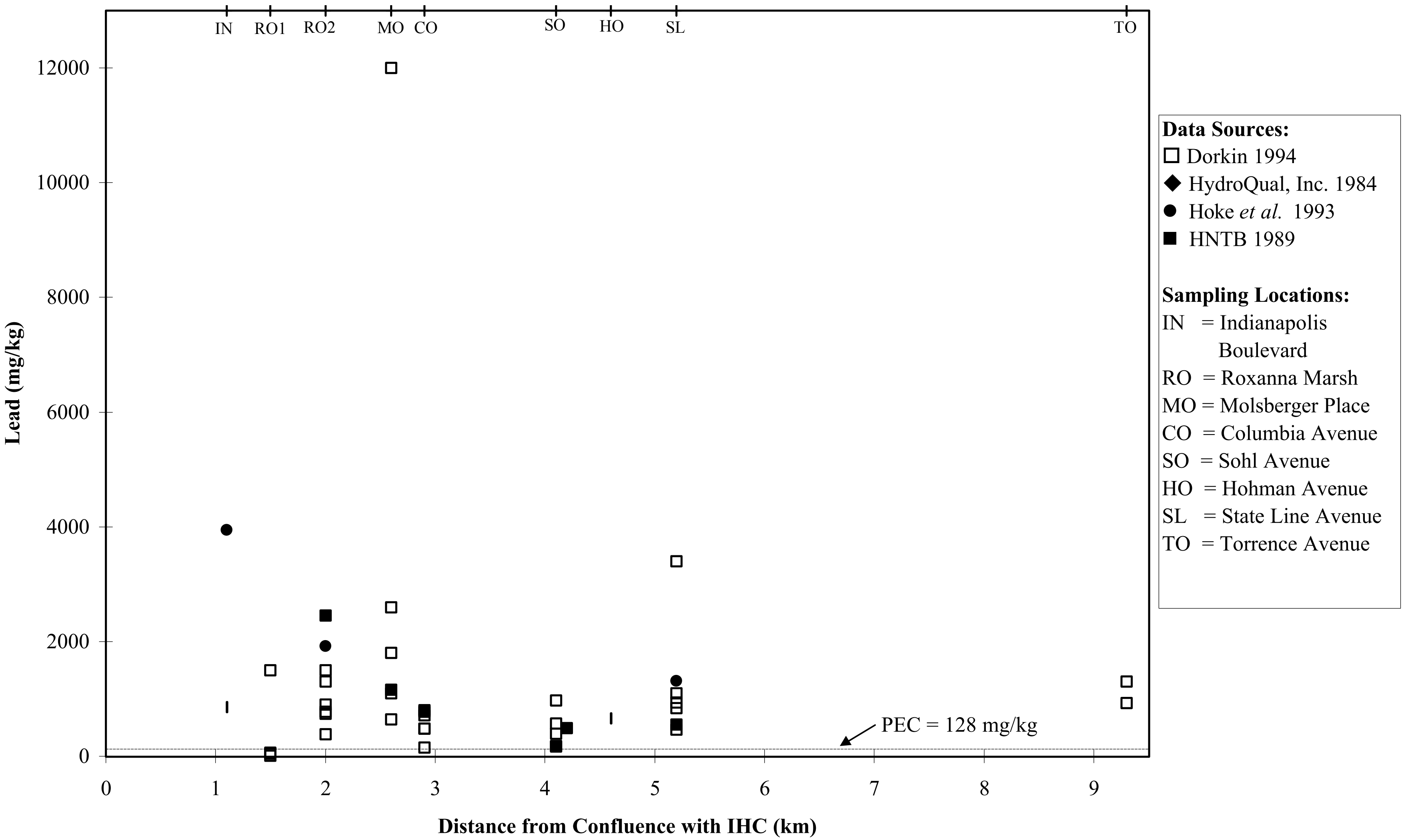

Figure 6. Spatial distribution of mercury in surficial sediments within the WBGCR.

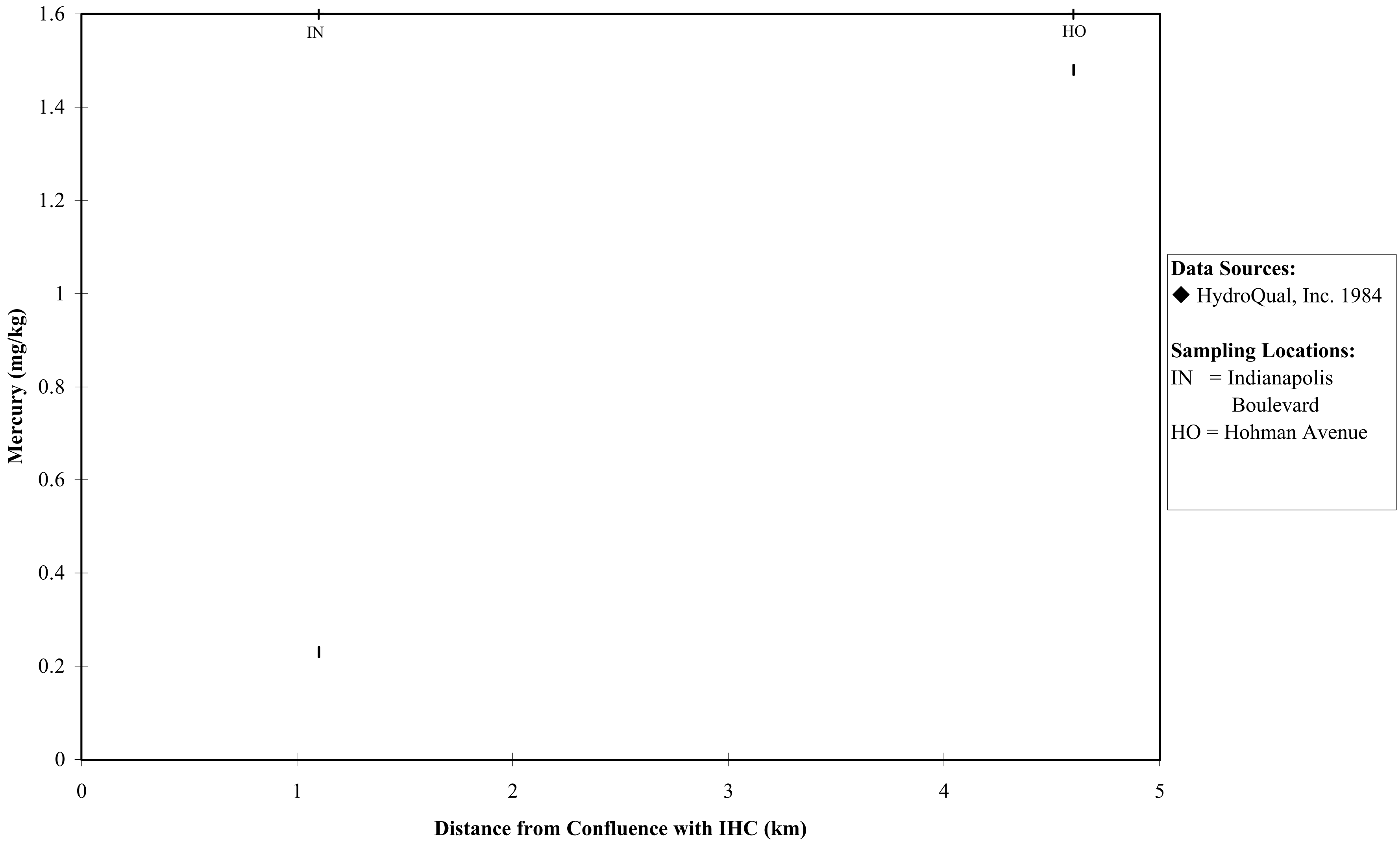

Figure 7. Spatial distribution of nickel in surficial sediments within the WBGCR.

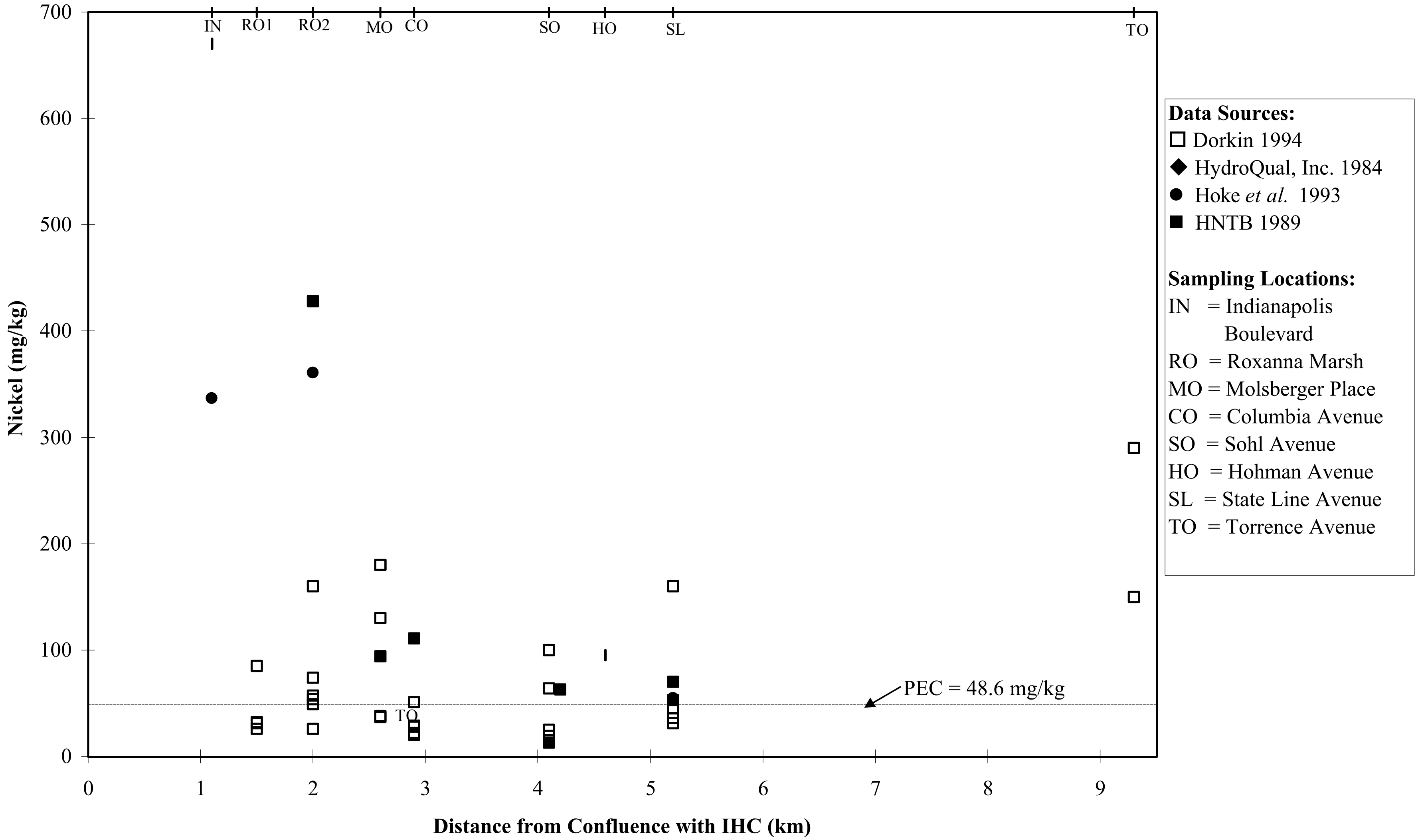

Figure 8. Spatial distribution of zinc in surficial sediments within the WBGCR.

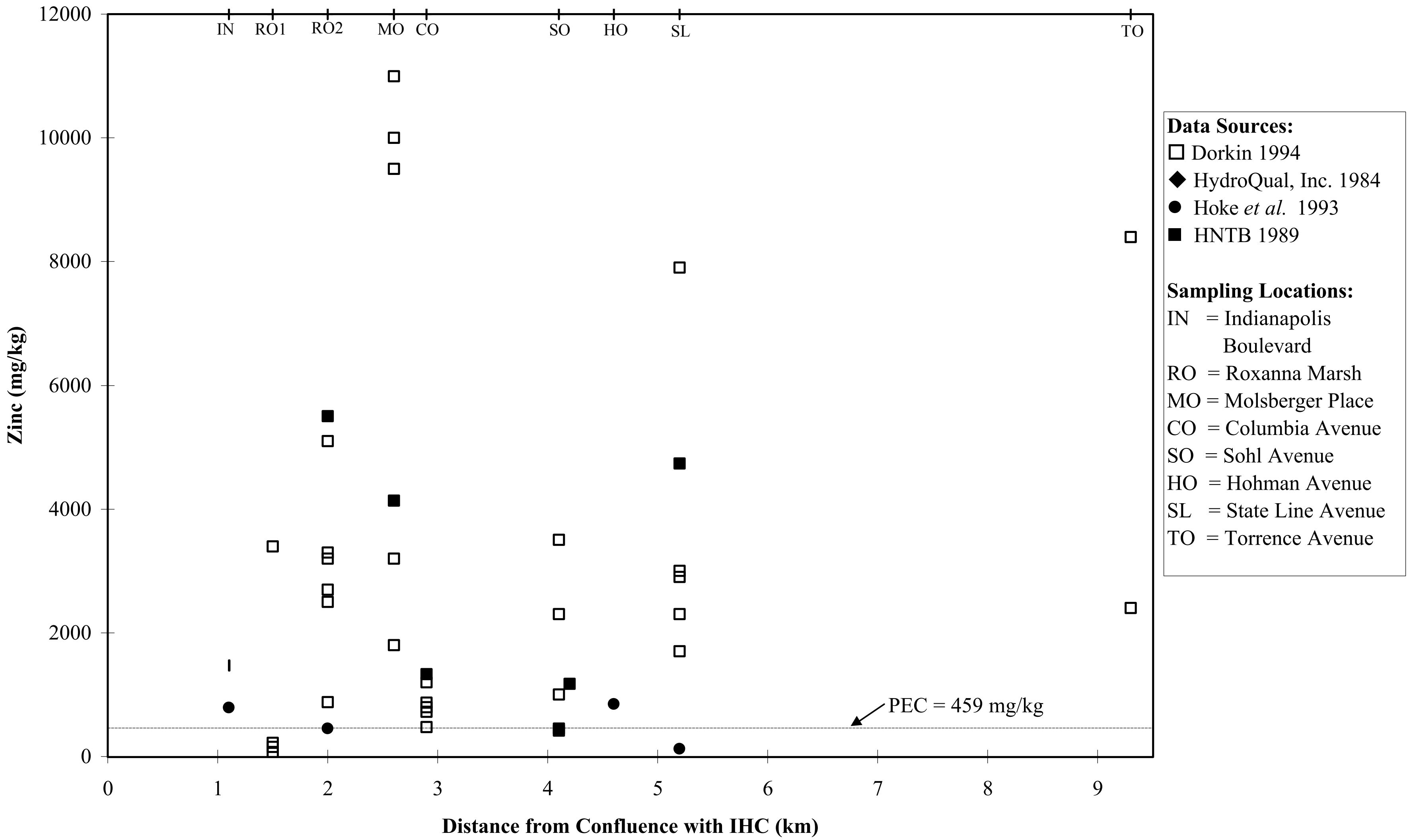

Figure 9. Spatial distribution of acenaphthene in surficial sediments within the WBGCR.

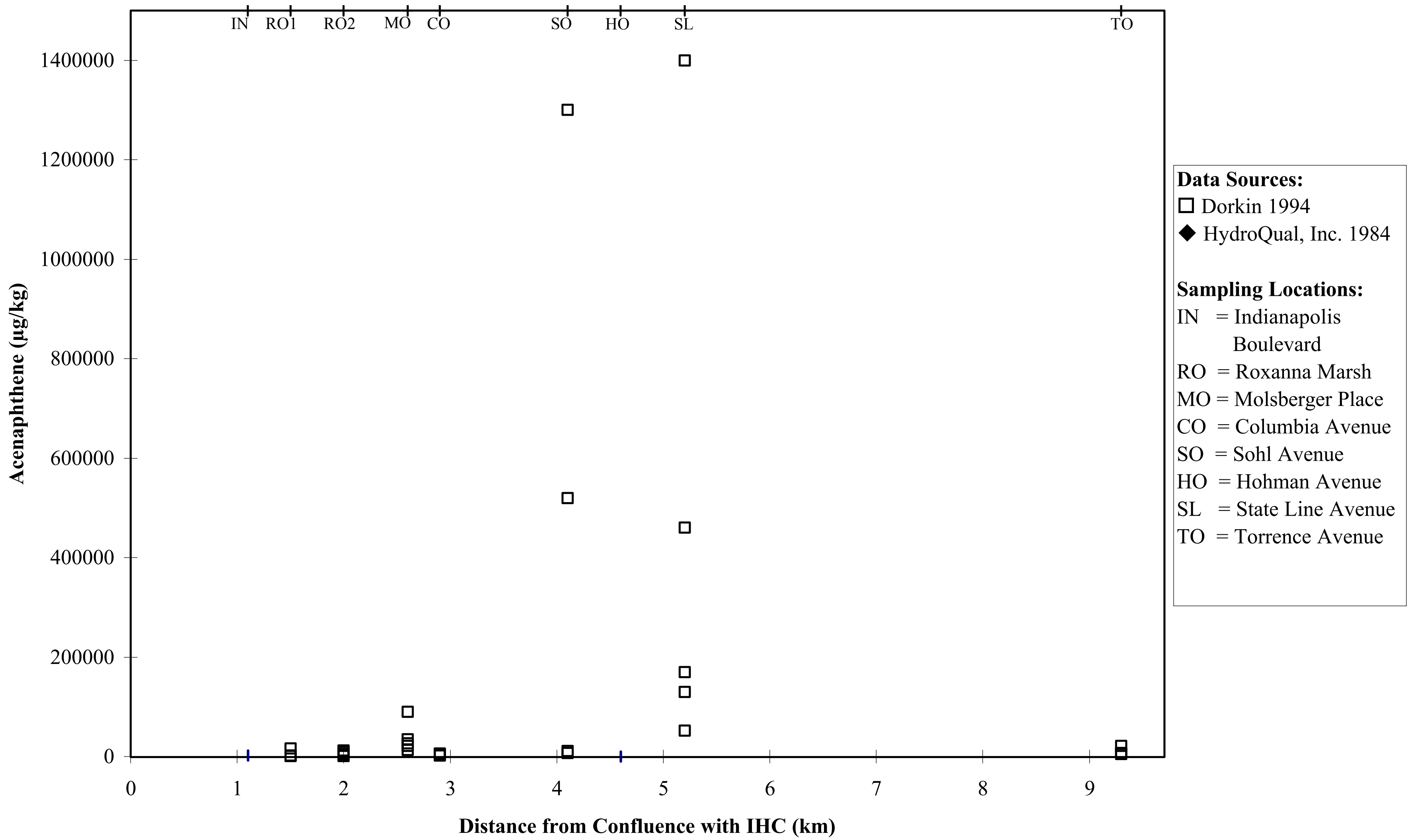

Figure 10. Spatial distribution of anthracene in surficial sediments within the WBGCR.

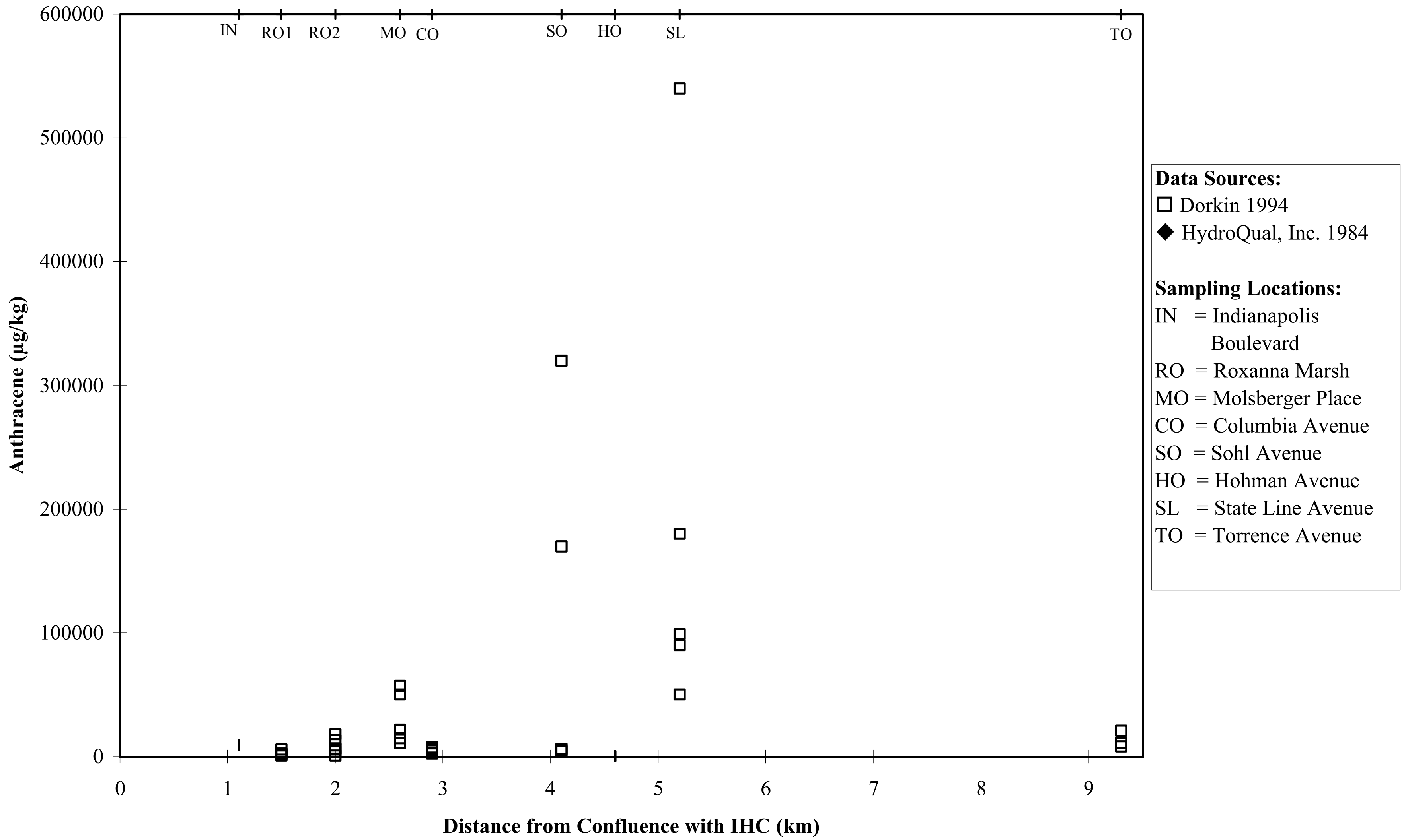

Figure 11. Spatial distribution of fluorene in surficial sediments within the WBGCR.

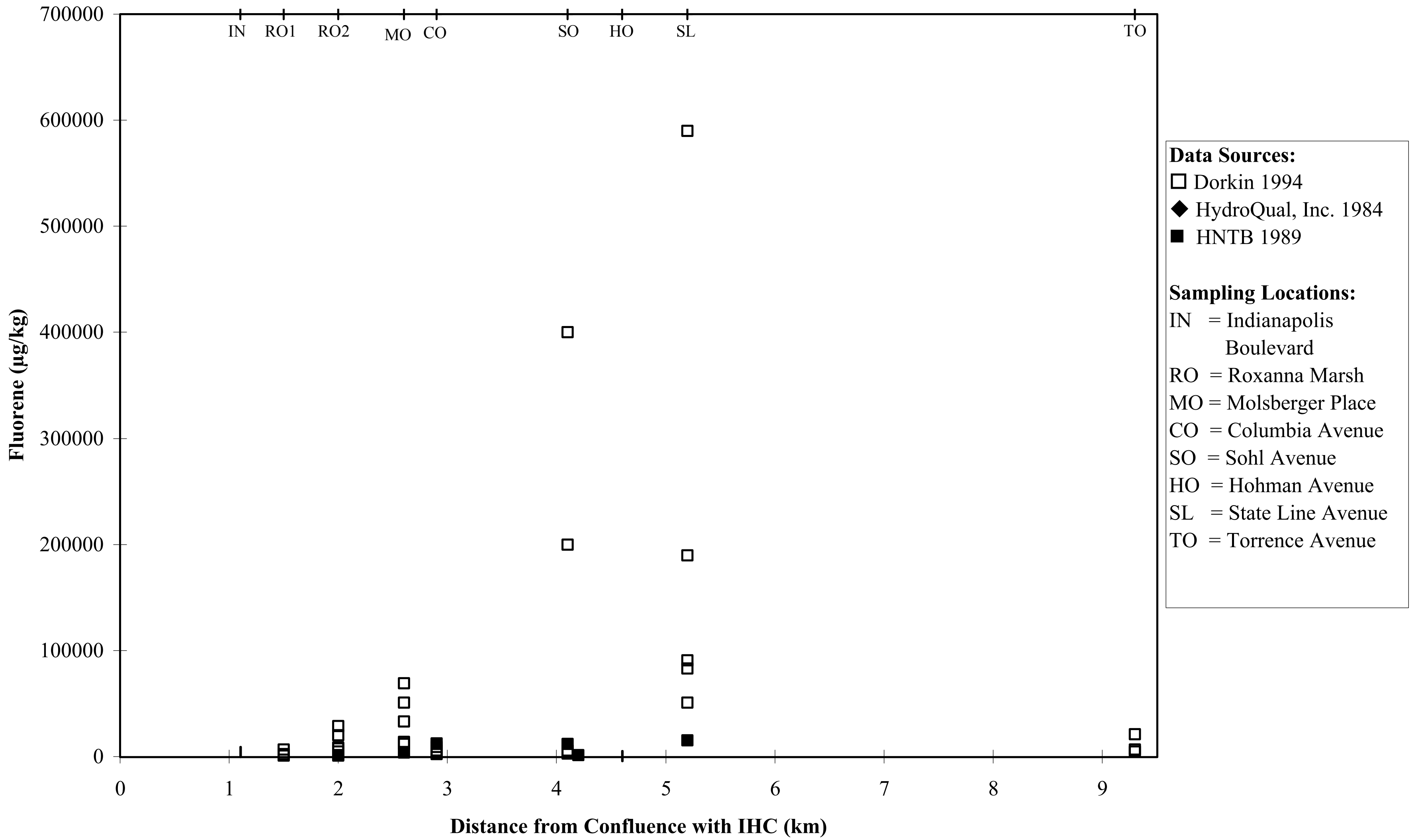

Figure 12. Spatial distribution of naphthalene in surficial sediments within the WBGCR.

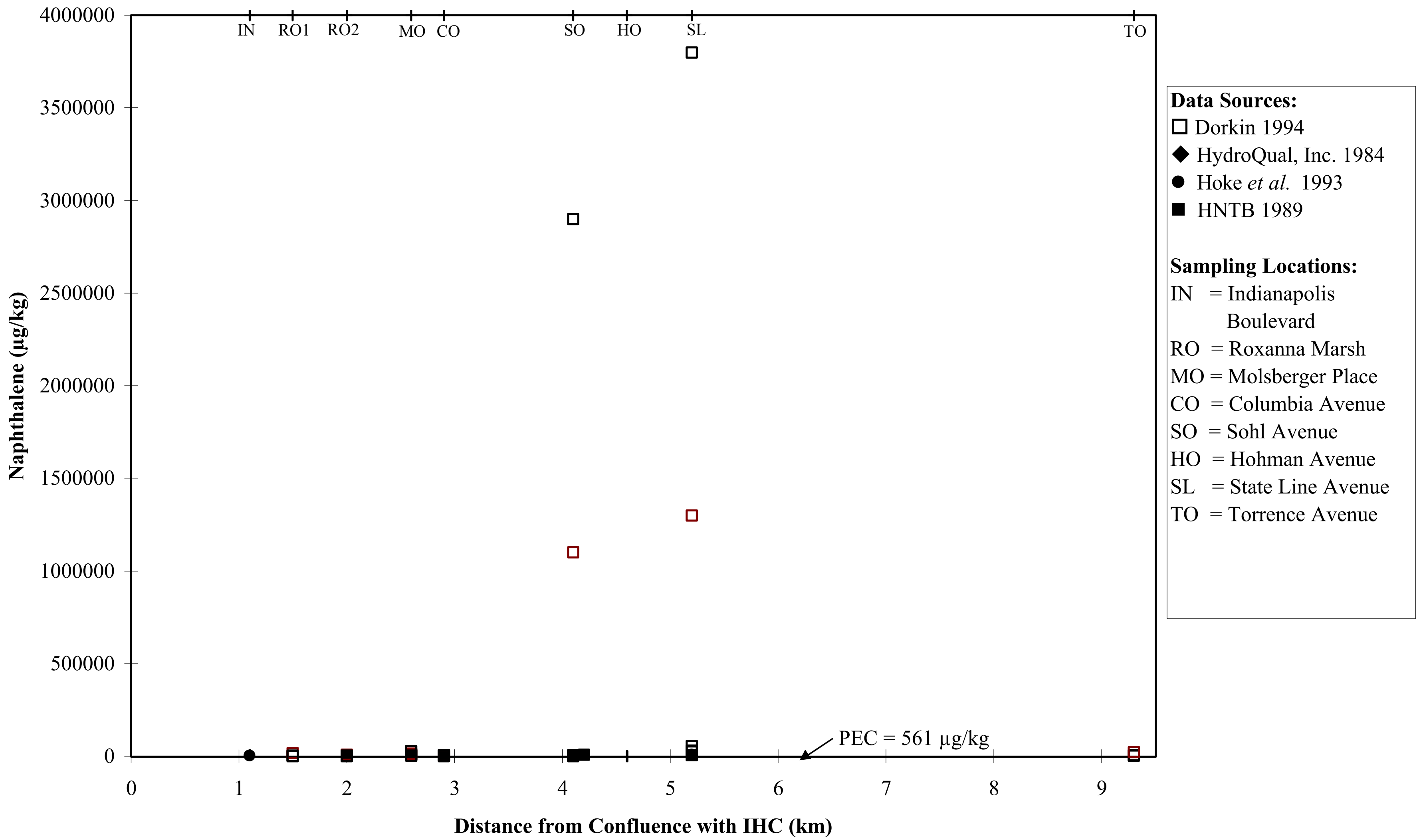

Figure 13. Spatial distribution of phenanthrene in surficial sediments within the WBGCR.

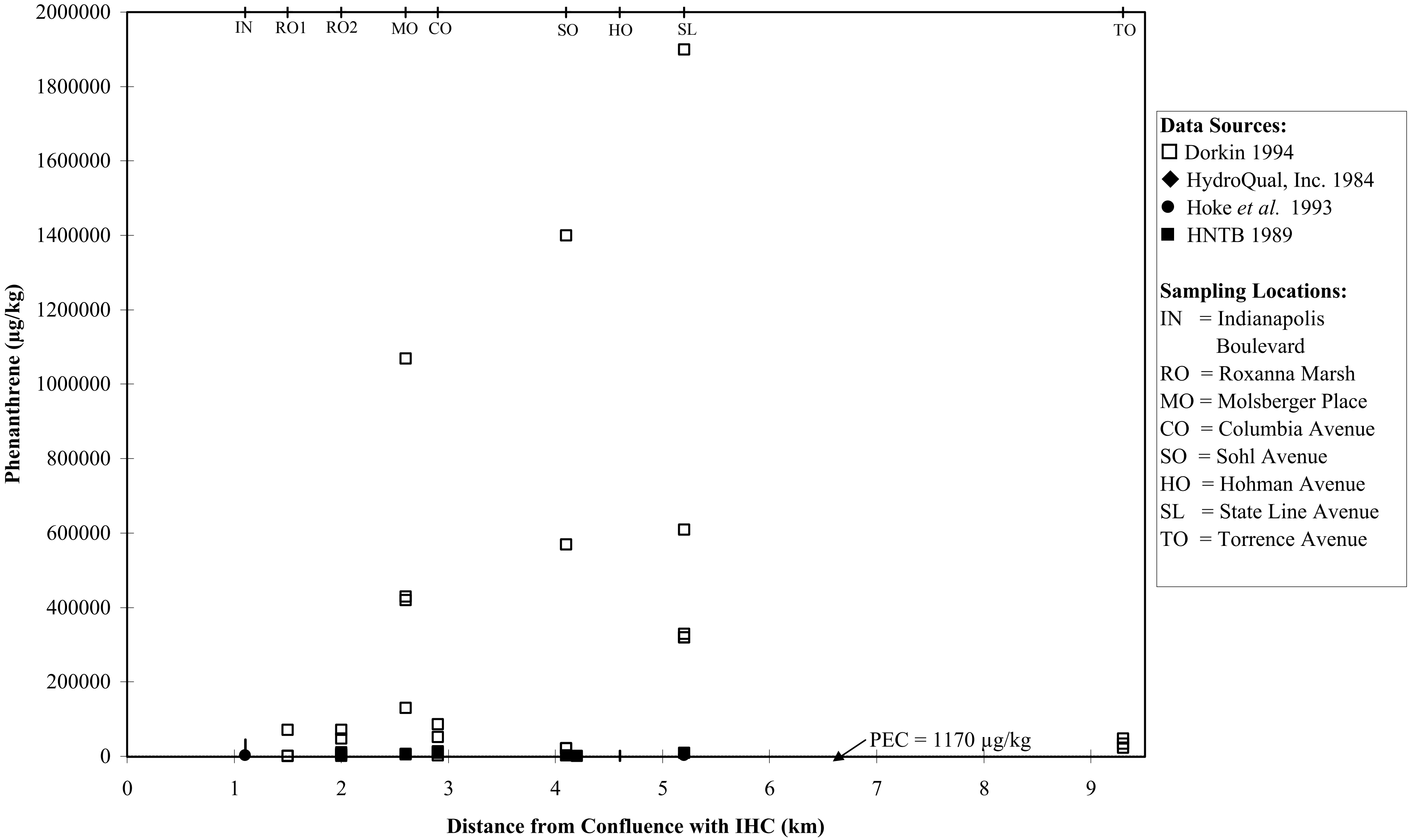

Figure 14. Spatial distribution of benz[a]anthracene in surficial sediments within the WBGCR.

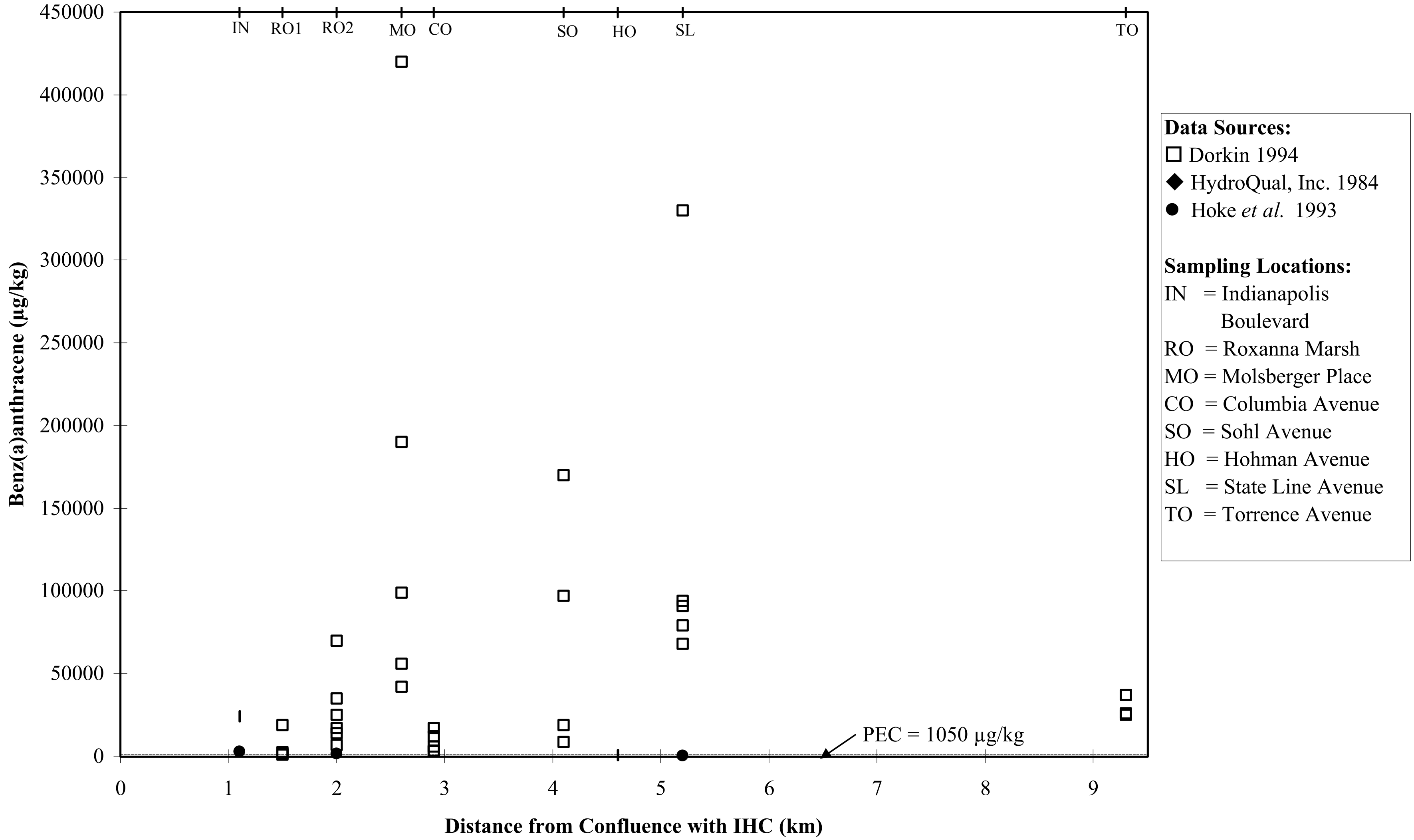

Figure 15. Spatial distribution of benzo(a)pyrene in surficial sediments within the WBGCR.

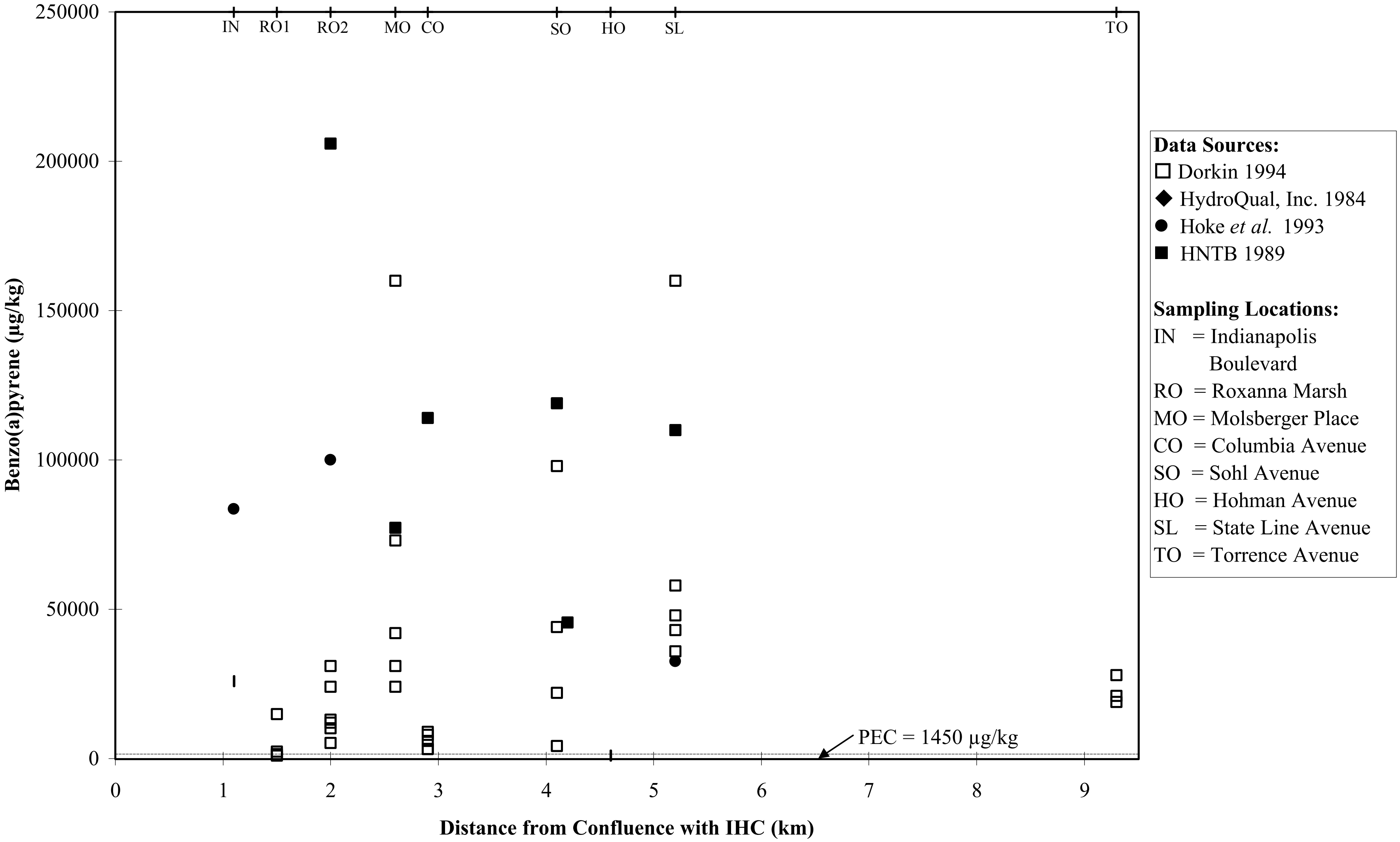

Figure 16. Spatial distribution of chrysene in surficial sediments within the WBGCR.

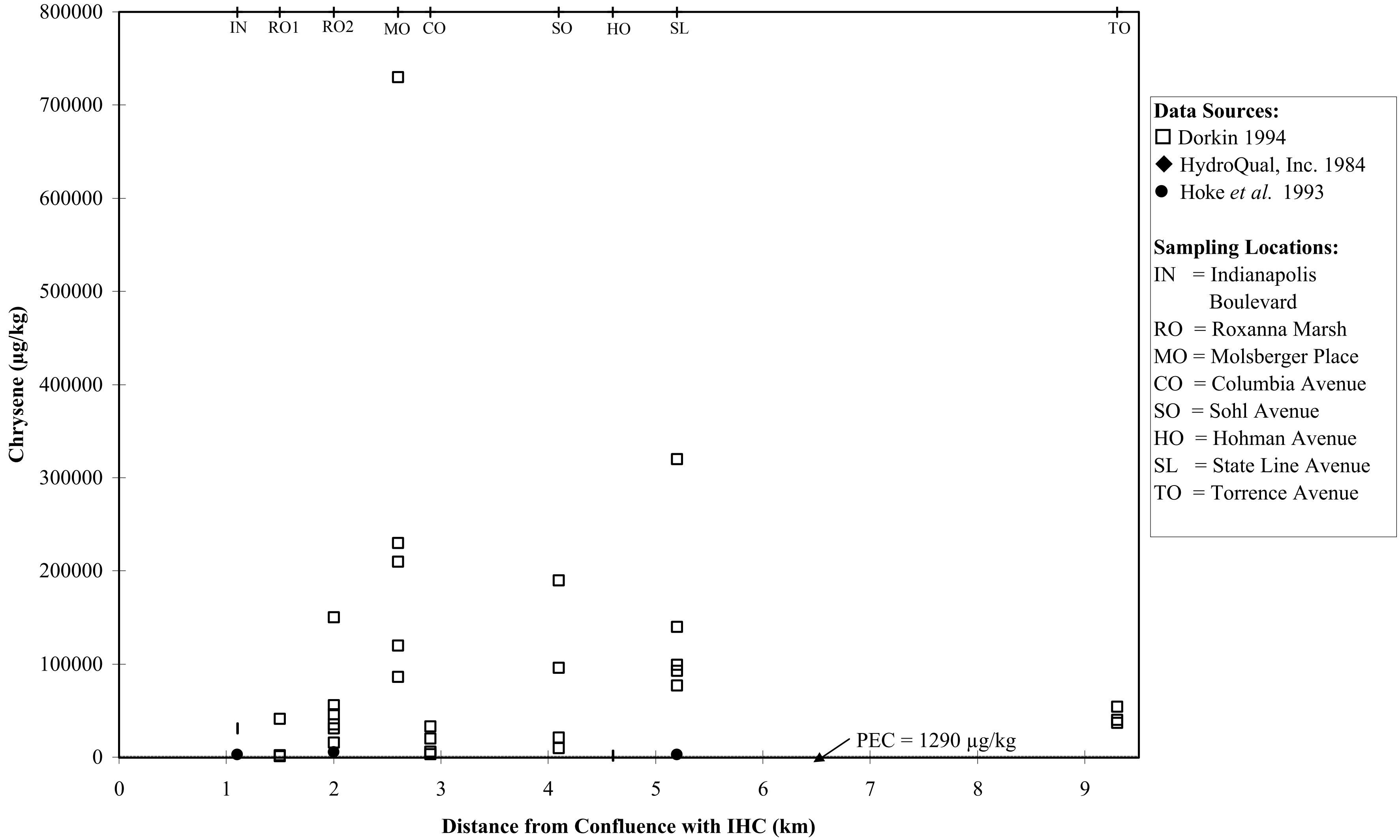

Figure 17. Spatial distribution of fluoranthene in surficial sediments within the WBGCR.

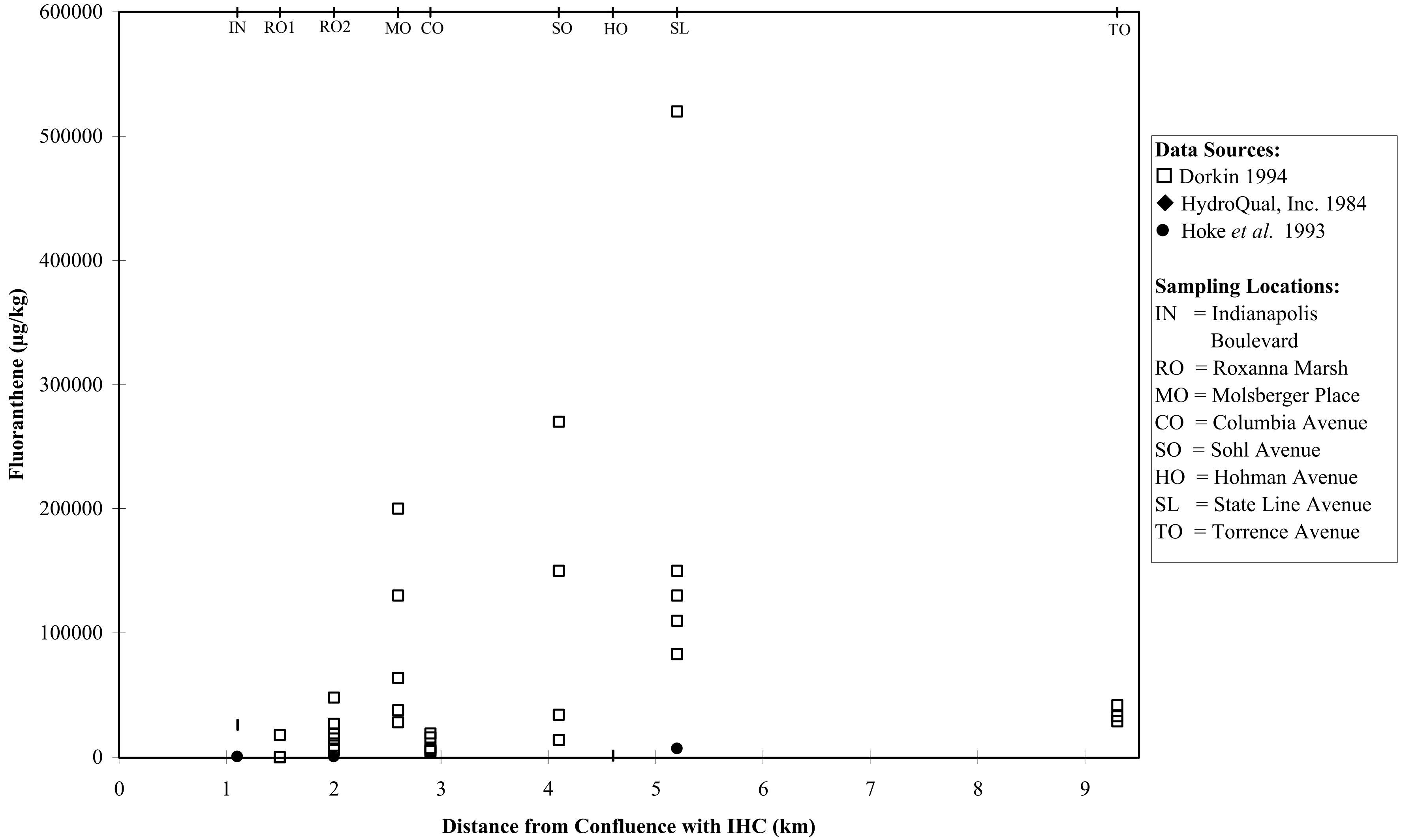

Figure 18. Spatial distribution of pyrene in surficial sediments within the WBGCR.

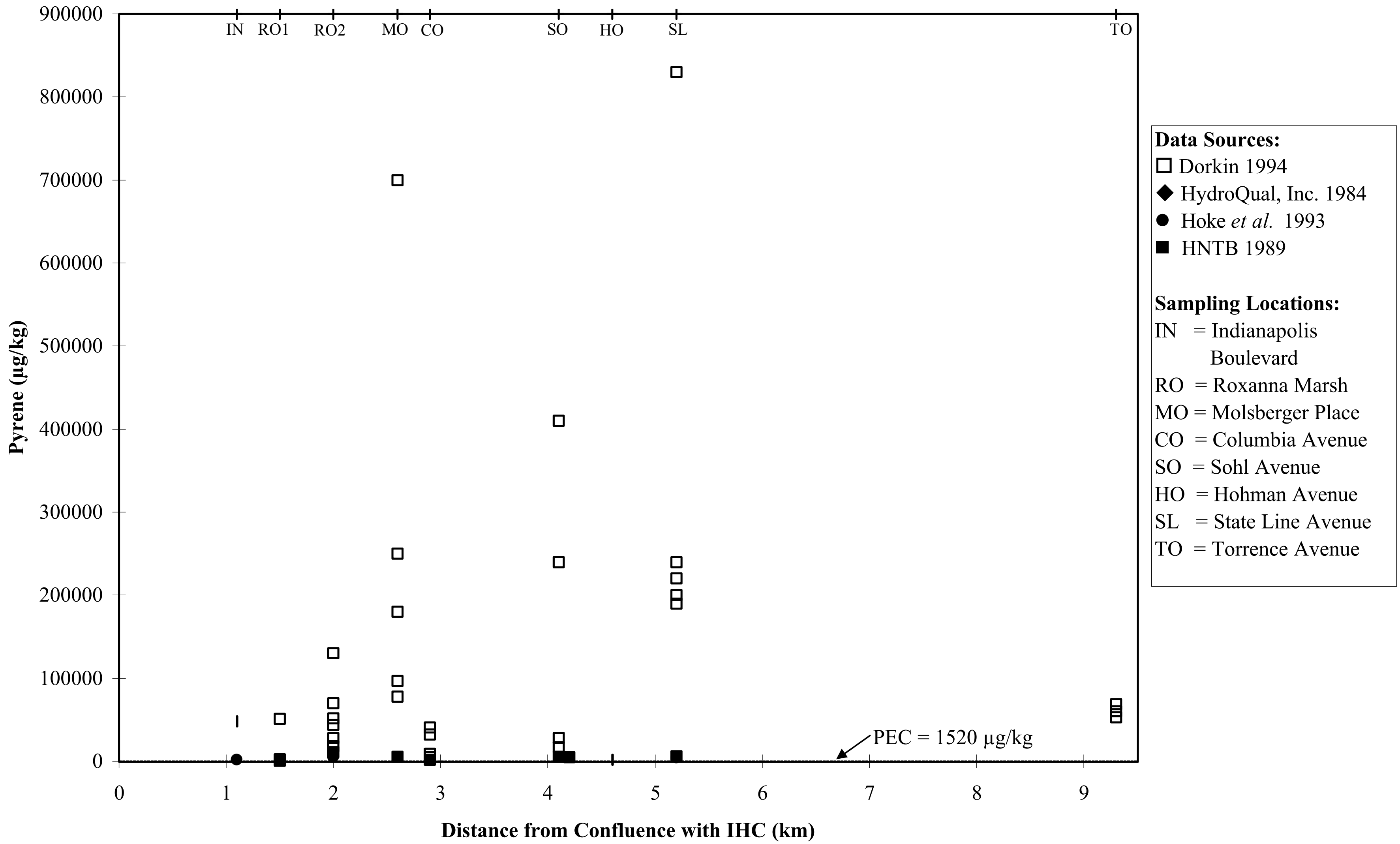

Figure 19. Spatial distribution of total PAHs in surficial sediments within the WBGCR.

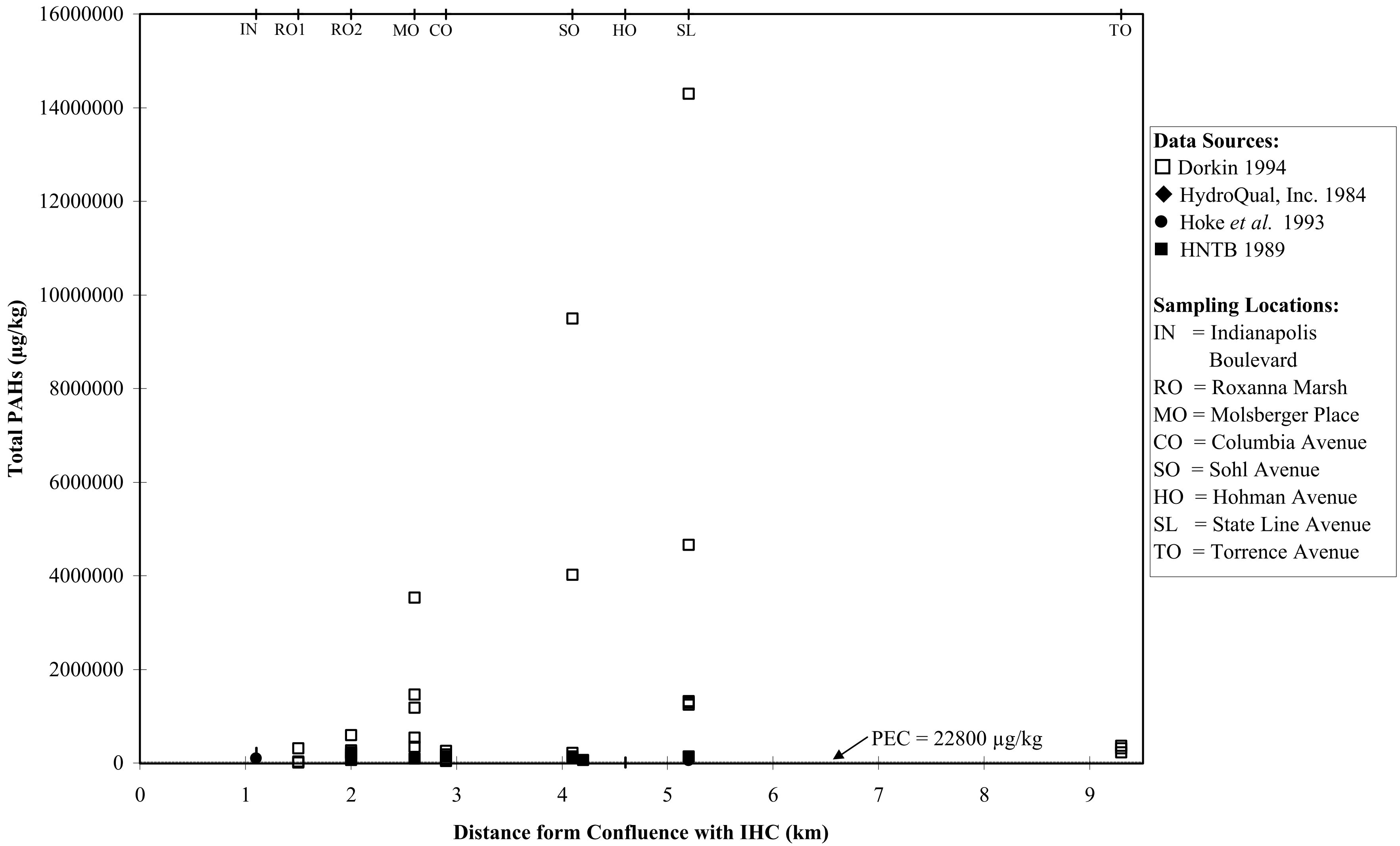

Figure 20. Spatial distribution of total PCBs in surficial sediments within the WBGCR.

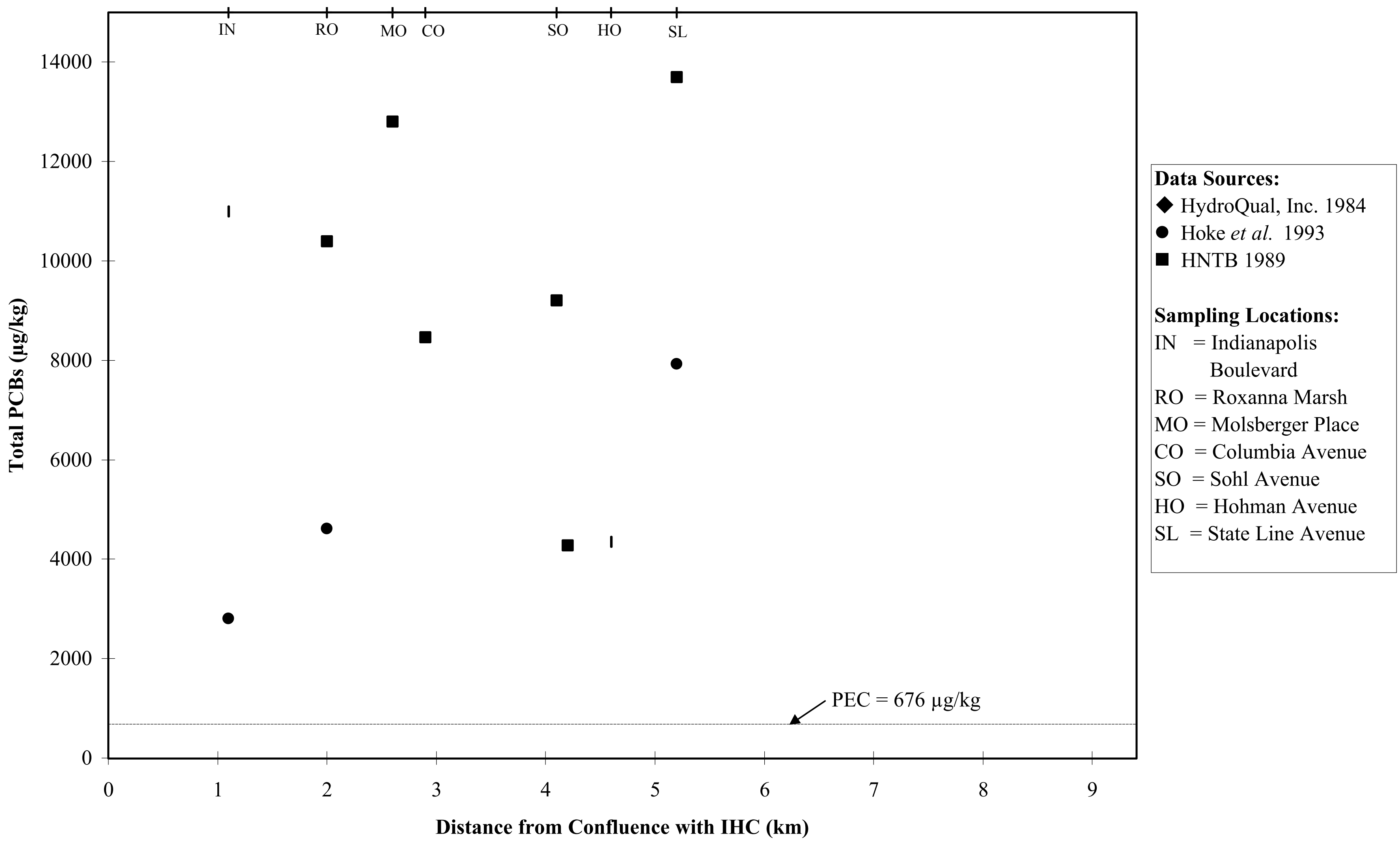

Figure 21. Spatial distribution of chlordane in surficial sediments within the WBGCR.

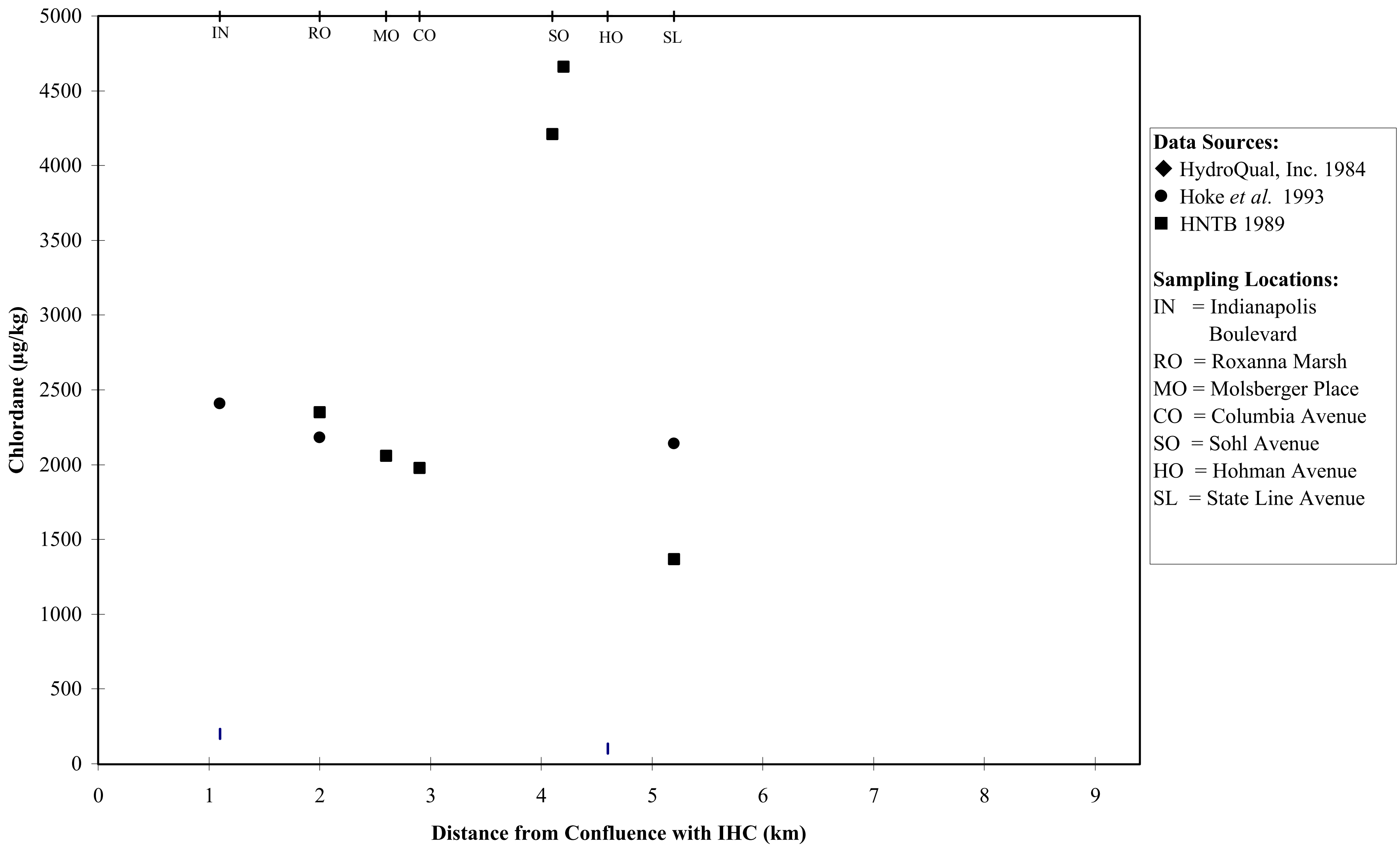

Figure 22. Spatial distribution of dieldrin in surficial sediments within the WBGCR.

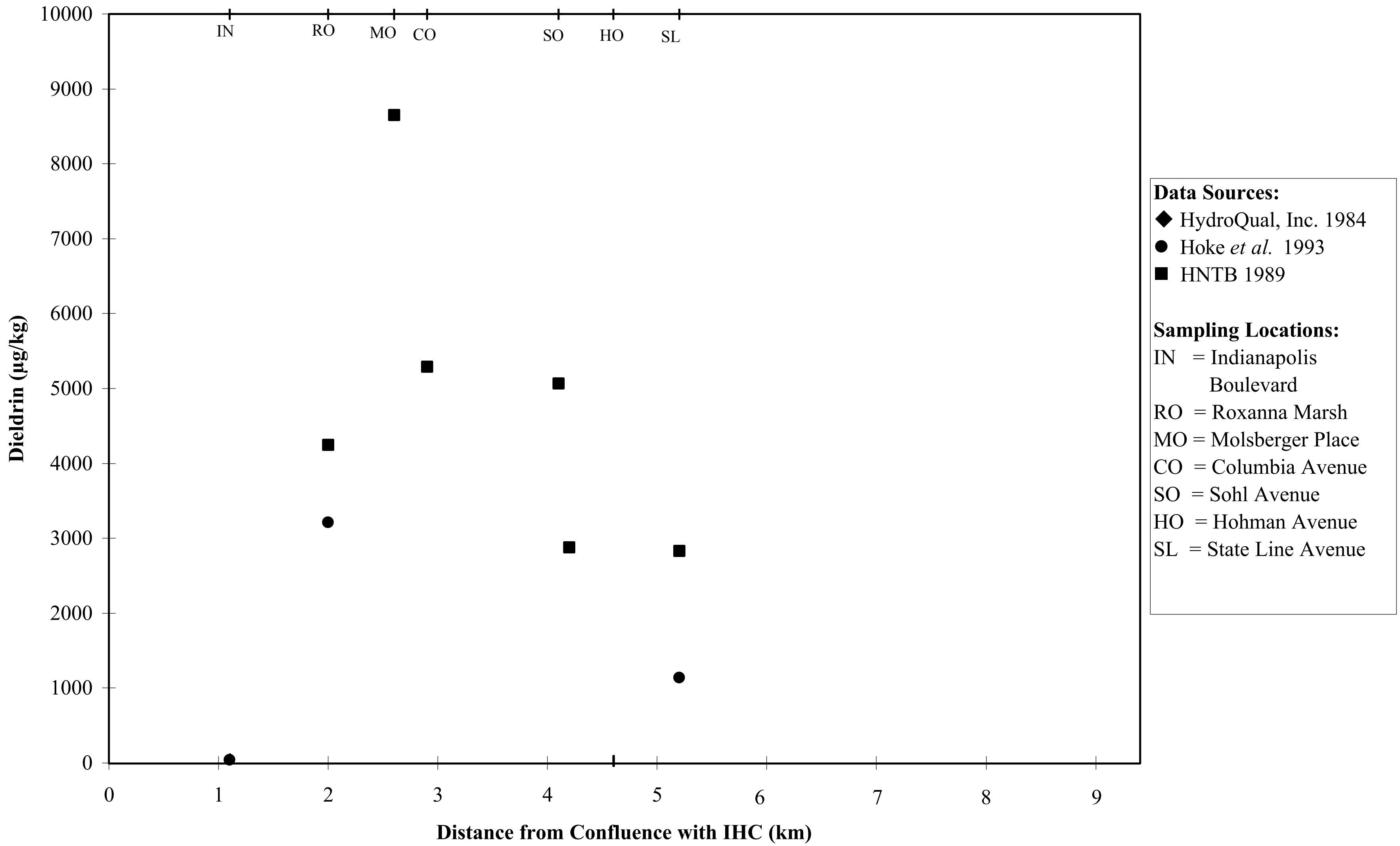

Figure 23. Spatial distribution of Sum DDD in surficial sediments within the WBGCR.

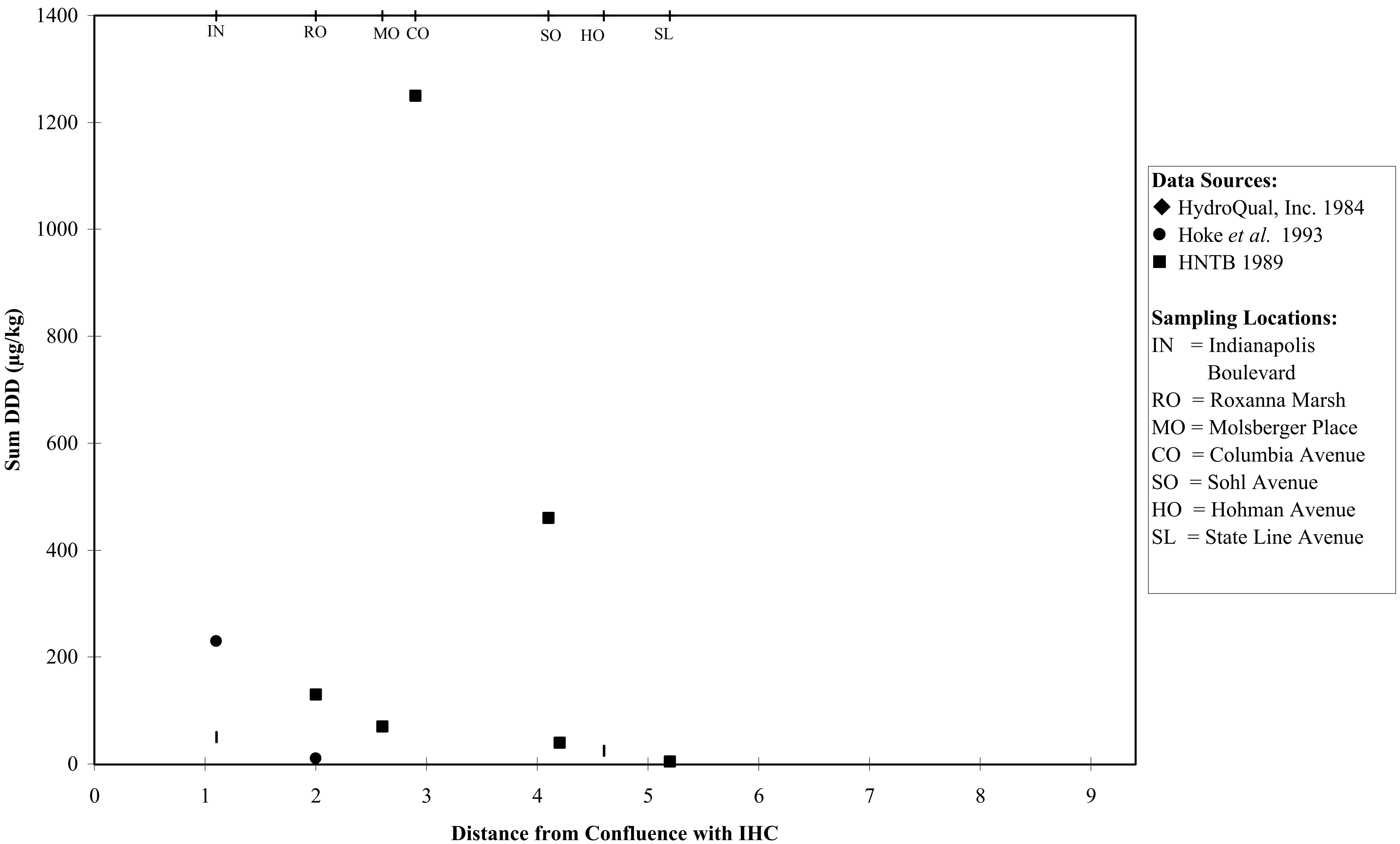

Figure 24. Spatial distribution of Sum DDE in surficial sediments within the WBGCR.

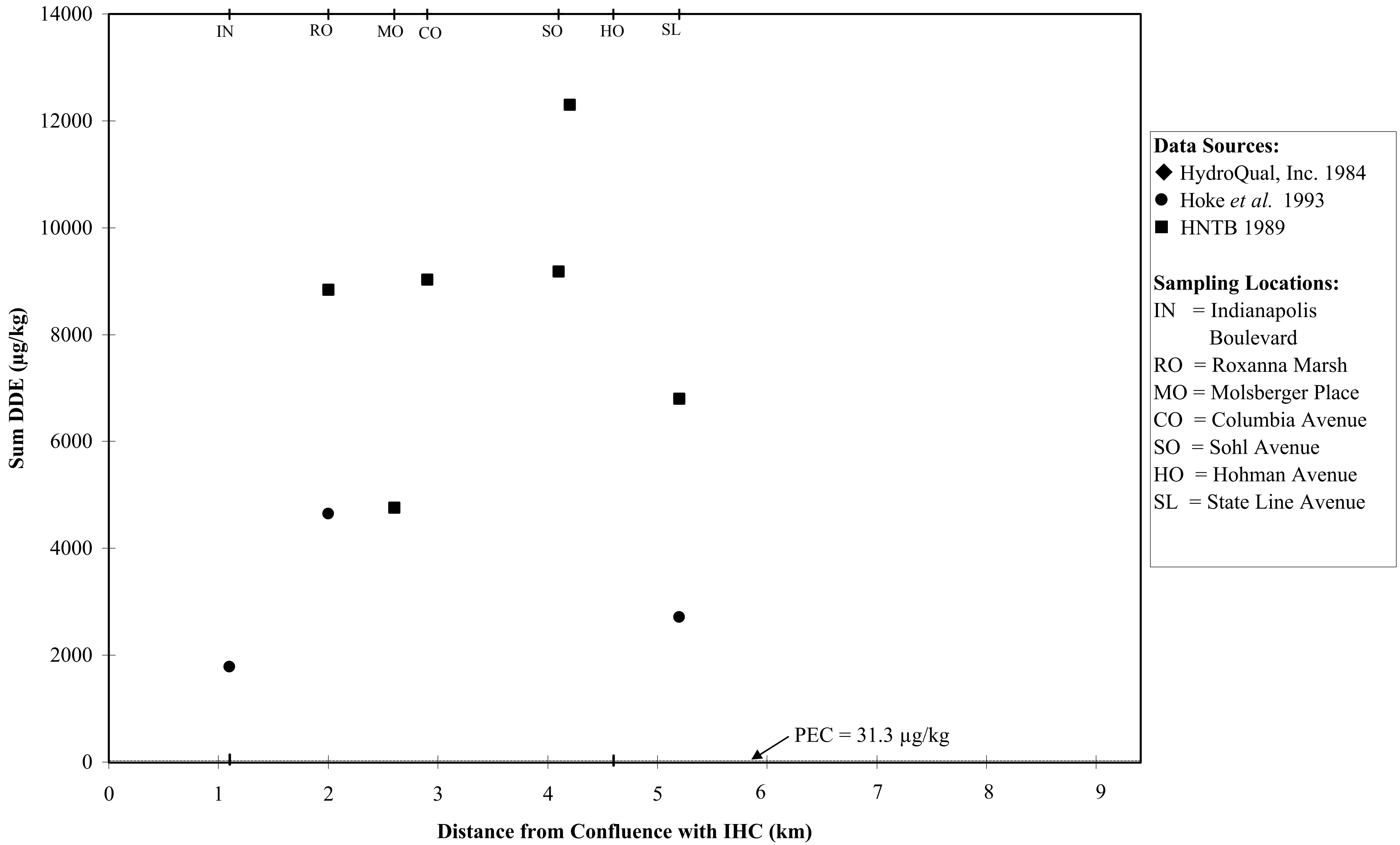

Figure 25. Spatial distribution of Sum DDT in surficial sediments within the WBGCR.

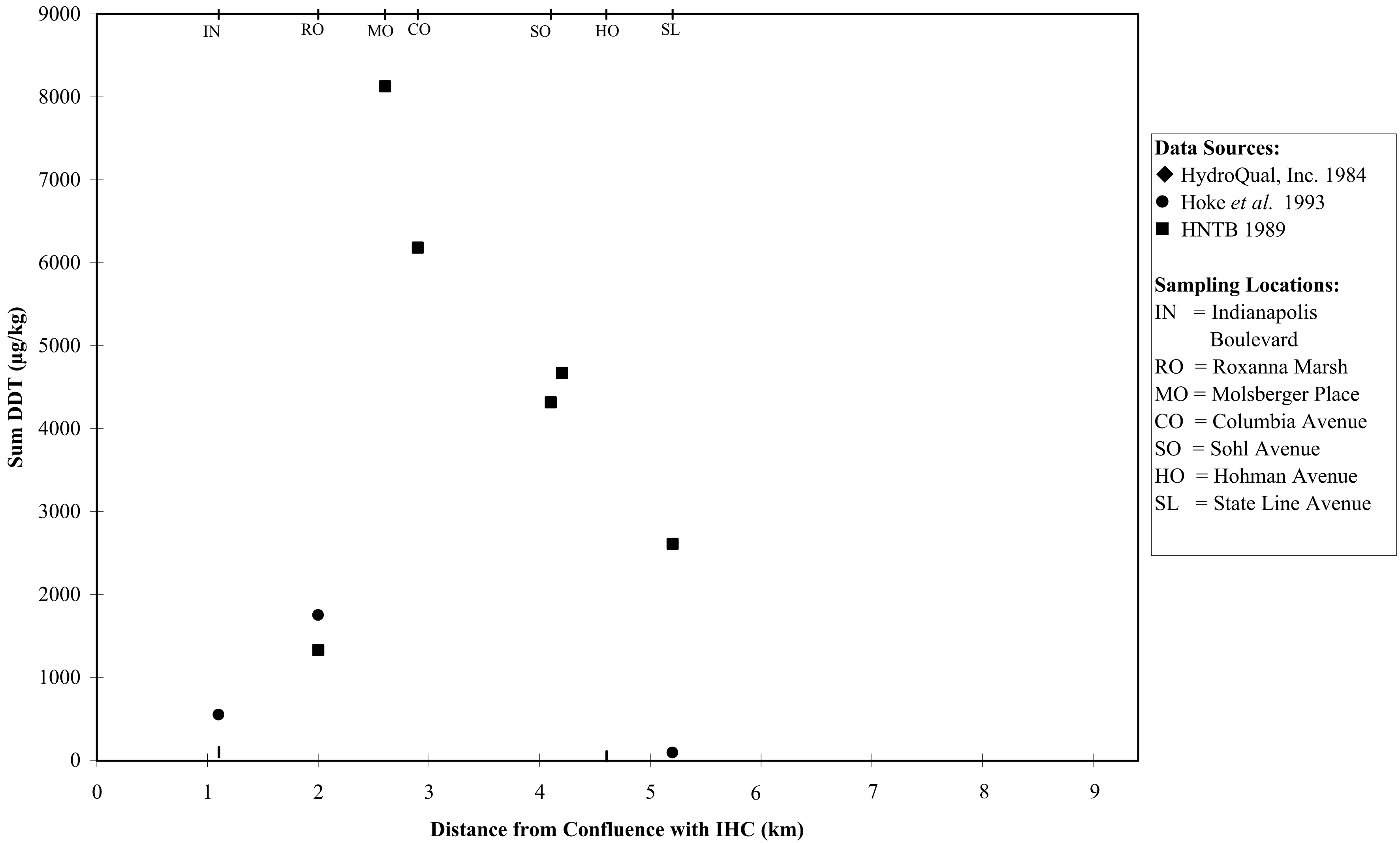

Figure 26. Spatial distribution of total DDT in surficial sediments within the WBGCR.

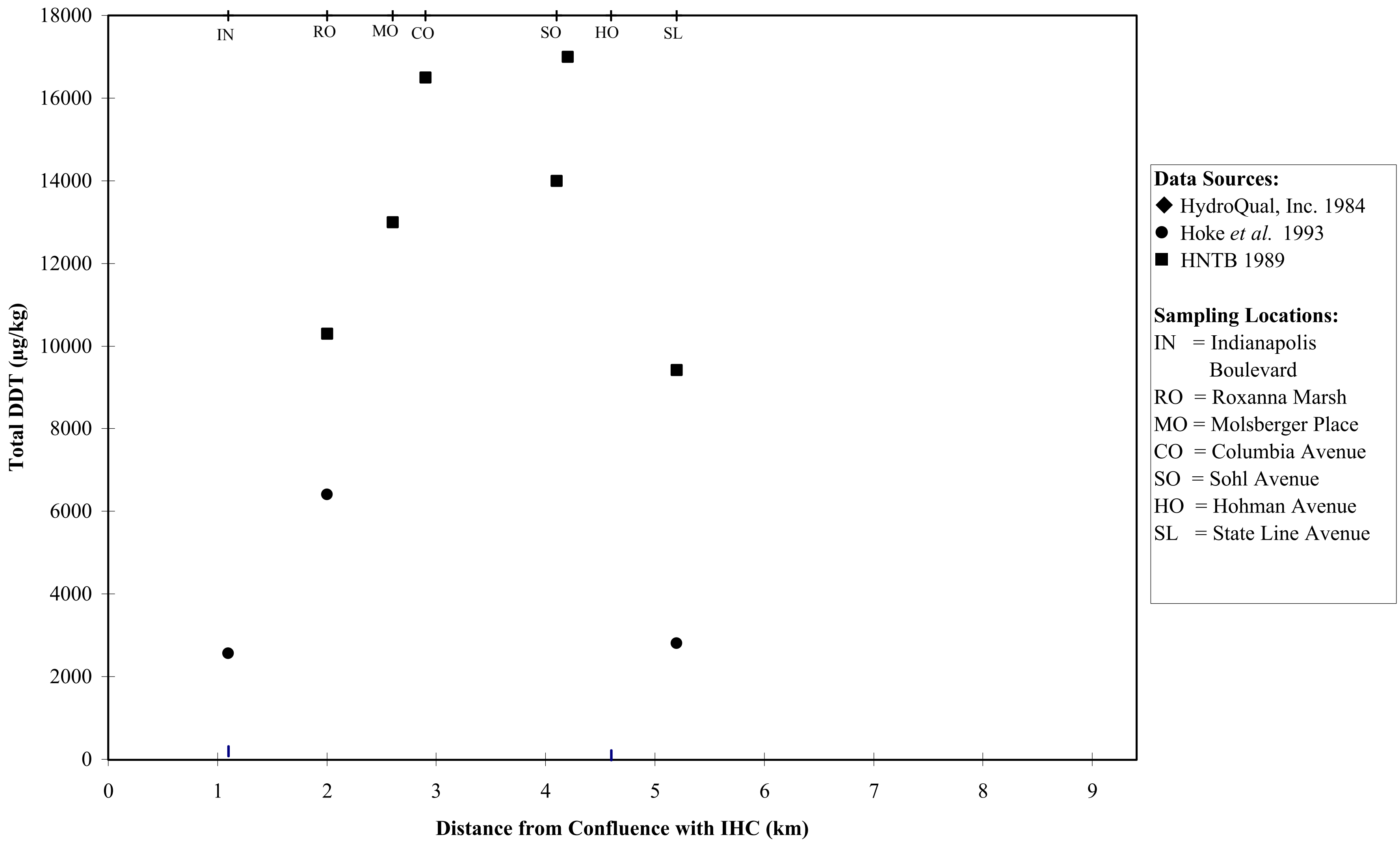

Figure 27. Spatial distribution of lindane (gamma-BHC) in surficial sediments within the WBGCR.

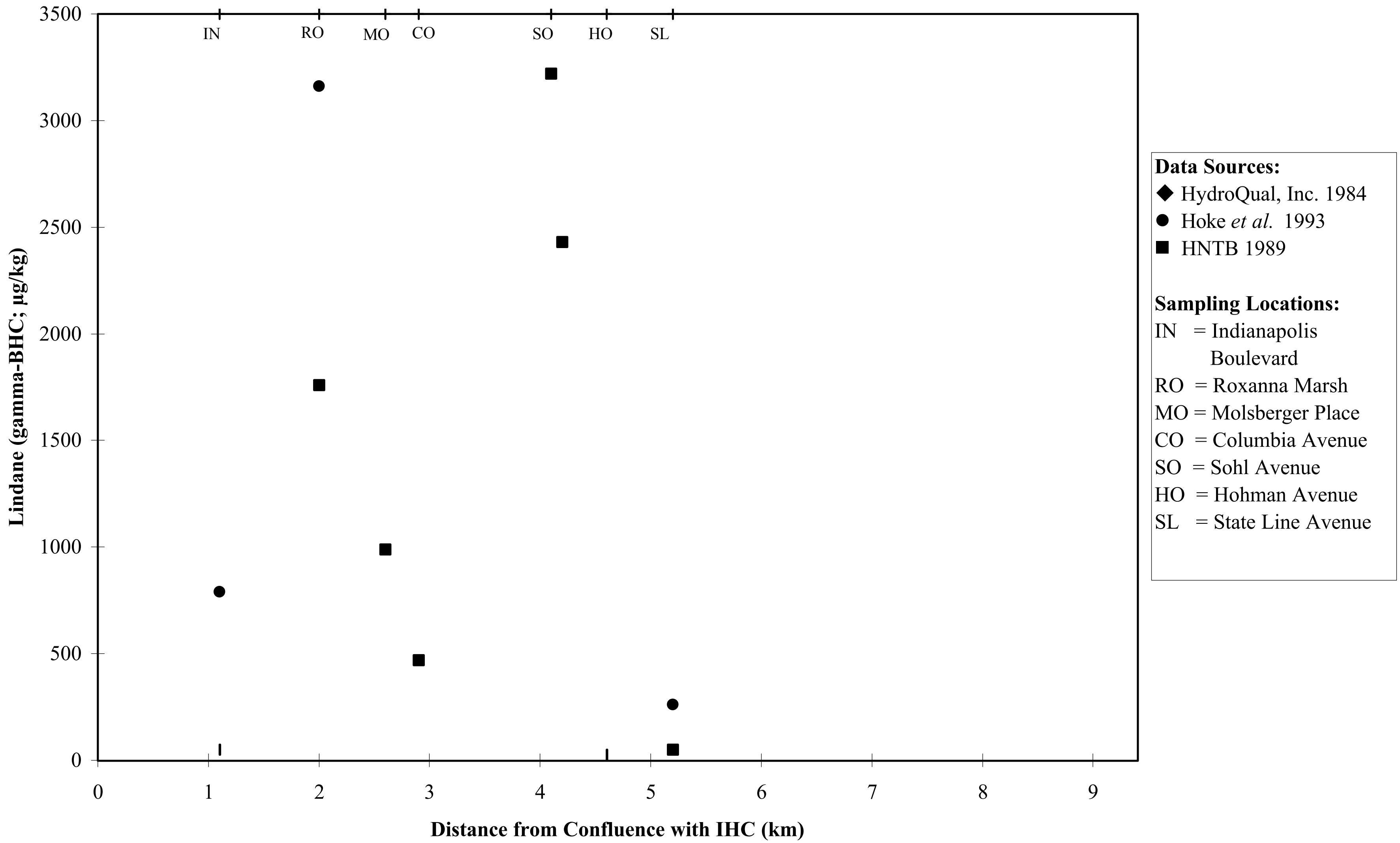

Figure 28. Spatial distribution of heptachlor epoxide in surficial sediments within the WBGCR.

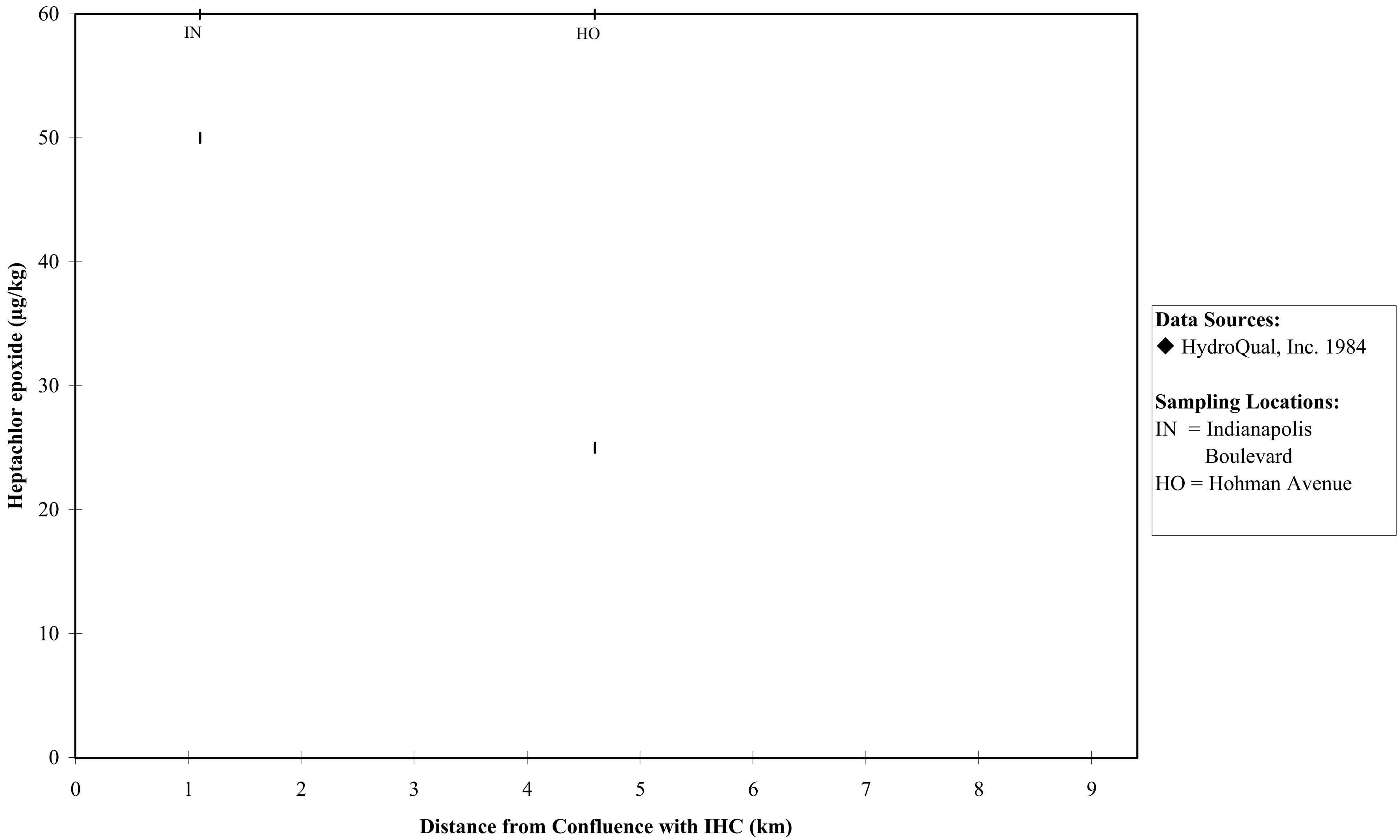

Figure 29. Spatial distribution of endrin in surficial sediments within the WBGCR.

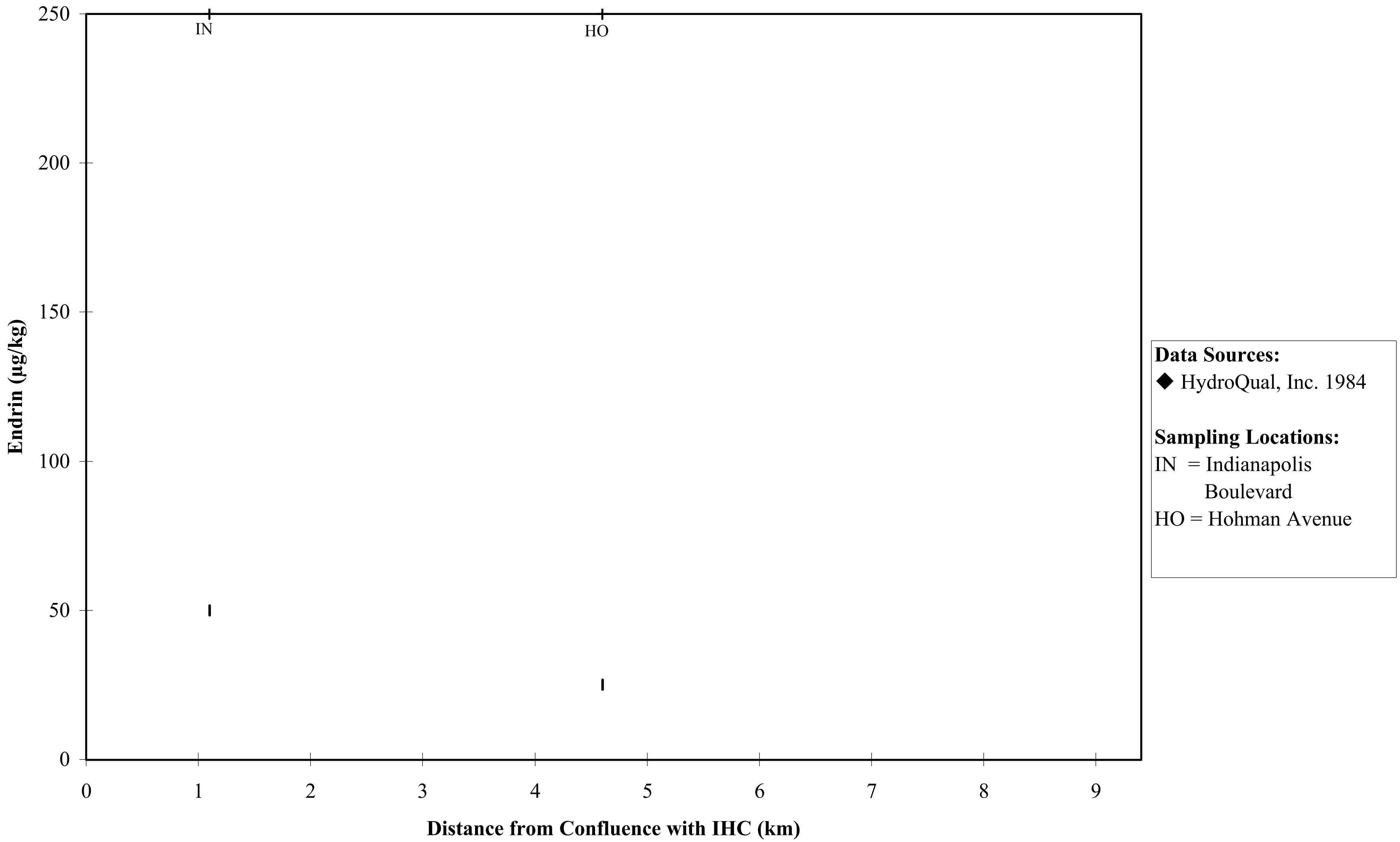

Figure 30. Spatial distribution mean PEC-quotients (PEC-Qs) in surficial sediments within the WBGCR.

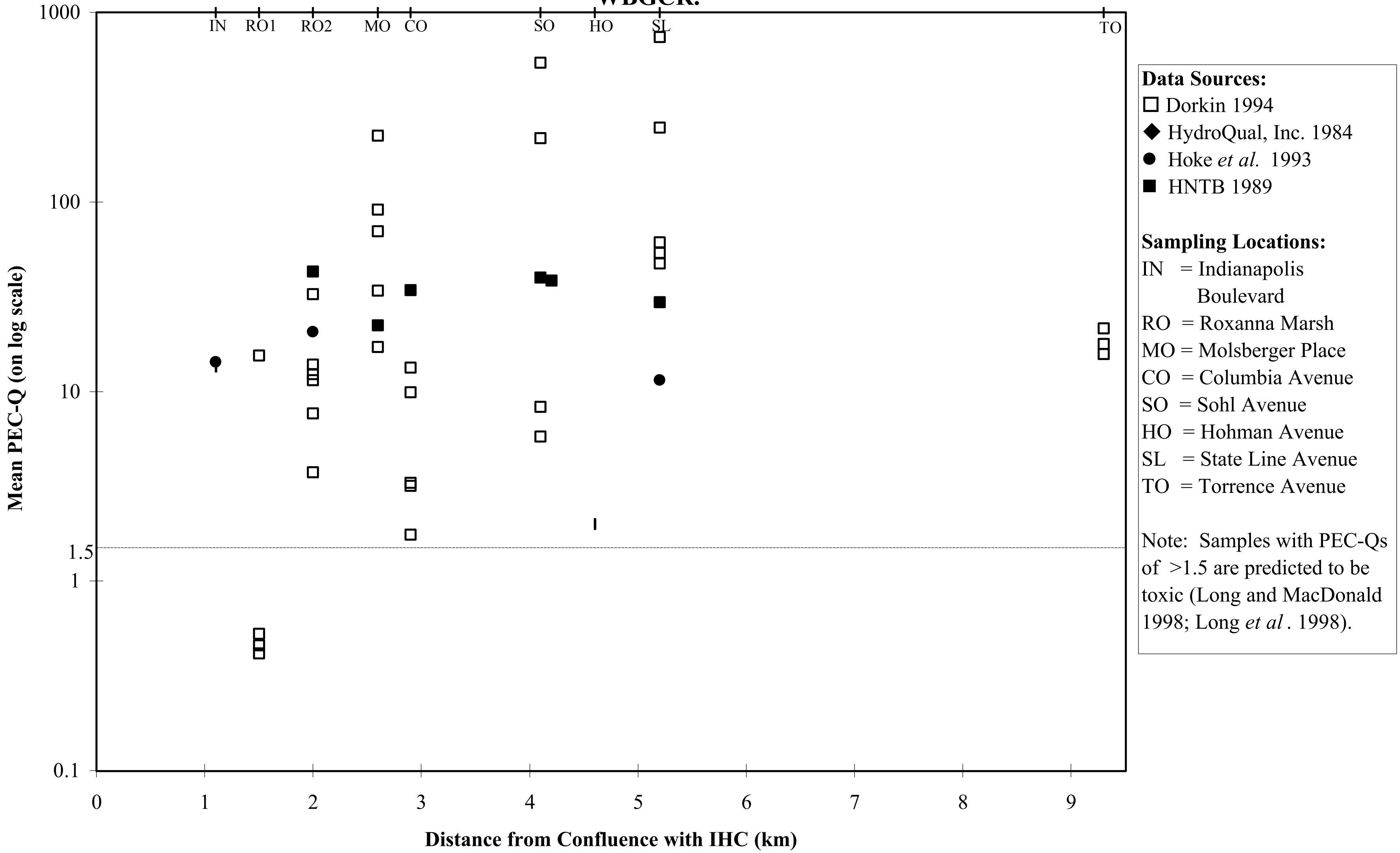

Figure 31. Spatial distribution of mean PEC-quotients (PEC-Qs) by depth within the WBGCR (HNTB 1989; Unger 1992; Dorkin 1994).