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U.S. Fish and Wildlife Service
Bloomington Field Office
Attn: Mr. Dan Sparks
620 South Walker Street
Bloomington, Indiana 47403

Subject: Development and Evaluation of Risk-Based Preliminary Remediation Goals for Selected Sediment-Associated Contaminants of Concern in the West Branch of the Grand Calumet River

Dear Mr. Sparks:

We are pleased to submit the final report entitled "Development and Evaluation of Risk-Based Preliminary Remediation Goals for Selected Sediment-Associated Contaminants of Concern" for the West Branch of the Grand Calumet River, Lake County, Indiana. The report has been revised to incorporate the edits and comments received from the Grand Calumet River Restoration Fund Council (EPA, IDEM, IDNR). Enclosed is one copy of the report for your file. We are also sending Jim Smith of the Indiana Department of Environmental Management three copies for filing. One electronic version of the document is included on CD for your convenience.

If you have any questions, feel free to call me at (425) 482-7840 or alternatively Jennifer Hawkins at (425) 482-7678.

Sincerely,
TETRA TECH EC

Gary Braun
Project Manager

Enclosure (1)

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Development and Evaluation of Risk-Based Preliminary Remediation Goals for Selected Sediment-Associated Contaminants of Concern in the West Branch of the Grand Calumet River

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List of Acronyms

%	percent
-d	-days
-h	-hours
-min	-minutes
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µmol/g	micromoles per gram
2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo- <i>p</i> -dioxin
AOC	Area of Concern
ARCS Program	Assessment and Remediation of Contaminated Sediments in the Great Lakes Program
ASTM	American Society for Testing and Materials
AVS	acid volatile sulfides
BSAF	sediment-biota bioaccumulation factor
CCBP	Central Corn Belt Plain
CCME	Canadian Council of Ministers of the Environment
CCREM	Canadian Council of Resource and Environment Ministers
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601 <i>et seq.</i>
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CI	confidence interval
COCs	contaminants of concern
COPCs	chemicals of potential concern
CSM	conceptual site model
CSO	combined sewer overflow
DDTs	<i>p,p'</i> -DDT, <i>o,p'</i> -DDT, <i>p,p'</i> -DDE, <i>o,p'</i> -DDE, <i>p,p'</i> -DDD, <i>o,p'</i> -DDD, and any metabolite or degradation product
DELT	deformities, fin erosion, lesions, and tumors
DL	detection limit
DO	dissolved oxygen
DQO	data quality objective
DuPont	E.I. du Pont de Nemours
DW	dry weight
EB	East Branch
EBGCR	East Branch of the Grand Calumet River
EBGCR-I	East Branch of the Grand Calumet River I
EBGCR-II	East Branch of the Grand Calumet River II
EC	Environment Canada
EC ₅₀	median effective concentration

ECBP	Eastern Corn Belt Plain
ECSD	East Chicago Sanitary District
EPT	Ephemeroptera, Plecoptera, Trichoptera (mayflies, stoneflies, caddisflies)
FIELDS	Fully Integrated Environmental Location Decision Support
FWENC	Foster Wheeler Environmental Corporation
gamma-BHC	gamma-hexachlorocyclohexane (lindane)
GCR	Grand Calumet River
GCRL	Grand Calumet River Lagoons
GCRRF	Grand Calumet River Restoration Fund
GIS	geographic information system
HC	Health Canada
HNTB	Howard, Needles, Tammen and Bergendoff Architects, Engineers, and Planners
HSD	Hammond Sanitary District
HMW PAHs	high molecular weight polycyclic aromatic hydrocarbons
IBI	Index of Biotic Integrity
ID	insufficient data
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
IEC	Industrial Economics, Inc.
IH	Indiana Harbor
IHAOC	Indiana Harbor Area of Concern
IHC	Indiana Harbor Ship Canal
IJC	International Joint Commission
IL	Illinois
IN	Indiana
IOT	incidence of toxicity
LC ₅₀	median lethal concentration
LEP	Little East Pond
LGB	Lake George Branch
LM	Lake Michigan
LMW PAHs	low molecular weight polycyclic aromatic hydrocarbons
LTI	Limno-Tech, Inc.
LWP	Little West Pond
mean PEC-Q	mean probable effect concentration quotient
MESL	MacDonald Environmental Sciences Ltd.
mg	milligrams
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mIBI	macroinvertebrate Index of Biotic Integrity
mm	millimeters

MOT	magnitude of toxicity
MOU	Memorandum of Understanding
MS	Microsoft
n	number of samples
NA	not applicable (i.e., all <DL values were >PEC; therefore total was not calculated)
NA'	not applicable (i.e., toxicity test or chemical analyses not performed).
ND	not determined; compounds were measured as less than the detection limit, but the detection limit is unknown
ND'	not determined; toxicity not determined because mortality was > 40%
ND''	not determined; the lab considered sample to be a hazard to personnel
NE	northeast
NG	no guideline available
NH ₃	unionized ammonia
NH ₄ ⁺	ionized ammonia
NIPSCO	Northern Indiana Public Service Company
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge and Elimination System
NR	not reported
NRDA	Natural Resource Damage Assessment
NT	not toxic
NW	northwest
NYSDEC	New York State Department of Environmental Conservation
OC	organic carbon
OEPA	Ohio Environmental Protection Agency
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PEC	probable effect concentration (consensus-based)
PEC-Q	probable effect concentration quotient
PRG	preliminary remediation goal
PRG-HR	preliminary remediation goal-high risk
PRG-IR	preliminary remediation goal-intermediate risk
QA/QC	quality assurance/quality control
QHEI	qualitative habitat evaluation index
RAO	remedial action objective
RAP	remedial action plan
RCRA	Resource Conservation and Recovery Act
RETEC	Remediation Technologies, Inc.
S.U.	standard unit

SAB	Science Advisory Board
SE	southeast
SEC	sediment effect concentration (consensus-based)
SEM	simultaneously extracted metals
SEM-AVS	simultaneously extracted metal minus acid volatile sulfides
SETAC	Society of Environmental Toxicology and Chemistry
SOD	sediment oxygen demand
SQG	sediment quality guideline
STP	sewage treatment plant
sum DDD	<i>p,p'</i> -DDD + <i>o,p'</i> -DDD
sum DDE	<i>p,p'</i> -DDE + <i>o,p'</i> -DDE
sum DDT	<i>p,p'</i> -DDT + <i>o,p'</i> -DDT
SVOC	semi-volatile organic compound
SW	southwest
T	toxic
TEC	threshold effect concentration (consensus-based)
TtEC	Tetra Tech Ec, Inc. (Formerly FWENC)
ThermoRetec	ThermoRetec Consulting Corporation
TOC	total organic carbon
Total DDT	<i>p,p'</i> -DDT, <i>o,p'</i> -DDT, <i>p,p'</i> -DDE, <i>o,p'</i> -DDE, <i>p,p'</i> -DDD, and <i>o,p'</i> -DDD
TRG	tissue residue guideline
U.S. Steel	United States Steel
USACE	United States Army Corps of Engineers
USC	United States Canal
USDOJ	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USS Lead	USS Lead Refinery, Inc.
VOC	volatile organic compound
WB	West Branch
WBGCR	West Branch of the Grand Calumet River
WBGCR-I	West Branch of the Grand Calumet River I
WBGCR-II	West Branch of the Grand Calumet River II
WW	wet weight
WWTP	wastewater treatment plant

Executive Summary

Introduction

This report was prepared to provide the United States Fish and Wildlife Service (USFWS), United States Environmental Protection Agency (USEPA), Indiana Department of Natural Resources (IDNR), and Indiana Department of Environmental Management (IDEM; i.e., the GCRRF Council; who are acting as the risk managers) with specialized technical support for evaluating the remedial alternatives for addressing sediment contamination in the West Branch of the Grand Calumet River (WBGCR). More specifically, this report was prepared to summarize the remedial action objectives (RAOs) that have been established by the risk managers for the site (Chapter 3); identify the contaminants of concern (COCs) in the WBGCR (Chapter 4); and, present the conceptual site model (CSM) as it relates to ecological receptors (Chapter 5; Appendix 1). The PRGs for whole sediments that were developed to address risks to the benthic invertebrate community are presented and evaluated (Chapter 6). Collectively, these RAOs and ecological risk-based PRGs are intended to provide USFWS, USEPA, IDEM, and IDNR with a basis for selecting a suite of PRGs that can be used to evaluate remedial alternatives and, ultimately, select a remedial option that will reduce risks to human health and/or ecological receptors to tolerable levels.

As part of this initiative, Tetra Tech EC, Inc. (TtEC 2005a) has conducted an assessment of the risks posed to human health associated with exposure to environmental media in the WBGCR. Collectively, the RAOs, the human health risk assessment, and the ecological risk-based PRGs are intended to provide USFWS, USEPA, IDEM, and IDNR with a basis for evaluating remedial alternatives and selecting a remedial option that will reduce risks to human health and/or ecological receptors to tolerable levels.

Background

Sediments throughout the WBGCR are highly contaminated with heavy metals and various organic compounds, including semivolatile organic compounds (SVOCs), chlorinated pesticides, and polychlorinated biphenyls (PCBs; MacDonald and Ingersoll 2000; FWENC 2002; 2003). The results of several investigations demonstrate that the concentrations of COCs in WBGCR sediments are sufficient to adversely affect a variety of ecological receptors in the WBGCR, including benthic invertebrates, fish, and aquatic-dependent wildlife (Ingersoll and MacDonald 1999;

MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a; 2002b). In addition, the results of whole-sediment and pore-water toxicity tests confirm that WBGCR sediments are toxic to benthic invertebrates and fish (Burton 1994; Kemble *et al.* 2002; 2003). Furthermore, the structure of benthic invertebrate communities are altered throughout the WBGCR, as evidenced by a shift toward pollution-sensitive species and a loss of preferred fish food organisms (e.g., mayflies, caddisflies, and stoneflies; Rainbolt 1993; Simon *et al.* 2000). Fish populations are also reduced in the WBGCR due to the loss or degradation of habitat associated with inputs of sewage sludge and other substances (Simon 1993; Simon and Moy 1999/2000; Simon *et al.* 2000).

Together, these studies show that natural resources in the WBGCR have been injured as a result of direct and/or indirect exposure to sediment-associated COCs and that contaminated sediments currently pose unacceptable risks to certain ecological receptors (i.e., sediment-dwelling organisms, fish, and aquatic-dependent wildlife). The results of the human health risk assessment that was recently conducted demonstrate that environmental conditions in the WBGCR also pose unacceptable risks to human health (TtEC 2005a). Accordingly, there is a need to identify, evaluate, and implement one or more remedial alternatives to address the risks posed to human health and ecological receptors associated with exposure to environmental contaminants in the WBGCR. This report presents the remedial action objectives (RAOs) and risk-based preliminary remediation goals (PRGs) for ecological receptors that were developed to support the remedial alternatives analysis and, ultimately, the clean-up of contaminated sediments in the WBGCR. Such PRGs define the concentrations of COCs in environmental media (i.e., sediments) that pose intermediate (PRG-IR) and high (PRG-HR) risks to sediment-dwelling organisms. The results of subsequent evaluations of the PRGs are also presented to support selection of clean-up goals that will provide an appropriate level of protection for ecological receptors.

Remedial Action Objectives

Remedial action objectives (RAOs) are important tools for managing the risks posed by exposure to environmental media in the vicinity of a contaminated site. More specifically, RAOs are established to describe the narrative intent of any remedial actions that are considered for addressing risks to human health and/or ecological receptors at the site (i.e., the desired future state of the site once remedial actions have been implemented to address risks to human health and/or ecological receptors). The RAOs for the WBGCR were developed by the Natural Resources Trustees, based on the input provided by stakeholders at a series of public meetings that have been

convened since the river was designated as a Great Lakes Area of Concern by the International Joint Commission in 1988.

A variety of environmental media within the WBGCR are known to be contaminated by toxic and/or bioaccumulative substances, including, surface water, sediment (including whole sediment and pore water), bank and upland soil, groundwater, and biological tissues. While RAOs are generated for each of these media types, this document focused on the establishment of RAOs primarily for sediments but also established RAOs for surface water and biological tissues.

The RAOs for sediments, surface water, and biological tissues are presented in Section 3.2 of this document and in TtEC (2005b).

To address the risks to aquatic receptors associated with direct exposure to contaminated sediments (and/or floodway soils), the following RAOs were established: Minimize or prevent exposure to whole sediments that are sufficiently contaminated to pose intermediate or high risks, respectively, to the microbial or benthic invertebrate communities and that would affect the prey base for fish; and, Minimize or prevent exposure to pore waters that are sufficiently contaminated to pose intermediate or high risks, respectively, to aquatic plant, benthic invertebrate, or fish communities (particularly for fish species that use sediment substrates for spawning).

For surface water, the RAOs for ecological receptors are to: Minimize or prevent exposure to surface waters that are sufficiently contaminated to pose intermediate or high risks, respectively to microorganisms, aquatic plants, aquatic invertebrates, or fish; and, Minimize risks to avian or mammalian species associated with direct contact with or ingestion of surface waters.

To address concerns relative to the bioaccumulation of COC in the tissues of aquatic organisms, the following RAOs were established: Reduce the concentrations of COCs in fish tissues to levels that are not associated with adverse effects on survival, growth, reproduction, or the incidence of lesions or tumors; Reduce the concentrations of COCs in the tissues of prey species to levels that do not pose unacceptable risks to insectivorous birds, sediment-probing birds, carnivorous-wading birds, piscivorous birds, or omnivorous mammals; and, Reduce the concentrations of COCs in fish to levels that do not pose unacceptable risks to human health.

Although RAOs were developed for surface water, it is important to understand that the GCRRF Council is not mandated to address this environmental medium directly. Rather, IDEM will address concerns relative to surface water quality through the development of TMDLs and the NPDES permitting process. Nevertheless, it is anticipated that surface water quality will improve once contaminated sediments have

been cleaned-up. Similarly, the concentrations of COCs in fish tissues are likely to decrease once sediment-focused remedial activities have been completed in the WBGCR.

Contaminants of Concern

The COCs are those toxic and bioaccumulative substances that occur in whole sediments in the WBGCR at concentrations sufficient to injure natural resources. Ingersoll and MacDonald (1999), MacDonald and Ingersoll (2000), and MacDonald *et al.* (2002a; 2002b) assessed injury to surface water resources (bed sediments) and biological resources (sediment-dwelling organisms, fish, and aquatic-dependent wildlife). Based on an analysis of multiple lines of evidence, these investigators concluded that the concentrations of a number of substances in WBGCR sediments were sufficient to injure ecological receptors in the study area. The substances that occurred in WBGCR sediments at concentrations sufficient to injure bed sediments and associated biological resources include: trace metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc); PAHs (13 individual PAHs and total PAHs); PCBs (total PCBs); pesticides (chlordane, DDTs, heptachlor, and lindane); phenol; and, unionized ammonia (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a; 2002b).

Conceptual Site Model

The development of a conceptual site model (CSM) represents an essential element of the problem formulation process for an ecological risk assessment because it enhances the level of understanding regarding the relationships between human activities and ecological receptors at the site under consideration. While an ecological risk assessment was not conducted on the WBGCR, development of a CSM was considered to be important for focusing limited resources on the exposure pathways and receptors that were the most relevant for addressing the risks associated with exposure to contaminated sediments. The CSM that was developed considered the available information on the sources and releases of COCs, environmental fate of the COCs, potential exposure pathways, and ecological receptors at risk. This information was then integrated to identify candidate assessment endpoints and to recommend an approach to the development of PRGs for ecological receptors in the WBGCR.

Preliminary Remediation Goals for Aquatic Receptors

The results of the various assessments of sediment injury that have been conducted indicated that contaminated sediments in the WBGCR pose unacceptable risks to benthic invertebrates, fish, and aquatic-dependent wildlife. Examination of the CSM that was developed for the WBGCR and supporting documentation provided a basis for recommending an approach to the development of PRGs for ecological receptors. The results of this analysis indicated that benthic invertebrate community is likely to be more sensitive to sediment-associated COCs than are microorganisms, aquatic plants or fish. For this reason, PRGs for the benthic invertebrate community were developed to support remedial action planning in the WBGCR.

The numerical PRGs for selected COCs and COC mixtures were developed largely using matching sediment chemistry and sediment toxicity data from the WBGCR. The sediment toxicity data included the results of 28-d, whole-sediment toxicity tests with the amphipod, *Hyalella azteca* (endpoint: survival). These data were supplemented with the results of 10-d whole-sediment toxicity tests that were found to be toxic to amphipods (i.e., *H. azteca*; under the assumption that samples that were toxic after 10-d exposure would still be toxic if the exposure duration was extended to 28-d). The results of the toxicity tests were expressed both in terms of magnitude of toxicity (MOT; i.e., percent survival) and incidence of toxicity (IOT; i.e., the proportion of samples within discrete concentrations that were found to be toxic, expressed as a percentage).

Using the MOT data, PRGs were derived for the following individual COCs: eight trace metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), 12 individual PAHs and PAH mixtures [anthracene, fluorene, naphthalene, phenanthrene, total LMW-PAHs, benz(a)anthracene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, fluoranthene, pyrene, total HMW-PAHs, and total PAHs]. IOT-based PRGs were also derived for all these COCs except benz(a)anthracene, benzo(a)pyrene, or dibenz(a,h)anthracene. The PRGs for metals were expressed on a DW-normalized basis, while the PRGs for PAHs and PCBs were expressed on a DW-normalized basis at 1%OC (DW@1%OC). In addition, a total of nine COC mixture models were developed (using both MOT and IOT data) to support the derivation of PRGs that would integrate the toxic effects of multiple chemical substances and classes (i.e., metals, PAHs, and/or PCBs).

The PRGs were derived from site-specific concentration-response models that quantified the relationship between COC concentration and the MOT or IOT (i.e., which were developed using non-linear regression analysis). For each COC and COC mixture, two PRGs were derived, including a PRG that defined the lower end of the range of concentrations that posed an intermediate risk (PRG-IR) and the lower end of the range of concentrations that posed a high risk (PRG-HR) to the benthic

invertebrate community. The PRG-IR is defined as the COC concentration that is associated with a 10% increase in the MOT or a 20% increase in the IOT, relative to reference conditions in the IHAOC. By comparison, the PRG-HR is defined as the COC concentration that is associated with a 20% increase in the MOT or a 50% increase in the IOT, relative to reference conditions in the IHAOC.

All of the PRGs that were derived in this investigation were evaluated to determine the extent to which they were consistent with the narrative RAOs. The results of this evaluation indicated that the majority of the PRGs for individual COCs or COC mixtures provide reliable bases for classifying whole-sediment samples as toxic or not toxic to the amphipod, *H. azteca*. Overall, the PRGs for PEC- $Q_{tPAHs(DW)}$ (Table ES-1), provided the highest correct classification rates (i.e., 89% for the PRG-IR and 93% of the PRG-HR; Table ES-2). Therefore, it could be argued that these PRGs provide the most reliable tools for classifying WBGCR sediments as toxic and not toxic, if both types of PRGs are to be applied (i.e., PRG-IR and PRG-HR).

Application of a single PRG (as opposed to a PRG-IR and PRG-HR) may provide certain advantages because it would be simpler to use and permit definitive classification of more sediment samples. For example, application of the PRG-HR for PEC- $Q_{tPAHs(DW)}$ of 5.76 alone to classify WBGCR sediments would yield acceptable correct classification rates, as 85% of the samples with concentrations below the PRG-HR were not toxic and 93% of the samples with concentrations above the PRG-HR were toxic (Table ES-2). Correct classification rates were similar for the PRG-IR for PEC- $Q_{tPAHs(DW@1\%OC)}$ of 0.167 (Table ES-1; i.e., 90% of the samples with concentrations below the PRG-IR were not toxic and 88% of the samples with concentrations above the PRG-IR were toxic; Table ES-2). Therefore, candidate remedial alternatives for addressing sediment contamination in the WBGCR could be evaluated using either of these PRGs; however, the PRG-IR PEC- $Q_{tPAHs(DW@1\%OC)}$ of 0.167 (Table ES-1) is more highly recommended because a higher proportion of intermediate risk samples (i.e., with concentrations between the PRG-IR and PRG-HR) would be correctly classified as toxic (i.e., 75% of the samples with these chemical characteristics were found to be toxic to the amphipod, *H. azteca*, in 28-d whole-sediment toxicity tests; n=4; Table ES-2). Therefore, it is concluded that the PRG-IR for PEC- $Q_{tPAHs(DW@1\%OC)}$ of 0.167 (Table ES-1) would provide a reliable basis for classifying sediments in the WBGCR and, in so doing, supporting the remedial alternatives analysis. This PRG corresponds to a total PAH concentration of roughly 3.8 mg/kg DW@1%OC or 30 mg/kg DW, assuming an average TOC is in the order of 8% (Table ES-3). Based on the evaluations that were conducted by MacDonald *et al.* (2002c; 2003a), it is likely that this PRG would also facilitate restoration of the microbial, aquatic plant, and fish communities (i.e., adverse effects on these receptor groups would be unlikely if the recommended benthic PRGs were used to select the preferred remedial alternative and guide remedial actions in the WBGCR).

Recently, MacDonald *et al.* (2005) developed and evaluated numerical PRGs for the IHAOC as a whole (including the WBGCR). The results of this study demonstrated that the MOT-based PRG-HR for $PEC-Q_{tPAH(DW@1\%OC)}$ would provide the most reliable basis for classifying sediment samples from the IHAOC as toxic and not toxic (overall correct classification rate of 86%). This PRG corresponds to a total PAH concentration of 3.4 mg/kg DW@1%OC or 27 mg/kg DW (Table ES-3). Because correct classification rates were similar for the IHAOC PRG (86%) and WBGCR PRG (89%) and because it is beneficial to establish PRGs consistently throughout the AOC, it is recommended that the IHAOC PRG be adopted for use in the remedial alternatives analysis for the WBGCR.

It is important to understand that the PRGs developed in this report are intended to provide a basis for classifying sediment samples as toxic or not toxic based on whole-sediment chemistry alone. Although PRGs were derived for eight trace metals, 12 individual PAHs and PAH classes, total PCBs, and various COC mixtures, no attempt was made to identify the substance or substances that were causing the observed toxicity in the WBGCR. Rather, the PRGs identify the concentrations of sediment-associated COCs that are associated with a specified incidence or magnitude of toxicity to amphipods. Nevertheless, Word *et al.* (2005) and Ingersoll *et al.* (2005) indicated that empirically- and mechanistically-derived SQGs for total PAHs and total PCBs are generally comparable, and are often consistent with the results of sediment spiking studies. Accordingly, such SQGs reflect causal rather than correlative effects and indicate that total PAHs and, to a lesser extent, total PCBs may be causing or substantially-contributing to the toxicity observed in many field-collected sediments. As the PRGs for total PAHs and total PCBs are generally consistent with such previously derived SQGs, it is not unreasonable to conclude that these substances are causing or substantially contributing to sediment toxicity in WBGCR sediment samples in which these PRGs are exceeded. Hence, the remedial alternatives that are ultimately implemented to address concerns related to contaminated sediments (i.e., based on exceedances of the recommended benthic PRGs) are likely to reduce the concentrations of key COCs to tolerable levels in the WBGCR and, thereby, result in tolerable levels of sediment toxicity.

Numerical PRGs for sediment-associated COCs are also needed to address risks to aquatic-dependent wildlife associated with the bioaccumulation of certain COCs in the tissues of aquatic organisms (i.e., prey species). However, rather than developing wildlife-based PRGs, the level of protection offered to avian and mammalian species by the benthic PRGs will be evaluated as a first step in the process. More specifically, GIS-based spatial analysis tools will be employed to estimate average concentrations of key bioaccumulative COCs (e.g., mercury and total PCBs) following implementation of the preferred remedial alternative. Simple bioaccumulation and food web models will then be used to estimate potential exposure and risks to aquatic-dependent wildlife, post-remediation. This approach

will provide a basis for determining if the benthic PRGs are likely to provide an adequate level of protection for aquatic-dependent wildlife. In addition, it will help to identify the bioaccumulative COCs for which wildlife-based PRGs may be needed (i.e., those that are predicted to occur in sediments at levels that could result in unacceptable levels of bioaccumulation) and, thereby, focus resources on priority COCs for wildlife.

Table ES-1. Summary of the concentration-response relationships derived based on incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-day toxicity tests (endpoint: survival). The preliminary remediation goals (PRGs) derived using these regression equations are also presented.

Mixture Model	Regression Equation Type	Regression Equation	n ¹	r ²	p	PRG-IR	PRG-HR
Mean PEC-Q _{metals} (DW)	Log3	$y = 101.1678/[1 + (x/2.4050)-1.1904]$	101	0.97	<0.0001	0.836	2.48
Mean PEC-Q _{metals} (DW@1%OC)	Sig3	$y = 69.7049/\{1 + e-[(x - 0.1424) / 0.0337]\}$	100	0.99	<0.0001	0.117	0.177
PEC-Q _{tPAHs} (DW)	Log3	$y = 111.1649/[1 + (x/6.5856)-1.1048]$	102	0.99	<0.0001	1.89	5.76
PEC-Q _{tPAHs} (DW@1%OC)	Log3	$y = 111.4346/[1 + (x/0.6430)-1.0254]$	102	0.98	<0.0001	0.167	0.555
PEC-Q _{PCBs} (DW)	NA	NA	NA	NA	NA	NA	NA
PEC-Q _{PCBs} (DW@1%OC)	Sig3	$y = 101.2808/\{1 + e-[(x - 0.7031) / 0.3607]\}$	61*	0.66	0.0408	0.249	0.715
Mean PEC-Q _{metals} (DW), tPAHs (DW), tPCBs (DW)	Sig4	$y = -2.7268 + 95.3141/\{1 + e-[(x - 4.9652) / 2.0054]\}$	104	0.95	0.0014	2.90	5.52
Mean PEC-Q _{metals} (DW@1%OC), tPAHs (DW@1%OC), tPCBs (DW)	Log3	$y = 103.0581/[1 + (x/0.4545)-2.2764]$	102	0.99	<0.0001	0.259	0.454
Mean PEC-Q _{metals} (DW), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	Log3	$y = 123.5285/[1 + (x/1.7154)-1.8642]$	103	0.99	<0.0001	0.764	1.43

¹Asterisk denotes that the concentration-response relationships were derived using data from the entire Indiana Harbor Area of Concern.

r² = correlation coefficient; p = p value for the F statistic (ANOVA); PEC-Q = probable effect concentration-quotient; DW = dry weight; OC = organic carbon; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; Log3 = 3 parameter logistic; Log4 = 4 parameter logistic; Sig3 = 3 parameter Sigmoidal; Sig4 = 4 parameter Sigmoidal; NA = not applicable - PRG could not be derived based on the concentration-response relationship; IR = intermediate risk; HR = high risk.

Table ES-2. Reliability of the incidence of toxicity-based preliminary remediation goals (PRGs) for mixtures of contaminants of concern in the West Branch Grand Calumet River (based on 28-day toxicity tests to the freshwater amphipod, *Hyalella azteca*; endpoint: survival).

Mixture Model	Incidence of Toxicity (%)				
	<PRG-IR	≥PRG-IR	PRG-IR to PRG-HR	>PRG-HR	≤PRG-HR
Mean PEC-Q _{metals} (DW)	13% (9 of 69)	62% (29 of 47)	52% (13 of 25)	73% (16 of 22)	23% (22 of 94)
Mean PEC-Q _{metals} (DW@1%OC)	15% (11 of 74)	64% (27 of 42)	33% (3 of 9)	73% (24 of 33)	17% (14 of 83)
PEC-Q _{tPAHs} (DW)	11% (9 of 81)	83% (29 of 35)	50% (4 of 8)	93% (25 of 27)	15% (13 of 89)
PEC-Q _{tPAHs} (DW@1%OC)	10% (8 of 82)	88% (30 of 34)	75% (3 of 4)	90% (27 of 30)	13% (11 of 86)
PEC-Q _{PCBs} (DW)	--	--	--	--	--
PEC-Q _{PCBs} (DW@1%OC)	44% (21 of 48)	18% (3 of 17)	14% (2 of 14)	33% (1 of 3)	37% (23 of 62)
Mean PEC-Q _{metals} (DW), tPAHs (DW), tPCBs (DW)	14% (11 of 81)	77% (27 of 35)	45% (5 of 11)	92% (22 of 24)	17% (16 of 92)
Mean PEC-Q _{metals} (DW@1%OC), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	10% (8 of 78)	79% (30 of 38)	38% (3 of 8)	90% (27 of 30)	13% (11 of 86)
Mean PEC-Q _{metals} (DW), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	12% (9 of 75)	71% (29 of 41)	29% (4 of 14)	93% (25 of 27)	15% (13 of 89)

IR = intermediate risk; HR = high risk; DW = dry weight; OC = organic carbon; PEC-Q = probable effect concentration-quotient; tPAHs = total polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls.

Bolded results indicate that the PRG met the evaluation criteria (see Section 6 for more details).

Table ES-3. Comparison of recommended preliminary remediation goals (PRGs) to other candidate benchmarks for assessing sediment quality conditions.

PRG/Benchmark	Total Polycyclic Aromatic Hydrocarbon (tPAH) Concentration (mg/kg)		Reference
	DW ¹	DW 1%OC	
Probable Effect Concentration	22.8	-	MacDonald <i>et al.</i> (2000)
Mean Threshold Effect Concentration	23.2	2.9	Swartz (1999)
PRG-HR_{tPAHs@1%OC} (0.149)	27.2	3.4	MacDonald <i>et al.</i> (2005)
PRG-IR_{tPAHs@1%OC} (0.167)	30.4	3.8	This study
∑ PAH Toxicity Threshold	31.2	3.9	Swartz (1999)
Screening Level Concentration	32.8	4.1	Neff <i>et al.</i> (1987)
Effects Range Median	44.8	-	Long <i>et al.</i> (1995)
PRG-HR_{tPAHs@1%OC} (0.555)	101	12.7	This study
Mean Median Effects Concentration	144	18	Swartz (1999)
∑ PAH mixture LC ₅₀	169	21.1	Swartz (1999)

DW = dry weight; OC = organic carbon; IR = indeterminate risk; HR = high risk; LC₅₀ = lethal concentration affecting 50% of the population.

¹Assuming an average of 8% OC in the West Branch Grand Calumet River

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Chapter 1 Introduction and Background

1.0 Study Area

The Grand Calumet River (GCR) is located in Lake County in northwestern Indiana (Figure 1). The river's watershed is relatively flat and comprises approximately 58 square kilometers of northern Indiana. The GCR comprises two east-west oriented branches that meet at the southern end of the Indiana Harbor Ship Canal (IHC). The East Branch of the GCR (EBGCR) originates at the Grand Calumet Lagoons, just east of the United States Steel Gary Works facility. The EBGCR flows west from this point for approximately 16 kilometers (km) to its confluence with the IHC.

The West Branch of the GCR (WBGCR) extends some 9.5 km from the IHC to the confluence with the Little Calumet River in northeastern Illinois. The WBGCR is complicated from a hydrological perspective, as a hydraulic divide is typically present in the vicinity of the Hammond Sanitary District (HSD) waste water treatment plant (WWTP) outfall just east of Columbia Avenue. As a result, the river typically flows both east and west from this location. However, the volume and direction of water flow through the river are also influenced by water levels in Lake Michigan. During periods of high lake levels, the river can flow from east to west throughout the WBGCR. Drops in the level of Lake Michigan since 1997 have resulted in reduced water levels in the river, which in turn have affected the direction of the flow. In this investigation, the study area consists of the portion of the WBGCR from Indianapolis Boulevard west to the Indiana-Illinois state line (Figure 2).

1.1 Background

Information from a number of sources indicates that the GCR drainage basin is one of the most highly industrialized areas of the United States (Bright 1988; Brannon *et*

al. 1989; Ryder 1993). The land surrounding the GCR includes primarily industrial and commercial properties, interspersed with residential areas. Some of the industries that operate, or have operated, in the area include steel mills, foundries, chemical plants, packing plants, a distillery, a concrete/cement fabricator, oil refineries, and milling and machining companies (Ryder 1993). Permitted discharges from industrial operations, municipal WWTPs, and other sources (Figure 3) contribute substantial quantities of wastewater to the river system. Non-point sources of contaminants to the system include urban and industrial runoff, combined sewer overflows (CSOs), leachate or overflow from a number of wastefills or ponds, and spills of pollutants in and around industrial operations (Brannon *et al.* 1989). Releases of waste and wastewater from these (and possibly other) sources have resulted in the contamination of surface water, ground water, sediment, and biota with a variety of toxic and bioaccumulative substances (MacDonald and Ingersoll 2000). Some of the chemicals that have been documented in environmental media in the GCR include heavy metals, phenols, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, cyanide, and several other organic chemicals (Crane 1996; Cohen *et al.* 2000).

In response to concerns regarding contamination in the watershed, the International Joint Commission (IJC) designated the GCR and IHC as one of 43 Great Lakes Areas of Concern (AOCs) under the Great Lakes Water Quality Agreement of 1978 (Agreement; IJC 1989). This designation indicated that aquatic resources within the area had been degraded to such an extent that one or more beneficial uses had been impaired. The Agreement directed that a Remedial Action Plan (RAP) be developed and implemented at each AOC to facilitate the restoration of the beneficial uses. In response to this imperative, Indiana Department of Environmental Management (IDEM) submitted a Stage 1 RAP to the IJC in 1991 and a Stage 2 RAP in 1997 (IDEM 1991; 1997).

Following settlement with Industrial Users of the Hammond Sanitary District in February 1997, a Trust Agreement for the Grand Calumet River Restoration Fund (GCRRF) was established by a Memorandum of Understanding (MOU) among the

United States Environmental Protection Agency (USEPA), United States Fish and Wildlife Service (USFWS), Indiana Department of Natural Resources (IDNR), and Indiana Department of Environmental Management (IDEM). Representatives of each of these organizations comprise the GCRRF Council, which is addressing and correcting environmental contamination in part of the area of concern. Settlements with responsible parties on the WBGCR provided funds for the GCRRF Council to initiate the cleanup of contaminated sediments and remediation and restoration of natural resources in the WBGCR. In the longer term, the State and its partners (USFWS, USEPA, and the U.S. Army Corps of Engineers) will develop and implement remedial and restoration strategies that address contaminated sediment-related issues elsewhere in the IHAOC. Such efforts will, to the extent possible, be coordinated with other relevant programs [e.g., Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), State Voluntary Remediation Program] and initiatives (e.g., development of total maximum daily load, environmental dredging feasibility study) to address broad environmental contamination issues within the AOC.

1.2 Effects of Contaminated Sediments on Ecological Receptors

As indicated above, the results of several investigations have demonstrated that the WBGCR has been contaminated by toxic and bioaccumulative substances. The sediments throughout the WBGCR are highly contaminated with heavy metals and various organic compounds, including semivolatile organic compounds (SVOCs), chlorinated pesticides, and PCBs (MacDonald *et al.* 2002a; 2002b). Although a baseline ecological risk assessment (BERA) has not been completed on the WBGCR, the results of several investigations demonstrate that ecological receptors have been adversely affected by exposure to chemicals of potential concern (COPCs) in the WBGCR.

In 1999, Ingersoll and MacDonald (1999) conducted an assessment of sediment injury in the WBGCR using data and information that had been collected between 1982 and 1994 (check these dates). The results of this investigation demonstrated that the concentrations of sediment-associated COPCs in the WBGCR were sufficient to injure sediment-dwelling organisms. In addition, the results of whole-sediment and pore-water toxicity tests confirmed that WBGCR sediments were harmful to benthic invertebrates and fish. Furthermore, the structure of benthic invertebrate communities were altered throughout the WBGCR, as evidenced by a shift toward pollution-tolerant species and a loss of preferred fish food organisms. Fish populations were also reduced in the WBGCR due to the loss or degradation of habitat associated with inputs of sewage sludge and other substances. Various metals (arsenic, cadmium, chromium, copper, lead, mercury, 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 (e.g., sediment oxygen demand, and unionized ammonia) were identified as the substances that were causing or substantially-contributing to sediment injury in the WBGCR [i.e., the contaminants of concern (COCs)].

Subsequently, MacDonald and Ingersoll (2000) and MacDonald *et al.* (2002a) conducted a broader assessment of sediment injury in the IHAOC, including the WBGCR from Indianapolis Boulevard to the Indiana/Illinois state line. The results of this follow-up investigation, which utilized data collected between 1970 and 2000, showed that the levels of COPCs (i.e., metals, PAHs, PCBs, unionized ammonia, and/or phenol) in whole sediment and pore water were sufficient to injure sediment-dwelling organisms. Several of these substances (i.e., metals, PAHs, and PCBs) were also significantly negatively correlated with amphipod (*H. azteca*) survival in 10-d toxicity tests (Ingersoll *et al.* 2002). In addition, the results of toxicity tests confirmed that whole sediments, pore water, and/or elutriates were toxic to aquatic organisms. That benthic invertebrate communities were significantly altered relative to reference sites provided further confirmatory evidence that injury to sediments and sediment-dwelling organisms had occurred in this reach of the river (MacDonald *et al.* 2002a).

MacDonald and Ingersoll (2000) and MacDonald *et al.* (2002b) also assessed injury to fish and wildlife resources in the WBGCR. The results of this study demonstrated that contaminated sediments were adversely affecting fish and wildlife species in at least four ways. First, pore-water samples from the WBGCR were shown to be severely toxic to fish. Second, alteration of benthic invertebrate communities resulted in a reduction in the abundance of preferred fish food organisms. Third, fish populations inhabiting the WBGCR were found to be severely reduced, most likely as a result of severe habitat degradation. Finally, the concentrations of sediment-associated contaminants frequently exceeded the levels that have been established to protect piscivorous wildlife species (e.g., herons, kingfishers, and mink; MacDonald *et al.* 2002b). Therefore, it was concluded that contaminated sediments were adversely affecting fish and wildlife resources utilizing habitats in the WBGCR.

Following the completion of the sediment injury assessments, the site was further characterized to determine the nature, magnitude, and spatial extent of contamination and associated effects on sediment-dwelling organisms (FWENC 2002; 2003; Kemble *et al.* 2002; 2003). The results of these follow-up sediment investigations showed that metals, PAHs, and/or PCBs were present at elevated levels (i.e., above probable effect concentrations; PECs) in all of the reaches examined. Sediments with elevated concentrations of these and other substances (e.g., DDTs) extended from the sediment-water interface to depths of up to 3.5 meters. Importantly, non-aqueous phase liquids (NAPL) were detected in sediments collected from several of the reaches investigated, suggesting that shallow groundwater may be also be contaminated by these substances (FWENC 2003). The results of toxicity tests conducted on the sediment samples collected in this investigation showed that the samples with elevated whole-sediment chemistry were frequently toxic to the amphipod, *Hyalella azteca*, in 28-day exposures (Kemble *et al.* 2002; 2003).

1.3 Functional Equivalence of Existing Studies to a Remedial Investigation

As indicated above, the results of several investigations have demonstrated that the WBGCR has been contaminated by toxic and bioaccumulative substances. The concentrations of a number of these substances in whole sediments and/or pore water are sufficient to injure bed sediments and sediment-dwelling organisms (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a). In addition, direct exposure to contaminated sediments has been shown to cause toxicity in benthic macroinvertebrates and fish (Simon 1986; Hoke *et al.* 1993; Kemble *et al.* 2002; 2003). Adverse effects on wildlife, through bioaccumulation in the food web, are also predicted based on the concentrations of certain COPCs in bed sediments (MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a).

Remedial investigations and associated feasibility studies are the building blocks of an environmental impact assessment (EIS) and are typically undertaken at hazardous waste sites that are being addressed under the CERCLA (i.e., for National Priority List sites and certain cooperative sites). The WBGCR is not a CERCLA (Superfund) site and it is not listed under Indiana's state cleanup program, therefore the formal remedial investigation/feasibility (RI/FS) study process does not apply. However, the documents and investigations that are being prepared and conducted are similar in many ways to an RI/FS. In general, RIs typically involve development of a conceptual site model (CSM), assessment of the fate and transport of COPCs, evaluation of the nature and extent of contamination, assessment of risks to ecological receptors, and assessment of risks to human health. Although a formal EIS or RI/FS has not been conducted on the WBGCR, it can be reasonably argued that the work that has been completed to date is consistent with the EIS or RI process for the following reasons:

- Information in the key elements of a conceptual site model (i.e., sources and releases of COPCs, environmental fate of COCs, potential exposure pathways, and ecological receptors at risk) has been generated by various

investigators and summarized by the Natural Resources Trustees (1997) in a manner that facilitated the development of an NRDA plan that could be used to assess injury to natural resources. A more cohesive CSM, that integrates the information from various sources, is presented in this document and in TtEC (2005a);

- The fate and transport of COCs in the WBGCR was evaluated by Bierman (1995);
- Historic studies on the sediment quality conditions in the WBGCR have been compiled, evaluated, and summarized to document the nature and extent of contamination (MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a; 2002b; 2003a);
- Two major sediment characterization efforts were conducted to document the nature and spatial extent of contamination in surface and subsurface sediments along the entire WBGCR (FWENC 2002; 2003);
- The equivalent of a screening-level ERA was conducted to assess injury to benthic invertebrates, fish, and wildlife in the WBGCR (MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a; 2002b);
- The equivalent of the baseline ERA was conducted to assess injury to sediments and sediment-dwelling organisms in the WBGCR (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a). That is, a risk-based approach was used in the assessment and the results were supported by multiple lines of evidence;
- These studies also resulted in identification of COCs at the site (i.e., those COPCs that were causing or substantially-contributing to sediment injury); and,
- A baseline human health risk assessment (HHRA) was completed by TtEC (2005a). Injury to human uses of the WBGCR was assessed in an earlier investigation (MacDonald *et al.* 2003b).

Work completed by USFWS, IDEM, and others on the WBGCR provides the information needed to estimate the hazards posed by environmental contaminants to ecological receptors in the WBGCR. Accordingly, the GCRRF Council decided to expedite the ERA process by focusing on key receptor groups (i.e., the benthic invertebrate community) and developing risk-based tools that can be used to classify sediment samples in terms of the risks that they pose to benthic organisms. This decision was made with the understanding that the microbial, aquatic plant, and fish communities are typically less sensitive to the COPCs that occur in WBGCR sediments than are benthic invertebrates (i.e., toxicity thresholds for whole-sediment chemistry that are protective of the benthic invertebrate community are typically lower than those for the other receptor groups; MacDonald *et al.* 2003a).

In making this decision, the GCRRF Council also considered the uncertainties associated with assessing risks to wildlife associated with indirect exposure to sediment-associated COPCs (i.e., through bioaccumulation and associated dietary exposure) and recognized that monitoring tissue residue levels in aquatic organisms during the restoration process would provide a more direct means of evaluating risks to aquatic-dependent wildlife than would assessing risks based on whole-sediment chemistry. It was further understood that remediation of contaminated sediments to address risks to the benthic community would likely reduce risks to wildlife (i.e., by reducing the concentrations of bioaccumulative COPCs in sediments and, thereby, likely resulting in lower levels of tissue-associated COPCs) and that application of a virtual remediation approach would provide a basis for determining if such risks would be reduced to tolerable levels.

1.4 Purpose of this Report

With the completion of the sediment injury report, the conclusion of the baseline human health risk assessments, and the establishment of remedial action objectives (RAOs; TtEC 2005b), risk managers now need to establish preliminary remediation

goals (PRGs) to support remedial action planning at the site. The RAOs articulate the narrative intent of any remedial actions that are undertaken to address risks to human health and/or ecological receptors at the site. The numerical PRGs complement the RAOs by defining the concentrations of sediment-associated COCs or COC mixtures that correspond to thresholds for intermediate and high risks to human health and ecological receptors (i.e., that will provide a high or moderate level of protection for humans, aquatic-dependent wildlife, and aquatic organisms that are exposed to sediment-associated COCs, either directly or indirectly). Establishment of such RAOs and PRGs enable risk managers to evaluate various remedial alternatives and identify the ones that will reduce risks to human health and/or ecological receptors at the site to acceptable levels.

The purpose of this report is to provide the GCRRF Council (i.e., risk managers) with key risk-based tools for evaluating remedial options for restoring beneficial uses in the WBGCR. More specifically, this document presents the PRGs that were developed to identify the concentrations of sediment-associated COCs that pose an intermediate risk and a high risk to sediment-dwelling organisms.

The benthic PRGs are intended to support the remedial alternatives analysis by defining the concentrations of COCs that pose tolerable risks to the benthic invertebrate community. Because previous studies have shown that benthic invertebrates tend to be relatively sensitive to sediment-associated COCs (MacDonald *et al.* 2003a), it is anticipated that the benthic PRGs will also provide an adequate level of protection for other ecological receptor groups. Nevertheless, GIS-based spatial analysis tools will also be used to estimate average concentrations of key bioaccumulative COCs (e.g., mercury and total PCBs) in sediment following implementation of the preferred remedial alternative. Simple bioaccumulation and food web models will then be used to estimate potential exposure and risks to aquatic-dependent wildlife, post-remediation. The results of this virtual remediation will be presented in the remedial alternatives development report.

This report is organized into a number of sections to facilitate access to the information associated with the PRGs for aquatic receptors including:

- Introduction (Chapter 1);
- Study Approach (Chapter 2);
- Establishment of Remedial Action Objectives (Chapter 3);
- Identification of Contaminants of Concern (Chapter 4);
- Development of a Conceptual Site Model (Chapter 5);
- Development and Evaluation of Preliminary Remediation Goals for Benthic Invertebrates (Chapter 6); and
- Summary and Conclusions (Chapter 7).

A series of technical appendices are also included to provide the reader with access to ancillary information related to the PRGs. Finally, a list of acronyms is provided to define the various terms that are used in this document.

Chapter 2 Study Approach

2.0 Introduction

This investigation was conducted to provide the Grand Calumet River Restoration Fund (GCRRF) Council (IDEM, IDNR, USFWS, and USEPA) with ecological risk-based PRGs for aquatic receptors for evaluating various remedial alternatives for the WBGCR. A step-wise approach was used in this study to derive such PRGs, which included:

- Establishment of RAOs (TtEC 2005b);
- Identification of COCs;
- Development of a conceptual site model (CSM);
- Compilation of matching sediment chemistry and toxicity data;
- Development of initial PRGs for the benthic invertebrate community (i.e., benthic PRGs, which are considered to be applicable to other aquatic receptors);
- Evaluation of the reliability of benthic PRGs; and,
- Final selection of PRGs for benthic receptors.

Each of these steps is described in the following sections of this document.

2.1 Establishment of Remedial Action Objectives

The first step in the PRG development process involved the establishment of RAOs for the WBGCR that apply to aquatic and aquatic-dependent organisms. Remedial action objectives are intended to describe the narrative intent of any remedial actions that are undertaken to address risks to the ecological receptors that are exposed to

COCs in the WBGCR. That is, the RAOs describe the desired future condition of the study area, once remedial actions have been completed. RAOs are important because they provide a basis for risk managers and the public to establish a shared vision for the future in a manner that guides the remedial action planning process. The process that was used to establish the RAOs for water, sediment, and biota in the WBGCR, involved soliciting input from GCRRF Council members regarding the interests and needs that have been expressed by government agencies, non-governmental organizations, and the public regarding the past, current, and future uses of the WBGCR. Using this information, the GCRRF Council members were asked to articulate ecosystem goals and objectives for the WBGCR that define the desired future condition of the river, based on the input that they have received from stakeholders at various public meetings conducted within the region. These ecosystem goals and objectives were then used to develop draft RAOs that describe the narrative intent of any remedial actions that are undertaken to address risks to aquatic receptors at the site. Subsequently, the draft RAOs were reviewed and refined by the risk managers to ensure that they will meet their needs during the remedial action planning (RAP) process (TtEC 2005b).

2.2 Identification of Contaminants of Concern

Identification of COCs (i.e., those substances that are causing or substantially-contributing to sediment injury) represents an essential element of the overall PRG development process. Ingersoll and MacDonald (1999) assessed sediment injury in the WBGCR to support the U.S. Department of Justice in litigation against Hammond Sanitary District for violations of the Clean Water Act. Subsequently, MacDonald and Ingersoll (2000) assessed injury to sediments and sediment-dwelling organisms in the IHAOC, including the WBGCR, to support a broader Natural Resource Damage Assessment of the study area. In addition to determining if sediment injury had occurred in the WBGCR, these investigators evaluated the spatial extent of sediment injury and identified the toxic and bioaccumulative COCs within the study

area. Subsequently, several additional studies were conducted to fill outstanding data gaps in the WBGCR (i.e., Kemble *et al.* 2002; 2003; FWENC 2002; 2003). Collectively, the results of these investigations were used to establish the COCs for ecological receptors for the WBGCR.

2.3 Development of a Conceptual Site Model

The third step in the PRG development process involved the development of a CSM that describes the key relationships between stressors and receptors in the WBGCR. The CSM was developed by compiling information on the sources and releases of COCs, the fate and transport of COCs, and the potential effects of these COCs on ecological receptors utilizing habitats in the WBGCR. This information was then used to identify the assessment endpoints of greatest importance relative to ecological receptors. The CSM and related information showed that it would be most efficient to derive PRGs for the benthic community because such PRGs would likely be protective of the microbial, aquatic plant, and fish communities (MacDonald *et al.* 2003a) and because they could be applied in a virtual remediation approach for determining if risks to aquatic-dependent wildlife would be reduced to tolerable levels by various remedial alternatives that rely on the benthic PRGs.

2.4 Compilation of Matching Sediment Chemistry and Toxicity Data

Development of site-specific PRGs for the WBGCR necessitates the compilation of matching sediment chemistry and sediment toxicity data from the study area (MacDonald *et al.* 2003a). To support the assessment of sediment injury in the WBGCR and IHAOC, the matching sediment chemistry and sediment toxicity data from the study area were acquired, evaluated, and compiled in a relational database

in MS Access format (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000). Since the original database was developed, several additional data sets on the WBGCR have been generated to fill identified data gaps, including additional assessments of sediment toxicity in Roxana Marsh (Kemble *et al.* 2002; FWENC 2002), in WBGCR mainstem (Kemble *et al.* 2003; FWENC 2003), and in the East Chicago Sanitary District (ECSA) outfall stream (ASci 2001). These data sets were acquired and evaluated to determine if they met project data quality objectives (see Appendix 2 for a summary of the selection criteria that were used to evaluate these candidate data sets). The data sets that met these selection criteria were incorporated into the project database (see Table 1 for a listing of the matching whole-sediment chemistry and toxicity data that were used in this investigation).

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

To support subsequent interpretation of the sediment chemistry data, the total concentrations of several chemical classes were determined for each sediment sample, using the procedures described in MacDonald and Ingersoll (2000). Specifically, the concentrations of total PAHs were calculated by summing the concentrations of up to 13 individual PAHs, including acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, benz(a)anthracene, dibenz(a,h)anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene. For PCBs, the concentrations of total PCBs were determined using various procedures, depending on how the data were reported in the original study. If only the concentrations of total PCBs was reported in the study, then those values were used directly. If the concentrations of various Aroclors (e.g., Aroclor 1242, Aroclor 1248) were reported, then the concentrations of the various Aroclors were summed to

determine the concentration of total PCBs. When the concentrations of the 16 to 20 National Institute of Standards and Technology (NIST) congeners were reported, then these concentrations were summed and multiplied by 2.1 to estimate total PCB concentrations (Lauenstein and Cantillo 1993). When the concentrations of more than 20 individual congeners were reported, these values were summed to determine total PCB concentrations. If both Aroclors and PCB congeners were measured, then the higher sums calculated using the two procedures was used to establish the concentration of total PCBs.

In calculating the total concentrations of the various chemical classes, less than detection limit values were assigned a value of one-half of the detection, except when the detection limit was greater than the consensus-based probable effect concentration (PEC; MacDonald *et al.* 2000; or an alternate sediment quality guideline if a PEC was not available). In this latter case, the less than detection limit result was not used in the calculation of the total concentration of the substance.

Simple chemical mixture models were developed to support the development of risk-based PRGs (MacDonald *et al.* 2000; USEPA 2000; Ingersoll *et al.* 2001; MacDonald *et al.* 2002c; 2003a). To facilitate the development of these models, PEC-quotients (PEC-Qs; i.e., COC concentration divided by the corresponding PEC) were calculated for each chemical and chemical class included in the list of COCs, on a dry weight (DW) basis or an organic carbon (OC)-normalized (i.e., at 1%OC) basis. Subsequently, mean PEC-Qs for metals were calculated for each sample using the PEC-Qs that were determined for up to eight metals (i.e., arsenic, cadmium, chromium, copper, lead, nickel, mercury, zinc; MacDonald *et al.* 2000; USEPA 2000; Ingersoll *et al.* 2001). The PEC-Qs for total PAHs or total PCBs were used directly to develop the chemical mixture models. In total, nine chemical mixtures were considered, including:

- Mean PEC-Q_{metals (DW)};
- Mean PEC-Q_{metals (DW@1%OC)};

- $PEC-Q_{tPAH (DW)}$;
- $PEC-Q_{tPAH (DW@1\%OC)}$;
- $PEC-Q_{tPCB (DW)}$;
- $PEC-Q_{tPCB (DW@1\%OC)}$;
- Mean $PEC-Q_{metals (DW), tPAHs (DW), tPCBs (DW)}$;
- Mean $PEC-Q_{metals (DW@1\%OC), tPAHs (DW@1\%OC), tPCBs (DW@1\%OC)}$; and,
- Mean $PEC-Q_{metals (DW), tPAHs (DW@1\%OC), tPCBs (DW@1\%OC)}$.

To support the compilation and subsequent analysis of the information on sediment quality conditions in the WBGCR, a relational project database was developed in MS Access format. All of the chemistry, toxicity, and benthic community data compiled in the database were georeferenced to facilitate mapping and spatial analysis using geographic information system (GIS)-based applications (i.e., ESRI's ArcView and Spatial Analyst programs).

2.5 Development of Initial Preliminary Remediation Goals for the Benthic Invertebrate Community

Initial PRGs for the benthic invertebrate community were developed for each of the COCs and the various chemical mixtures using the following procedures. In the first step of the process, the matching sediment chemistry and sediment toxicity data that were most relevant for deriving concentration-response relationships were identified. More specifically, the results of 28-d toxicity tests with the amphipod, *Hyaella azteca*, conducted on whole-sediment samples from the WBGCR were used preferentially in the derivation of PRGs. These data were augmented by the results of 10-d whole-sediment toxicity tests in the WBGCR database that were designated as toxic to *H. azteca*. This species was targeted for data collection due to its relative

sensitivity (i.e., the results of earlier studies suggested that midges, *Chironomus dilutus*, are less sensitive to sediment-associated COPCs in many Great Lakes AOCs; USEPA 2000; Ingersoll *et al.* 2001) and availability of high quality data for the study area. These latter data were compiled along with the 28-d toxicity tests results assuming samples that were found to be toxic in 10-d exposures would also be toxic if the duration of exposure had been extended to 28 days. Samples that were found to be not toxic in 10-d toxicity tests with this species were not used, because it was not possible to determine if such samples would be toxic or not toxic in 28-d exposures. The results of toxicity tests which employed photoactivation were not used to derive the PRGs (Kemble *et al.* 2002; 2003).

In the second step of the process, reference sediment samples were identified. In this investigation, a reference sediment was defined as a whole sediment from a location near the area of concern used to assess sediment conditions exclusive of the material(s) of interest (ASTM 2004a). To identify reference sediment samples, the project database was screened to identify samples within the WBGCR database in which the concentrations of all measured COCs were less than the corresponding PEC (MacDonald *et al.* 2000), mean PEC-Qs were <0.1 (USEPA 2000; MacDonald *et al.* 2003a) and 28-d whole-sediment toxicity data were available. A total of 35 of the 105 samples within the WBGCR database met these criteria and were used to define the normal range of background conditions (i.e., the 95% prediction limits; MacDonald *et al.* 2002a).

Next, the matching sediment toxicity and chemistry data for each COC and COC mixture were compiled from the project database. These data were screened on a COC-by-COC basis to identify the samples that were most relevant for deriving PRGs. Toxic samples in which the measured concentration of a COC was less than the average concentration of that substance in the not toxic samples from the same study were not used to derive the PRGs for that substance (i.e., using the procedures of Field *et al.* 1999; 2002). More specifically, data for this screening procedure provides a basis for identifying the concentrations of a COC that could, possibly, be toxic to amphipods (i.e., when present in complex mixtures with other COCs). The

remaining data for a COC or COC mixture were then sorted in order of ascending concentrations and compiled into groups of 15 samples. For each group of samples, the average concentration of the COC or COC mixture, the average survival of amphipods, and the incidence of toxicity (i.e., proportion of samples that were toxic) were calculated. These summarized data were then plotted and used to develop site-specific concentration-response relationships (i.e., by fitting non-linear regressions to the data; Ingersoll *et al.* 2001; MacDonald *et al.* 2002c; 2003a). The summarized data were fitted using three-parameter sigmoidal models, four-parameter sigmoidal models, three-parameter logistic models, or four-parameter logistic models. The model of best fit was selected based on a visual examination of the plot and the resultant correlation coefficient (r^2 value). Only statistically significant regressions ($p < 0.05$; as determined based on the ANOVA F statistic) were used to define the concentration-response relationships. Such relationships were developed based on the observed incidence of toxicity (IOT; percent toxic samples) and the observed magnitude of toxicity (MOT; percent mortality; MacDonald *et al.* 2003a).

For certain substances (i.e., total PCBs), the available matching sediment chemistry and sediment toxicity data from the WBGCR did not support the derivation of site-specific concentration-response relationships (i.e., $n < 60$). In such cases, it was necessary to augment the available data with matching sediment chemistry and sediment toxicity data from elsewhere in the IHAOC, elsewhere in Great Lakes Basin and elsewhere in the United States (USEPA 2000). Accordingly, the data in the SedTox database were accessed and appended to the project database to facilitate the development of the concentration-response models for PCBs.

Following the development of the concentration-response relationships, the normal range of response rates for amphipods exposed to reference sediment samples was determined (i.e., following the procedure outlined in MacDonald *et al.* 2002c). First, the distribution of the response data was evaluated and found to approximate a beta distribution. Next, the response data for the identified reference sediment samples were transformed to create a normal distribution and the 2.5th and 97.5th percentile values were calculated. Following reverse transformation, the 2.5th percentile

response value (i.e., 93.5% survival) was used to define the lower limit of the normal range of amphipod responses following exposure to reference sediment samples from the WBGCR. By comparison, the incidence of sediment toxicity for amphipods exposed to reference sediment samples was determined by calculating the percent of reference samples that were toxic to amphipods (i.e., 1 of the 35 reference samples were toxic; 3%). Therefore, the survival of amphipods, *Hyalella azteca*, in 28-d toxicity tests tends to be high (i.e., $\geq 93.5\%$) and the incidence of toxicity tends to be low (i.e., 3%; 1 of 35) in reference sediment samples from the WBGCR.

The risk-based PRGs were derived for the various COCs and COC mixtures by considering the response rates for amphipods exposed to relatively uncontaminated (i.e., reference) sediment samples. More specifically, the concentrations of COCs that posed a low risk to sediment-dwelling organisms were determined by calculating the response rate that represented a 10% decrease in survival from that for reference samples. This target response rate is consistent with the approach that was used to develop PRGs in the Calcasieu Estuary (MacDonald *et al.* 2003a). Using this approach sediment samples with amphipod survival rates of $>84.2\%$ were considered to pose a low risk to sediment-dwelling organisms. The COC concentrations that corresponded to this response rate were determined using the concentration-response relationships that were established using the matching sediment chemistry and toxicity data. This concentration was used directly as the preliminary PRG-Intermediate Risk (PRG-IR) for that COC (MacDonald *et al.* 2003a).

The concentrations of COCs that were considered to pose a high risk to sediment-dwelling organisms were derived using a similar procedure. Specifically, the response rate of amphipods exposed to sediments from the study area that represented a 20% decrease in survival from that for amphipods exposed to reference sediment samples was determined here as well. Using this approach, sediment samples with survival rates of amphipods of $<74.8\%$ were considered to pose a high risk to sediment-dwelling organisms. The concentration that corresponded to this response rate was determined using the concentration-response relationships that were derived using the matching sediment chemistry and toxicity data for each COC and COC

mixture. This concentration was adopted as the preliminary PRG-High Risk (PRG-HR) for the COC and COC mixture (MacDonald *et al.* 2003a).

The PRGs that were based on the incidence of toxicity to amphipods were developed using procedures that were consistent with those that were used to derive the PRGs based on magnitude of toxicity (MacDonald *et al.* 2003a). First, the incidence of toxicity for reference sediment samples was determined by calculating the proportion of reference samples that were toxic to amphipods in whole-sediment toxicity tests (i.e., 3%). Then, the incidence of toxicity that corresponded to a 20% and 50% increase over reference conditions was determined (i.e., 22.4 and 51.5% incidence of toxicity, respectively). These target incidences of toxicity are consistent with the approach that was used to derive PRGs in the Calcasieu Estuary (MacDonald *et al.* 2003a). Using the corresponding concentration-response models, the concentrations that represented a 20% and 50% increase over reference conditions were calculated for each COC and COC mixture, and adopted as the preliminary PRG-IR and preliminary PRG-HR, respectively.

Application of the aforementioned procedures facilitated the development of two sets of initial PRGs (i.e., based on magnitude of toxicity and incidence of toxicity). Each set of PRGs was intended to establish the concentrations of COCs and COC mixtures that are associated with low ($<PRG-IR$), intermediate (i.e., moderate; $\geq PRG-IR$ and $\leq PRG-HR$), and high ($>PRG-HR$) risks to sediment-dwelling organisms. These PRGs were then evaluated to determine which would provide the most reliable tools for assessing various remedial alternatives for the WBGCR. See MacDonald *et al.* (2002c; 2003a) for more information on the approach that was used to derive concentration response relationships).

2.6 Evaluation of the Reliability of the Benthic Preliminary Remediation Goals

Two sets of PRGs (i.e., PRGs based on the incidence of toxicity and PRGs based on the magnitude of toxicity) were derived and considered for selection as the benthic PRGs for the WBGCR. Because the objective of this evaluation was to establish a single set of benthic PRGs that could be used to guide remedial actions within the river, both sets of PRGs were evaluated to determine which PRGs were most consistent with the RAOs that have been established for the site (i.e., to assess their reliability).

The reliability evaluation of the PRGs consisted of several steps. In the first step of the process, individual sediment samples were classified into three groups based on the concentration of the selected COC or COC mixture (e.g., total PAH concentrations below the PRG-IR, between the PRG-IR and PRG-HR, and above the PRG-HR). The samples that were classified into the low risk group based on chemical concentration were predicted to be not toxic to benthic invertebrates. The accuracy of this prediction was then evaluated by determining the proportion of samples within the low risk group that actually posed a low risk to benthic invertebrates, based on the results of the whole-sediment toxicity tests with *H. azteca*. A similar procedure was used to assess the reliability of PRG-HRs.

The criteria for evaluating the reliability of the PRG-IRs (i.e., IOT- and MOT-based PRGs) were established on an *a priori* basis, using the RAOs that are established for the WBGCR. These criteria were then used to select the PRGs that were most consistent with the sediment management narratives described in the RAOs. More specifically, the PRG-IRs were considered to be reliable if the incidence of toxicity was <20% at concentrations of COCs or COC mixtures below the PRG-IR (i.e., primary criterion) and if the incidence of toxicity was >50% at concentrations of COCs or COC mixtures above the PRG-IR (i.e., secondary criterion). Therefore, the probability of observing false negative results would be less than 20% at COC concentrations below the PRG-IR (i.e., <20% of the samples with COC

concentrations below the PRG-IR would be toxic). Additionally, the probability of observing false positive results at COC concentrations above the PRG-IR would be less than 50%. The primary criterion provides a means of determining how consistent the PRG-IR is with the RAOs, while the secondary criterion provides a basis for determining if a reasonable concentration-response relationship was established (i.e., to verify that the incidence of toxicity increases with increasing COC concentrations).

The criteria for evaluating the PRG-HRs were also established using the sediment management narratives articulated in the RAOs. More specifically, the PRG-HRs were considered to be reliable if the incidence of toxicity was >80% at COC concentrations above the PRG-HR (i.e., primary criterion) and if the incidence of toxicity was <50% at COC concentrations between the PRG-IR and the PRG-HR (i.e., secondary criterion). Therefore, the probability of observing false positive results would be less than 20% at concentrations of COCs or COC mixtures above the PRG-HR (i.e., $\geq 80\%$ of the samples with concentrations above the PRG-HR would be classified as toxic). Additionally, the probability of observing false negative results would be less than 20% at concentrations of COCs or COC mixtures below the PRG-HR (see Appendix E1 and E2 of MacDonald *et al.* 2002c; MacDonald *et al.* 2003a for the underlying rationale for these criteria). The primary criterion provides a basis for verifying that the PRG is consistent with its narrative intent, while the secondary criterion provides a means of confirming that a reasonable concentration-response relationship was established.

2.7 Final Selection of the Benthic Preliminary Remediation Goals

The results of the reliability evaluation were used to select the PRGs that are most consistent with the sediment management objectives described in the RAOs. More specifically, this evaluation was undertaken to identify the PRGs that, if applied in the WBGCR, would result in false positive and false negative rates of $\leq 20\%$.

Accordingly, the PRGs (PRG-IR and PRG-HR) for each COC and COC mixture that best satisfied these criteria were identified. If these criteria could be met using a single PRG (i.e., a PRG-IR or PRG-HR), then that PRG was recommended for the COC or COC mixture because it would simplify the remedial alternatives evaluation process.

Chapter 3 Development of Preliminary Remedial Action Objectives

3.0 Introduction

Remedial action objectives provide the foundation upon which restoration cleanup alternatives are developed. RAOs are usually developed once risk managers have determined that significant risks to human health and/or the environments are present at a site. These risks, together with other regulatory requirements [e.g., applicable or relevant and appropriate requirements (ARARs)], are considered as the RAOs are defined. Significant risks to human health and the environment have been documented for the WBGCR (Crane 1996; MacDonald and Ingersoll 2000; TtEC 2005a). This chapter is intended to provide ready access to the RAOs that were established for the WBGCR by the GCRRF Council, as articulated in TtEC 2005b).

Remedial action objectives are required to support remedial action planning for the WBGCR. The RAOs are needed to clearly articulate the intent of any remedial actions that may be undertaken to address risks to human health and/or ecological receptors at the site. PRGs are then developed to address the RAOs. PRGs are the target concentrations in the affected media that correspond to the specific RAOs. For example: if the RAO is protection of humans from incidental ingestion of sediments during recreational activities, the PRG may be the concentrations of the COCs that correspond to an acceptable risk level.

Establishment of RAOs, and associated PRGs, will also enable risk managers to evaluate the various remedial alternatives that are identified for the WBGCR relative to their ability to reduce risks to human health and ecological receptors to acceptable levels and their relative costs. The development of RAOs requires a long-term vision for the water body that reflects the interests and needs of stakeholders, as articulated in ecosystem goals and objectives (Section 4.1). The following subsections describe

candidate ecosystem goals, ecosystem objectives, and preliminary RAOs that were developed based on the current understanding of the stakeholder interests, as expressed by the GCRRF Council. The GCRRF Council has held ten public meetings since February 20, 2002 to gain such public input. It is anticipated that these RAOs may be further refined based on additional comments that are provided by the public.

3.1 Long-Term Ecosystem Goals and Objectives

Ecosystem goals are broad narrative statements that define the management goals that have been established for a specific ecosystem. Definition of management goals for the aquatic ecosystem is a fundamental step towards the development of defensible plans for assessing and managing the ecosystem under investigation. Establishment of ecosystem goals requires input from a number of sources to ensure that societal values are adequately represented. Open consultation with the public is the primary source of information for defining these goals; however, input from government agencies, non-government agencies, and other stakeholders is also essential to the process. Importantly, information on the past, current, and potential future uses of the aquatic resources within the basin should be solicited to support the development of ecosystem goals.

Restoration of natural resources and their uses has been identified as an important long-term goal for the WBGCR. However, this goal is too general to support the development of meaningful planning, research, and management initiatives for the WBGCR. To be useful, this ecosystem goal must be further clarified and refined to establish specific objectives that are more closely linked with ecosystem science (Harris *et al.* 1987). In turn, more-specific ecosystem objectives support the identification of indicators and metrics that provide the information needed to more directly assess the health and integrity of the ecosystem. [See MacDonald and Ingersoll (2002) for a more detailed discussion of the ecosystem-based framework for assessing and managing contaminated sediments].

As indicated earlier in this document, in order to expedite the restoration alternative development and evaluation process, the RAOs will focus on the benthic invertebrate community as the key ecological receptor group; that is, risk-based tools will be used to classify sediment in terms of the risks that they pose to benthos. The GCRRF Council made this decision based on the fact that benthic invertebrates are typically more sensitive to the WBGCR COPCs than other ecological receptors (e.g., microbial, aquatic plant, and fish communities). It is generally believed for the WBGCR that remediating the contaminated sediments and focusing on the reduction of risks to the benthic community will result in a corresponding reduction of risks to wildlife by reducing the concentrations of COPCs that bioaccumulate in sediments. The following is a list of some of the ecosystem objectives that have been identified to date (see <http://www.in.gov/idem/land/federal/nrda/grandcalumet/index.html>):

- Restore benthic conditions to a state that will support a healthy and diverse benthic community;
- Restore aquatic environmental conditions to a state that will:
 - reduce the incidence, magnitude, and extent of undesirable algal growth (eutrophication) and support healthy and diverse periphyton communities,
 - support a healthy and diverse fish community (at minimum, conditions should be sufficient to support a balanced warm-water fishery),
 - reduce the incidence of fish tumors and other deformities to background levels,
 - reduce the incidence of bird or animal deformities or reproductive problems to background levels, and
 - reduce the frequency of, or eliminate, fish consumption advisories;
- Restore aquatic, wetland, and terrestrial habitats to a state that will support healthy, diverse, and self-sustaining populations of aquatic-dependent avian and mammalian species; and

- Restore other human uses of the WBGCR, including primary contact recreation (i.e., swimming and wading) and secondary contact recreation (i.e., boating, hiking, etc.).

These ecosystem objectives provide a basis for establishing RAOs that reflect the interests and needs of stakeholders relative to the restoration of natural resource values within the WBGCR. In addition, achievement of these ecosystem objectives would eliminate 11 of the 14 use impairments that were identified in the Stage One Remedial Action Plan (RAP) for the IHAOC (IDEM 1991). The other use impairments that were identified in the Stage One RAP were related to drinking water quality, navigational dredging, and associated effects on agriculture and industry, and are not relevant to the WBGCR. Therefore, ecosystem objectives for restoring these beneficial uses were not identified for the WBGCR.

The ecosystem objectives listed above describe the desired future state of the WBGCR ecosystem. While it would be desirable to achieve all of these objectives, past uses of the watershed and ongoing industrial and urban land uses have the potential to influence the feasibility and effectiveness of restoration actions in the basin. Accordingly, it may not be realistic to expect that all of these ecosystem objectives will be achieved in the near term. Based on the preceding discussion, restoration of the benthic conditions will be a primary objective for this site. Nevertheless, it is appropriate to develop RAOs for the WBGCR that reflect these ecosystem objectives and provide a basis for developing restoration plans that will increase the likelihood of meeting them in the longer term.

3.2 Preliminary Remedial Action Objectives

Remedial action objectives are needed for each of the environmental media that have been degraded in association with human activities within the WBGCR, including surface water, ground water, soil, sediment, and biological tissues. However, while

this document presents the RAOs for surface water, sediments, and biological tissues, as stated earlier, the GCRRF Council does not have a mandate to develop and implement a restoration plan to address all of these media types. The GCRRF Council was charged specifically to identify remedial alternatives to address contaminated sediment-related issues only. It is anticipated that remedial measures that are implemented to address sediment contamination will also improve surface water quality and reduce the concentrations of bioaccumulative substances in the tissues of aquatic organisms. Concerns relative to surface water quality are also being addressed by IDEM and the U.S. Army Corps of Engineers through the development of total maximum daily loads (TMDLs) for selected COPCs in the Grand Calumet River basin.

As a result of this mandate, the RAOs presented in the following subsections have been segregated into primary RAOs (those addressing risks to benthic organisms exposed to contaminated sediments and pore water) and secondary RAOs (those addressing risk to other receptors exposed to sediment, pore water, surface water, and biological tissues).

3.2.1 Primary RAOs

3.2.1.1 Whole Sediment and Pore Water

The primary RAO for whole sediment and pore water that addresses risks to benthic invertebrates associated with direct exposure to contaminated sediments is presented below:

- ***RAO for benthic invertebrates:*** Minimize or prevent exposure to whole sediment and pore water that are sufficiently contaminated to pose intermediate or high risks, respectively, to the benthic invertebrate communities.

3.2.2 Secondary RAOs

3.2.2.1 Whole Sediment and Pore Water

The secondary RAOs for whole sediment and pore water that address risks to aquatic receptors and humans associated with direct exposure to contaminated sediments are presented below:

- **RAO for aquatic receptors:** Minimize or prevent exposure to whole sediments and pore waters that are sufficiently contaminated to pose intermediate or high risks, respectively, to microbial, aquatic plant, or fish communities (particularly for fish species that use sediment substrates for spawning and/or early rearing).
- **RAO for aquatic-dependent wildlife:** Minimize risks to sediment-probing bird associated with ingestion of sediments during feeding activities.
- **RAO for humans:** Minimize risks to human health associated with direct contact with sediments during primary contact recreation (swimming or wading) or maintenance activities (e.g., maintenance utility workers).

3.2.2.2 Surface Water

The RAOs for surface water that address risks to aquatic receptors, aquatic-dependent wildlife, and human health associated with exposure to contaminated surface water are presented below:

- **RAO for aquatic receptors:** Minimize or prevent exposure to surface waters that are sufficiently contaminated to pose intermediate or high risks, respectively to microorganisms, aquatic plants, aquatic invertebrates, or fish.
- **RAO for aquatic-dependent wildlife:** Minimize risks to avian or mammalian species associated with direct contact with or ingestion of surface waters.

- **RAO for humans:** Minimize risks to human health associated with incidental ingestion of surface waters during primary or secondary contact recreation.

3.2.2.3 *Biological Tissues*

The RAOs for the tissues of aquatic organisms (i.e., invertebrates and fish) that address risks to fish, aquatic-dependent wildlife, and human health associated with the bioaccumulation of COCs in the food web are presented below:

- **RAO for fish:** Reduce the concentrations of COCs in fish tissues to levels that are not associated with adverse effects on survival, growth, reproduction, or the incidence of lesions or tumors in fish.
- **RAO for aquatic-dependent wildlife:** Reduce the concentrations of COCs in the tissues of prey species to levels that do not pose unacceptable risks to insectivorous birds, sediment-probing birds, carnivorous-wading birds, piscivorous birds, piscivorous mammals, or omnivorous mammals.
- **RAO for humans:** Minimize or prevent exposure to fish tissues that are sufficiently contaminated to pose unacceptable excess lifetime cancer risks. Additionally, prevent exposure to fish tissues that are sufficiently contaminated to cause a non-cancer hazard index of greater than one.

Chapter 4 Identification of Contaminants of Concern

4.0 Introduction

This chapter provides a brief overview of the available information on the historic sources of contamination in the IHAOC in general and the WBGCR in particular. In addition, the COPCs that were initially identified by the trustees in the NRDA plan are described (Natural Resources Trustees 1997). Finally, the COCs for ecological receptors (i.e., for which PRGs are needed) are identified based on the sediment injury assessments (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a; 2002b) and data gap studies (Kemble *et al.* 2002; 2003; FWENC 2002; 2003) that have been conducted on the WBGCR.

4.1 Historic Sources of Contamination

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

- Eight major permitted industrial point-source dischargers [i.e., permitted under the National Pollutant Discharge Elimination System (NPDES)], including U.S. Steel, LTV Steel, ISPAT Inland Steel, PRAXAIR, CERESTA, BP Amoco, NIPSCO, and State Line Energy (IDEM 2004);

- Fifty-two properties listed in the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) as containing potentially uncontrolled hazardous wastes that require investigation;
- More than 400 facilities subject to regulation under the RCRA, which means that they generate, transport, treat, store, or dispose of hazardous wastes; and,
- Three municipal WWTPs (i.e., that are operated by the Hammond, Gary, and East Chicago Sanitary Districts).

In total, it was estimated that the IHAOC also received more than 11 billion gallons/year of untreated stormwater via 12 CSO outfalls (IDEM 1991). The locations of existing and historic outfalls within the IHAOC are shown in Figure 3.

4.1.1 Contaminant Sources in the West Branch of the Grand Calumet River

The WBGCR has received inputs of environmental contaminants from several sources over the past century. The available information on known major and minor sources of environmental contaminants to the WBGCR include:

- The East Chicago Sanitary District (ECSD) WWTP, which is located on the north side of the West Branch, just east of Indianapolis Boulevard. The plant is an oxidation ditch facility with mixed media filtration designed for an average daily flow of 15.0 million gallons/day (MGD), and achieves advanced wastewater treatment with a low carbonaceous biological oxygen demand (BOD), low total suspended solids, and a highly nitrified effluent. Disinfection is accomplished by ultraviolet light.
- The ECSD also operates a flow-through 80-million-gallon lagoon for CSO storage and treatment adjacent to the ECSD WWTP, north of the West Branch on the east side of Indianapolis Boulevard. Discharge of the settled

effluent is to the ECSD discharge channel located just east of Indianapolis Boulevard. The ECSD operates a separate stormwater pumping station located on the south side of the West Branch in Reach 2.

- The Sanitary District of Hammond (HSD) WWTP, located on the north bank of the West Branch, east of Columbia Avenue. The plant is an activated sludge facility with mixed media filtration designed for an average daily flow of 48.0 MGD of high-strength industrial waste, and achieves advanced wastewater treatment with a low carbonaceous BOD, low total suspended solids and a highly nitrified, dechlorinated effluent. Peak monthly flows average 55.0 MGD in the spring.

HSD is required to construct a detention basin to store peak wet weather flows pursuant to the consent agreement between HSD, USEPA, and IDEM. The location of this basin is most likely on the north side of the West Branch, west of Columbia Avenue. A new outfall to the West Branch from this basin may have to be constructed in the event that peak flows exceed the combined treatment/storage capacity at the HSD.

HSD is required to close its former sludge lagoons located on the north bank of the West Branch, east of Columbia Avenue. All sludge from the lagoons has been removed by the HSD. The lagoons were previously known to be contributing high ammonia loads to the West Branch. Now that the sludge has been removed, the extent of residual contamination contribution to the WBGCR is unknown.

- HSD also maintains a number of CSOs (i.e., at Johnson Avenue, Sohl Avenue, and Columbia Avenue) that discharge stormwater and untreated wastewater to the river during runoff events (Ryder 1993; HNTB 1995; Bell 1995).

The Columbia Avenue CSO located on the north side of the West Branch, just east of Columbia Avenue, operated by the HSD. This CSO is a major source of high strength untreated wastewater during rain events and is a major cause of non-attainment in the West Branch. The existing consent

agreement between HSD, EPA and IDEM requires that this CSO be eliminated by 2009.

The Johnson Avenue CSO located on the north side of the West Branch, just east of Johnson/Sohl Avenue, operated by the HSD. This CSO is a major source of high-strength untreated wastewater during rain events and is a major cause of nonattainment in the West Branch. The existing consent agreement between HSD, EPA and IDEM requires that this CSO be eliminated by 2009. HSD has advised EPA and IDEM that the possible route for the force main to phase out the CSO would be on the north side of the West Branch south of the City Baptist School.

The Sohl Avenue CSO located on the south side of the West Branch, just east of Sohl Avenue, operated by the HSD. This CSO is a major source of untreated wastewater during rain events and is a major cause of nonattainment in the West Branch. The existing consent agreement between HSD, EPA, and IDEM requires that this CSO be eliminated by 2009. HSD has advised EPA and IDEM that the possible route for the force main to phase out the CSO would be on the north side of the West Branch south of the City Baptist School.

The HSD has completed construction of a new separate stormwater outfall to the West Branch to facilitate its sewer separation of neighborhoods south of the West Branch with a storm drain installed along Howard Street. The outfall of this drain has been completed and enters the WBGCR at the end of Howard Street (1 block west of Columbia Avenue) in Reach 3.

- The NIPSCO/NiSource Manufactured Gas Plant (MGP) located on the south side of the West Branch, just west of Hohman Avenue. This MGP continues to be a source of constituents to the West Branch. A plan for voluntary remediation of the site by NIPSCO/NiSource has been submitted to IDEM for approval. The plan as presented would cut off the flow of constituents from the site to the West Branch.

- Contaminated sediment with coal tar characteristics within the West Branch from Hohman Avenue to the state line (Reaches 6 & 7). A plan for voluntary remediation of the West Branch Grand Calumet River from Hohman Avenue west to the extension of its property line (east of the next railroad bridge) has been submitted by NIPSCO/NiSource to IDEM for approval. The plan involves partial excavation of contaminated material followed by capping.
- Contaminated groundwater in Reach 4 has been documented by EPA as part of a well installation and sampling effort in the spring of 2004. A report to partially delineate the extent of contamination is still under preparation.
- The American Steel Foundries discharge is located on the north side of the West Branch between Calumet and Sohl Avenues in Reach 5. This is a minor industrial discharger.
- The Flexicore Cement discharge is located on the north side of the West Branch west of Hohman Avenue in Reach 7. This is a minor industrial discharger that discharges treated sanitary wastewater.

Some of the substances that have been released include total organic carbon (TOC; in the form of sewage particulates, etc.), nutrients, metals, oil and grease, phenolics, PAHs, phthalates, pesticides, and PCBs (Bright 1988; Polls *et al.* 1993; Hoke *et al.* 1993; Dorkin 1994; Ingersoll and MacDonald 1999).

In addition to these point-source discharges, there are a number of potential nonpoint sources of contaminants to the river (e.g., pipeline crossings, such as those maintained by BP/Amoco Pipeline, Buckeye/NORCO Pipeline, Westshore Pipeline, and Wolverine Pipeline; hazardous waste sites; etc.). Currently, there are 78 RCRA-listed sites located within 1 mile of the river channel; 10 of these sites are listed in the toxics release inventory, and spills have occurred at 10 of these sites.

A number of studies have been conducted to assess the nature, severity, and extent of contamination in the WBGCR (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000; FWENC 2002b; 2003; IDEM 2003). The results of these investigations demonstrate that surface water, groundwater, sediment, floodway soils, and biological tissues in the WBGCR have been contaminated by a variety of toxic and bioaccumulative substances. Of particular concern relative to the evaluation of restoration alternatives, sediments throughout the WBGCR are highly contaminated with heavy metals, PAHs, chlorinated pesticides, and PCBs (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a; 2002b; FWENC 2002b; 2003). In addition, PCBs and various organochlorine pesticides have been detected in fish tissues from the WBGCR.

4.2 Identification of Chemicals of Potential Concern

The Natural Resources Trustees (1997) developed an assessment plan for the IHAOC that focused on natural resource injuries and damages which are associated with the release of PCBs, oil and oil-related compounds, and metals. The purpose of this section is to briefly describe the three categories of COPCs that were identified by the Natural Resources Trustees (1997), focusing on general characteristics, sources, and environmental effects. More information on the sources, releases, environmental fate, and effects of these and other COPCs in the WBGCR is provided in MacDonald and Ingersoll (2000).

4.2.1 Polychlorinated Biphenyls

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

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

The chemical stability of PCBs makes them highly persistent in the environment after they have been released. Because they have relatively high octanol-water partitioning coefficients and low water solubilities, PCBs tend to accumulate in soils and sediments. Having accumulated in these environmental media, PCBs become available to biological organisms, typically moving through the food chain from invertebrates to fish, birds, mammals, and other wildlife. Despite general declines in observed concentrations of PCBs in wildlife since the manufacture of PCBs ceased more than 25 years ago, concentrations still occur at levels in certain areas that are sufficient to cause adverse effects in exposed organisms. The results of field and laboratory studies indicate that PCBs can be associated with a range of such effects, including impaired reproductive ability in fish, mammals and birds (Beyer *et al.* 1996; Eisler 1986).

For PCBs, non-polar narcosis represents a primary mode of toxicity. However, a subset of the 209 PCB congeners also exhibit dioxin-like activity (i.e., the non-ortho, mono-ortho, and di-ortho substituted PCBs). The toxicity of these 12 PCB congeners is typically evaluated by applying their respective toxicity equivalency factors (TEFs) to calculate the total 2,3,7,8-TCDD toxic equivalents (TEQs) that are associated with an environmental sample (van den Berg *et al.* 1998). In such calculations, the concentrations of 2,3,7,8-substituted dioxins and furans must also be considered.

4.2.2 Oil and Oil-Related Compounds

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

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

4.2.3 Metals

Metals are naturally-occurring elements that are often found, as a result of industrial and commercial activity, at elevated concentrations in the environment. The group of metals that can be toxic, particularly at high concentrations, are commonly referred to as the “heavy metals”. These metals include aluminum, arsenic, beryllium, bismuth, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, strontium, thallium, tin, titanium, and zinc. Cadmium, lead, and mercury are among the more prominent metals that have been associated with adverse effects observed in natural resources. Adverse effects associated with exposure to metals have been

observed in invertebrates, fish, birds and mammals, including reduced growth, impaired reproduction, and mortality (Beyer *et al.* 1996).

4.3 Identification of Contaminants of Concern for Ecological Receptors

In 2000, MacDonald and Ingersoll (2000) conducted an evaluation of sediment injury in the IHAOC, including the WBGCR. Based on the input provided by the Natural Resources Trustees (1997), the COPCs in the WBGCR included metals, oil and oil-related compound, and PCBs. Further evaluation of the preliminary COPCs indicated that the following substances occurred in whole sediment or pore water in the WBGCR at concentrations sufficient to injure sediment-dwelling organisms:

- Conventional variables (i.e., unionized ammonia);
- Metals (i.e., arsenic, cadmium, copper, lead, mercury, nickel, and zinc);
- PAHs (i.e., 13 individual PAHs and total PAHs);
- PCBs (i.e., total PCBs); and,
- Other substances (i.e., phenol).

Accordingly, these substances were designated as the toxic COCs in the WBGCR (MacDonald and Ingersoll 2000). The bioaccumulative COCs in the WBGCR included total PCBs, chlordane, total DDTs, heptachlor, and lindane (MacDonald and Ingersoll 2000). The toxic COCs were identified as the highest priority for developing PRGs for sediments, while the bioaccumulative COCs were identified as the highest priority substances for establishing PRGs for fish tissues (i.e., for the protection of fish, aquatic-dependent wildlife, and/or human health; also see TtEC 2005a).

Chapter 5 Conceptual Site Model

5.0 Introduction

The development of a conceptual site model (CSM) represents a particularly important component of the problem formulation process for an ecological risk assessment because it enhances the level of understanding regarding the relationships between human activities and ecological receptors at the site under consideration. Specifically, the CSM describes key relationships between stressors and assessment endpoints (e.g., survival, growth, and reproduction of fish). In so doing, the CSM provides a framework for predicting effects on ecological receptors and a template for generating risk questions and testable hypotheses (USEPA 1997; 1998). The CSM also provides a means of highlighting what is known and what is not known about a site. In this way, the CSM provides a basis for identifying data gaps and designing monitoring programs to acquire the information necessary to complete an assessment.

Conceptual site models consist of two main elements, including: a set of hypotheses that describe predicted relationships between stressors, exposures, and assessment endpoint responses (along with a rationale for their selection); and, diagrams that illustrate the relationships presented in the risk hypotheses. The following sections of this chapter summarize information on the sources and releases of COCs, the fate and transport of these substances, the pathways by which ecological receptors are exposed to the COCs, and the potential effects of these substances on the ecological receptors that occur in the WBGCR. This information was used to develop a CSM diagram that summarizes the hypotheses regarding how ecological receptors will be exposed to and respond to COCs in the WBGCR. The resultant CSM provides a basis for identifying key stressor-receptor pairs and, in so doing, identifying the key receptor groups for which numerical PRGs are required.

5.1 Sources and Releases of Contaminants of Concern

There are a number of natural and anthropogenic sources of toxic and bioaccumulative substances to the WBGCR. Natural sources of such substances include weathering and erosion of terrestrial soils, bacterial decomposition of vegetation and animal matter, and long-range transport of substances originating from forest fires or other natural combustion sources. Anthropogenic sources of COCs in the WBGCR include industrial wastewater discharges, municipal WWTP discharges, stormwater discharges, surface water recharge by contaminated groundwater, non-point source discharges, spills associated with production and transport activities, and deposition of substances that were originally released into the atmosphere.

The WBGCR receives NPDES permitted discharges of treated wastewater from four facilities, including Hammond Sanitary District WWTP, East Chicago WWTP, American Steel Foundries, and Flexicore Cement. In addition, storm water is discharged into the river during precipitation and/or snow melt events via the combined sewer overflows that are located at Johnson Street, Sohl Avenue, and Columbia Avenue. Other potential sources of COCs within the WBGCR include a manufactured gas plant in Reach 6, releases of non-aqueous phase liquid (NAPL) from groundwater in Reach 4 (and possibly other reaches as well), and leaks from pipelines at various locations on the river (see Figure 2 for information on the location of the various reaches). A summary of the available information on the sources of environmental contaminants in the WBGCR is presented Chapter 4.

5.2 Environmental Fate of Contaminants of Concern

Upon release into aquatic ecosystems, COCs partition into environmental media (i.e., water, sediment, and/or biota) in accordance with their physical and chemical properties and the characteristics of the receiving water body. As a result of such partitioning, COCs can occur at elevated levels in surface water, bottom sediments,

and/or the tissues of aquatic organisms. MacDonald and Ingersoll (2000) provided a general description of the fate and transport of various metals, PAHs, PCBs, and selected other substances that are released into the environment. A more detailed analysis of the fate and transport of the COCs that have been discharged from the HSD facilities (i.e., sewage treatment plant and CSOs) in Hammond is provided by Bierman (1995). To facilitate the development of a conceptual model that links stressors to receptors, the COCs can be classified into three groups based on their fate and effects in the aquatic ecosystem, including bioaccumulative substances, toxic substances that partition primarily into sediments, and toxic substances that partition primarily into water.

5.3 Potential Exposure Pathways

Once released to the environment, there are three pathways through which ecological receptors can be exposed to COCs. These routes of exposure include direct contact with contaminated environmental media, ingestion of contaminated environmental media, and inhalation of contaminated air. For ecological receptors, this latter exposure pathway was considered to be insignificant and, hence, was not addressed in the PRG development process. The exposure routes that apply to each of the categories of COCs are described below.

Aquatic organisms (e.g., microorganisms, aquatic plants, aquatic invertebrates, and fish) and aquatic-dependent wildlife species (e.g., amphibians, reptiles, birds, and mammals) can be exposed to *bioaccumulative substances* via several pathways. First, direct contact with contaminated water or sediment can result in the uptake of bioaccumulative substances through the gills or through the skin of aquatic organisms. This route of exposure is particularly important for sediment-dwelling organisms because many bioaccumulative COCs tend to accumulate in sediments upon release into the environment. Ingestion of contaminated sediments and/or prey species also

represents an important route of exposure to bioaccumulative substances for aquatic organisms, particularly for benthic macroinvertebrates, fish, amphibians, and reptiles.

For aquatic-dependent wildlife species, ingestion of contaminated prey species represents the primary route of exposure to bioaccumulative substances. The groups of wildlife species that are likely to be exposed to bioaccumulative substances through this pathway include fish, reptiles, amphibians, insectivorous birds, sediment-probing birds, carnivorous wading birds, piscivorous birds, and omnivorous mammals. For sediment-probing birds, incidental ingestion of sediments also represents a potential route of exposure to bioaccumulative substances.

Aquatic organisms and aquatic-dependent wildlife species can be exposed to ***toxic substances that partition into sediments*** through several pathways. For aquatic organisms, such as microbiota, aquatic plants, benthic macroinvertebrates, benthic fish, and amphibians, direct contact with contaminated sediment and/or contaminated pore water represents the most important route of exposure to toxic substances that partition into sediments. However, ingestion of contaminated sediments can also represent an important exposure pathway for certain species (e.g., oligochaetes that process sediments to obtain food). Direct contact with contaminated sediments also represents a potential exposure pathway for benthic fish, amphibians, and reptiles; however, it is less important for reptiles than for other aquatic organisms.

For aquatic-dependent wildlife species, ingestion of contaminated sediments represents the principal route of exposure to toxic substances that partition into sediments. Of the wildlife species that occur in the WBGCR, sediment-probing birds are the most likely to be exposed through this pathway.

Aquatic organisms and aquatic-dependent wildlife species can be exposed to ***toxic substances that partition into surface water*** through several pathways. For aquatic organisms, such as microbiota, aquatic plants, aquatic invertebrates, pelagic fish, and amphibians, direct contact with contaminated surface water represents the most

important route of exposure to toxic substances that partition into water. This exposure route involves uptake through the gills and/or through the skin.

For aquatic-dependent wildlife species, ingestion of contaminated water represents the principal route of exposure to toxic substances that partition into surface water. While virtually all aquatic-dependent wildlife species are exposed to toxic substances that partition into surface water, this pathway is likely to account for a minor proportion of the total exposure for most of these species (CCME 1999; MacDonald *et al.* 2002c). The surface microlayer also represents a potential exposure route for ecological receptors; however, the importance of this exposure route is difficult to assess (i.e., due to technical difficulties associated with sampling and other factors).

5.4 Ecological Receptors at Risk in the West Branch Grand Calumet River

There are a wide variety of ecological receptors that could be exposed to contaminated environmental media in the WBGCR. The aquatic species that occur in the WBGCR can be classified into six main groups, including microbiota (e.g., bacteria, fungi and protozoa), aquatic plants (including phytoplankton, periphyton, and aquatic macrophytes), aquatic invertebrates (including zooplankton and benthic invertebrates), fish, amphibians, and reptiles. Birds and mammals represent the principal aquatic-dependent wildlife species that occur in the WBGCR. See Appendix 1 for a description of the species that utilize or ought to utilize aquatic habitats in the WBGCR.

As indicated in Section 5.2, the COCs in the WBGCR were classified into three categories based on their predicted environmental fate. By considering this information, in conjunction with the exposure pathways that apply to these groups of COCs (Section 5.3), it is possible to identify the receptors that are potentially at risk due to exposure to contaminated environmental media in the WBGCR. For

bioaccumulative substances, the groups of aquatic organisms that are most likely to be exposed to bioaccumulative contaminants include benthic invertebrates, fish, amphibians (e.g., American toads), and reptiles (e.g., snapping turtles). Aquatic-dependent birds (e.g., great blue herons) and mammals (e.g., raccoons) can also be exposed to bioaccumulative COCs through the consumption of aquatic organisms that utilize habitats within the WBGCR.

Toxic substances that partition into sediments pose a potential risk to a variety of aquatic organisms and aquatic-dependent wildlife species. The groups of aquatic organisms that are most likely to be exposed to sediment-associated contaminants include microbiota, aquatic plants, benthic invertebrates, benthic fish, and amphibians. Although reptiles can come in contact with contaminated sediments, it is unlikely that significant dermal uptake would occur. Sediment-probing birds (e.g., black-bellied plover) are the principal group of aquatic-dependent wildlife species that are likely to be exposed to sediment-associated contaminants.

For toxic substances that partition into surface water, aquatic plants, aquatic invertebrates, fish, and amphibians represent the principal groups of exposed aquatic organisms. Although ingestion represents a potential exposure route for reptiles, birds, and mammals, this pathway is likely to represent a relatively minor source of exposure to this group of substances for aquatic-dependent wildlife species (CCME 1999).

5.5 Overview of the Conceptual Site Model

A representation of the relationships between the three groups of chemical stressors, the associated exposure pathways, and the ecological receptors at risk is presented in Figure 4. These relationships support the development of a series of risk hypotheses that are illustrated in Figure 4. This CSM and associated information provide a basis for selecting the assessment endpoints that are most relevant for deriving PRGs.

5.6 Selection of Assessment Endpoints

The CSM for the WBGCR (Figure 4) illustrates the relationships between chemical stressors and key receptor groups within the study area. In turn, these relationships facilitate the identification of assessment endpoints that reflect the risk hypotheses for ecological receptors utilizing habitats within the WBGCR. The list of candidate assessment endpoints includes:

- Activity of microbiota;
- Survival, growth, and reproduction of aquatic plants;
- Survival and growth of benthic invertebrates;
- Survival, growth, and reproduction of fish;
- Survival, growth, and reproduction of amphibians;
- Survival, growth, and reproduction of reptiles;
- Survival and reproduction of insectivorous birds;
- Survival and reproduction of sediment-probing birds;
- Survival and reproduction of carnivorous wading birds;
- Survival and reproduction of piscivorous birds; and,
- Survival and reproduction of omnivorous mammals.

5.7 Recommended Approach to the Development of Preliminary Remediation Goals to Address Risks to Ecological Receptors

Assessment Endpoint - Activity of the Aquatic Microbial Community: As the microbial community supports a number of critical ecosystem functions, it is important to evaluate the effects of environmental contaminants on this group of

ecological receptors. Aquatic microorganisms, including bacteria, protozoans, and fungi, can be exposed to environmental contaminants through direct contact with contaminated surface water, through contact with contaminated sediments, and through contact with contaminated pore water. Of these, exposure to contaminated sediments probably represents the primary route of exposure for epibenthic and infaunal microbial species. For this reason, it is important to evaluate the effects of exposure to contaminated sediments on the activity of microbial community (i.e., the rate at which microorganisms perform essential ecosystem functions, such as processing organic carbon). In this way, it is possible to determine if contaminated sediments are likely to be adversely affecting the key functions that are provided by the microbial community.

The effects on the microbial community associated with exposure to sediment-associated COCs have not been evaluated in the WBGCR. However, MacDonald *et al.* (2002c) evaluated the risks to the microbial community associated with exposure to contaminated sediments in the Calcasieu Estuary. In that investigation, the results of solid-phase toxicity tests with the bacterium, *Vibrio fisheri* (i.e., the measurement endpoint), were used to evaluate effects on the activity of the microbial community (i.e., the assessment endpoint) associated with exposure to whole sediments. The results of this investigation indicated that the benthic invertebrate community tended to be more sensitive to sediment-associated COCs than was the microbial community [i.e., as indicated by a higher frequency of toxicity following exposure to split whole-sediment samples; i.e., 12% for *V. fisheri* (n=89), 31% for the amphipod, *Hyaella azteca* (n=89; 58% for the amphipod, *Ampelisca abdita* (n=89)]. In addition, there was a low incidence of toxicity to microbes (i.e., 11%) when COC concentrations were below the recommended PRG-IRs for the benthic invertebrate community (i.e., mean PEC-Q of 0.244; MacDonald *et al.* 2003a). Because the COCs in the WBGCR are similar to those in the Calcasieu Estuary and because PRGs for the benthic invertebrate community are likely to provide an adequate level of protection for the microbial community (MacDonald *et al.* 2003a), development of PRGs for the microbial community was considered to be a relatively low priority for the WBGCR.

Assessment Endpoint - Survival, Growth and Reproduction of Aquatic Plants:

Because aquatic plants represent essential components of the aquatic ecosystem and they support many critical ecosystem functions (i.e., carbon processing, nutrient cycling, etc.), it is important to evaluate the effects on this group of ecological receptors associated with exposure to COCs. Aquatic plants can be exposed to COCs through direct contact with contaminated surface water, through contact with contaminated sediments, and/or, through contact with contaminated pore water. Evaluation of risks to aquatic plants associated with exposure to COCs via one or more of these exposure routes provides a basis for determining if contaminated sediments are likely to be adversely affecting the key functions that are provided by the aquatic plant community.

The effects on the aquatic plant community associated with exposure to COCs in surface water, pore water, or whole sediment have not been evaluated in the WBGCR. However, MacDonald *et al.* (2002c) evaluated the risks to the aquatic plant community associated with exposure to contaminated pore water in the Calcasieu Estuary. In that investigation, the results of pore-water toxicity tests with the alga, *Ulva fasciata* (i.e., the measurement endpoint), were used to evaluate effects on the survival, growth, and reproduction of aquatic plants (i.e., the assessment endpoint). This exposure route was selected because it represented a worst case exposure scenario (i.e., in terms of the concentrations and availability of COCs). The results of this investigation indicated that the benthic invertebrate community tended to more sensitive to sediment-associated COCs than was the aquatic plant community [i.e., as indicated by a higher frequency of toxicity following exposure to split samples; i.e., 20% for *U. fasciata* (n=45), 31% for *H. azteca* (n=89; 58% for *A. abdita* (n=89)]. In addition, there was a low incidence of toxicity to aquatic plants (i.e., 15%) when COC concentrations were below the recommended PRG-IRs for the benthic invertebrate community (i.e., mean PEC-Q of 0.244; MacDonald *et al.* 2003a). Because the COCs in the WBGCR are similar to those in the Calcasieu Estuary and because the PRGs for the benthic invertebrate community are likely to provide an adequate level of protection for the aquatic plant community, development of PRGs

for the aquatic plant community was considered to be a relatively lower priority for the WBGCR then development of PRGs for benthic invertebrates.

Assessment Endpoint - Survival, Growth, and Reproduction of Benthic Invertebrates: The benthic invertebrate community represents an essential component of aquatic food webs, providing an important source of food for many species of fish, amphibians, reptiles, birds, and mammals. As such, it is important to evaluate the effects of environmental contaminants on this group of ecological receptors. Benthic macroinvertebrates can be exposed to environmental contaminants through direct contact with contaminated surface water, through contact with contaminated sediments, through contact with contaminated pore water, and/or consumption of contaminated food. Of these, exposure to contaminated whole sediments probably represents the primary route of exposure for epibenthic and infaunal invertebrate species. For this reason, it is important to evaluate the effects of exposure to contaminated sediments on the survival and growth of benthic invertebrates. In this way, it is possible to determine if contaminated sediments are likely to be adversely affecting the key functions that are provided by the benthic invertebrate community.

The effects on benthic invertebrates associated with exposure to contaminated WBGCR sediments were evaluated by Ingersoll and MacDonald (1999), MacDonald and Ingersoll (2000), and MacDonald *et al.* (2002a). The results of these investigations showed that certain COC and COC mixtures occurred in WBGCR sediments at concentrations sufficient to injure sediment-dwelling organisms. In addition, the results of whole-sediment toxicity tests conducted with a variety of test organisms demonstrated that WBGCR sediments were toxic to sediment-dwelling organisms. Furthermore, the structure of benthic invertebrate communities were altered in the WBGCR, as evidenced by the loss of mayflies, caddisflies, and stoneflies (i.e., EPT taxa) and a proliferation of pollution-tolerant species (i.e., oligochaetes and chironomids) at certain sites. Other sites were characterized by low species richness and low total abundance of benthic invertebrates. This information

shows that the benthic community in the WBGCR is severely degraded and that development of risk-based PRGs for the benthic community should be a high priority. The survival and growth of sensitive members of the benthic invertebrate community (i.e., amphipods), as measured in longer-term toxicity tests (i.e., 28 days), represent the most relevant measurement endpoints for developing PRGs for the benthic invertebrate community (i.e., that will support the survival and growth of benthic invertebrates).

Assessment Endpoint - Survival, Growth, and Reproduction of Benthic Fish: The fish community represents an essential component of aquatic food webs, providing an important source of food for many species of birds and mammals. Fish at lower trophic levels in aquatic food webs (i.e., those species that consume aquatic plants, detritus, or invertebrates) also represent important prey species for carnivorous fish species. As such, it is important to evaluate the effects of environmental contaminants on this group of ecological receptors.

Benthic fish species (e.g., carp) can be exposed to environmental contaminants through several exposure routes, including contact with contaminated surface water (including the surface microlayer), contact with contaminated sediments, and/or contact with contaminated pore water. In addition, consumption of contaminated prey organisms can represent an important exposure route for those species that consume infaunal invertebrate species or other fish. For this reason, it is important to evaluate the effects of contaminated surface water, pore water, and sediments on the survival, growth, and reproduction of fish.

MacDonald and Ingersoll (2000) and MacDonald *et al.* (2002b) assessed injury to fish in the WBGCR associated with exposure to contaminated sediments using three lines of evidence, including whole-sediment toxicity, fish health, and fish community structure. The results of this investigation showed that sediments from the WBGCR were toxic to fathead minnows (*Pimephales promelas*) in 10-d exposures. In addition, the frequency of deformities, fin erosion, lesions, and tumors (i.e., DELT

abnormalities) in fish from the WBGCR (2.8 to 10.8%) was higher than the upper limit of the normal frequency of DELT abnormalities for fish from relatively uncontaminated water bodies in Indiana (<1.3%; such water bodies were used as reference areas for the WBGCR because data on suitable reference areas within the WBGCR or IHAOC were not available for fish). Furthermore, the results of this study showed that fish communities in the WBGCR were severely degraded. At all of the stations sampled, species richness was low (1 to 4 species) and catches were typically dominated by pollution-tolerant, exotic species. Impacts on the fish community are associated with severely degraded habitats in the WBGCR, including low dissolved oxygen, contaminated sediments, frequent bypass events from a municipal discharger, and combined sewer overflows (Simon and Moy 1999/2000).

Information from at least two studies indicates that fish tend to be similarly or less sensitive to contaminated sediments than are benthic invertebrates. More specifically, Burton (1994) exposed fathead minnows and amphipods (*H. azteca*) to contaminated sediments from seven locations on the WBGCR. The results of these toxicity tests showed that the survival of fathead minnows (*P. promelas*) exposed to these samples for 10 days averaged 44%, while the survival of amphipods exposed to splits of the same sediment samples averaged 14%. Therefore, benthic invertebrates tended to be more sensitive to the effects of the COPCs in WBGCR than were fish. However, all of the samples that were designated as toxic to invertebrates were also found to be toxic to fish. Similarly, MacDonald *et al.* (2002c) evaluated the risks to the fish community associated with exposure to contaminated pore water in the Calcasieu Estuary. In that investigation, the results of pore-water toxicity tests with redfish, *Sciaenops ocellatus*, (endpoint: survival and hatching success) were used to evaluate effects on the survival, growth, and reproduction of fish (i.e., the assessment endpoint) associated with exposure to contaminated sediments. This exposure route was selected because it represents a worst case exposure scenario (i.e., in terms of the concentrations and availability of COCs). The results of this investigation indicated that the benthic invertebrate community tended to be more sensitive to sediment-associated COCs than was the fish community [i.e., as indicated by a higher frequency of toxicity following exposure to split samples; i.e., 0% for *S. ocellatus*

(n=45), 31% for *H. azteca* (n=89) 58% for *A. abdita* (n=89); i.e., based on comparisons to the results for samples from reference areas]. The incidence of toxicity to fish was higher than that for invertebrates, when survival in samples from the site was compared to control results, however. In addition, there was a low incidence of toxicity to fish (i.e., 0%) when COC concentrations were below the recommended PRG-IRs for the benthic invertebrate community (i.e., mean PEC-Q of 0.244; MacDonald *et al.* 2003a). Because the COCs in the WBGCR are similar to those in the Calcasieu Estuary and because the PRGs for the benthic invertebrate community are likely to provide an adequate level of protection for the fish community, development of PRGs for the fish community was considered to be a relatively lower priority for the WBGCR than was development of PRGs for benthic invertebrates.

Assessment Endpoint - Survival, Growth and Reproduction of Amphibians:

Amphibians, including frogs, toads, and salamanders, play an important role in freshwater ecosystems. More specifically, amphibians are essential components of aquatic food webs, both as consumers of lower trophic level aquatic organisms and prey for many species of fish, reptiles, birds, and mammals. As such, it is important to evaluate the effects on this group of ecological receptors associated with exposure to environmental contaminants.

Assessment of the risks to amphibians associated with exposure to COCs in the WBGCR is challenging for several reasons. First, amphibians can be exposed to toxic or bioaccumulative substances through contact with contaminated surface water, contact with contaminated whole sediments (particularly during estivation), and/or consumption of contaminated aquatic organisms. While information is available on the toxicity of certain water-borne COCs to various amphibian species, few data are available on the effects of sediment-associated or tissue-borne COCs on this receptor group. Therefore, it is not possible to conduct an integrated assessment of risks without making assumptions regarding the relative sensitivity of amphibian species to environmental contaminants in a manner that facilitates estimation of toxicity

reference values. In addition, systematic studies on the distribution, abundance, and structure of amphibian communities have not been conducted within the study area. Likewise, investigations to assess the health of amphibians in the WBGCR have not been conducted.

Due to the lack of appropriate toxicity data and field studies, it is not possible to develop amphibian-specific PRGs for sediment in the WBGCR. While this is a limitation in terms of identifying final PRGs for evaluating the various remedial alternatives, the available toxicity data indicate that invertebrates and fish tend to be as or more sensitive to the COCs in WBGCR sediments than are the amphibians represented in the toxicological data sets. For example, cladocerans (*Daphnia sp.*) are at least 100 times more sensitive to the effects of cadmium than are clawed toad (*Xenopus laevis*; Environment Canada and Health Canada 1994). In addition, Fidler *et al.* (1991) reported that invertebrates and/or fish were 10 to 100 times more sensitive to the effects of various PAHs (i.e., benzo(a)pyrene, naphthalene, and phenanthrene) than were amphibians. For benzene, the toxicity thresholds for rainbow trout (*Oncorhynchus mykiss*) and the leopard frog (*Rana pipiens*) were similar (Environment Canada and Health Canada 1993). Although not all of the COCs in the WBGCR were considered in the above comparative toxicity evaluation, the available data suggest that PRGs that are developed to protect the benthic invertebrate community may provide an acceptable level of protection for the amphibian community as well. Post-restoration monitoring should be used to confirm that the selected remedial alternative reduces risks to amphibians to tolerable levels.

Assessment Endpoint - Survival, Growth and Reproduction of Reptiles: Reptiles, including turtles, lizards, and snakes, represent important elements of freshwater ecosystems. In some cases (e.g., snapping turtles), reptiles represent predatory species that occupy apex or near apex positions in aquatic food webs. In other cases, reptiles (particularly juveniles and smaller species) can be prey for various species of fish, reptiles, birds, and mammals. As such, it is important to evaluate the effects on

this group of ecological receptors associated with exposure to environmental contaminants.

Reptiles can be exposed to toxic or bioaccumulative substances through contact with contaminated surface water, contact with contaminated sediments, and/or consumption of contaminated aquatic organisms. It is likely, however, that consumption of prey organisms that have accumulated COC in their tissues represents the principal exposure route for this receptor group. Evaluation of the risks to reptiles posed by exposure to tissue-borne COCs is challenging because few data are available from toxicological studies on these species and because no data are available on the distribution, abundance, structure and health of reptilian communities in the WBGCR. In the absence of relevant toxicological data and the results of well-designed field studies, it is not possible to assess risks to this receptor group or to develop reptilian-specific PRGs for sediment in the WBGCR.

Assessment Endpoint - Survival and Reproduction of Aquatic-Dependent Birds and Mammals: Aquatic-dependent bird and mammal species are integrally linked to aquatic ecosystems as a result of their reliance on aquatic organisms for food. These species can be classified into five groups based on their feeding habits, including insectivorous birds (i.e., birds that eat insects), sediment-probing birds (i.e., species that eat benthic macroinvertebrates), carnivorous-wading birds (i.e., species that eat various types of aquatic organisms, including invertebrates, small fish, reptiles, and amphibians), piscivorous birds (i.e., species that eat fish), and omnivorous mammals (i.e., species that eat a variety of plants and animals). Although certain piscivorous mammals (e.g., mink) may occur at the study area, their presence has not been confirmed. These ecological receptors can be exposed to environmental contaminants through dermal contact with contaminated surface water (including the surface microlayer) or sediments (i.e., dermal exposure) and/or consumption of contaminated surface water; however, most of their exposure is likely to be associated with the consumption of contaminated prey items. Due to their reliance on aquatic organisms

for food, it is important to evaluate the effects on these groups of ecological receptors associated with exposure to environmental contaminants.

MacDonald and Ingersoll (2000) and MacDonald *et al.* (2002b) assessed injury to piscivorous wildlife species using two lines of evidence: whole-sediment chemistry and tissue chemistry. The results of this investigation demonstrated that the concentrations of total PCBs and several organochlorine pesticides were sufficient in WBGCR sediments to bioaccumulate in fish to levels that pose a risk to piscivorous wildlife. In addition, the available tissue residue data indicate that total PCBs and several organochlorine pesticides have accumulated in the tissues of fish from the WBGCR to levels that are sufficient to injure the wildlife species that feed primarily on fish. As no data were available on COC levels in invertebrate, amphibian, or reptile tissues, it is not possible to reliably determine if consumption of these organisms poses unacceptable risks to aquatic-dependent wildlife in the WBGCR.

Although it is possible to develop avian-specific PRGs for sediment in the WBGCR, such PRGs would specify the average concentrations of sediment-associated COCs within the foraging ranges of focal species for each of the four groups of aquatic-dependent birds. PRGs, so derived, would not be comparable to the PRGs that are derived for the benthic community (i.e., which specify the concentrations of COCs that need to be achieved to protect locally-important benthic invertebrate populations; i.e., which apply to individual sediment samples). Accordingly, it is more efficient to derive benthic PRGs, apply them in various remedial alternative scenarios, and determine if the average COC concentrations in sediments have been reduced to levels that would be protective of avian species. The same approach is recommended for managing risks to aquatic-dependent mammals associated with exposure to bioaccumulative substances. Using this approach, virtual remediation would be used to determine if candidate remedial alternatives would reduce risks to aquatic-dependent wildlife to tolerable levels.

Virtual remediation is a GIS-based approach in which the benthic PRGs will be used to identify areas that require active remediation (e.g., removal, capping) to result in

sediment quality conditions sufficient to support the benthic community. Following virtual remediation of these areas, the concentrations of sediment-associated COCs will be designated as equal to those in reference sediment samples. Then, the average concentrations of bioaccumulative COCs will be calculated for areas that are consistent with the foraging ranges of various aquatic-dependent wildlife species. Using relevant BSAFs, these data will then be used to predict the future concentrations of these COCs in fish tissues. The predicted tissue residue levels in fish will then be compared to the selected benchmarks for tissue chemistry to determine if unacceptable risks to aquatic-dependent wildlife would still occur. In addition, the estimated future PCB levels in fish will be compared to the State of Indiana fish consumption guidelines to determine if the proposed remedial alternative is likely to be protective of human health.

Chapter 6. Development and Evaluation of the Preliminary Remediation Goals for Aquatic Receptors

6.0 Introduction

Information from a number of studies indicates that sediments in the WBGCR have been contaminated by historic releases of toxic and/or bioaccumulative substances (Dorkin 1994; URS Greiner Woodward Clyde 1999; ThermoRetec 1999; FWENC 2002; 2003). Based on a review and evaluation of the data collected prior to 2000, Ingersoll and MacDonald (1999), MacDonald and Ingersoll (2000), and MacDonald *et al.* (2002a; 2002b) concluded that metals, PAHs, and/or PCBs were present in WBGCR sediments at concentrations that were sufficient to injure sediment-dwelling organisms and other ecological receptors within the study area. Because risk-based tools were used in those assessments (i.e., concentration-response relationships expressed in terms of mean PEC-Qs and associated incidence of toxicity to amphipods), it is reasonable to conclude that exposure to contaminated sediments has posed unacceptable risks to ecological receptors that utilize habitats, or ought to utilize habitats, within the WBGCR. The substances that occurred at concentrations sufficient to cause or substantially-contribute to sediment injury (i.e., the contaminants of concern; COCs) were identified in Chapter 4 of this report.

Following the assessment of injury to ecological receptors associated with exposure to contaminated sediments, it is necessary to evaluate various remedial alternatives to identify the one(s) that will effectively mitigate these risks. In addition to information on technical feasibility and costs, evaluation of candidate remedial options requires an understanding of the desired future condition of the ecosystem (i.e., remedial action objectives; RAOs) and the development of tools that define the concentrations of COCs that are required to reduce risks to aquatic receptors to tolerable levels. Such tools are generally referred to as preliminary remediation goals

(PRGs; Suter *et al.* 2000) and, in this investigation define the concentrations of individual COCs or COC mixtures that correspond to thresholds for intermediate (PRG-IRs) and high (PRG-HR) risks to ecological receptors (MacDonald *et al.* 2003a). To be confident that the PRGs will provide reliable tools for guiding remedial action planning, risk managers need to evaluate the extent to which the PRGs are consistent with the RAOs that have been established for the site (Suter *et al.* 2000).

This chapter describes the strategy that was used to derive and evaluate PRGs for the WBGCR. Such PRGs are intended to define the concentrations of selected COCs in whole-sediment samples that would pose tolerable and unacceptable risks to aquatic receptors. Although the PRGs were explicitly developed to define intermediate and high risk thresholds for benthic invertebrates, they are also considered to be applicable to other aquatic receptors (e.g., microbes; fish; see Chapter 4 for rationale).

This chapter provides an overview of the RAOs that were established for the WBCGR (also see Chapter 3) and a brief description of the procedures that were used to derive the benthic PRGs (more detailed methods are described in Chapter 2). In addition, the benthic PRGs for selected sediment-associated COCs and COC mixtures are presented. Furthermore, the procedures that were used to evaluate the benthic PRGs and the results of this evaluation are included in this chapter (also see Chapter 2). Finally, PRGs for whole sediments that provide the desired level of protection for aquatic receptors are recommended. These PRGs are intended to provide USFWS, USEPA, IDNR, IDEM, and, the IH AOC Citizen's Advisory for the Remediation of the Environment (CARE) Committee with the tools that they require to evaluate the remedial alternatives that are proposed to mitigate risks to aquatic organisms, aquatic-dependent wildlife, and to human health in the WBGCR.

6.1 Remedial Action Objectives for the West Branch Grand Calumet River

The RAOs for aquatic receptors are described in Chapter 3 of this report and in TtEC (2005b). Briefly, these RAOs state that exposure to whole sediment or associated pore water that is sufficiently contaminated to pose intermediate risks to the microbial community, aquatic plant community, benthic invertebrate community, or benthic fish community should be minimized. Similarly, the RAOs indicate that exposure to whole sediment or pore water that is sufficiently contaminated to pose high risks to the microbial community, aquatic plant community, benthic invertebrate community, or benthic fish community should be prevented.

6.2 Preliminary Remediation Goals for Selected Sediment-Associated COCs for the Benthic Invertebrate Community

The RAOs that were established for the WBGCR indicate the remedial alternative(s) that is ultimately selected for implementation must reduce risks to aquatic receptors to tolerable levels (i.e., eliminate exposures that pose high risks and minimize exposures that pose intermediate risks to aquatic receptors). In this investigation, PRGs for the benthic invertebrate community were developed to define the concentrations of COCs that pose tolerable and unacceptable risks to aquatic receptors. The benthic PRGs were considered to be relevant to other aquatic receptors because several studies have shown that benthic invertebrates are as or more sensitive to contaminated sediments than are fish, microbes, or aquatic plants. Therefore, the remainder of this report focuses on sediment PRGs for the benthic invertebrate community.

Two types of PRGs were developed in this investigation. First, PRG-IRs were developed to define the concentrations of COCs in whole-sediment samples below

which adverse effects on sediment-dwelling organisms are likely to be observed only infrequently (i.e., <20% of the whole-sediment samples tested would be toxic, based on the results of 28-d toxicity tests with the amphipod, *H. azteca*) or the magnitude of such effects would be limited (i.e., amphipod survival would be reduced by less than 10% relative to reference samples). In addition, PRG-HRs were developed to define the concentrations of COCs in whole-sediment samples above which adverse effects on sediment-dwelling organisms are likely to be frequently observed (i.e., >50% of the whole-sediment samples tested would be toxic, based on the results of 28-d toxicity tests with the amphipod, *H. azteca*) or the magnitude of such effects would be substantial (i.e., amphipod survival would be reduced by greater than 20% relative to reference samples). Accordingly, both incidence of toxicity (IOT) and magnitude of toxicity (MOT)-based PRG-IRs and PRG-HRs were developed for each COC and COC mixture.

The benthic PRGs presented in this chapter were derived using a step-wise process. In the first step of this process, matching whole-sediment chemistry and whole-sediment toxicity data from the WBGCR were evaluated and compiled in the project database. Then, the chemistry and toxicity data for individual COCs and COC mixtures were retrieved from the database, sorted in order of increasing concentrations, and summarized to determine the IOT, average MOT, and geometric mean concentration for each group of 15 samples (termed a concentration interval). The summarized data for each COC or COC mixture were then plotted and fitted using regression analysis (i.e., using linear, three parameter logistic, four parameter logistic, three or four parameter logistic or sigmoidal models). Each of the resultant site-specific concentration-response relationships was then examined to determine if it was statistically significant (i.e., by ANOVA) and the model of best fit was selected for each COC and COC mixture (i.e., based on the correlation coefficients).

The site-specific concentration-response relationships were used directly to establish the PRG-IRs and PRG-HRs for the benthic invertebrate community. More specifically, the PRG-IRs were derived by determining the concentrations of each COC and COC mixture that corresponded to a 20% increase in the IOT or a 10%

increase in the MOT (i.e., relative to reference conditions). The PRG-HRs define the concentrations of COCs and COC mixtures that correspond to a 50% increase in the IOT or a 20% increase in the MOT. The methods that were used to develop the PRGs are described in more detail in Section 2.5.

MacDonald and Ingersoll (2000) and MacDonald *et al.* (2002a) assessed injury to sediment-dwelling organisms in the WBGCR using a simple chemical mixture model that provided a basis for predicting sediment toxicity to the amphipod, *H. azteca* [i.e., using data on the concentrations of metals, PAHs, and/or PCB, expressed on a dry weight (DW) basis]. This model was developed using matching sediment chemistry and sediment toxicity data from studies conducted throughout the Great Lakes Basin and elsewhere in the United States. The concentrations of total organic carbon (TOC) in the 140 sediment samples that were used to generate the chemical mixture model averaged roughly 3% (i.e., 95% C.I. of 0 to 7.37%). Within this range of TOC concentrations, the level of organic carbon in individual sediment samples did not appear to influence the concentration-response relationship that was developed (USEPA 2000; Ingersoll *et al.* 2001). However, sediment samples from the WBGCR exhibited a much broader range of TOC concentrations (i.e., averaging 8.9%; 95% C.I. of 0 to 21.9%). With TOC varying by more than a factor of 25 among the samples collected in the WBGCR, organic carbon levels could influence the bioavailability and, hence, toxicity of non-polar organic chemicals in the WBGCR (Di Toro *et al.* 1991; Ankley *et al.* 1996; Word *et al.* 2005). For this reason, the influence of TOC on the toxicity of sediment-associated COCs was evaluated through the development and evaluation of various chemical mixture models derived using DW- or OC-normalized concentrations (Word *et al.* 2005).

In total, 17 distinct chemical mixture models were developed to describe the relationship between COC concentration and sediment toxicity in the WBGCR. These models were developed using the results of 28-d whole-sediment toxicity tests with *H. azteca*. These data were supplemented by the results of 10-d whole-sediment toxicity tests that were found to be toxic to this amphipod, under the assumption that exposure to the same sediments would have resulted in toxicity had the duration of

exposure been extended to 28 days from 10 days. For each of the three major groups of COCs (i.e., metals, PAHs and PCBs), chemical mixture models were developed using DW- and OC (i.e., DW@1%OC)-normalized chemistry data for both magnitude of toxicity (Table 2) and incidence of toxicity (Table 3; the DW model for PCBs developed based on incidence of toxicity was not significant, however). In addition, three approaches to combining the major groups of COCs into a single chemical mixture model were explored (Table 2 and 3).

For mixtures of metals, concentration-response relationships were developed using DW- and OC (i.e., DW@1%OC)-normalized concentrations for both magnitude of toxicity (Figure 5) and incidence of toxicity (Figure 6). While organic carbon-normalization reduced some of the variability in the data (as evidenced by slightly improved correlation coefficients), all of the models fit the underlying data well (i.e., r^2 of 0.95 to 0.99) and were highly significant (i.e., $p \leq 0.0001$; Table 2 and 3). For this reason and because OC-normalization is not routinely conducted for metals (Long *et al.* 1998), the concentration-response relationships for individual metals were developed using DW concentrations only.

The concentration-response relationships that were developed for total PAHs were also developed using DW- and OC (i.e., DW@1%OC)-normalized concentration data. As was the case for metals, such relationships were developed for both magnitude of toxicity (Figure 7) and incidence of toxicity (Figure 8). All four of the models fit the underlying data well (i.e., r^2 of 0.98 to 0.99) and were significant (i.e., $p < 0.0001$; Table 2 and 3). For this reason and because OC-normalization is frequently used for PAHs (Di Toro *et al.* 1991; Swartz *et al.* 1995; Ankley *et al.* 1996), the concentration-response relationships for individual PAHs and total PCBs were developed using OC-normalized concentrations only.

The matching sediment chemistry and toxicity that were available for the WBGCR did not support the development of concentration-response relationships for total PCBs. For this reason, the WBGCR database on total PCBs was expanded to include relevant data from elsewhere in the IHAOC. The expanded database supported the

development of significant concentration-response relationships for magnitude of toxicity (DW and 1%OC; Figure 9) and incidence of toxicity (1%OC only; Figure 10). The correlation coefficients for the total PCB relationships were lower than those that were obtained for metals or total PAHs (i.e., r^2 of 0.46 to 0.77), indicating a higher level of variability in the underlying data. All three concentration-response relationships were found to be significant (i.e., $p < 0.05$; Table 2 and 3). Therefore all of the resultant PRGs were evaluated to determine the extent to which they were consistent with the RAOs.

In addition to the models that were developed for each of the three major chemical classes, combined models were also developed to quantify the relationships between COC concentrations and toxicity to amphipods. For both magnitude of toxicity (Figure 11) and incidence of toxicity (Figure 12), concentration-response models were developed using: (1) DW-normalized concentrations of metals, total PAHs, and total PCBs; (2) OC-normalized concentrations of metals, total PAHs, and total PCBs; and, (3) DW-normalized concentrations of metals and OC-normalized concentrations of total PAHs and total PCBs. All of the combined models fit the underlying data well (i.e., r^2 of 0.95 to 0.99) and were significant (i.e., $p < 0.0001$ to 0.0014; Table 2 and 3). Therefore, all of the PRGs derived from the combined models were further evaluated.

In addition to the various chemical mixture models, concentration-response relationships were also developed for eight trace metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), four low molecular weight PAHs (LMW-PAHs; anthracene, fluorene, naphthalene, and phenanthrene), total LMW-PAHs, five high molecular weight PAHs [HMW-PAHs; benz(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene], total HMW-PAHs, total PAHs, and total PCBs. These models were based on the magnitude of toxicity to amphipods, *H. azteca*, in 28-d toxicity tests (Figure 13 to 33) and on the incidence of toxicity to amphipods, *H. azteca*, in 28-d toxicity tests (Figure 34 to 51). The concentration-response relationships for the individual metals were derived using the DW-normalized sediment chemistry data. In contrast, the models for the individual PAHs,

LMW-PAHs, HMW-PAHs, total PAHs, and total PCBs were developed using whole-sediment chemistry expressed on a DW basis at 1%OC. All of the models generated for individual COCs or groups of COCs fit the underlying data well (i.e., r^2 of 0.68 to 0.99) and were significant (i.e., $p \leq 0.0001$ to 0.035; Table 4 and 5).

Two types of PRGs were developed for each COC and COC mixture using the concentration-response relationships, including a PRG-IR (i.e., intermediate risk) and PRG-HR (i.e., high risk). The PRG-IRs define the concentrations of individual COCs and COC mixtures that correspond with a 10% increase in the magnitude of toxicity relative to reference conditions (i.e., the lower 95% prediction limit for amphipod survival in reference sediment samples was 93.5%; a survival rate of 84.2% represents a 10% increase in the magnitude of toxicity) or a 20% increase in the incidence of toxicity compared to reference conditions (i.e., an increase in the incidence of toxicity from 3% to 22.4%). The PRG-HRs define the concentrations of individual COCs and COC mixtures that correspond with a 20% increase in the magnitude of toxicity relative to reference conditions (i.e., a survival rate of 74.8% represents a 20% increase in the magnitude of toxicity) or a 50% increase in the incidence of toxicity compared to reference conditions (i.e., an increase in the incidence of toxicity from 3% to 51.5%). The PRGs for COC mixtures based on magnitude of toxicity are presented in Table 2, while the PRGs for COC mixtures based on incidence of toxicity are presented in Table 3. Tables 4 and 5 present the PRGs for individual COCs based on magnitude of toxicity and incidence of toxicity, respectively.

6.3 Reliability of the Preliminary Remediation Goals for the Benthic Invertebrate Community

The reliability of the PRGs for sediment-dwelling organisms was evaluated to identify a single set of PRGs that could be recommended for managing risks to the benthic invertebrate community and other aquatic receptors associated with exposure to contaminated sediments. This evaluation was designed to determine the extent to

which the PRGs were consistent with the RAOs that have been established for the WBGCR (i.e., to minimize or prevent exposure to whole sediments that are sufficiently contaminated to pose intermediate or high risks, respectively, to the benthic invertebrate community). Accordingly, the probability of encountering samples that are toxic to benthic invertebrates should be low (i.e., <20%) at COC concentrations below the PRG-IR and higher (i.e., >50%) at COC concentrations above the PRG-IR. Similarly, samples that are toxic to benthic invertebrates should be frequently encountered (i.e., >80%) at COC concentrations above the PRG-HR and less frequently encountered (i.e., <50%) at COC concentrations below the PRG-HR.

The reliability of the PRGs that were derived for COCs and COC mixtures in the WBGCR was evaluated on a substance-by-substance basis using a step-wise approach. As a first step, the sediment samples represented in the WBGCR database were sorted into three groups, based on the measured concentration of the COC or COC mixture under consideration (i.e., those with concentrations <PRG-IR, PRG-IR to PRG-HR, and >PRG-HR). Then, the incidence of toxicity within each of these three concentration ranges was determined using the results of the 28-d whole-sediment toxicity tests with *H. azteca* (i.e., number of toxic samples divided by the number of samples in the group, times 100; to express the result as a percentage). The percent incidence of toxicity \geq PRG-IR and \leq PRG-HR was also calculated for each COC and COC mixture. These results were then compared to the evaluation criteria (see above) to determine if the PRG-IR and/or PRG-HR would provide a basis for classifying sediment samples in a manner that was consistent with the RAOs.

The results of this evaluation indicated that the PRGs for individual COCs, generated based on magnitude of toxicity, generally provided a reliable basis for classifying sediment samples from the WBGCR as toxic or not toxic. The incidence of toxicity to the amphipod, *H. azteca*, was less than 20% when COC concentrations were below the PRG-IRs for 19 of the 21 COCs and COC classes considered (Table 6). The PRG-IRs for nickel and total PCBs were less reliable, as indicated by the relatively elevated incidence of toxicity at COC concentrations below the PRG-IRs (i.e., 22%

and 45%, respectively). By comparison, the incidence of whole-sediment toxicity ranged from 50 to 95% when COC concentrations equaled or exceeded the PRG-IRs for 20 of the 21 substances considered (Table 6). The incidence of toxicity above the PRG-IR was only 19% for total PCBs, however (Table 6). Above the PRG-HRs, the incidence of toxicity ranged from 88 to 94% for 13 of the 21 substances evaluated (Table 6). The incidence of toxicity was lower above the PRG-HR for total PCB concentrations (17%) and seven trace metals (i.e., 56 to 75%; Table 6). By comparison, the incidence of toxicity was generally low at COC concentrations equal to or below the PRG-HRs, ranging from 9 to 19% for 18 of the 21 substances considered. A higher incidence of toxicity was observed when the concentrations of cadmium (21%), nickel (24%), and total PCBs (42%) were less than or equal to their respective PRG-HRs (Table 6).

The PRGs for individual COCs generated based on incidence of toxicity also provided a reliable basis for classifying sediment samples from the WBGCR as toxic or not toxic. The incidence of toxicity to the amphipod, *H. azteca*, was less than 20% when COC concentrations were below the PRG-IRs for 17 of the 18 COCs and COC classes for which PRGs were derived (Table 7). The PRG-IR for total PCBs was less reliable (i.e., the incidence of toxicity at COC concentrations below the PRG-IR was 45%; Table 7). By comparison, the incidence of whole-sediment toxicity ranged from 50 to 91% when COC concentrations equaled or exceeded the PRG-IRs for 17 of the 18 substances considered (Table 7). The incidence of toxicity at total PCB concentrations above the PRG-IR was only 19%, however. Above the PRG-HRs, the incidence of toxicity ranged from 82 to 100% for 12 of the 18 substances for which models were developed, indicating that those PRG-HRs were reliable (Table 7). The PRG-HRs for arsenic, cadmium, chromium, lead, mercury, and nickel were found to be less reliable (Table 7). The incidence of toxicity at COC concentrations equal to or below the PRG-HRs ranged from 10 to 36% for the 18 substances considered. Overall, the PRGs based on magnitude of toxicity were somewhat more reliable than the PRGs based on incidence of toxicity.

The PRGs for individual substances were shown to provide a reliable basis for classifying sediment samples in the WBGCR as toxic and not toxic and, hence, to support the evaluation of remedial alternatives for addressing risks to ecological receptors. However, application of PRGs for multiple substances simultaneously can be somewhat challenging. For this reason, a number of simple chemical mixture models were also developed and used to develop PRGs that would provide a more comprehensive basis for classifying sediments in the WBGCR. As was the case for the PRGs for individual COCs, the PRGs generated using the COC mixture models were also evaluated to assess their reliability.

The results of this evaluation demonstrated that the magnitude of toxicity-based PRGs for the various chemical mixtures generally provided a reliable basis for classifying WBGCR sediments as toxic and not toxic. More specifically, the incidence of sediment toxicity was generally low when the PRG-IRs were not exceeded, ranging from 10 to 15% for seven of the eight chemical mixture models considered (Table 8). The incidence of toxicity was higher (i.e. 47%) below the PRG-IR for $PEC-Q_{IPCBs (DW@1\%OC)}$, however (Table 8). At or above the PRG-IR, the incidence of toxicity ranged from 61 to 88% for seven of the eight chemical mixture models considered (Table 8). Again, only the PRG-IR for the PCB mixture model ($DW@1\%OC$) was found to be less reliable (i.e., incidence of toxicity of 15% when the PRG-IR was equaled or exceeded; Table 8). In general, the PRG-HRs provided a reliable basis for classifying WBGCR sediments, with the incidence of toxicity ranging from 84% to 90% when the PRG-HR was exceeded for five of the nine chemical mixture models (Table 8). The PRG-HRs for mean $PEC-Q_{metals (DW \text{ and } DW@1\%OC)}$ and $PEC-Q_{IPCBs (DW \text{ and } DW@1\%OC)}$ were less reliable, as indicated by the relatively low incidence of toxicity above the PRG-HRs (i.e., 63%, 68%, 19%, and 20%, respectively; Table 8). At $PEC-Q$ values at or below the PRG-HRs, the incidence of toxicity tended to be relatively low (i.e., 11 to 18% for seven of the nine chemical mixture models; Table 8). A relatively higher incidence of toxicity was observed when total PCB concentrations (DW or $DW@1\%OC$) were below the PRG-HRs (i.e., 45 and 40%, respectively). These results show that, with the exception of metals and total PCBs,

the magnitude of toxicity-based PRGs for chemical mixtures are reliable and can be used to evaluate remedial alternatives in the WBGCR.

These results also showed that the incidence of toxicity-based PRGs can be used to reliably classify WBGCR sediments as toxic and not toxic. For seven of the eight chemical mixture models considered, the incidence of sediment toxicity below the PRG-IR ranged from 10 to 15% (Table 9). However, the incidence of toxicity was higher (i.e., 44%) below the PRG-IR for PEC- $Q_{\text{tPCBs (DW@1\%OC)}}$ (Table 9). By comparison, the incidence of toxicity at or above the PRG-IR ranged from 62 to 88% for seven of the eight chemical mixture models considered. Again, only the PRG-IR for PEC- $Q_{\text{tPCBs (DW@1\%OC)}}$ was found to be less reliable; i.e., incidence of toxicity of 18% when the PRG-IR was equaled or exceeded (Table 9). Importantly, the incidence of toxicity ranging from 90 to 93% when the PRG-HR was exceeded for five of the eight chemical mixture models (Table 9), indicating that the PRG-HRs generally provide a reliable basis for classifying WBGCR sediments. Only the PRG-HRs for mean PEC- $Q_{\text{metals (DW and DW@1\%OC)}}$ and PEC- $Q_{\text{tPCBs (DW@1\%OC)}}$ were less reliable, as indicated by the relatively lower incidence of toxicity above the PRG-HR (i.e., 73%, 73%, and 33%, respectively; Table 9). At or below the PRG-HRs, the incidence of toxicity was 13 to 17% for six of the eight chemical mixture models; Table 9). A relatively higher incidence of toxicity was observed when the mean PEC- $Q_{\text{metals (DW)}}$ and PEC- $Q_{\text{tPCBs (DW@1\%OC)}}$ values were below the PRG-IRs i.e., 23% and 37%, respectively). These results show that, with the exception of trace metals and total PCBs, the incidence of toxicity-based PRGs are reliable and can be used to evaluate remedial alternatives in the WBGCR.

Comparison of the results of this evaluation indicates that the reliability of the two types of PRGs (i.e., IOT-based and MOT-based PRGs) were similarly reliable. Among the nine models that were evaluated, five met all of the evaluation criteria that were established for the IOT- and MOT-based PRGs (Table 9). Therefore, any one of these five models could be used to evaluate the remedial alternatives that are proposed for addressing the issues related to sediment contamination in the WBGCR. Overall, the IOT-based PRGs for PEC- $Q_{\text{tPAHs (DW)}}$, provided the highest correct

classification rates (i.e., 89% for the PRG-IR and 93% for the PRG-HR; Table 9). Therefore, it could be argued that these PRGs provide the most reliable tools for classifying WBGCR sediments as toxic and not toxic. Interestingly, application of the IOT-based PRG-HR for $PEC-Q_{tPAHs(DW)}$ alone to classify WBGCR sediments would yield acceptable correct classification rates, as 85% of the samples with concentrations below the PRG-HR were not toxic and 93% of the samples with concentrations above the PRG-HR were toxic (Table 9). Correct classification rates were similar for the IOT or MOT-based PRG-IR for $PEC-Q_{tPAHs(DW@1\%OC)}$ (i.e., 90% of the samples with concentrations below the PRG-IR were not toxic and 88% of the samples with concentrations above the PRG-IR were toxic; Tables 8 and 9). Therefore, candidate remedial alternatives for addressing sediment contamination in the WBGCR could be evaluated using either of these PRGs. Because the WBGCR database includes only a limited number of samples with values that fall between the PRG-IRs and PRG-HRs for $PEC-Q_{tPAHs(DW \text{ or } DW@1\%OC)}$ and because the IOT-based PRG-IR for $PEC-Q_{tPAHs(DW@1\%OC)}$ correctly classifies these samples as toxic or non-toxic more frequently than the PRG-IR for $PEC-Q_{tPAHs(DW)}$, it is prudent to recommend the OC-normalized PRG-IR (0.167; Table 3) for evaluating remedial alternatives in the WBGCR (Table 9).

Information on the characteristics of whole-sediment samples in which COC concentrations were less than and greater than the most highly recommended PRGs provides a means of further assessing how well they meet the narrative intent of the RAOs. As indicated above, only 10% (8 of 82 samples) of the whole-sediment samples with less than the IOT-based PRG-IR for $PEC-Q_{tPAHs(DW@1\%OC)}$ were toxic to amphipods in 28-d toxicity tests (Table 8). The average control-adjusted survival of amphipods in these samples was 71.5% (i.e., compared to a lower 95% prediction limit of 93.5% for reference sediment samples). By comparison, 88% of the samples (30 of 34 samples) with $PEC-Q_{tPAH(DW@1\%OC)}$ concentrations equal to or greater than the PRG-IR were toxic to this amphipod species in 28-d exposures. The average control-adjusted survival of amphipods in these samples was 23.4%. Therefore, it is concluded that the IOT-based PRG-IR for $PEC-Q_{tPAHs(DW@1\%OC)}$ (0.167; Table 3) would provide a reliable basis for classifying sediments in the WBGCR and, in so

doing, supporting the remedial alternatives analysis. Based on the evaluations that were conducted by MacDonald *et al.* (2002c; 2003a), it is likely that this PRG would also facilitate restoration of the microbial, aquatic plant, and fish communities in the WBGCR.

Comparison of the most highly recommended PRG from this study to other candidate benchmarks for assessing sediment quality conditions indicates that the value is within the range of values that have been established for other uses, as shown below:

PRG/Benchmark	Total PAH Concentration (mg/kg)		Reference
	DW ¹	DW 1%OC	
Probable Effect Concentration	22.8	-	MacDonald <i>et al.</i> (2000)
Mean Threshold Effect Concentration	23.2	2.9	Swartz (1999)
PRG-HR_{tPAHs@1%OC} (0.149)	27.2	3.4	MacDonald <i>et al.</i> (2005)
PRG-IR_{tPAHs@1%OC} (0.167)	30.4	3.8	This study
∑ PAH Toxicity Threshold	31.2	3.9	Swartz (1999)
Screening Level Concentration	32.8	4.1	Neff <i>et al.</i> (1987)
Effects Range Median	44.8	-	Long <i>et al.</i> (1995)
PRG-HR_{tPAHs@1%OC} (0.555)	101	12.7	This study
Mean Median Effects Concentration	144	18.0	Swartz (1999)
∑ PAH mixture LC ₅₀	169	21.1	Swartz (1999)

¹Assuming an average of 8%OC in the WBGCR

In particular, agreement between the recommended PRG-IR_{tPAHs@1%OC} (0.167; 3.8 mg/kg DW@1%OC) and the threshold for significant amphipod mortality (3.9 mg/kg DW@1%OC; Swartz 1999) confirms that the PRG is likely to identify total PAH

concentrations that will be protective of sensitive benthic organisms. This PRG is also comparable to the PRG- $HR_{tPAHs(DW@1\%OC)}$ for IHAOC as a whole (MacDonald *et al.* 2005).

It is important to understand that the PRGs developed in this report are intended to provide a basis for classifying sediment samples as toxic or not toxic based on whole-sediment chemistry alone. Although PRGs were derived for eight trace metals, 12 individual PAHs and PAH classes, total PCBs, and various COC mixtures, no attempt was made to identify the substance or substances that were causing the observed toxicity in the WBGCR. Rather, the PRGs identify the concentrations of sediment-associated COCs that are associated with a specified incidence or magnitude of toxicity to amphipods. Nevertheless, Word *et al.* (2005) and Ingersoll *et al.* (2005) indicated that empirically- and mechanistically-derived SQGs for total PAHs and total PCBs are generally comparable, and are often consistent with the results of sediment spiking studies. Accordingly, such SQGs reflect causal rather than correlative effects and indicate that total PAHs and, to a lesser extent, total PCBs may be causing or substantially-contributing to the toxicity observed in many field-collected sediments. As the PRGs for total PAHs and total PCBs are generally consistent with such previously derived SQGs, it is not unreasonable to conclude that these substances are causing or substantially contributing to sediment toxicity in WBGCR sediment samples in which these PRGs are exceeded. Hence, the remedial alternatives that are ultimately implemented to address concerns related to contaminated sediments (i.e., based on exceedances of the recommended benthic PRGs) are likely to reduce the concentrations of key COCs to tolerable levels in the WBGCR and, thereby, result in tolerable levels of sediment toxicity.

Chapter 7 Summary and Conclusions

7.0 Introduction

This report was prepared to provide the United States Fish and Wildlife Service (USFWS), United States Environmental Protection Agency (USEPA), Indiana Department of Natural Resources (IDNR), and Indiana Department of Environmental Management (IDEM; i.e., the GCRRF Council; who are acting as the risk managers) with specialized technical support for evaluating the remedial alternatives for addressing sediment contamination in the West Branch of the Grand Calumet River (WBGCR). More specifically, this report was prepared to summarize the remedial action objectives (RAOs) that have been established by the risk managers for the site (Chapter 3); identify the contaminants of concern (COCs) in the WBGCR (Chapter 4); and, present the conceptual site model (CSM) as it relates to ecological receptors (Chapter 5; Appendix 1). The preliminary remediation goals (PRGs) for whole sediments that were developed to address risks to the benthic invertebrate community are presented and evaluated (Chapter 6). Collectively, these RAOs and ecological risk-based PRGs are intended to provide USFWS, USEPA, IDEM, and IDNR with a basis for selecting a suite of PRGs that can be used to evaluate remedial alternatives and, ultimately, select a remedial option that will reduce risks to human health and/or ecological receptors to tolerable levels.

As part of this initiative, Tetra Tech EC, Inc. (TtEC 2005a) has conducted an assessment of the risks posed to human health associated with exposure to environmental media in the WBGCR. Collectively, the RAOs, the human health risk assessment, and the ecological risk-based PRGs are intended to provide USFWS, USEPA, IDEM, and IDNR with a basis for evaluating remedial alternatives and selecting a remedial option that will reduce risks to human health and/or ecological receptors to tolerable levels.

7.1 Background

Sediments throughout the WBGCR are highly contaminated with heavy metals and various organic compounds, including semivolatile organic compounds (SVOCs), chlorinated pesticides, and polychlorinated biphenyls (PCBs; MacDonald and Ingersoll 2000; FWENC 2002; 2003). The results of several investigations demonstrate that the concentrations of COCs in WBGCR sediments are sufficient to adversely affect a variety of ecological receptors in the WBGCR, including benthic invertebrates, fish, and aquatic-dependent wildlife (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a; 2002b). In addition, the results of whole-sediment and pore-water toxicity tests confirm that WBGCR sediments are toxic to benthic invertebrates and fish (Burton 1994; Kemble *et al.* 2002; 2003). Furthermore, the structure of benthic invertebrate communities are altered throughout the WBGCR, as evidenced by a shift toward pollution-sensitive species and a loss of preferred fish food organisms (e.g., mayflies, caddisflies, and stoneflies; Rainbolt 1993; Simon *et al.* 2000). Fish populations are also reduced in the WBGCR due to the loss or degradation of habitat associated with inputs of sewage sludge and other substances (Simon 1993; Simon and Moy 1999/2000; Simon *et al.* 2000).

Together, these studies show that natural resources in the WBGCR have been injured as a result of direct and/or indirect exposure to sediment-associated COCs and that contaminated sediments currently pose unacceptable risks to certain ecological receptors (i.e., sediment-dwelling organisms, fish, and aquatic-dependent wildlife). The results of the human health risk assessment that was recently conducted demonstrate that environmental conditions in the WBGCR also pose unacceptable risks to human health (TtEC 2005a). Accordingly, there is a need to identify, evaluate, and implement one or more remedial alternatives to address the risks posed to human health and ecological receptors associated with exposure to environmental contaminants in the WBGCR. This report presents the RAOs and risk-based PRGs for ecological receptors that were developed to support the remedial alternatives analysis and, ultimately, the clean-up of contaminated sediments in the WBGCR.

Such PRGs define the concentrations of COCs in environmental media (i.e., sediments) that pose intermediate (PRG-IR) and high (PRG-HR) risks to sediment-dwelling organisms. The results of subsequent evaluations of the PRGs are also presented to support selection of clean-up goals that will provide an appropriate level of protection for ecological receptors.

7.2 Remedial Action Objectives

Remedial action objectives are important tools for managing the risks posed by exposure to environmental media in the vicinity of a contaminated site. More specifically, RAOs are established to describe the narrative intent of any remedial actions that are considered for addressing risks to human health and/or ecological receptors at the site (i.e., the desired future state of the site once remedial actions have been implemented to address risks to human health and/or ecological receptors). The RAOs for the WBGCR were developed by the Natural Resources Trustees, based on the input provided by stakeholders at a series of public meetings that have been convened since the river was designated as a Great Lakes Area of Concern by the International Joint Commission in 1988.

A variety of environmental media within the WBGCR are known to be contaminated by toxic and/or bioaccumulative substances, including, surface water, sediment (including whole sediment and pore water), bank and upland soil, groundwater, and biological tissues.

The RAOs for sediments, surface water, and biological tissues are presented in Section 3.2 of this document and in TtEC (2005b).

To address the risks to aquatic receptors associated with direct exposure to contaminated sediments (and/or floodway soils), the following RAOs were established: Minimize or prevent exposure to whole sediments that are sufficiently

contaminated to pose intermediate or high risks, respectively, to the microbial or benthic invertebrate communities and that would affect the prey base for fish; and, Minimize or prevent exposure to pore waters that are sufficiently contaminated to pose intermediate or high risks, respectively, to aquatic plant, benthic invertebrate, or fish communities (particularly for fish species that use sediment substrates for spawning).

For surface water, the RAOs for ecological receptors are to: Minimize or prevent exposure to surface waters that are sufficiently contaminated to pose intermediate or high risks, respectively to microorganisms, aquatic plants, aquatic invertebrates, or fish; and, Minimize risks to avian or mammalian species associated with direct contact with or ingestion of surface waters.

To address concerns relative to the bioaccumulation of COC in the tissues of aquatic organisms, the following RAOs were established: Reduce the concentrations of COCs in fish tissues to levels that are not associated with adverse effects on survival, growth, reproduction, or the incidence of lesions or tumors; Reduce the concentrations of COCs in the tissues of prey species to levels that do not pose unacceptable risks to insectivorous birds, sediment-probing birds, carnivorous-wading birds, piscivorous birds, or omnivorous mammals; and, Reduce the concentrations of COCs in fish to levels that do not pose unacceptable risks to human health.

Although RAOs were developed for surface water, it is important to understand that the GCRRF Council is not mandated to address this environmental medium directly. Rather, IDEM will address concerns relative to surface water quality through the development of TMDLs and the NPDES permitting process. Nevertheless, it is anticipated that surface water quality will improve once contaminated sediments have been cleaned-up. Similarly, the concentrations of COCs in fish tissues are likely to decrease once sediment-focused remedial activities have been completed in the WBGCR.

7.3 Contaminants of Concern

The COCs are those toxic and bioaccumulative substances that occur in whole sediments in the WBGCR at concentrations sufficient to injure natural resources. Ingersoll and MacDonald (1999), MacDonald and Ingersoll (2000), and MacDonald *et al.* (2002a; 2002b) assessed injury to surface water resources (bed sediments) and biological resources (sediment-dwelling organisms, fish, and aquatic-dependent wildlife). Based on an analysis of multiple lines of evidence, these investigators concluded that the concentrations of a number of substances in WBGCR sediments were sufficient to injure ecological receptors in the study area. The substances that occurred in WBGCR sediments at concentrations sufficient to injure bed sediments and associated biological resources include: trace metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc); PAHs (13 individual PAHs and total PAHs); PCBs (total PCBs); pesticides (chlordane, DDTs, heptachlor, and lindane); phenol; and, unionized ammonia (Ingersoll and MacDonald 1999; MacDonald and Ingersoll 2000; MacDonald *et al.* 2002a; 2002b).

7.4 Conceptual Site Model

The development of a conceptual site model (CSM) represents an essential element of the problem formulation process for an ecological risk assessment because it enhances the level of understanding regarding the relationships between human activities and ecological receptors at the site under consideration. While an ecological risk assessment was not conducted on the WBGCR, development of a CSM was considered to be important for focusing limited resources on the exposure pathways and receptors that were the most relevant for addressing the risks associated with exposure to contaminated sediments. The CSM that was developed considered the available information on the sources and releases of COCs, environmental fate of the COCs, potential exposure pathways, and ecological receptors at risk. This information was then integrated to identify candidate assessment endpoints and to

recommend an approach to the development of PRGs for ecological receptors in the WBGCR.

7.5 Preliminary Remediation Goals for Aquatic Receptors

The results of the various assessments of sediment injury that have been conducted indicated that contaminated sediments in the WBGCR pose unacceptable risks to benthic invertebrates, fish, and aquatic-dependent wildlife. Examination of the CSM that was developed for the WBGCR and supporting documentation provided a basis for recommending an approach to the development of PRGs for ecological receptors. The results of this analysis indicated that benthic invertebrate community is likely to be more sensitive to sediment-associated COCs than are microorganisms, aquatic plants or fish. For this reason, PRGs for the benthic invertebrate community were developed to support remedial action planning in the WBGCR.

The numerical PRGs for selected COCs and COC mixtures were developed largely using matching sediment chemistry and sediment toxicity data from the WBGCR. The sediment toxicity data included the results of 28-d, whole-sediment toxicity tests with the amphipod, *Hyaella azteca* (endpoint: survival). These data were supplemented with the results of 10-d whole-sediment toxicity tests that were found to be toxic to amphipods (i.e., *H. azteca*; under the assumption that samples that were toxic after 10-d exposure would still be toxic if the exposure duration was extended to 28-d). The results of the toxicity tests were expressed both in terms of magnitude of toxicity (MOT; i.e., percent survival) and incidence of toxicity (IOT; i.e., the proportion of samples within discrete concentrations that were found to be toxic, expressed as a percentage).

Using the MOT data, PRGs were derived for the following individual COCs: eight trace metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), 12 individual PAHs and PAH mixtures [anthracene, fluorene, naphthalene,

phenanthrene, total LMW-PAHs, benz(a)anthracene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, fluoranthene, pyrene, total HMW-PAHs, and total PAHs]. IOT-based PRGs were also derived for all these COCs except benz(a)anthracene, benzo(a)pyrene, or dibenz(a,h)anthracene. The PRGs for metals were expressed on a DW-normalized basis, while the PRGs for PAHs and PCBs were expressed on a DW-normalized basis at 1%OC (DW@1%OC). In addition, a total of nine COC mixture models were developed (using both MOT and IOT data) to support the derivation of PRGs that would integrate the toxic effects of multiple chemical substances and classes (i.e., metals, PAHs, and/or PCBs).

The PRGs were derived from site-specific concentration-response models that quantified the relationship between COC concentration and the MOT or IOT (i.e., which were developed using non-linear regression analysis). For each COC and COC mixture, two PRGs were derived, including a PRG that defined the lower end of the range of concentrations that posed an intermediate risk (PRG-IR) and the lower end of the range of concentrations that posed a high risk (PRG-HR) to the benthic invertebrate community. The PRG-IR is defined as the COC concentration that is associated with a 10% increase in the MOT or a 20% increase in the IOT, relative to reference conditions in the IHAOC. By comparison, the PRG-HR is defined as the COC concentration that is associated with a 20% increase in the MOT or a 50% increase in the IOT, relative to reference conditions in the IHAOC.

All of the PRGs that were derived in this investigation were evaluated to determine the extent to which they were consistent with the narrative RAOs. The results of this evaluation indicated that the majority of the PRGs for individual COCs or COC mixtures provide reliable bases for classifying whole-sediment samples as toxic or not toxic to the amphipod, *H. azteca*. Overall, the PRGs for $PEC-Q_{IPAHs(DW)}$ (Table 3), provided the highest correct classification rates (i.e., 89% for the PRG-IR and 93% of the PRG-HR; Table 9). Therefore, it could be argued that these PRGs provide the most reliable tools for classifying WBGCR sediments as toxic and not toxic, if both types of PRGs are to be applied (i.e., PRG-IR and PRG-HR).

Application of a single PRG (as opposed to a PRG-IR and PRG-HR) may provide certain advantages because it would be simpler to use and permit definitive classification of more sediment samples. For example, application of the PRG-HR for $PEC-Q_{tPAHs (DW)}$ of 5.76 alone to classify WBGCR sediments would yield acceptable correct classification rates, as 85% of the samples with concentrations below the PRG-HR were not toxic and 93% of the samples with concentrations above the PRG-HR were toxic (Table 9). Correct classification rates were similar for the PRG-IR for $PEC-Q_{tPAHs (DW@1\%OC)}$ of 0.167 (Table 3; i.e., 90% of the samples with concentrations below the PRG-IR were not toxic and 88% of the samples with concentrations above the PRG-IR were toxic; Table 9). Therefore, candidate remedial alternatives for addressing sediment contamination in the WBGCR could be evaluated using either of these PRGs; however, the PRG-IR $PEC-Q_{tPAHs (DW@1\%OC)}$ of 0.167 (Table 3) is more highly recommended because a higher proportion of intermediate risk samples (i.e., with concentrations between the PRG-IR and PRG-HR) would be correctly classified as toxic (i.e., 75% of the samples with these chemical characteristics were found to be toxic to the amphipod, *H. azteca*, in 28-d whole-sediment toxicity tests; n=4; Table 9). Therefore, it is concluded that the PRG-IR for $PEC-Q_{tPAHs (DW@1\%OC)}$ of 0.167 (Table 3) would provide a reliable basis for classifying sediments in the WBGCR and, in so doing, supporting the remedial alternatives analysis. This PRG corresponds to a total PAH concentration of roughly 3.8 mg/kg DW@1%OC or 30 mg/kg DW, assuming an average TOC is in the order of 8%. Based on the evaluations that were conducted by MacDonald *et al.* (2002c; 2003a), it is likely that this PRG would also facilitate restoration of the microbial, aquatic plant, and fish communities (i.e., adverse effects on these receptor groups would be unlikely if the recommended benthic PRGs were used to select the preferred remedial alternative and guide remedial actions in the WBGCR).

Recently, MacDonald *et al.* (2005) developed and evaluated numerical PRGs for the IHAOC as a whole (including the WBGCR). The results of this study demonstrated that the MOT-based PRG-HR for $PEC-Q_{tPAH(DW@1\%OC)}$ would provide the most reliable basis for classifying sediment samples from the IHAOC as toxic and not toxic (overall correct classification rate of 86%). This PRG corresponds to a total PAH

concentration of 3.4 mg/kg DW@1%OC or 27 mg/kg DW. Because correct classification rates were similar for the IHAOC PRG (86%) and WBGCR PRG (89%) and because it is beneficial to establish PRGs consistently throughout the AOC, it is recommended that the IHAOC PRG be adopted for use in the remedial alternatives analysis for the WBGCR.

It is important to understand that the PRGs developed in this report are intended to provide a basis for classifying sediment samples as toxic or not toxic based on whole-sediment chemistry alone. Although PRGs were derived for eight trace metals, 12 individual PAHs and PAH classes, total PCBs, and various COC mixtures, no attempt was made to identify the substance or substances that were causing the observed toxicity in the WBGCR. Rather, the PRGs identify the concentrations of sediment-associated COCs that are associated with a specified incidence or magnitude of toxicity to amphipods. Nevertheless, Word *et al.* (2005) and Ingersoll *et al.* (2005) indicated that empirically- and mechanistically-derived SQGs for total PAHs and total PCBs are generally comparable, and are often consistent with the results of sediment spiking studies. Accordingly, such SQGs reflect causal rather than correlative effects and indicate that total PAHs and, to a lesser extent, total PCBs may be causing or substantially-contributing to the toxicity observed in many field-collected sediments. As the PRGs for total PAHs and total PCBs are generally consistent with such previously derived SQGs, it is not unreasonable to conclude that these substances are causing or substantially contributing to sediment toxicity in WBGCR sediment samples in which these PRGs are exceeded. Hence, the remedial alternatives that are ultimately implemented to address concerns related to contaminated sediments (i.e., based on exceedances of the recommended benthic PRGs) are likely to reduce the concentrations of key COCs to tolerable levels in the WBGCR and, thereby, result in tolerable levels of sediment toxicity.

Numerical PRGs for sediment-associated COCs are also needed to address risks to aquatic-dependent wildlife associated with the bioaccumulation of certain COCs in the tissues of aquatic organisms (i.e., prey species). However, rather than developing wildlife-based PRGs, the level of protection offered to avian and mammalian species

by the benthic PRGs will be evaluated as a first step in the process. More specifically, GIS-based spatial analysis tools will be employed to estimate average concentrations of key bioaccumulative COCs (e.g., mercury and total PCBs) following implementation of the preferred remedial alternative. Simple bioaccumulation and food web models will then be used to estimate potential exposure and risks to aquatic-dependent wildlife, post-remediation. This approach will provide a basis for determining if the benthic PRGs are likely to provide an adequate level of protection for aquatic-dependent wildlife. In addition, it will help to identify the bioaccumulative COCs for which wildlife-based PRGs may be needed (i.e., those that are predicted to occur in sediments at levels that could result in unacceptable levels of bioaccumulation) and, thereby, focus resources on priority COCs for wildlife.

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Appendix 1 Receptors at Risk in the West Branch of the Grand Calumet River

A1.0 Introduction

Ecological risk assessment is the process by which the risks to ecological receptors associated with exposure to various stressors is evaluated. In general, the problem formulation phase of the ERA is focused on establishing linkages between specific human activities and potential effects on valued ecosystem components. For chemical stressors, this process typically involves: identification of contaminant sources and releases; determination of contaminants of potential concern (COPCs); evaluation of the environmental fate and transport of each COPC; identification and evaluation of various exposure pathways (i.e., the environmental media through which receptors may be exposed to contaminants); and, identification of the ecological receptors (i.e., plants and animals) that may be exposed to the COPCs. In this way, it is possible to identify the conditions that pose the greatest ecological risks (i.e., when ecological receptors are actually exposed to hazardous levels of environmental contaminants).

In the environment, a variety of species are likely to be exposed to COPCs. Each of these receptors may be exposed to a chemical via one or more exposure routes and have the potential to exhibit different types and severity of effects. While information on the effects of each chemical on each component of the ecosystem would provide comprehensive information for evaluating ecological risks, it is neither practical nor feasible to directly evaluate risks to all of the individual components of the ecosystem at a site (USEPA 1997). Thus, risk assessments typically consider the mechanisms of ecotoxicity for each contaminant or group of contaminants to determine which receptors are likely to be most at risk. This information must include an understanding of how the adverse effects of the contaminant could be expressed (e.g., eggshell thinning in birds) and of how the form of the chemical in the environment could influence its bioavailability and toxicity.

A critical element of the problem formulation process is the identification of the ecological receptors that occur within the study area. In the WBGCR, the ecological receptors potentially at risk include the plants and animals that utilize aquatic, wetland, and terrestrial habitats within the watershed. More specifically, the ecological receptors potentially at risk due to historic and ongoing discharges of contaminants into surface waters include microbial communities, aquatic plant communities, benthic macroinvertebrate communities, fish communities, reptile and amphibian communities, and aquatic-dependent bird and mammal communities. While other groups of ecological receptors are known to occur within this ecosystem (e.g., terrestrial insects, terrestrial plants), they are considered to be of secondary importance from an aquatic risk management perspective due to the low potential for exposure to water-borne or sediment-associated contaminants. The following sections of this appendix provide descriptions of the various groups of ecological receptors that occur within the WBGCR.

A1.1 Microbial Community

Microbial communities, which consist of the bacteria, protozoans, and fungi, play several essential roles in aquatic ecosystems. First, microbes degrade and transform detrital organic matter in a manner that makes it readily available to detritus feeders. In addition, microbial communities play a number of key roles in the cycling and transformation of nutrients in sediments and the water column. For example, the microbial community is an essential element of the nitrogen cycle, in which atmospheric nitrogen is converted, through a series of steps, into nitrates, nitrites, and ammonia. These forms of nitrogen represent essential plant nutrients and are the basic building blocks for protein synthesis. The sulfur cycle in aquatic environments, in which hydrogen sulfide is converted to sulfate (which is incorporated into plant and animal tissues), is also mediated by the microbial community (Odum 1975). The microbial community also supports primary productivity by transforming phosphorus into forms that can be readily used by aquatic plants (i.e., phosphate). Finally, carbon cycling (i.e., between the dissolved and particulate forms) in aquatic ecosystems is

dependent on the microbial community. Although it is likely that a variety of microbial species utilize habitats in the WBGCR, no information was located on the identity or distribution of such organisms.

A1.2 Aquatic Plant Communities

The aquatic plant communities in lotic (i.e., running water) ecosystems consist of periphyton, aquatic macrophytes, and riparian vegetation. Periphyton are the small non-vascular plants that grow on other aquatic plants or on the bottom of the watercourse. Aquatic macrophytes is the general term applied to either large vascular or non-vascular plants that grow in freshwater, estuarine, and marine systems (including both submergent and emergent plants). Riparian vegetation is the term that is applied to the vascular plants that grow along the edge of watercourses. As primary producers, aquatic plants transform the sun's energy into organic matter. As such, aquatic plants represent a primary food source for a variety of plant-eating invertebrates (i.e., herbivores, which are also known as primary consumers). Hence, aquatic plants represent essential elements of aquatic ecosystems.

Periphyton Communities

Periphyton are non-vascular aquatic plants that grow on the firm substrates, such as firm sediments (i.e., sand and gravel), rocks, shells, and aquatic macrophytes. Periphyton species are autotrophic organisms that use the sun's energy to convert inorganic materials, such as carbon, nitrogen, and phosphorus) into organic matter, such as proteins, lipids, and sugars. Periphyton represents an important source of food for benthic and epibenthic invertebrates that feed by grazing on small plants (Odum 1975).

There are many different species of algae that can comprise periphyton communities, which generally fall into seven main groups. The blue-green algae (cyanophyta) are

the most primitive group of algae, with cell structure like that of bacteria (i.e., the cells lack certain membranous structures, such as nuclear membranes, mitochondria, and chloroplasts; Bell and Woodcock 1968). Blue-green algae can occur in unicellular, filamentous, and colonial forms, many of which are enclosed in gelatinous sheathes. Many species of blue-green algae can utilize nitrogen from the atmosphere as a nutrient (termed nitrogen fixation), which makes them adaptable to a variety of environmental conditions.

The green algae (chlorophyta) encompass a large and diverse group of phytoplankton species that are largely confined to freshwater ecosystems. Green algae can occur as single cells, colonies, or filaments of cells. The chrysophytes are comprised of three groups of algae (diatoms - bacillariophyceae; yellow-green algae - xanthophyceae; golden-brown algae - chrysophyceae) which are linked by a common set of features, including a two-part cell wall, the presence of a flimmer flagella, the deposition of silica in the cell wall, and the accumulation of the food reserve, leucosin (Bell and Woodcock 1968). The four other groups of phytoplankton include the desmids and the dinoflagellates (i.e., pyrrophytes; which a unicellular, flagellate algae), cryptomonads (i.e., cryptophytes; which a typically flagellate algae that grow well under cold, low light conditions), euglenoids (i.e., euglenophytes; which are unicellular, flagellate algae that are only rarely planktonic), brown algae (i.e., phaeophytes), and red algae (i.e., rhodophytes; Bell and Woodcock 1968). The latter two groups are only sparsely represented in freshwater ecosystems.

Although a variety of periphytic algal species are likely to occur in the WBGCR, no information was located on the identity or distribution of such organisms.

Aquatic Macrophyte Communities

Aquatic macrophyte communities are comprised of the large vascular and non-vascular plants that grow in a waterbody. Aquatic macrophytes can grow under the surface of the water (i.e., submergent plants, such as milfoil) or emerge from the surface of the water (i.e., emergent plants, such as bullrushes; Bell and Woodcock 1968).

Aquatic macrophytes play a number of important roles in freshwater and estuarine ecosystems. As autotrophic organisms, aquatic macrophytes can account for much of the primary productivity in aquatic systems, particularly in wetlands and other shallow areas that favor the establishment of marsh plants. In this role, macrophytes represent an important food source for aquatic organisms, either for grazers that can process these plant materials directly or those species that consume the bacteria that decompose these plant tissues following their death (Odum 1975). In addition, aquatic macrophytes provide habitats that are utilized by a variety of aquatic invertebrates species. These habitats also represent important as spawning and nursery areas for many fish species.

Choi (1999/2000) compiled information on wetland flora of the Grand Calumet River. Based on this review, it is apparent that the WBGCR supports several types of wetland plant communities that historically may have included over 1400 aquatic and riparian plant species. However, recent surveys indicate that more than half of these species no longer occur and that more than 100 alien species have invaded wetland habitats in the study area. Currently, Roxanna Marsh is considered to be a severely degraded riparian wetland that is infested by alien and invasive species, such as purple loosestrife (*Lythrum salicaria*), the reed (*Phragmites communis*), narrow-leaved cattail (*Typha augustifolia*), and broad-leaved cattail (*T. latifolia*; Choi 1999/2000). Nevertheless, Choi (1999/2000) classified this area as high quality habitat with special conservation needs. Choi (1999/2000) also indicated that restoration activities should focus on reestablishing marsh, sedge meadow, and wet prairie habitats, as these were probably the most common in the region's pre-settlement landscape.

Riparian Vegetation

Riparian vegetation encompasses the vascular and, to a lesser extent, non-vascular terrestrial plants that grow along the margins of the watercourses in the study area. Some of the woody species that occur in the WBGCR riparian zone include: boxelder (*Acer negundo*), eastern cottonwood (*Populus deltoides*), and various willow species (*Salix spp.*; Choi 1999/2000).

A1.3 Invertebrate Communities

The invertebrate communities in freshwater ecosystems consist primarily of zooplankton and benthic macroinvertebrate communities. Zooplankton is the term that is used to describe the small animals that remain suspended in the water column in aquatic systems. In contrast, benthic macroinvertebrates are the small animals that live in (i.e., infaunal species) or on (i.e., epibenthic species) the sediments in aquatic systems. In lotic ecosystems, benthic invertebrates are the most prevalent and important species. Aquatic invertebrates (i.e., primary consumers) represent essential elements of aquatic food webs because they consume aquatic plants (i.e., primary producers) and provide an important food source for fish and many other aquatic organisms.

Benthic invertebrates is the term that is used to describe the assemblage of animals that live in and on the sediments in freshwater and estuarine ecosystems. Benthic animals are extremely diverse and are represented by nearly all taxonomic groups from protozoa to large invertebrates. The groups of organisms that are commonly associated with benthic communities include protozoa, sponges (i.e., Porifera), coelenterates (such as *Hydra*), flatworms (i.e., Platyhelminthes), bryozoans, aquatic worms (i.e., oligochaetes), crustaceans (such as isopods and amphipods), mollusks (such as mussels and clams), and aquatic insects (such as dragonflies, mayflies, stoneflies, true flies, caddisflies, and aquatic beetles). Because benthic invertebrate communities are difficult to study in a comprehensive manner, benthic ecologists often focus on the relatively large members of benthic invertebrate communities, which are termed benthic macroinvertebrates. These organisms are usually operationally defined as those that are retained on a 0.5 mm sieve.

Benthic invertebrates represent key elements of aquatic food webs because they consume aquatic plants (i.e., such primary producers as algae and aquatic macrophytes) and detritus. In this way, these organisms facilitate energy transfer to fish, birds, and other organisms that consume aquatic invertebrates. Rainbolt (1993) evaluated the structure of benthic invertebrate communities in the WBGCR, using

data collected by deploying multi-plate sampler throughout the river. The results of this study indicated that pollution-tolerant oligochaetes or chironomids (Ceratopogonidae, Stratiomyidae, Empididae, Ephydriidae, and Muscidae) were the dominant taxa at the five sites that were sampled. Pollution-sensitive mayflies (Ephemeroptera), caddisflies (Plecoptera), or stoneflies (Trichoptera) were not observed in any of the samples collected. Gastropods (Lymnaeidae and Physidae) and coleopterans (Hydrophilidae and Curculionidae) were observed at one of the sampling sites.

A1.4 Fish Community

Fish are key elements of freshwater ecosystems. As one of the most diverse groups of vertebrates, fish are able to occupy a wide range of ecological niches and habitats (Hoese and Moore 1998). As such, fish represent important components of aquatic food webs by processing energy from aquatic plants (i.e., primary producers), zooplankton and benthic macroinvertebrate species (i.e., primary consumers), or detritivores. In addition, fish represent important prey species for piscivorous (fish-eating) wildlife, including reptiles, birds, and mammals. Furthermore, many fish species support important subsistence, sport, and/or commercial fisheries.

A number of studies have been conducted to evaluate fish communities in the GCR basin. The results of an investigation conducted near the turn of the century indicate that the GCR historically supported a relatively diverse warm-water fish community (Meek and Hildebrand 1910). The species that were recorded at that time included: Bowfin (*Amia calva*), carp (*Cyprinus carpio*), golden shiner (*Notemigonus crysoleucus*), emerald shiner (*Notropis antherinoides*), spottail shiner (*N. hudsonius*), bluntnose minnow (*Pimephales notatus*), white sucker (*Catostomus commersoni*), channel catfish (*Ictalurus punctatus*), black bullhead (*Ameiurus melas*), brown bullhead (*A. nebulosus*), yellow bullhead (*I. natalis*), tadpole madtom (*Noturus gyrinus*), northern pike (*Esox lucius*), grass pickerel (*E. americanus*), central mudminnow (*Umbra limi*), green sunfish (*Lepomis cyanellus*), pumpkinseed (*L.*

gibbosus), bluegill (*L. macrochirus*), black crappie (*Pomoxis nigromaculatus*), yellow perch (*Perca flavescens*), Logperch (*Percina caprodes*), and freshwater drum (*Aplodinotus grunniens*).

More recent collections indicate that species diversity is much lower now than it was historically. During 1985, 1986, 1987, and 1988, the USFWS use a boat-mounted electroshocker to collect fish at three stations on the WBGCR (Simon *et al.* 1988). A total of four species captured during investigation, including carp, goldfish, golden shiner, and gizzard shad (*Dorosoma cepedianum*). In 1990, the USFWS collected fish in the vicinity of Indianapolis Boulevard during two sampling events (T. Simon, USFWS, Bloomington, Indiana, unpublished data). A total of 10 species were collected during this survey, including: carp, goldfish, carp/goldfish hybrid, golden shiner, rudd (*Scardinius erythrophthalmus*), bluntnose minnow, fathead minnow (*Pimephales promelas*), black bullhead, green sunfish, and pumpkinseed. More recently (1992), Simon (1993) collected fish at five locations on the WBGCR, including four stations located west of Indianapolis Boulevard and one station located east of Indianapolis Boulevard. The results of this investigation showed that species diversity was low west of Indianapolis Boulevard, with a total of five species collected (carp, goldfish, golden shiner, bluntnose minnow, and rudd). East of Indianapolis Boulevard, ten fish species were collected, including carp, goldfish, golden shiner, bluntnose minnow, fathead minnow, rudd, white sucker, black bullhead, green sunfish, and pumpkinseed. More recently, chinook salmon (*Oncorhynchus tshawytschaw*) have been observed in the WBGCR (Hudak 1996).

A1.5 Amphibians

Although amphibians are known to utilize habitats within the WBGCR, no information was located on the number and identity of the species in this sub-basin. Nevertheless, Mierzwa *et al.* (1999/2000) compiled a list of amphibian species that may have occurred within the IHAOC historically, including:

Salamanders: Eastern tiger salamander (*Ambystoma tigrinum tigrinum*); blue-spotted salamander (*A. laterale*); mudpuppy (*Necturus maculosus*); redback salamander (*Plethodon cinereus*); eastern red-spotted newt (*Notophthalmus viridescens*).

Frogs and Toads: northern cricket frog (*Acris crepitans blanchardi*); American toad (*Bufo americanus*); Fowler's toad (*B. fowleri*); gray tree frog (*Hyla versicolor*); spring peeper (*Pseudacris crucifer crucifer*); western chorus frog (*P. triseriata triseriata*); bullfrog (*Rana catesbeiana*); green frog (*R. clamitans melanota*); northern leopard frog (*R. pipiens*).

Of these amphibian species, the following are considered to have been extirpated from the study area (Mierzwa *et al.* 1999/2000): mudpuppy and redback salamander.

A1.6 Reptiles

Numerous reptile species utilize freshwater habitats in the vicinity of Lake Michigan. However, little information was located on the number or identity of turtles and snakes that occur within the WBGCR. Nevertheless, Mierzwa *et al.* (1999/2000) compiled a list of reptilian species that may have utilized habitats within the study area historically, including:

Turtles: snapping turtles (*Chelydra serpentina serpentina*); midland painted turtles (*Chrysemys picta marginata*); spotted turtle (*Clemmys guttata*); Blanding's turtle (*Emydoidea blandingii*), eastern Box turtle (*Terrapene carolina carolina*); common map turtle (*Graptemys geographica*); common musk turtle (*Sternotherus odoratus*).

Lizards: six-lined racerunner (*Cnemidophorus sexlineatus*); five-lined skink (*Eumeces fasciatus*); western slender glass lizard (*Ophisaurus attenuatus attenuatus*).

Snakes: Chicago garter snake (*Thamnophis sirtalis semifasciata*); plains garter snake (*T. radix radix*); black rat snake (*Elaphe obsoleta obsoleta*); eastern hognose snake (*Heterodon platirhinos*); blue racer (*Coluber constrictor*); western fox snake (*E. vulpina vulpina*); milk snake (*Lampropeltis triangulum*); common water snake (*Nerodia sipedon*); smooth green snake (*Opheodrys vernalis*); Queen snake (*Regina septemvittata*); midland brown snake (*Storeria dekayi wrightorum*); western ribbon snake (*T. proximus proximus*); eastern garter snake (*T. sirtalis sirtalis*).

Of these, five reptilian species are considered to have been extirpated from the area, including the blue racer, fox snake, five-lined skink, map turtle, and the smooth green snake (Mierzwa *et al.* 1999/2000).

A1.7 Birds and Mammals

The GCR watershed and surrounding environs provide suitable habitat for a substantial number of bird species. Hudak (1996) listed a total of 124 resident and migratory bird species that have been recorded in the vicinity of Indiana Harbor, Indiana harbor Ship Canal, Lake George Branch, and the Grand Calumet River. By comparison, Brock (1999/2000) identified over 40 winter resident bird species in the Grand Calumet River corridor and over 160 species that migrate through the area. Collectively, this information shows that the Grand Calumet River basin supports a diverse assemblage of avian species, at least on a seasonal basis.

In addition to identifying the avian species that utilize habitats in the Grand Calumet River basin, Brock (1999/2000) evaluated distribution of these species in the area. The results of this study show that most of the avian species that have been documented in the WBGCR were observed using habitats in the Roxanna Marsh reach. Nevertheless, habitats both west and east of Roxanna Marsh were utilized by a variety of birds. Some of the important aquatic-dependent bird species that have been documented in the WBGCR include:

Insectivorous Birds: A number of insectivorous birds have been observed primarily in the Roxanna Marsh reach of the WBGCR, including tree swallows (*Tachycineta bicolor*); cliff swallows (*Hirundo pyrrhonota*), barn swallows (*H. rustica*), bank swallows (*Riparia riparia*), willow flycatchers (*Empidonax trailii*), and purple martin (*Progne subis*). These species are important from a risk management perspective because they typically feed on emergent insects (which are exposed to contaminated sediments during their larval stages).

Sediment-Probing Birds: A variety of shorebirds (i.e., sediment-probing species) have been observed in the vicinity of Roxanna Marsh, including black-bellied plovers (*Pluvialis squatarola*), American golden plover (*P. dominicus*), semipalmated plover (*Charadrius semipalmatus*), killdeer (*C. vociferus*), American avocet (*Recurvirostra americana*), greater yellowlegs (*Tringa melanoleuca*), lesser yellowlegs (*T. flavipes*), solitary sandpiper (*T. solitaria*), spotted sandpiper (*Actitis macularia*), red knot (*Calidris canutus*), marbled godwit (*Limosa fedoa*), Hudsonian godwit (*L. haemastica*), stilt sandpiper (*C. himantopus*), ruddy turnstone (*Arenaria interpres*), sanderling (*C. alba*), semipalmated sandpiper (*C. pusilla*), western sandpiper (*C. mauri*), least sandpiper (*C. minutilla*), white-rumped sandpiper (*C. fuscicollis*), Baird's sandpiper (*C. bairdii*), pectoral sandpiper (*C. melanotos*), dunlin (*C. alpina*), stilt sandpiper (*C. himantopus*), long-billed dowitcher (*Limnodromus scolopaceus*), and red-necked phalarope (*Phalaropus lobatus*; Brock 1999/2000; Hudak 1996). These species utilized this area extensively when Roxanna Marsh was characterized primarily as mud flats. The use of this area by these species diminished in recent years as emergent aquatic vegetation has become more prevalent.

Carnivorous Wading Birds: Habitats within the WBGCR are utilized by a variety of carnivorous wading birds, including: American bittern (*Botaurus lentiginosus*); least bittern (*Ixobrychus exilis*); great blue herons (*Ardea herodias*), great egrets (*A. albus*), cattle egrets (*Bubulcus ibis*), black-crowned

night herons (*Nycticorax nycticorax*), and little green herons (*Butorides striatus*; Brock 1999/2000).

Piscivorous Birds: Some of the piscivorous birds that have observed within the WBGCR include pied-billed grebes (*Podilymbus podiceps*), horned grebe (*Podiceps auritus*), eared grebe (*P. nigricollis*) double-crested cormorants (*Phalacrocorax auritus*), hooded merganser (*Lophodytes cucullatus*), red-breasted merganser (*Mergus serrator*), belted kingfishers (*Ceryle alcyon*), osprey (*Pandion haliaetus*), and bald eagles (*Haliaeetus leucocephalus*).

A1.8 Mammals

A variety of mammalian species utilize habitats within the Grand Calumet River basin. Based on a review of the available literature and the results of recent field investigations, Whitaker (1999/2000) identified nearly forty mammalian species that occur within the basin, including:

Carnivores: coyote (*Canis latrans*); red fox (*Vulpes vulpes*); gray fox (*Urocyon cinereoargenteus*); racoon (*Procyon lotor*); least weasel (*Mustela nivalis*); long-tailed weasel (*M. frenata*); mink (*M. vison*); badger (*Taxidea taxus*); striped skunk (*Mephitis mephitis*).

Rodents: eastern chipmunk (*Tamias striatus*); woodchuck (*Marmota monax*); Franklin's ground squirrel (*Spermophilus franklinii*); thirteen-lined ground squirrel (*S. tridecemlineatus*); gray squirrel (*Sciurus carolinensis*); fox squirrel (*S. niger*); red squirrel (*Tamiasciurus hudsonicus*); southern flying squirrel (*Glaucomys volans*); American beaver (*Castor canadensis*); white-footed mouse (*Peromyscus leucopus*); prairie deer mouse (*P. maniculatus bairdii*); common vole (*Scalopus aquaticus*); prairie vole (*Microtus ochrogaster*); meadow vole (*M. pennsylvanicus*); pine vole (*M. pinetorum*); common muskrat (*Ondatra zibethicus*); southern bog lemming (*Synaptomys cooperi*);

meadow jumping mouse (*Zapus hudsonius*); Norway rat (*Ratus norvegicus*); house mouse (*Mus musculus*).

Lagomorphs: eastern cottontail (*Sylvilagus floridanus*).

Bats: little brown myotis (*Myotis lucifugus*); eastern red bat (*Lasiurus borealis*); silver-haired bat (*Lasionycteris noctivagans*); big brown bat (*Eptesicus fuscus*).

Insectivores: least shrew (*Cryptotis parva*); northern short-haired shrew (*Blarina brevicauda*); masked shrew (*Sorex cinereus*); pygmy shrew (*Microsorex hoyi*).

Other Mammals: white-tailed deer (*Odocoileus virginiana*); opossum (*Didelphus virginiana*).

According to Whitaker (1999/2000), the following mammalian species have been extirpated from the Grand Calumet River area: American porcupine (*Erethizon dorsatum*), gray wolf (*Canis lupus*); black Bear (*Ursus americanus*), fisher (*Martes pennanti*), river otter (*Lutra canadensis*); mountain lion (*Felis concolor*); Canada lynx (*F. lynx*), bobcat (*F. rufus*), bison (*Bison bison*); and, American elk (*Cervus canadensis*). Accordingly, the aquatic-dependent mammalian species that still occur or have the potential to occur within the study is quite limited and include: raccoons, mink, beaver, and muskrat. Raccoons consume a wide variety of foods, including benthic invertebrates, and are commonly observed in the study area. Mink are primarily piscivorous species that could occur within the study area. While mink have not been observed in the WBGCR, they still might be present. This is because mink are very secretive and visually hard to spot (Gottschang 1981). Moreover, the WBGCR contains suitable riparian cover habitat for mink in certain reaches of the river (Allen 1986).

Appendix 2 Criteria for Evaluating Candidate Data Sets

A2.0 Introduction

A project database was developed to support the assessment of sediment injury in the Grand Calumet River Lagoons, Grand Calumet River, Indiana Harbor Canal, Lake George Branch, US Canal, Indiana Harbor, and the waters of nearshore Lake Michigan. The database is comprised of sediment chemistry and/or biological effects data from the study area. These data were used to evaluate the severity and extent of sediment injury in the study area. To assure that the data used in the assessment met project data quality objectives, all of the candidate data sets were critically evaluated prior to inclusion in the database. However, the screening process was also designed to be flexible to assure that professional judgement could also be used when necessary in the evaluation process. In this way, it was possible to include as many data sets as possible and, subsequently, use them to the extent that the data quality and quantity dictate. In total, more than 125 data sets were evaluated to obtain the information needed to accomplish these objectives.

A2.1 Criteria for Evaluating Whole Sediment, Pore Water, and Tissue Chemistry

The whole sediment, pore water, and tissue chemistry data from the study area were used to evaluate the severity and extent of sediment injury in the Assessment Area and to identify contaminants of concern. Data from individual studies were considered to be acceptable for use in this report if:

- Samples were collected within the study area (see Natural Resources Trustees 1997 for a complete description of the study area);

- Samples were collected from any sediment horizon (samples representing surficial sediments were used to assess injury to sediments and biological resources; samples of sub-surface sediments were used to assess sediment injury);
- Appropriate procedures were used for collecting, handling, and storing sediments (e.g., ASTM 2004c) and other samples;
- The concentrations of chemicals of concern were measured in samples (see Natural Resources Trustees 1997 for a list of hazardous substances);
- Appropriate analytical methods were used to generate chemistry data. The methods that were considered to be appropriate included USEPA approved methods, other standardized methods (e.g., ASTM methods, SW-846 methods), or methods that have been demonstrated to be equivalent or superior to standard methods; and,
- Data quality objectives (DQOs) were met. The criteria that were used to evaluate data quality included:
 - the investigator indicated that DQOs had been met,
 - analytical detection limits were reported and lower than the PECs (measurements with detection limits above the PECs were included in the project database, but not used in data analyses; accuracy and precision of the chemistry data were reported and within acceptable ranges for the method; sample contamination was not noted (i.e., analytes were not detected in method blanks),
 - in the absence of complete QA/QC information, chemistry data were considered to be acceptable if they were generated post-1985 for use in a regulatory context (i.e., it was assumed that the USEPA QA/QC guidelines were likely met for such data),
 - the results of a detailed third party review indicated that the data were acceptable, and/or,
 - professional judgement indicated that the data set was likely to be of sufficient quality to be used in the assessment (i.e., in conjunction with author communications and/or other investigations); and,

- Incomplete information was available to conduct a full evaluation or certain data quality objectives were not met, but best professional judgement indicated that the data set was likely to be of sufficient quality to be used in the assessment.

A2.2 Criteria for Evaluating Biological Effects Data

Information on the effects of contaminated sediments on sediment-dwelling organisms and other aquatic species were used to evaluate the severity and extent of injury to sediments and biological resources in the Assessment Area. Data from individual studies were considered to be acceptable for this purpose if:

- Sediment samples were collected within the study area (see Natural Resources Trustees 1997 for a complete description of the study area);
- Appropriate procedures were used for collecting, handling, and storing sediments (e.g., ASTM 2004c);
- Sediments were not frozen before toxicity tests were initiated (ASTM 2004a; 2004b);
- The responses in the negative control and/or reference groups were within accepted limits (i.e., ASTM 2002; 2004a; 2004b; 2004d; 2004e);
- Adequate environmental conditions were maintained in the test chambers during toxicity testing (i.e., ASTM 2004a; 2004b);
- The endpoint(s) measured were ecologically-relevant (i.e., likely to influence the organism's viability in the field) or indicative of ecologically-relevant endpoints; and,
- Data on the status of benthic invertebrate communities were not evaluated prior to use.

Table 1. Listing of the matching whole-sediment chemistry and toxicity data used to derive and evaluate preliminary remediation goals (PRGs) for the West Branch Grand Calumet River.

Reference	Sampling Date	Area	n	COCs						Sediment Toxicity	
				Metals	SEM & AVS	PAHs	PCB - Aroclors	PCB - Congeners	Phenol	<i>Hyalella azteca</i> (10-d)	<i>Hyalella azteca</i> (28-d)
Burton (1994); Dorkin (1994)	1993	Within Study Area	7	*		*			*	*	
URS Greiner Woodward Clyde (1998)	1998	Within Study Area	3	*		*	*		*	*	
ThermoRetec (1999)	1998	Within Study Area	1	*		*			*	*	
FWEC (2002); Kemble <i>et al.</i> (2002)	2002	Within Study Area	62	*	*	*	*			*	
FWEC (2003); Kemble <i>et al.</i> (2003)	2002	Within Study Area	43	*	*	*	*	*	*	*	

AVS = acid volatile sulfides; SEM = simultaneously extractable metals; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; IH = Indiana Harbor; USC = United States Canal; EBGCR = East Branch Grand Calumet River; IHC = Indiana Harbor Canal; LGB = Lake George Branch; WBGCR = West Branch Grand Calumet River.

Table 2. Summary of the concentration-response relationships derived based on magnitude of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-day toxicity tests (endpoint: survival). The preliminary remediation goals (PRGs) derived using these regression equations are also presented.

Mixture Model	Regression Equation Type	Regression Equation	n ¹	r ²	p	PRG-IR	PRG-HR
Mean PEC-Q _{metals} (DW)	Log3	$y = 101.1849/[1 + (x/3.4774)1.1786]$	101	0.95	0.0001	0.894	1.44
Mean PEC-Q _{metals} (DW@1%OC)	Log4	$y = 34.9833 + 65.7438/[1 + (x/0.1638)2.4027]$	100	0.99	<0.0001	0.104	0.137
PEC-Q _{tPAHs} (DW)	Log3	$y = 100.1841/[1 + (x/10.7556)-0.9472]$	102	0.98	<0.0001	1.86	3.44
PEC-Q _{tPAHs} (DW@1%OC)	Log3	$y = 99.9180/[1 + (x/1.0300)0.9909]$	102	0.99	<0.0001	0.189	0.342
PEC-Q _{PCBs} (DW)	Linear	$y = 79.0695 - 2.1172x$	64*	0.46	0.0439	NA	2.02
PEC-Q _{PCBs} (DW@1%OC)	Log3	$y = 92.9279/[1 + (x/0.8809)1.7513]$	61*	0.77	0.0115	0.241	0.392
Mean PEC-Q _{metals} (DW), tPAHs (DW), tPCBs (DW)	Sig4	$y = 15.5565 + 91.9927/\{1 + e[-(x - 6.1384) / -2.9308]\}$	104	0.97	0.0003	2.98	4.40
Mean PEC-Q _{metals} (DW@1%OC), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	Log3	$y = 99.5794/[1 + (x/0.6613)1.7768]$	102	0.99	<0.0001	0.254	0.355
Mean PEC-Q _{metals} (DW), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	Log3	$y = 99.7775/[1 + (x/1.7674)2.3690]$	103	0.99	<0.0001	0.867	1.11

¹Asterisk denotes that the concentration-response relationships were derived using data from the entire Indiana Harbor Area of Concern.

r² = correlation coefficient; p = p value for the F statistic (ANOVA); PEC-Q = probable effect concentration-quotient; DW = dry weight; OC = organic carbon; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; Log3 = 3 parameter logistic; Log4 = 4 parameter logistic; Sig3 = 3 parameter Sigmoidal; Sig4 = 4 parameter Sigmoidal; NA = not applicable - PRG could not be derived based on the concentration-response relationship; IR = intermediate risk; HR = high risk.

Table 3. Summary of the concentration-response relationships derived based on incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-day toxicity tests (endpoint: survival). The preliminary remediation goals (PRGs) derived using these regression equations are also presented.

Mixture Model	Regression Equation Type	Regression Equation	n ¹	r ²	p	PRG-IR	PRG-HR
Mean PEC-Q _{metals} (DW)	Log3	$y = 101.1678/[1 + (x/2.4050)-1.1904]$	101	0.97	<0.0001	0.836	2.48
Mean PEC-Q _{metals} (DW@1%OC)	Sig3	$y = 69.7049/\{1 + e-[(x - 0.1424) / 0.0337]\}$	100	0.99	<0.0001	0.117	0.177
PEC-Q _{tPAHs} (DW)	Log3	$y = 111.1649/[1 + (x/6.5856)-1.1048]$	102	0.99	<0.0001	1.89	5.76
PEC-Q _{tPAHs} (DW@1%OC)	Log3	$y = 111.4346/[1 + (x/0.6430)-1.0254]$	102	0.98	<0.0001	0.167	0.555
PEC-Q _{PCBs} (DW)	NA	NA	NA	NA	NA	NA	NA
PEC-Q _{PCBs} (DW@1%OC)	Sig3	$y = 101.2808/\{1 + e-[(x - 0.7031) / 0.3607]\}$	61*	0.66	0.0408	0.249	0.715
Mean PEC-Q _{metals} (DW), tPAHs (DW), tPCBs (DW)	Sig4	$y = -2.7268 + 95.3141/\{1 + e-[(x - 4.9652) / 2.0054]\}$	104	0.95	0.0014	2.90	5.52
Mean PEC-Q _{metals} (DW@1%OC), tPAHs (DW@1%OC), tPCBs (DW)	Log3	$y = 103.0581/[1 + (x/0.4545)-2.2764]$	102	0.99	<0.0001	0.259	0.454
Mean PEC-Q _{metals} (DW), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	Log3	$y = 123.5285/[1 + (x/1.7154)-1.8642]$	103	0.99	<0.0001	0.764	1.43

¹Asterisk denotes that the concentration-response relationships were derived using data from the entire Indiana Harbor Area of Concern.

r² = correlation coefficient; p = p value for the F statistic (ANOVA); PEC-Q = probable effect concentration-quotient; DW = dry weight; OC = organic carbon; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; Log3 = 3 parameter logistic; Log4 = 4 parameter logistic; Sig3 = 3 parameter Sigmoidal; Sig4 = 4 parameter Sigmoidal; NA = not applicable - PRG could not be derived based on the concentration-response relationship; IR = intermediate risk; HR = high risk.

Table 4. Summary of the concentration-response relationships derived based on magnitude of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-day toxicity tests (endpoint: survival). The preliminary remediation goals (PRGs) derived using these regression equations are also presented.

Contaminant of Concern (COC)	Regression Equation Type	Regression Equation	n ¹	r ²	p	PRG-IR	PRG-HR
Metals (mg/kg DW)							
Arsenic	Log3	$y = 105.5401/[1 + (x/53.2463)1.0170]$	103	0.90	0.0011	13.8	22.2
Cadmium	Log3	$y = 102.7889/[1 + (x/26.5629)0.7739]$	101	0.88	0.0019	3.77	7.46
Chromium	Log3	$y = 116.9480/[1 + (x/227.4460)0.5696]$	105	0.91	0.0006	43.3	83.1
Copper	Log3	$y = 96.9099/[1 + (x/246.5520)1.4270]$	95	0.94	0.0002	65.5	105
Lead	Log3	$y = 108.4981/[1 + (x/763.7392)0.5554]$	116*	0.85	0.0035	81.5	182
Mercury	Log3	$y = 101.0455/[1 + (x/5.4939)0.9778]$	100	0.95	<0.0001	1.06	1.88
Nickel	Sig3	$y = 1337.6104/\{1 + e[-(x + 15.1749)/-5.8681]\}$	99	0.68	0.0328	0.673	1.41
Zinc	Log4	$y = -48.6592 + 151.8709/[1 + (x/3471.4912)0.5151]$	101	0.96	0.0008	79.7	200
Polycyclic Aromatic Hydrocarbons (PAHs; µg/kg @ 1%OC)							
2-Methylnaphthalene	NA	NA	NA	NA	NA	NA	NA
Acenaphthene	NA	NA	NA	NA	NA	NA	NA
Acenaphthylene	NA	NA	NA	NA	NA	NA	NA
Anthracene	Log4	$y = 15.5301 + 84.9800/[1 + (x/322.2654)1.6782]$	105*	0.99	<0.0001	137	196
Fluorene	Log4	$y = 8.7378 + 92.8475/[1 + (x/550.3408)1.2456]$	87	0.99	<0.0001	169	267
Naphthalene	Sig4	$y = 22.3410 + 78.6863/\{[1 + e[-(x-226.6769)/-65.1768]]\}$	80	0.99	<0.0001	142	181
Phenanthrene	Log4	$y = -14.5088 + 118.8109/[1 + (x/5815.7863)0.5625]$	84	0.99	<0.0001	344	812
Total LMW-PAHs	Log4	$y = 4.2585 + 102.0042/[1 + (x/3829.1184)0.6564]$	94	0.98	<0.0001	539	1120
Benz(a)anthracene	Log4	$y = 8.1912 + 92.5369/[1 + (x/1518.1445)1.1503]$	100	0.99	<0.0001	403	668
Benzo(a)pyrene	Log4	$y = 30.0371 + 70.0192/[1 + (x/527.0645)2.8122]$	100	0.99	<0.0001	341	430
Chrysene	Log4	$y = 4.9927 + 95.8336/[1 + (x/2700.7032)1.1432]$	100	0.99	<0.0001	689	1140
Dibenz(a,h)anthracene	NA	NA	NA	NA	NA	NA	NA
Fluoranthene	Log4	$y = 16.1375 + 84.3398/[1 + (x/1258.1217)1.3343]$	100	0.99	<0.0001	431	677
Pyrene	Log4	$y = -15.3676 + 117.5893/[1 + (x/6537.1416)0.8099]$	101	0.99	<0.0001	792	1500
Total HMW-PAHs	Log4	$y = -112.2664 + 213.1921/[1 + (x/78190.3568)0.7645]$	101	0.99	<0.0001	3120	5950
Total PAHs	Log4	$y = -50.2645 + 152.3696/[1 + (x/69023.1838)0.6936]$	102	0.99	<0.0001	3770	7690

Table 4. Summary of the concentration-response relationships derived based on magnitude of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-day toxicity tests (endpoint: survival). The preliminary remediation goals (PRGs) derived using these regression equations are also presented.

Contaminant of Concern (COC)	Regression Equation Type	Regression Equation	n ¹	r ²	p	PRG-IR	PRG-HR
<i>Polychlorinated Biphenyls (PCBs; µg/kg @ 1%OC)</i>							
Total PCBs	Log3	$y = 95.6660/[1 + (x/559.0349)^{1.5070}]$	61*	0.79	0.0088	149	240

¹Asterisk denotes that the concentration-response relationships were derived using data from the entire Indiana Harbor Area of Concern.

r² = correlation coefficient; p = p value for the F statistic (ANOVA); PEC-Q = probable effect concentration-quotient; DW = dry weight; OC = organic carbon; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; Log3 = 3 parameter logistic; Log4 = 4 parameter logistic; Sig3 = 3 parameter Sigmoidal; Sig4 = 4 parameter Sigmoidal; NA = not applicable - PRG could not be derived based on the concentration-response relationship; IR = intermediate risk; HR = high risk.

Table 5. Summary of the concentration-response relationships derived based on incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-day toxicity tests (endpoint: survival). The preliminary remediation goals (PRGs) derived using these regression equations are also presented.

Contaminant of Concern (COC)	Regression Equation Type	Regression Equation	n ¹	r ²	p	PRG-IR	PRG-HR
Metals (mg/kg DW)							
Arsenic	Sig4	$y = -690.5114 + 769.1322 / \{1 + e^{-[(x + 55.6818)/27.0274]}\}$	103	0.82	0.0258	13	33.8
Cadmium	Log3	$y = 128.3237 / [1 + (x/35.6679) - 0.6971]$	101	0.79	0.0094	3.84	20.1
Chromium	Log3	$y = 57.5668 / [1 + (x/42.8528) - 1.7023]$	105	0.91	0.0007	32.9	151
Copper	Sig3	$y = 88.0610 / \{1 + e^{-[(x - 77.2768)/23.7032]}\}$	111*	0.99	<0.0001	51.8	85.4
Lead	Sig4	$y = 61.7450 - 19618.3426 / \{1 + e^{-[(x + 805.7509)/-142.2080]}\}$	116*	0.80	0.0348	77.4	269
Mercury	Log4	$y = -2.9494 + 461.3115 / [1 + (x/113.4060) - 0.6135]$	100	0.92	0.0039	1.1	4.27
Nickel	Log3	$y = 98.2751 / [1 + (x/1.7534) - 0.7749]$	115*	0.85	0.0034	0.363	1.99
Zinc	Log4	$y = -0.6221 + 133.5597 / [1 + (x/1071.2325) - 0.6997]$	101	0.95	0.0010	114	566
Polycyclic Aromatic Hydrocarbons (PAHs; µg/kg @ 1%OC)							
2-Methylnaphthalene	NA	NA	NA	NA	NA	NA	NA
Acenaphthene	NA	NA	NA	NA	NA	NA	NA
Acenaphthylene	NA	NA	NA	NA	NA	NA	NA
Anthracene	Log4	$y = -1.9214 + 103.5750 / [1 + (x/347.0787) - 1.2876]$	92	0.99	<0.0001	139	365
Fluorene	Log3	$y = 99.8332 / [1 + (x/324.3496) - 2.1270]$	87	0.99	<0.0001	181	334
Naphthalene	Log4	$y = 0.7317 + 99.0466 / [1 + (x/151.2643) - 1.6443]$	80	0.98	0.0001	69.8	156
Phenanthrene	Sig4	$y = -1108.2161 + 1207.8374 / \{1 + e^{-[(x + 8422.6903)/3466.9413]}\}$	84	0.99	<0.0001	883	2610
Total LMW-PAHs	Log4	$y = -4.1950 + 102.1588 / [1 + (x/1419.9079) - 1.0975]$	94	0.99	<0.0001	548	1670
Benzo(a)anthracene	NA	NA	NA	NA	NA	NA	NA
Benzo(a)pyrene	NA	NA	NA	NA	NA	NA	NA
Chrysene	Sig4	$y = -35.0215 + 125.1636 / \{1 + e^{-[(x - 888.4909)/882.2912]}\}$	100	0.99	<0.0001	743	1600
Dibenz(a,h)anthracene	NA	NA	NA	NA	NA	NA	NA
Fluoranthene	NA	NA	NA	NA	NA	NA	NA
Pyrene	Log4	$y = -1.9070 + 112.3228 / [1 + (x/2799.3156) - 1.1336]$	101	0.98	<0.0001	900	2570
Total HMW-PAHs	Log4	$y = 0.3140 + 114.8765 / [1 + (x/10644.0548) - 1.2810]$	101	0.99	<0.0001	3470	8970
Total PAHs	Log4	$y = -1.9240 + 117.4105 / [1 + (x/15400.0394) - 0.9375]$	102	0.98	<0.0001	3680	12700

Table 5. Summary of the concentration-response relationships derived based on incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-day toxicity tests (endpoint: survival). The preliminary remediation goals (PRGs) derived using these regression equations are also presented.

Contaminant of Concern (COC)	Regression Equation Type	Regression Equation	n ¹	r ²	p	PRG-IR	PRG-HR
<i>Polychlorinated Biphenyls (PCBs; µg/kg @ 1%OC)</i>							
Total PCBs	Linear	$y = 11.7065 + 0.0659x$	61*	0.71	0.0045	162	604

¹Asterisk denotes that the concentration-response relationships were derived using data from the entire Indiana Harbor Area of Concern.

r² = correlation coefficient; p = p value for the F statistic (ANOVA); PEC-Q = probable effect concentration-quotient; DW = dry weight; OC = organic carbon; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; Log3 = 3 parameter logistic; Log4 = 4 parameter logistic; Sig3 = 3 parameter Sigmoidal; Sig4 = 4 parameter Sigmoidal; NA = not applicable - PRG could not be derived based on the concentration-response relationship; IR = intermediate risk; HR = high risk.

Table 6. Reliability of the magnitude of toxicity-based preliminary remediation goals (PRGs) for individual contaminants of concern in the West Branch Grand Calumet River (based on 28-day toxicity tests to the freshwater amphipod, *Hyalella azteca*; endpoint: survival).

Contaminant of Concern	Incidence of Toxicity (%)				
	<PRG-IR	≥PRG-IR	PRG-IR to PRG-HR	>PRG-HR	≤PRG-HR
Metals (mg/kg DW)					
Arsenic	15% (11 of 72)	61% (27 of 44)	29% (2 of 7)	68% (25 of 37)	16% (13 of 79)
Cadmium	13% (9 of 68)	60% (29 of 48)	67% (8 of 12)	58% (21 of 36)	21% (17 of 80)
Chromium	12% (8 of 67)	61% (30 of 49)	67% (4 of 6)	60% (26 of 43)	16% (12 of 73)
Copper	16% (14 of 87)	83% (24 of 29)	33% (1 of 3)	88% (23 of 26)	17% (15 of 90)
Lead	13% (7 of 55)	51% (31 of 61)	22% (2 of 9)	56% (29 of 52)	14% (9 of 64)
Mercury	17% (12 of 71)	50% (19 of 38)	30% (3 of 10)	57% (16 of 28)	19% (15 of 81)
Nickel	22% (18 of 81)	57% (20 of 35)	38% (5 of 13)	68% (15 of 22)	24% (23 of 94)
Zinc	10% (7 of 73)	72% (31 of 43)	64% (7 of 11)	75% (24 of 32)	17% (14 of 84)
Polycyclic Aromatic Hydrocarbons (PAHs; µg/kg 1% OC normalized)					
<i>Low Molecular Weight (LMW) PAHs</i>					
2-Methylnaphthalene	--	--	--	--	--
Acenaphthene	--	--	--	--	--
Acenaphthylene	--	--	--	--	--
Anthracene	10% (7 of 72)	85% (28 of 33)	0% (0 of 1)	88% (28 of 32)	10% (7 of 73)
Fluorene	11% (7 of 65)	88% (29 of 33)	75% (3 of 4)	90% (26 of 29)	14% (10 of 69)
Naphthalene	13% (9 of 69)	95% (19 of 20)	100% (2 of 2)	94% (17 of 18)	15% (11 of 71)
Phenanthrene	14% (10 of 73)	88% (22 of 25)	50% (1 of 2)	91% (21 of 23)	15% (11 of 75)
Total LMW-PAHs	11% (8 of 70)	81% (30 of 37)	50% (4 of 8)	90% (26 of 29)	15% (12 of 78)
<i>High Molecular Weight (HMW) PAHs</i>					
Benz(a)anthracene	9% (7 of 80)	85% (29 of 34)	0% (0 of 1)	88% (29 of 33)	9% (7 of 81)
Benzo(a)pyrene	9% (7 of 78)	81% (29 of 36)	0% (0 of 3)	88% (29 of 33)	9% (7 of 81)
Chrysene	9% (7 of 81)	88% (29 of 33)	0% (0 of 0)	88% (29 of 33)	9% (7 of 81)
Dibenz(a,h)anthracene	--	--	--	--	--
Fluoranthene	9% (7 of 79)	83% (29 of 35)	0% (0 of 2)	88% (29 of 33)	9% (7 of 81)
Pyrene	9% (7 of 78)	81% (30 of 37)	25% (1 of 4)	88% (29 of 33)	10% (8 of 82)
Total HMW-PAHs	10% (8 of 81)	85% (29 of 34)	50% (1 of 2)	88% (28 of 32)	11% (9 of 83)
Total PAHs	10% (8 of 82)	88% (30 of 34)	100% (1 of 1)	88% (29 of 33)	11% (9 of 83)
Polychlorinated Biphenyls (PCBs; µg/kg 1% OC normalized)					
Total PCBs	45% (20 of 44)	19% (4 of 21)	22% (2 of 9)	17% (2 of 12)	42% (22 of 53)

IR = intermediate risk; HR = high risk; DW = dry weight; OC = organic carbon.

Bolded results indicate that the PRG met the evaluation criteria (see Section 6 for more details).

Table 7. Reliability of the incidence of toxicity-based preliminary remediation goals (PRGs) for individual contaminants of concern in the West Branch Grand Calumet River (based on 28-day toxicity tests to the freshwater amphipod, *Hyalella azteca*; endpoint: survival).

Contaminant of Concern	Incidence of Toxicity (%)				
	<PRG-IR	≥PRG-IR	PRG-IR to PRG-HR	>PRG-HR	≤PRG-HR
Metals (mg/kg DW)					
Arsenic	15% (10 of 67)	57% (28 of 49)	46% (12 of 26)	70% (16 of 23)	24% (22 of 93)
Cadmium	13% (9 of 68)	60% (29 of 48)	57% (16 of 28)	65% (13 of 20)	26% (25 of 96)
Chromium	13% (8 of 64)	58% (30 of 52)	50% (10 of 20)	63% (20 of 32)	21% (18 of 84)
Copper	16% (14 of 85)	77% (24 of 31)	33% (1 of 3)	82% (23 of 28)	17% (15 of 88)
Lead	13% (7 of 55)	51% (31 of 61)	29% (4 of 14)	57% (27 of 47)	16% (11 of 69)
Mercury	17% (12 of 71)	50% (19 of 38)	22% (4 of 18)	75% (15 of 20)	18% (16 of 89)
Nickel	18% (13 of 74)	60% (25 of 42)	48% (12 of 25)	76% (13 of 17)	25% (25 of 99)
Zinc	15% (12 of 79)	70% (26 of 37)	33% (4 of 12)	88% (22 of 25)	18% (16 of 91)
Polycyclic Aromatic Hydrocarbons (PAHs; µg/kg 1% OC normalized)					
<i>Low Molecular Weight (LMW) PAHs</i>					
2-Methylnaphthalene	--	--	--	--	--
Acenaphthene	--	--	--	--	--
Acenaphthylene	--	--	--	--	--
Anthracene	10% (7 of 72)	85% (28 of 33)	50% (2 of 4)	90% (26 of 29)	12% (9 of 76)
Fluorene	10% (7 of 67)	88% (29 of 33)	75% (3 of 4)	90% (26 of 29)	14% (10 of 71)
Naphthalene	12% (8 of 65)	91% (20 of 22)	50% (1 of 2)	95% (19 of 20)	13% (9 of 67)
Phenanthrene	15% (11 of 75)	91% (21 of 23)	100% (2 of 2)	90% (19 of 21)	17% (13 of 77)
Total LMW-PAHs	11% (8 of 70)	81% (30 of 37)	55% (6 of 11)	92% (24 of 26)	17% (14 of 81)
<i>High Molecular Weight (HMW) PAHs</i>					
Benz(a)anthracene	--	--	--	--	--
Dibenz(a,h)anthracene	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--
Chrysene	9% (7 of 81)	88% (29 of 33)	100% (1 of 1)	88% (28 of 32)	10% (8 of 82)
Fluoranthene	--	--	--	--	--
Pyrene	10% (8 of 79)	81% (29 of 36)	50% (3 of 6)	87% (26 of 30)	13% (11 of 85)
Total HMW-PAHs	10% (8 of 81)	85% (29 of 34)	60% (3 of 5)	90% (26 of 29)	13% (11 of 86)
Total PAHs	10% (8 of 81)	86% (30 of 35)	60% (3 of 5)	90% (27 of 30)	13% (11 of 86)
Polychlorinated Biphenyls (PCBs; µg/kg 1% OC normalized)					
Total PCBs	45% (20 of 44)	19% (4 of 21)	15% (3 of 20)	100% (1 of 1)	36% (23 of 64)

IR = intermediate risk; HR = high risk; DW = dry weight; OC = organic carbon.

Bolded results indicate that the PRG met the evaluation criteria (see Section 6 for more details).

Table 8. Reliability of the magnitude of toxicity-based preliminary remediation goals (PRGs) for mixtures of contaminants of concern in the West Branch Grand Calumet River (based on 28-day toxicity tests to the freshwater amphipod, *Hyalella azteca*; endpoint: survival).

Mixture Model	Incidence of Toxicity (%)				
	<PRG-IR	≥PRG-IR	PRG-IR to PRG-HR	>PRG-HR	≤PRG-HR
Mean PEC-Q _{metals} (DW)	14% (10 of 70)	61% (28 of 46)	50% (4 of 8)	63% (24 of 38)	18% (14 of 78)
Mean PEC-Q _{metals} (DW@1%OC)	15% (11 of 74)	64% (27 of 42)	25% (1 of 4)	68% (26 of 38)	15% (12 of 78)
PEC-Q _{tPAHs} (DW)	11% (9 of 81)	83% (29 of 35)	40% (2 of 5)	90% (27 of 30)	13% (11 of 86)
PEC-Q _{tPAHs} (DW@1%OC)	10% (8 of 82)	88% (30 of 34)	100% (1 of 1)	88% (29 of 33)	11% (9 of 83)
PEC-Q _{PCBs} (DW)	--	--	--	19% (4 of 21)	45% (20 of 44)
PEC-Q _{PCBs} (DW@1%OC)	47% (21 of 45)	15% (3 of 20)	10% (1 of 10)	20% (2 of 10)	40% (22 of 55)
Mean PEC-Q _{metals} (DW), tPAHs (DW), tPCBs (DW)	14% (11 of 81)	77% (27 of 35)	50% (4 of 8)	85% (23 of 27)	17% (15 of 89)
Mean PEC-Q _{metals} (DW@1%OC), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	10% (8 of 78)	79% (30 of 38)	29% (2 of 7)	90% (28 of 31)	12% (10 of 85)
Mean PEC-Q _{metals} (DW), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	11% (9 of 80)	81% (29 of 36)	60% (3 of 5)	84% (26 of 31)	14% (12 of 85)

IR = intermediate risk; HR = high risk; DW = dry weight; OC = organic carbon; PEC-Q = probable effect concentration-quotient; tPAHs = total polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls.

Bolded results indicate that the PRG met the evaluation criteria (see Section 6 for more details).

Table 9. Reliability of the incidence of toxicity-based preliminary remediation goals (PRGs) for mixtures of contaminants of concern in the West Branch Grand Calumet River (based on 28-day toxicity tests to the freshwater amphipod, *Hyalella azteca*; endpoint: survival).

Mixture Model	Incidence of Toxicity (%)				
	<PRG-IR	≥PRG-IR	PRG-IR to PRG-HR	>PRG-HR	≤PRG-HR
Mean PEC-Q _{metals} (DW)	13% (9 of 69)	62% (29 of 47)	52% (13 of 25)	73% (16 of 22)	23% (22 of 94)
Mean PEC-Q _{metals} (DW@1%OC)	15% (11 of 74)	64% (27 of 42)	33% (3 of 9)	73% (24 of 33)	17% (14 of 83)
PEC-Q _{tPAHs} (DW)	11% (9 of 81)	83% (29 of 35)	50% (4 of 8)	93% (25 of 27)	15% (13 of 89)
PEC-Q _{tPAHs} (DW@1%OC)	10% (8 of 82)	88% (30 of 34)	75% (3 of 4)	90% (27 of 30)	13% (11 of 86)
PEC-Q _{PCBs} (DW)	--	--	--	--	--
PEC-Q _{PCBs} (DW@1%OC)	44% (21 of 48)	18% (3 of 17)	14% (2 of 14)	33% (1 of 3)	37% (23 of 62)
Mean PEC-Q _{metals} (DW), tPAHs (DW), tPCBs (DW)	14% (11 of 81)	77% (27 of 35)	45% (5 of 11)	92% (22 of 24)	17% (16 of 92)
Mean PEC-Q _{metals} (DW@1%OC), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	10% (8 of 78)	79% (30 of 38)	38% (3 of 8)	90% (27 of 30)	13% (11 of 86)
Mean PEC-Q _{metals} (DW), tPAHs (DW@1%OC), tPCBs (DW@1%OC)	12% (9 of 75)	71% (29 of 41)	29% (4 of 14)	93% (25 of 27)	15% (13 of 89)

IR = intermediate risk; HR = high risk; DW = dry weight; OC = organic carbon; PEC-Q = probable effect concentration-quotient; tPAHs = total polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls.

Bolded results indicate that the PRG met the evaluation criteria (see Section 6 for more details).

Figure 1. Map of IHAOC showing the boundaries of the reaches of the assessment area (as designated by MacDonald and Ingersoll 2000).

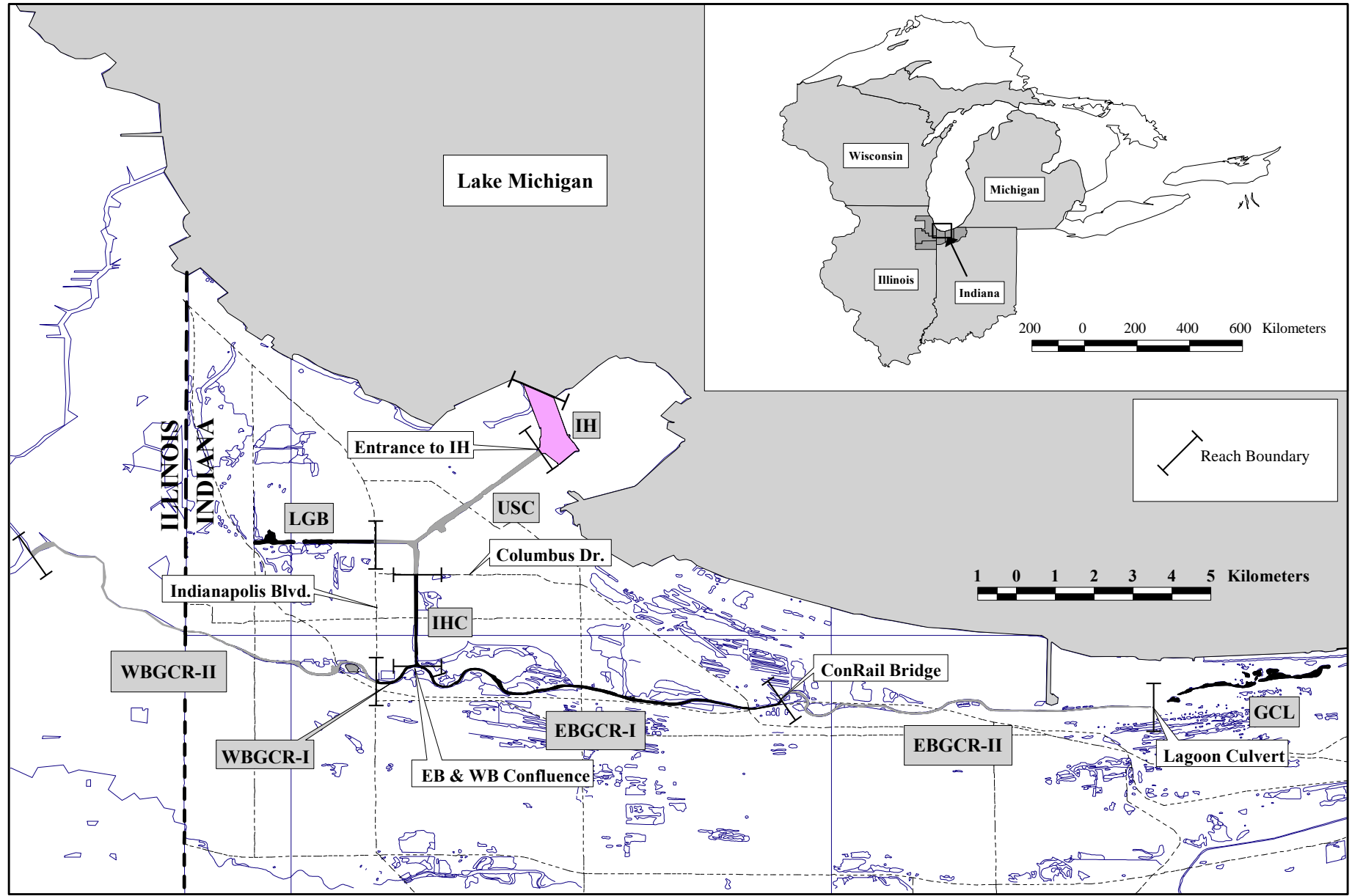


Figure 2. Map of WBGCR study area, showing the boundaries of the river reaches (as designated in FWEC 2003).

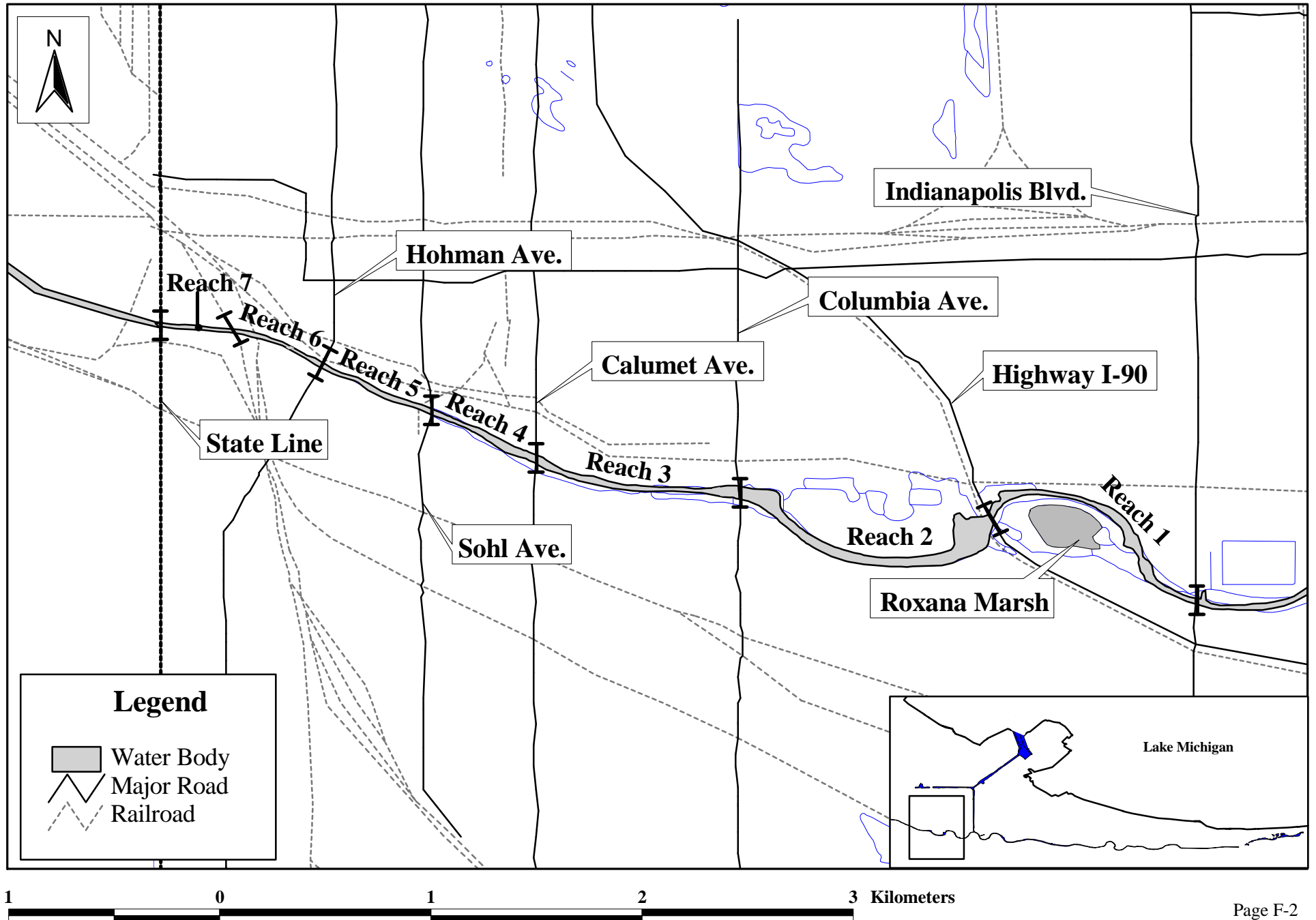


Figure 3. Map of the IHAOC showing the locations of discharges to receiving waters.

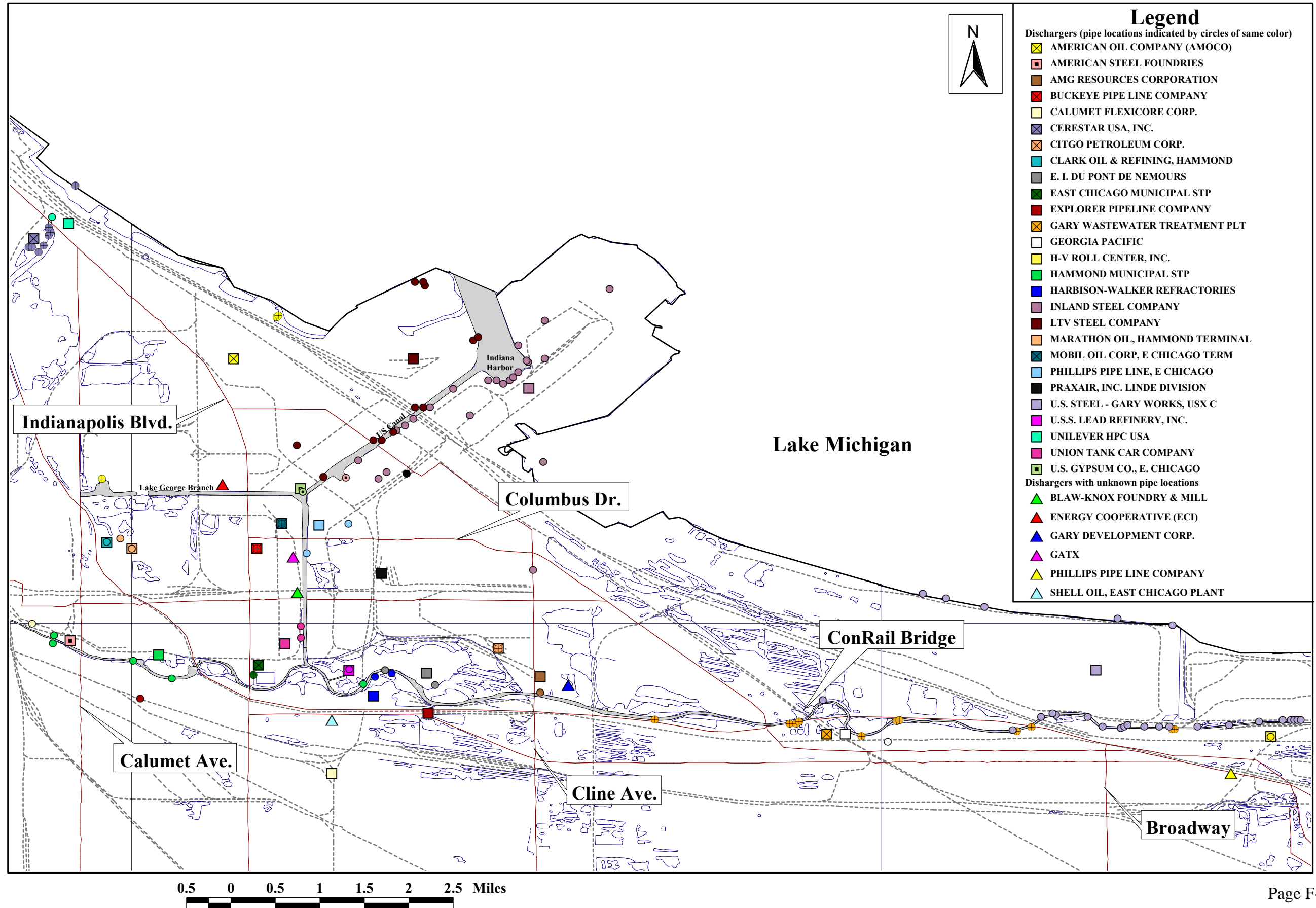


Figure 4. Conceptual model diagram illustrating exposure pathways and potential effects for all categories of COPCs (after MacDonald *et al.* 2002c).

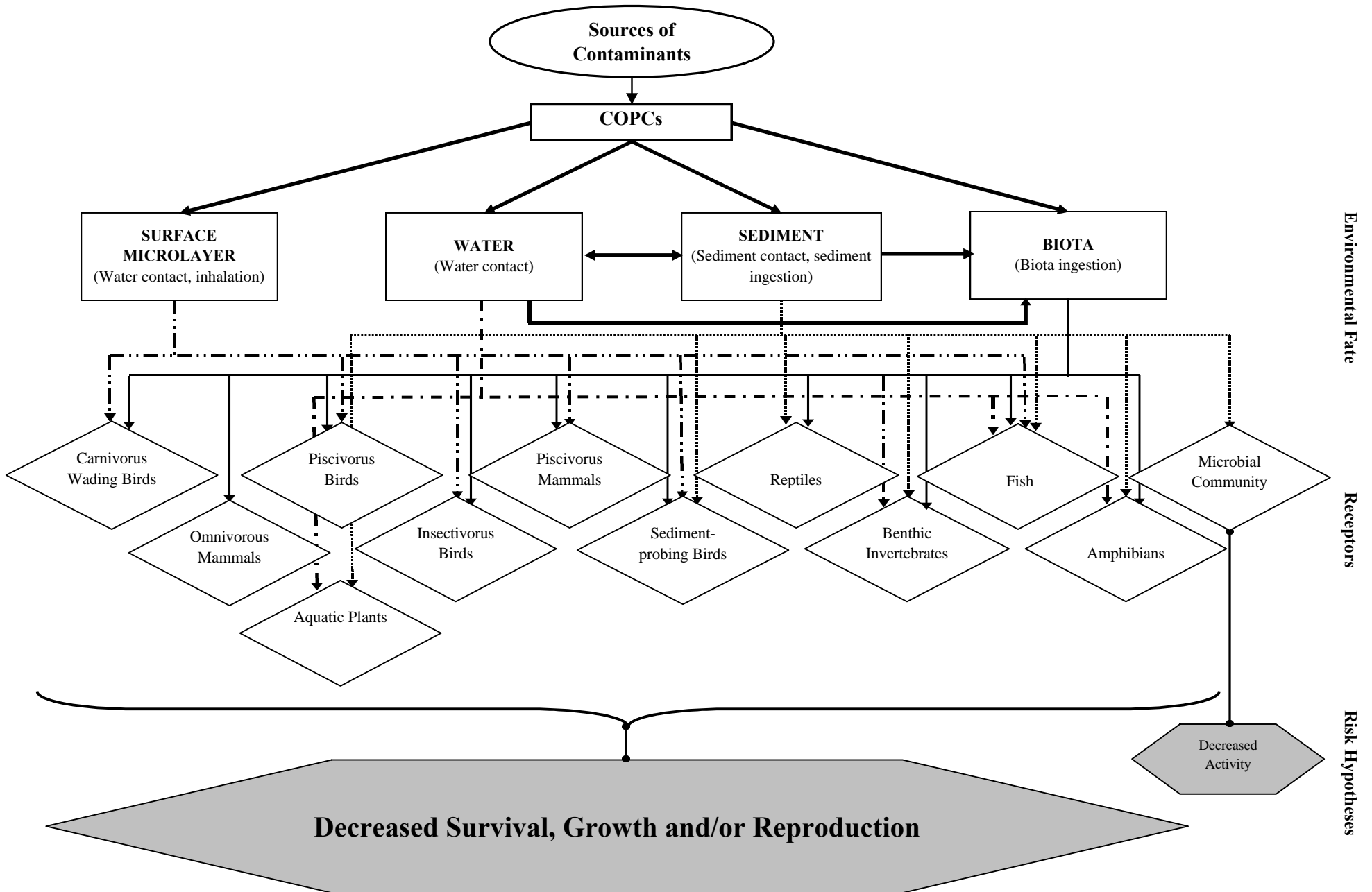


Figure 5. Relationship between the geometric mean of the Mean PEC-Q_{metals} (DW and DW @ 1%OC) and the average survival of the freshwater amphipod, *Hyalella azteca*, in 10-d (toxic samples only) and 28-d toxicity tests (i.e., magnitude of toxicity).

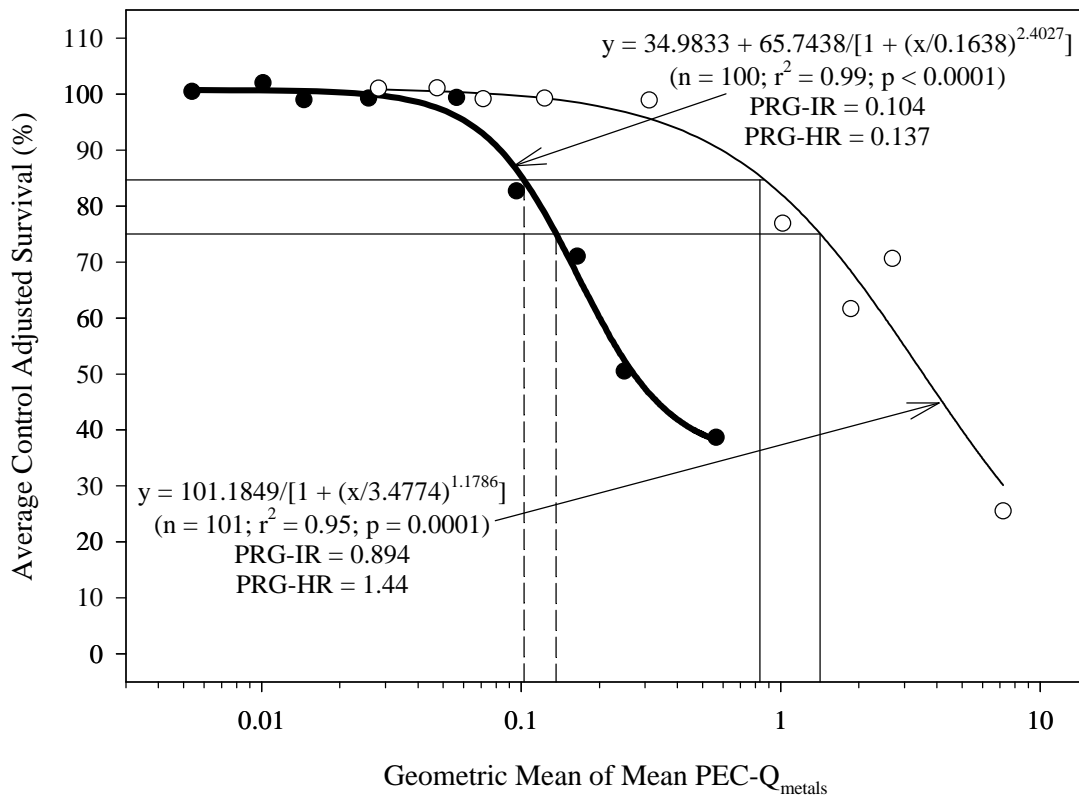


Figure 6. Relationship between the geometric mean of the Mean PEC-Q_{metals} (DW and DW @ 1%OC) and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 10-d (toxic samples only) and in 28-d toxicity tests.

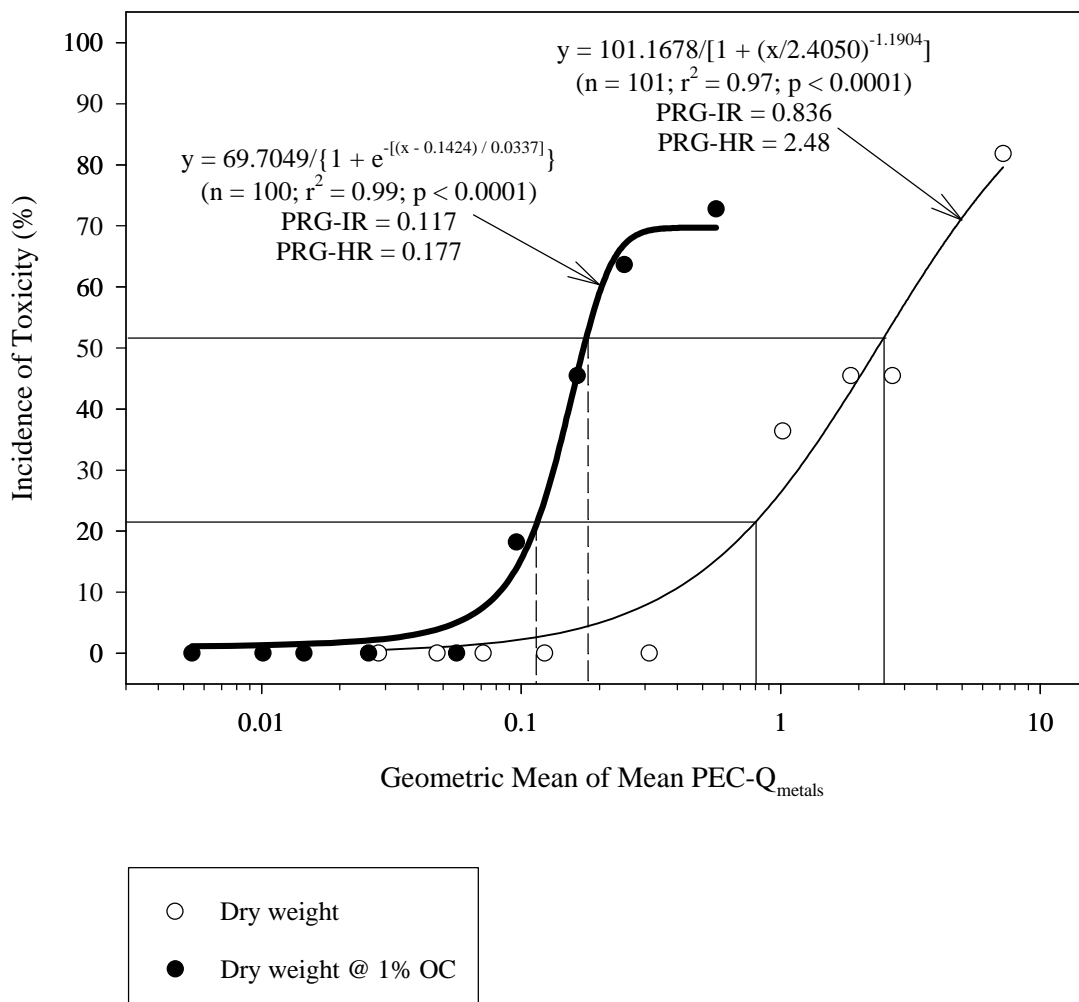


Figure 7. Relationship between the geometric mean of the PEC-Q_{tPAHs} (DW and DW @ 1%OC) and the average survival of the freshwater amphipod, *Hyaella azteca*, in 10-d (toxic samples only) and 28-d toxicity tests (i.e., magnitude of toxicity).

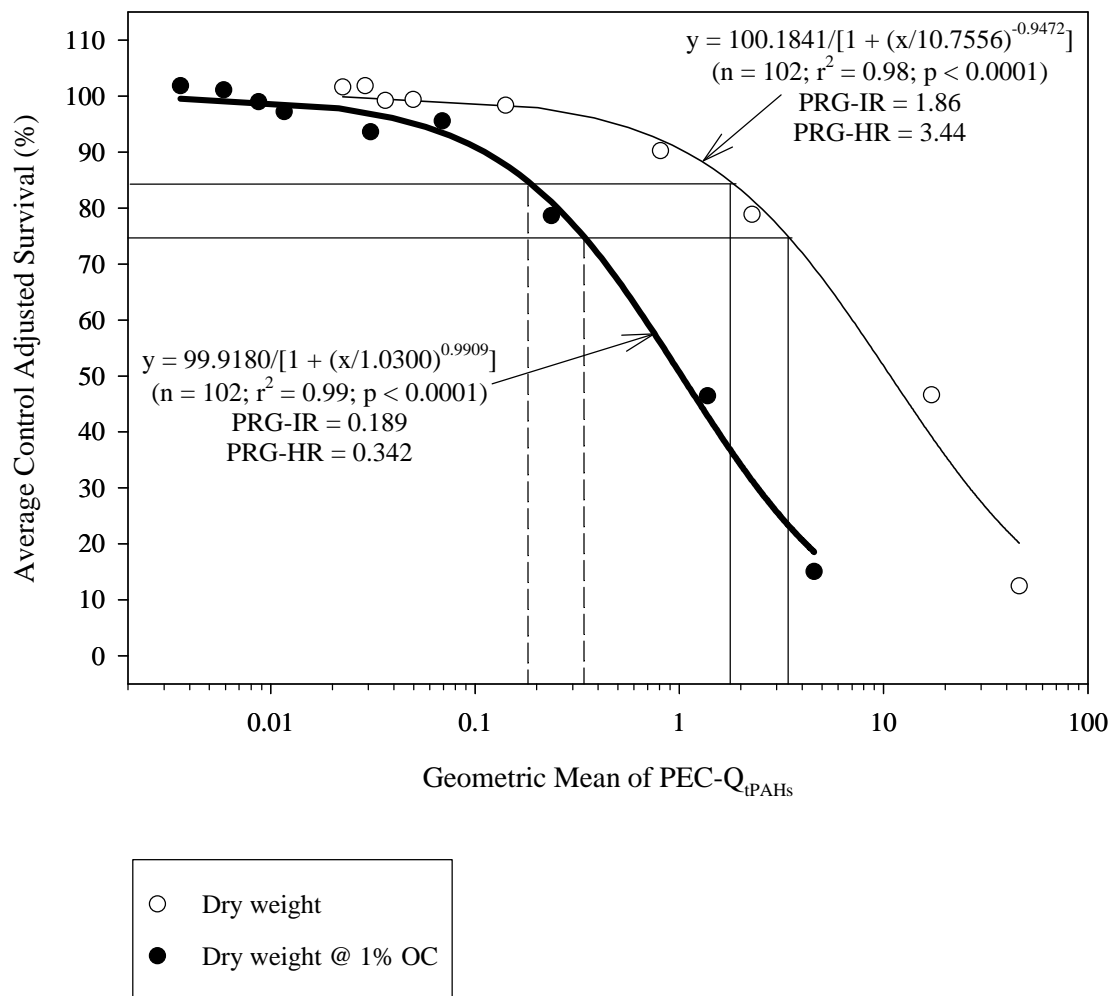


Figure 8. Relationship between the geometric mean of the PEC-Q_{tPAHs} (DW and DW @ 1%OC) and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 10-d (toxic samples only) and in 28-d toxicity tests.

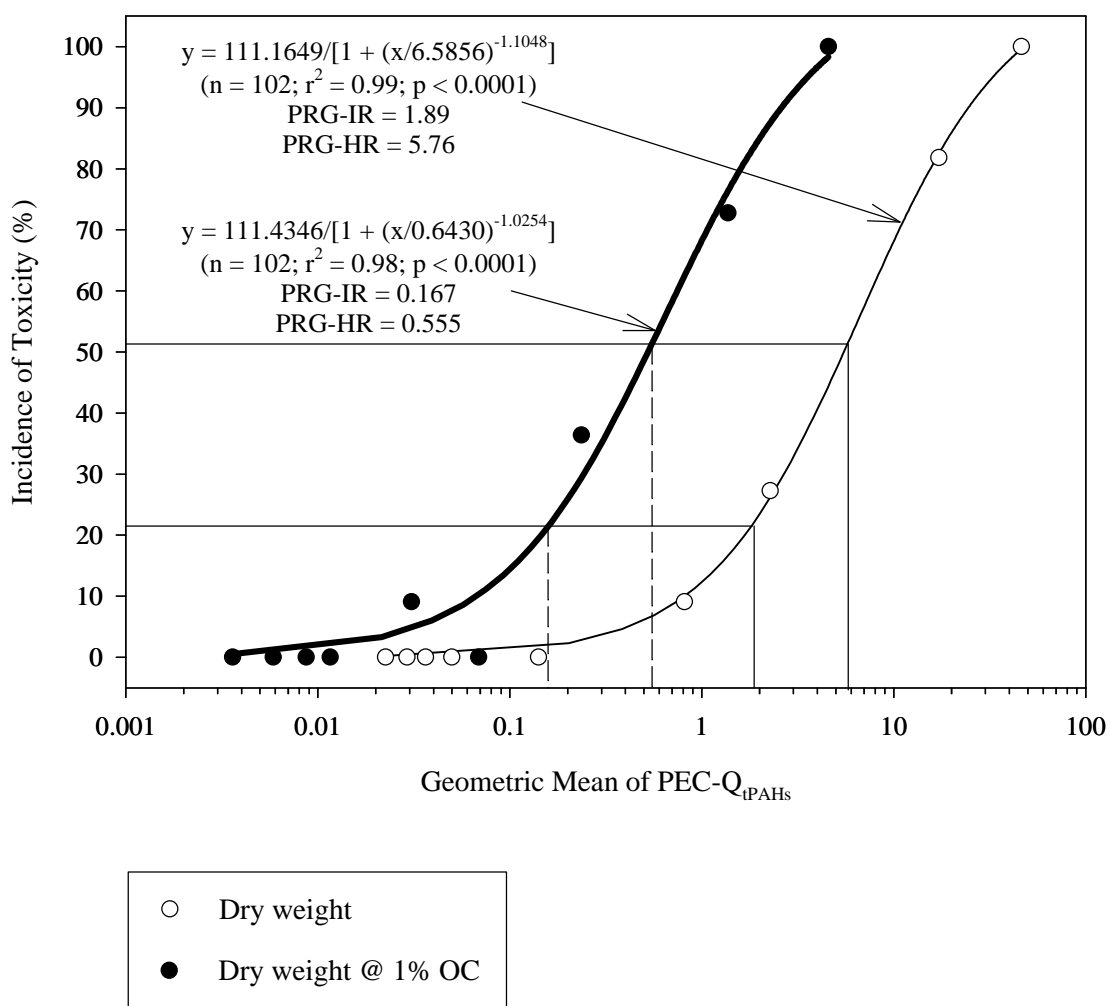


Figure 9. Relationship between the geometric mean of the PEC-Q_{IPCBs} (DW and DW @ 1%OC) and the average survival of the freshwater amphipod, *Hyalella azteca*, in 10-d (toxic samples only) and 28-d toxicity tests (i.e., magnitude of toxicity).

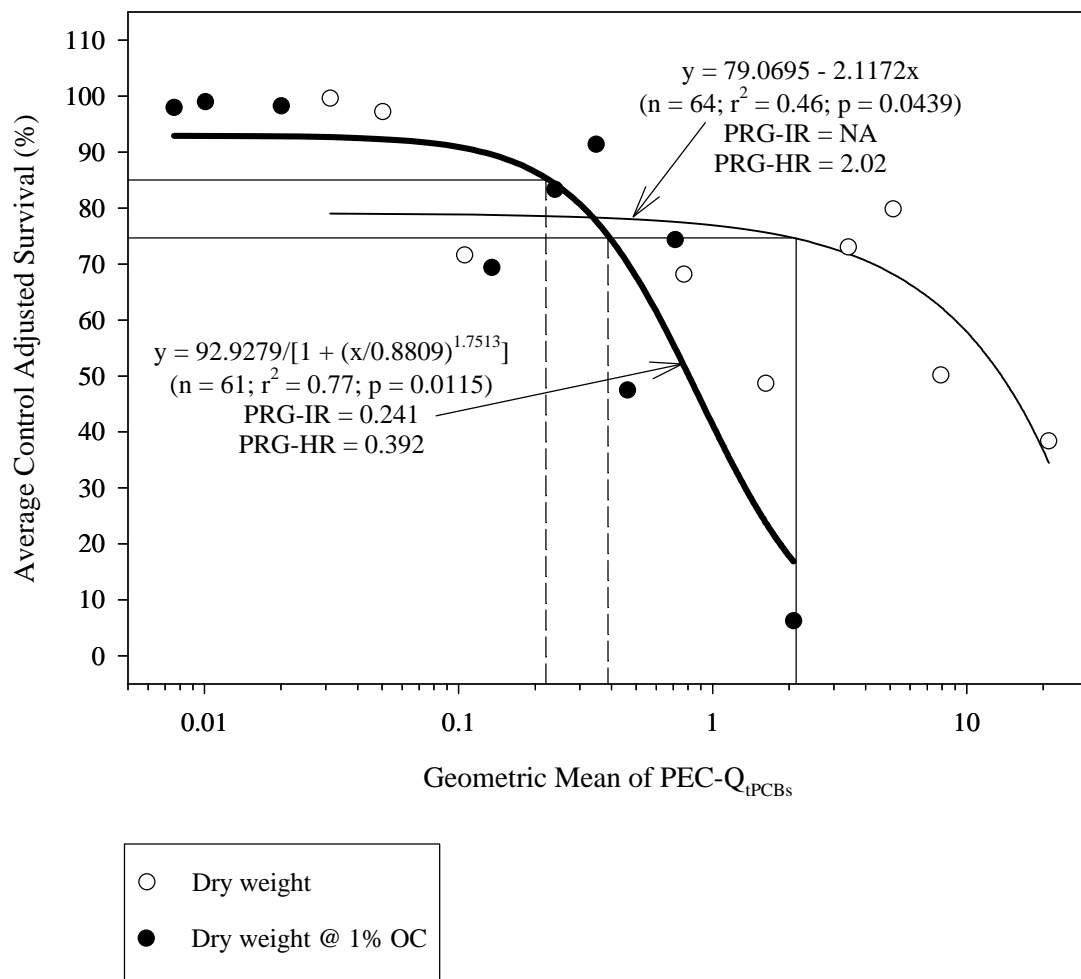


Figure 10. Relationship between the geometric mean of the PEC- Q_{tPCBs} (DW @ 1%OC) and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

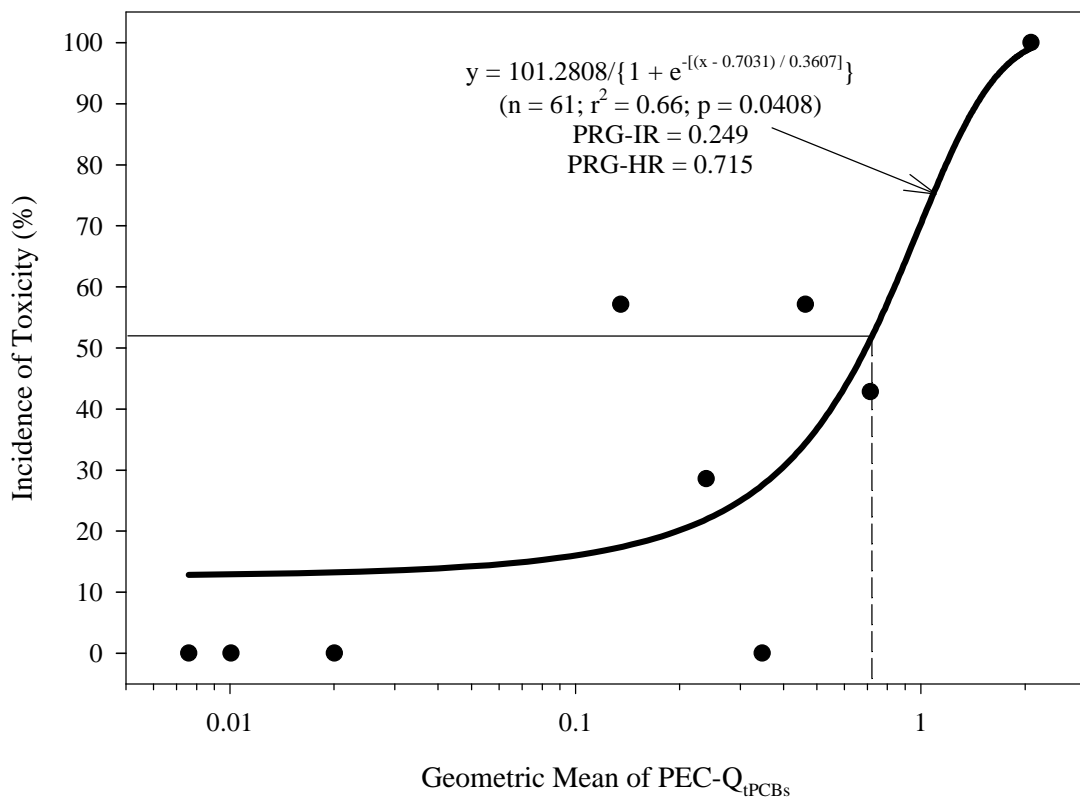
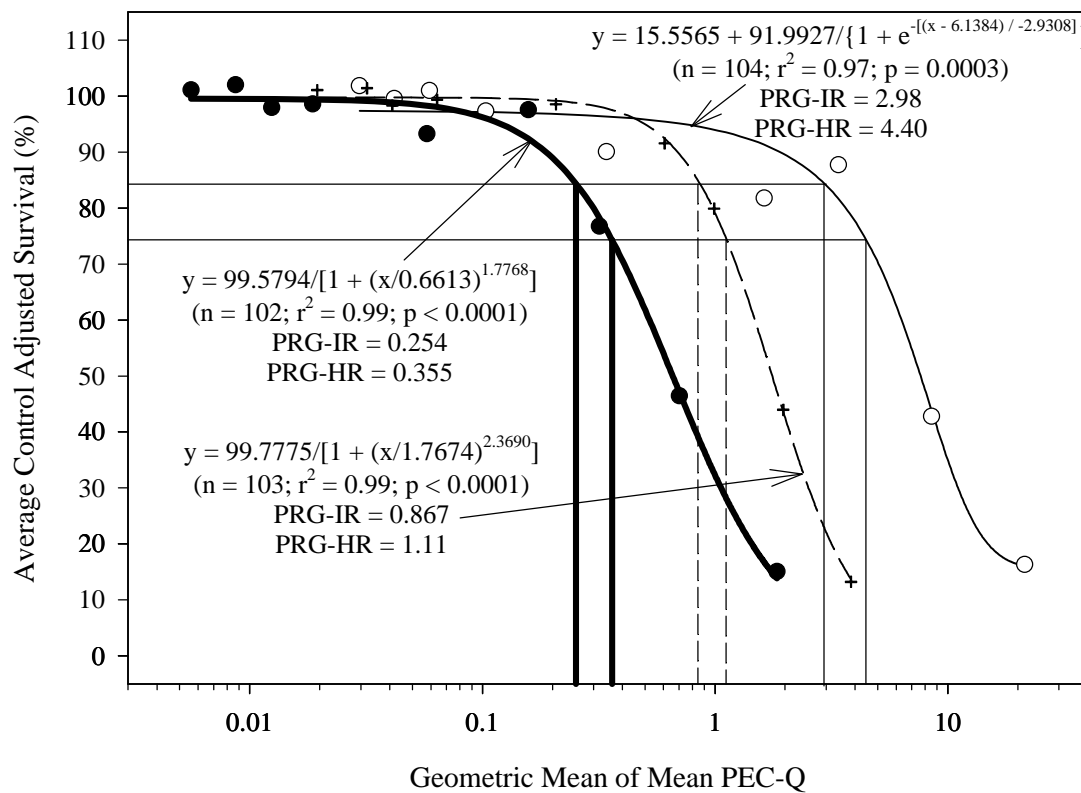
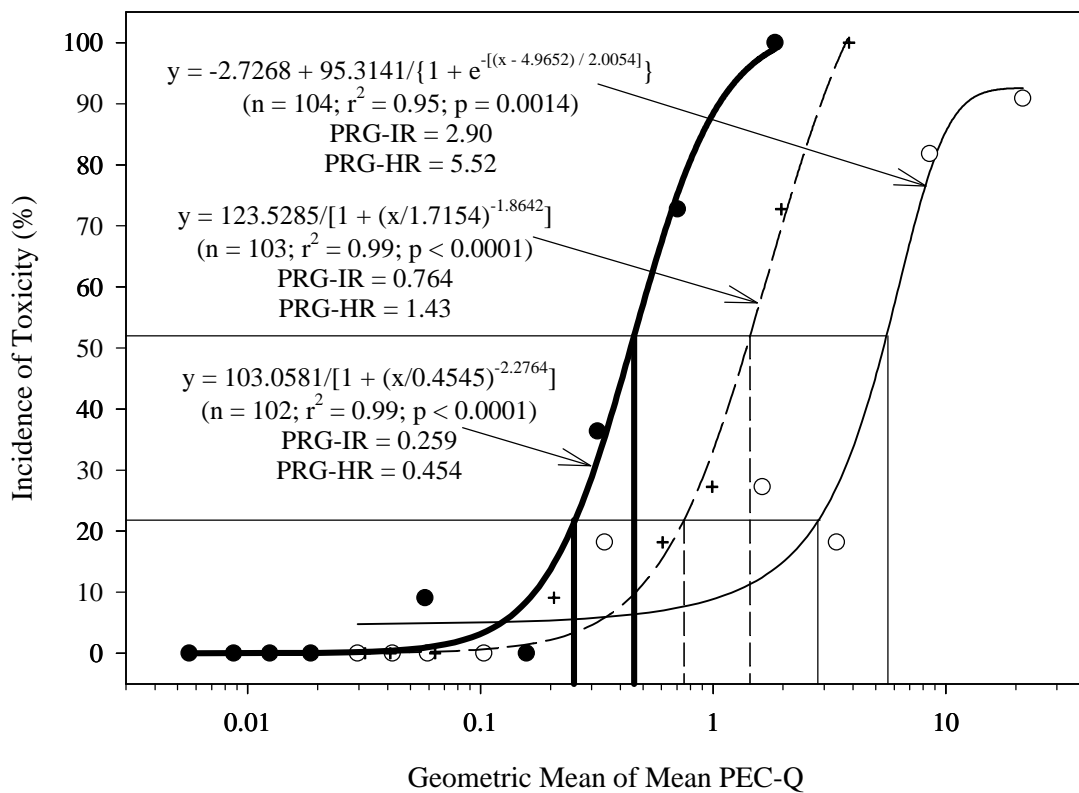


Figure 11. Relationship between the geometric mean of the Mean PEC-Q (DW; DW @ 1%OC; and DW for metals and DW @ 1%OC for tPAHs and tPCBs) and the average survival of the freshwater amphipod, *Hyalella azteca*, in 10-d (toxic samples only) and 28-d toxicity tests (i.e., magnitude of toxicity).



- Dry weight
- Dry weight @ 1% OC
- + Dry weight for metals and dry weight @ 1% OC for tPAHs and tPCBs

Figure 12. Relationship between the geometric mean of the Mean PEC-Q (DW; DW @ 1%OC; and DW @ 1%OC for tPAHs and tPCBs) and the incidence of toxicity to the freshwater amphipod, *Hyaella azteca*, in 10-d (toxic samples only) and in 28-d toxicity tests.



- Dry weight
- Dry weight @ 1% OC
- + Dry weight for metals and dry weight @ 1% OC for tPAHs and tPCBs

Figure 13. Relationship between the geometric mean of arsenic concentration and average survival of the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

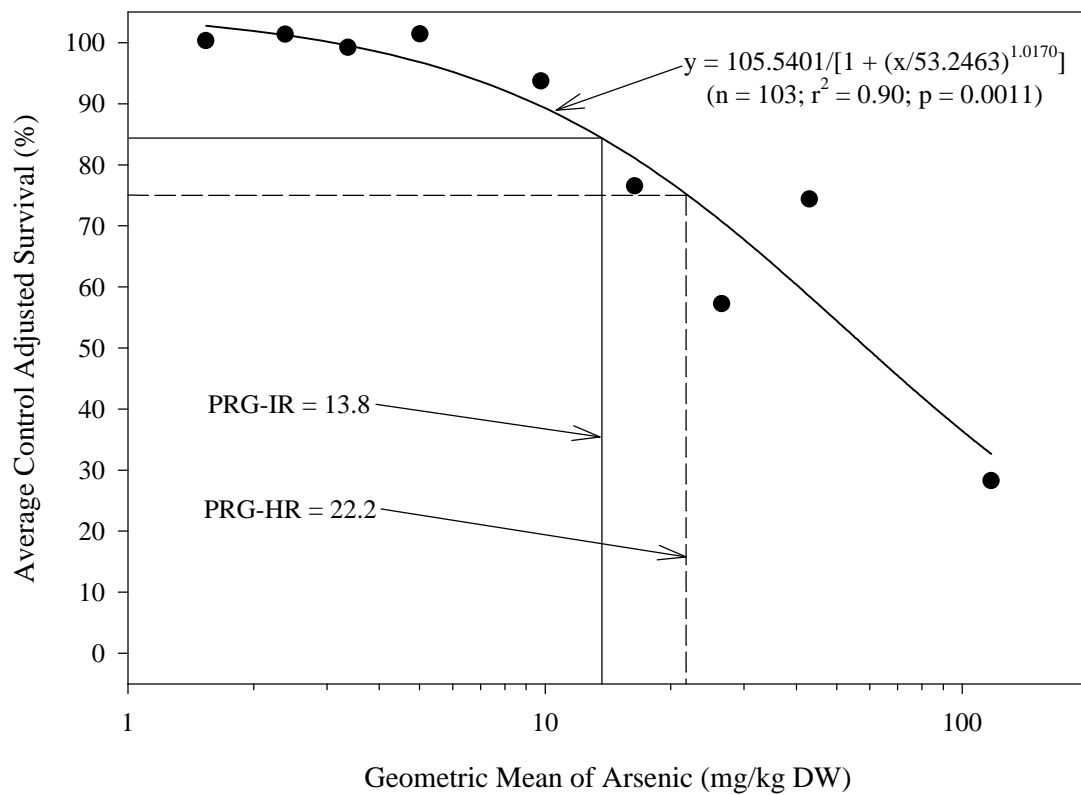


Figure 14. Relationship between the geometric mean of cadmium concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

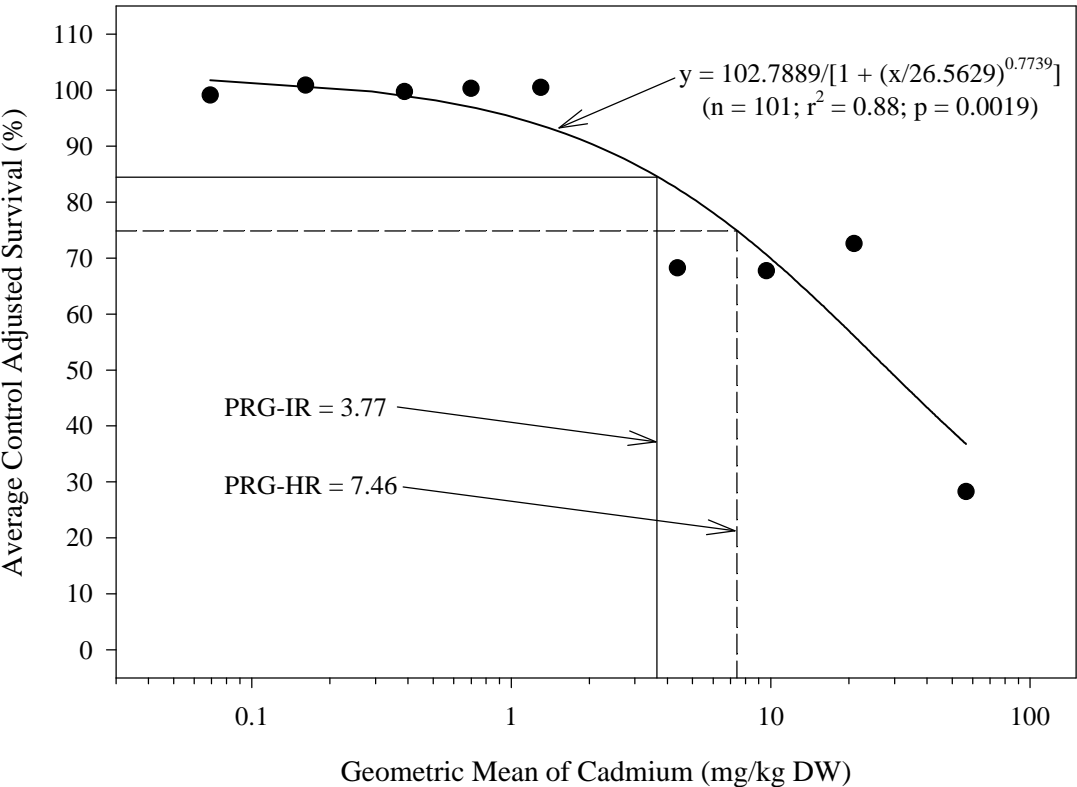


Figure 15. Relationship between the geometric mean of chromium concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

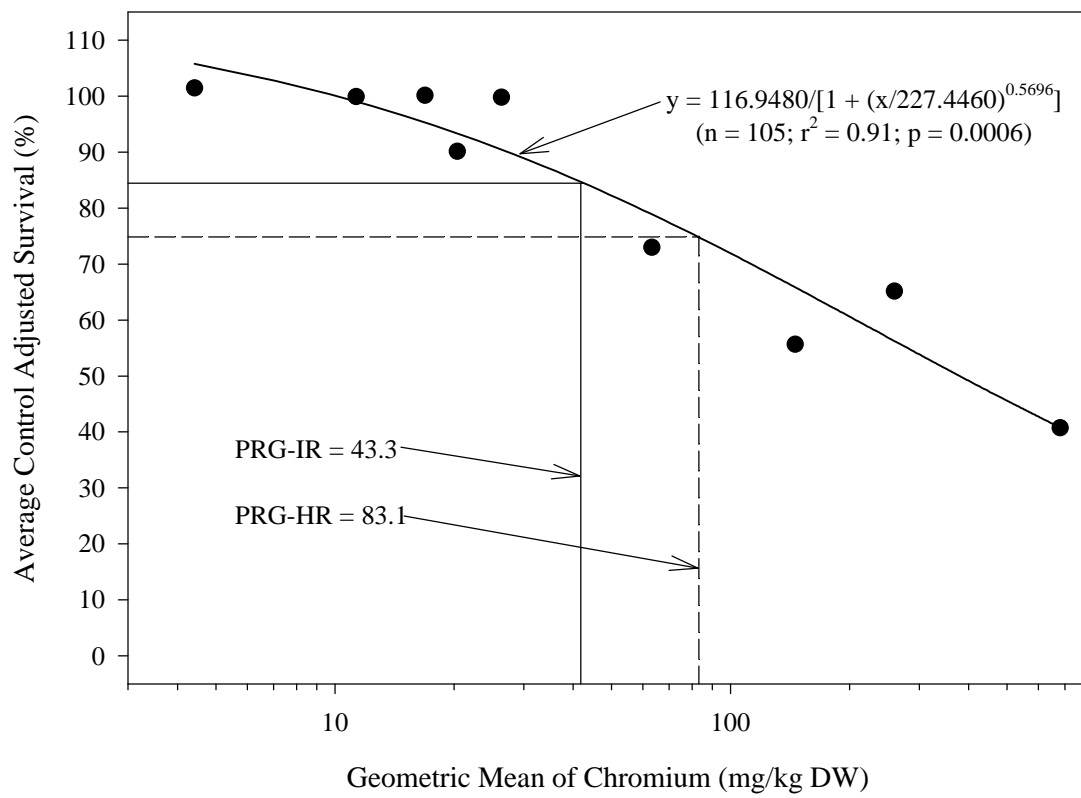


Figure 16. Relationship between the geometric mean of copper concentration and average survival of the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

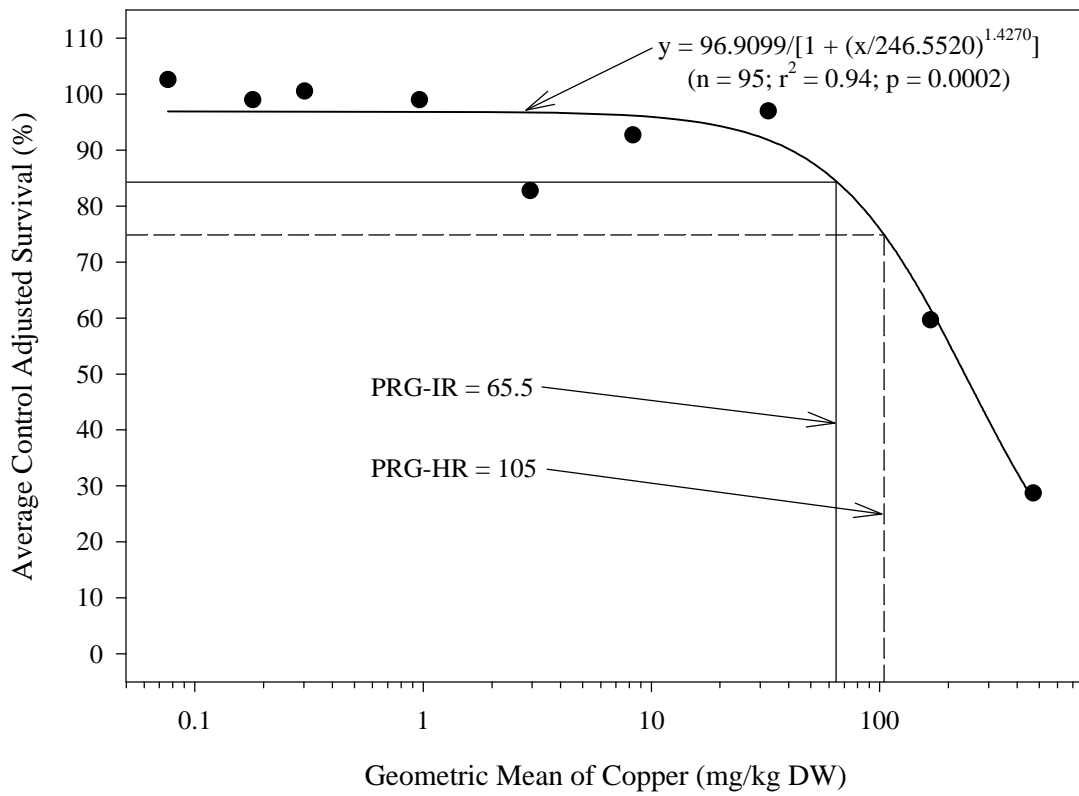


Figure 17. Relationship between the geometric mean of lead concentration and average survival of the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

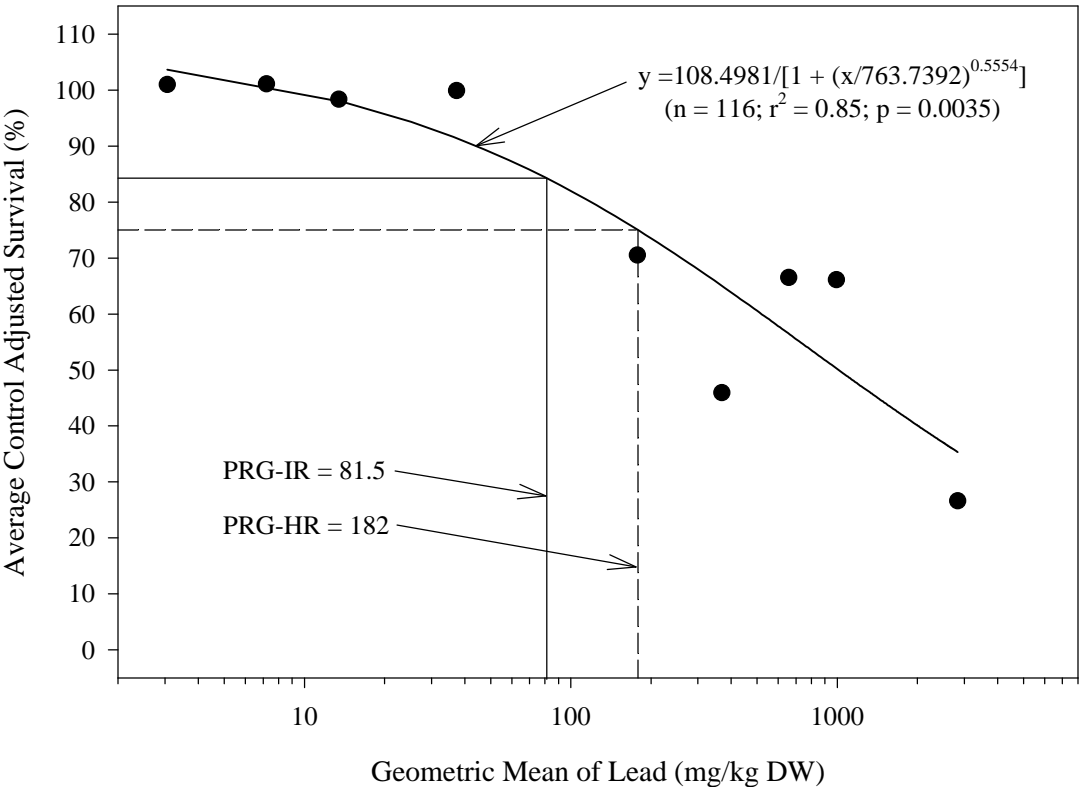


Figure 18. Relationship between the geometric mean of mercury concentration and average survival of the freshwater amphipod, *Hyaletta azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

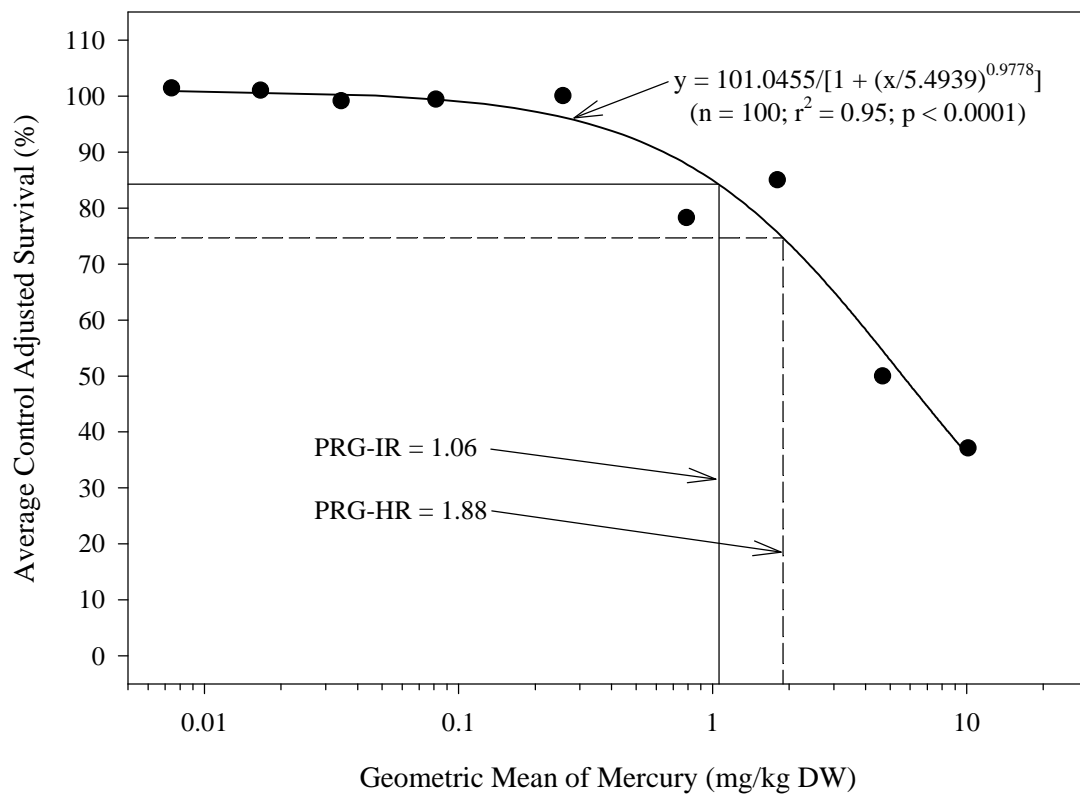


Figure 19. Relationship between the geometric mean of nickel concentration and average survival of the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

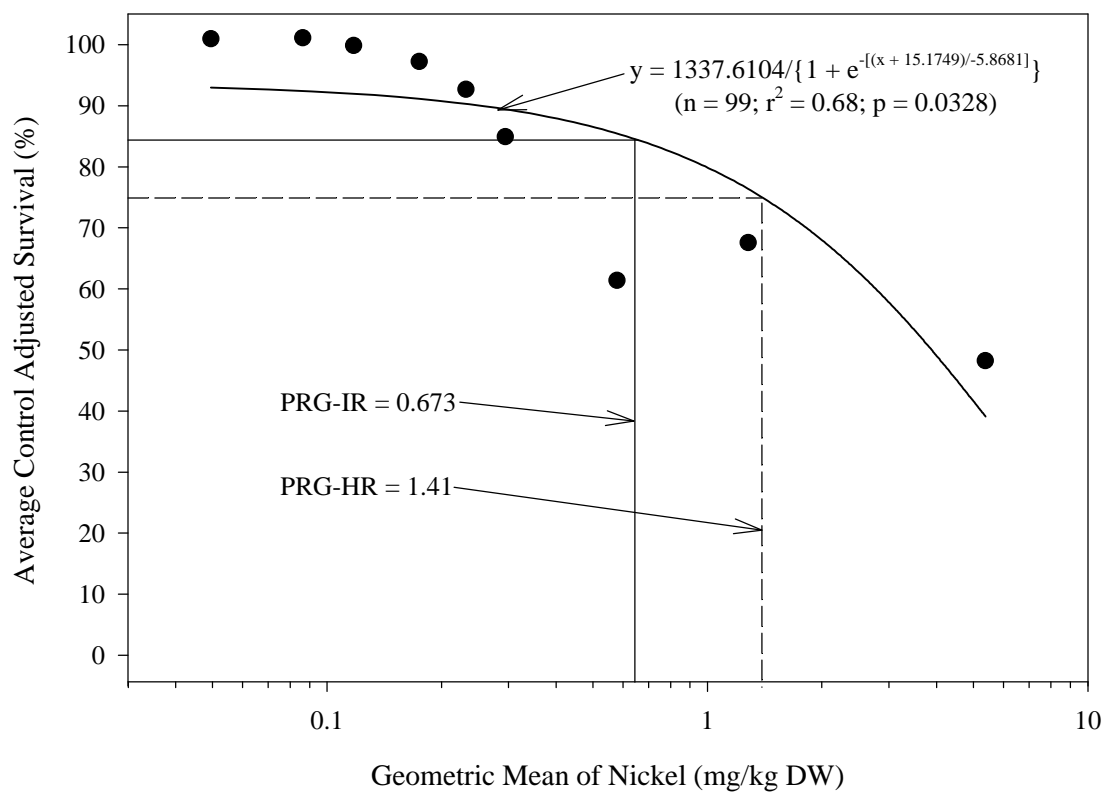


Figure 20. Relationship between the geometric mean of zinc concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

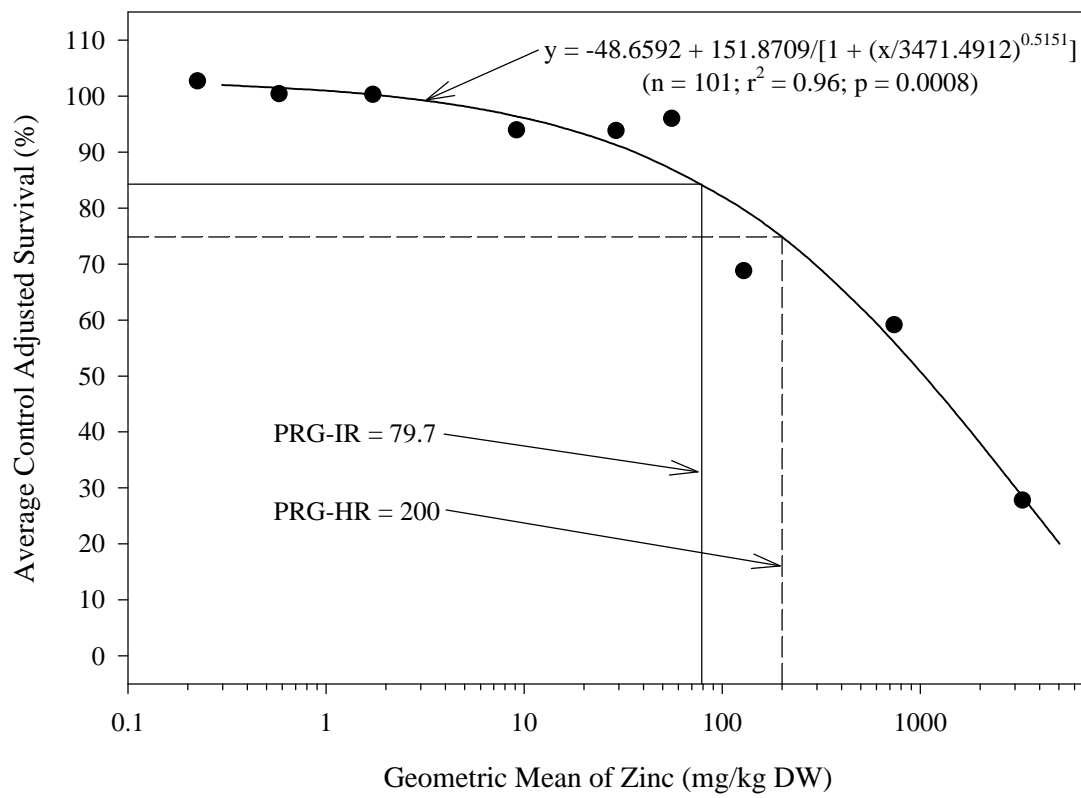


Figure 21. Relationship between the geometric mean of anthracene concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

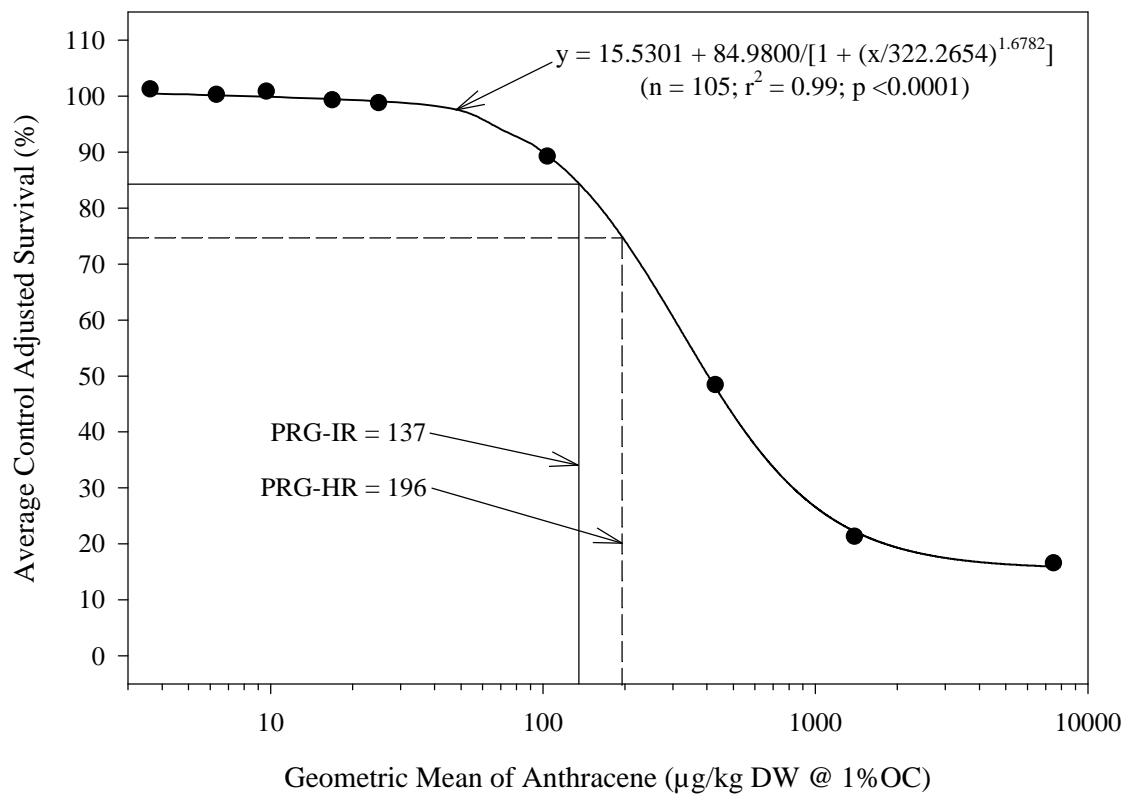


Figure 22. Relationship between the geometric mean of fluorene concentration and average survival of the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

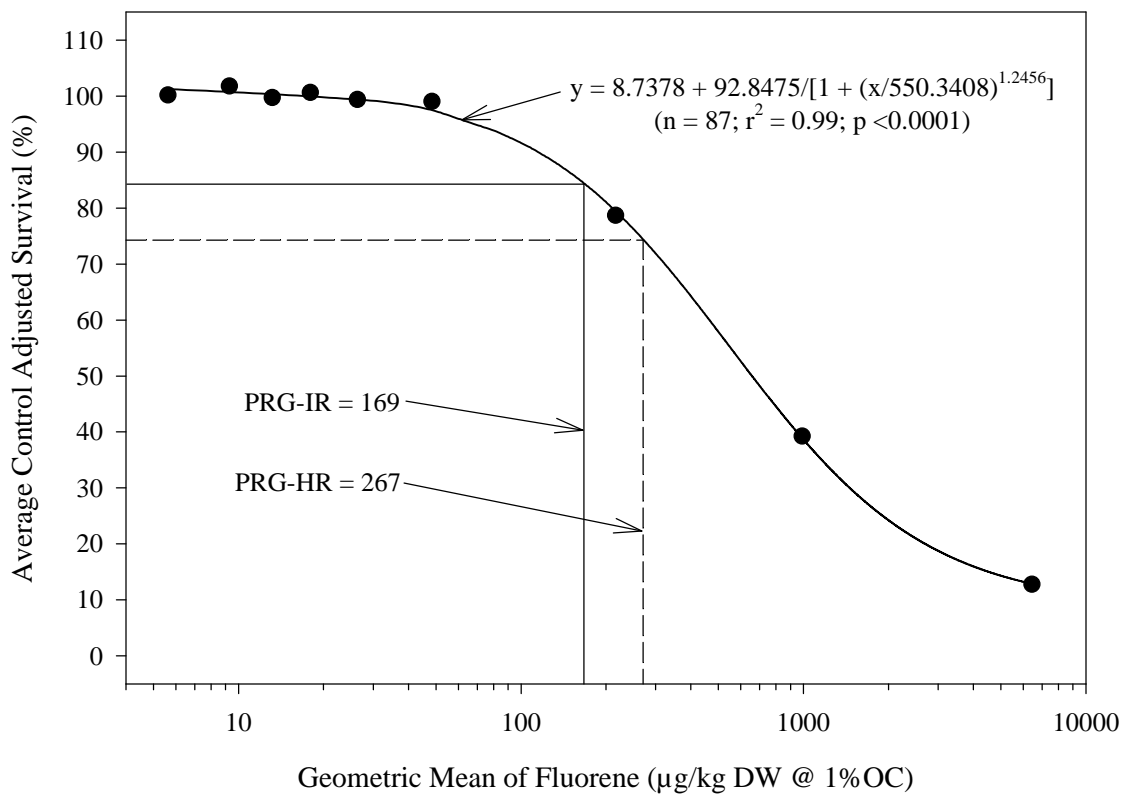


Figure 23. Relationship between the geometric mean of naphthalene concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

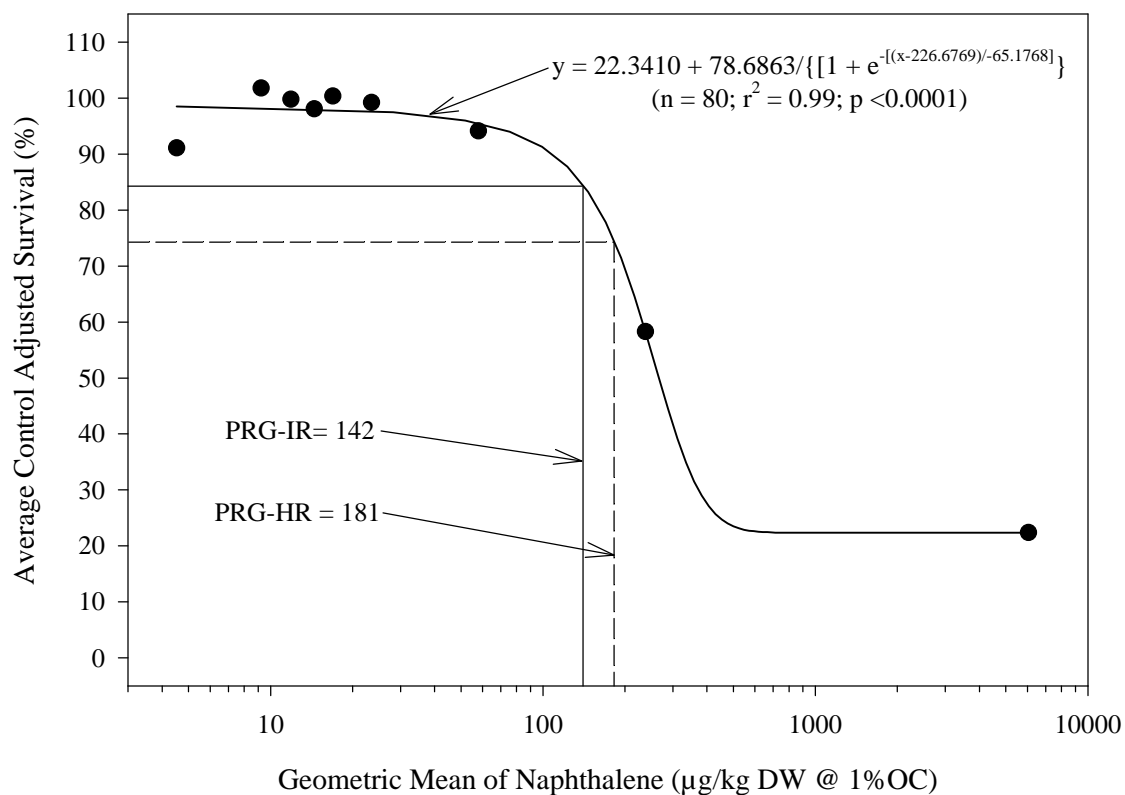


Figure 24. Relationship between the geometric mean of phenanthrene concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

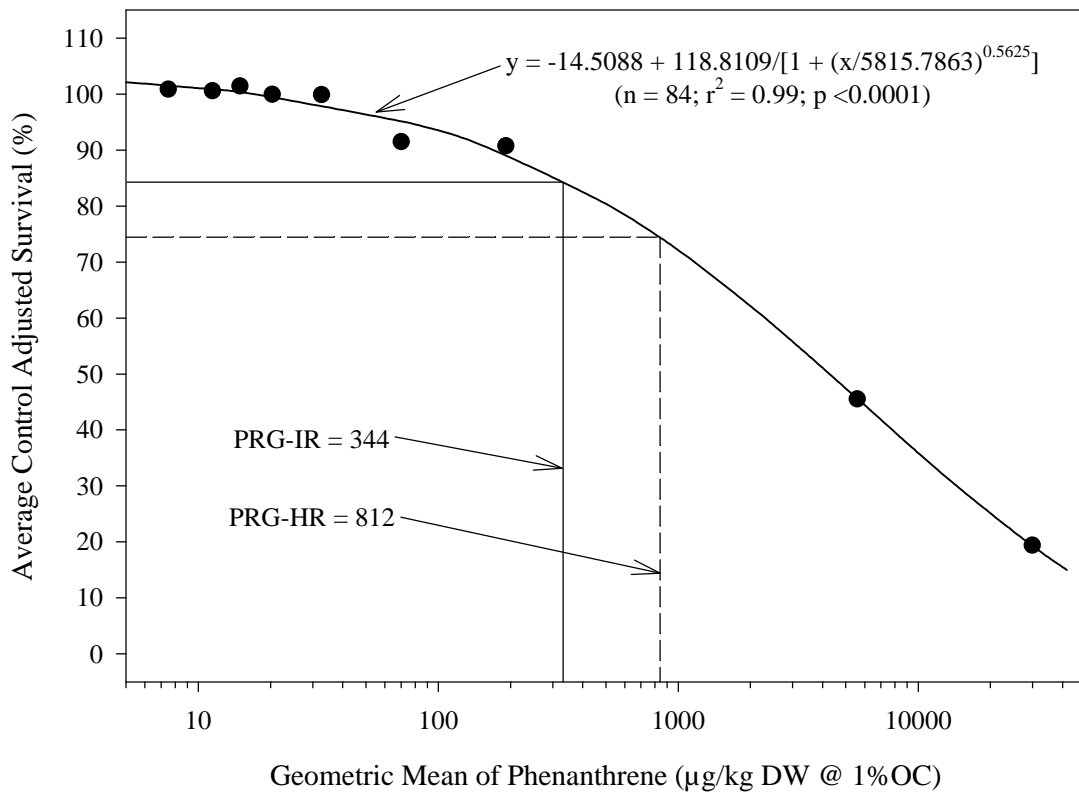


Figure 25. Relationship between the geometric mean of total low molecular weight-polycyclic aromatic hydrocarbon (LMW-PAH) concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

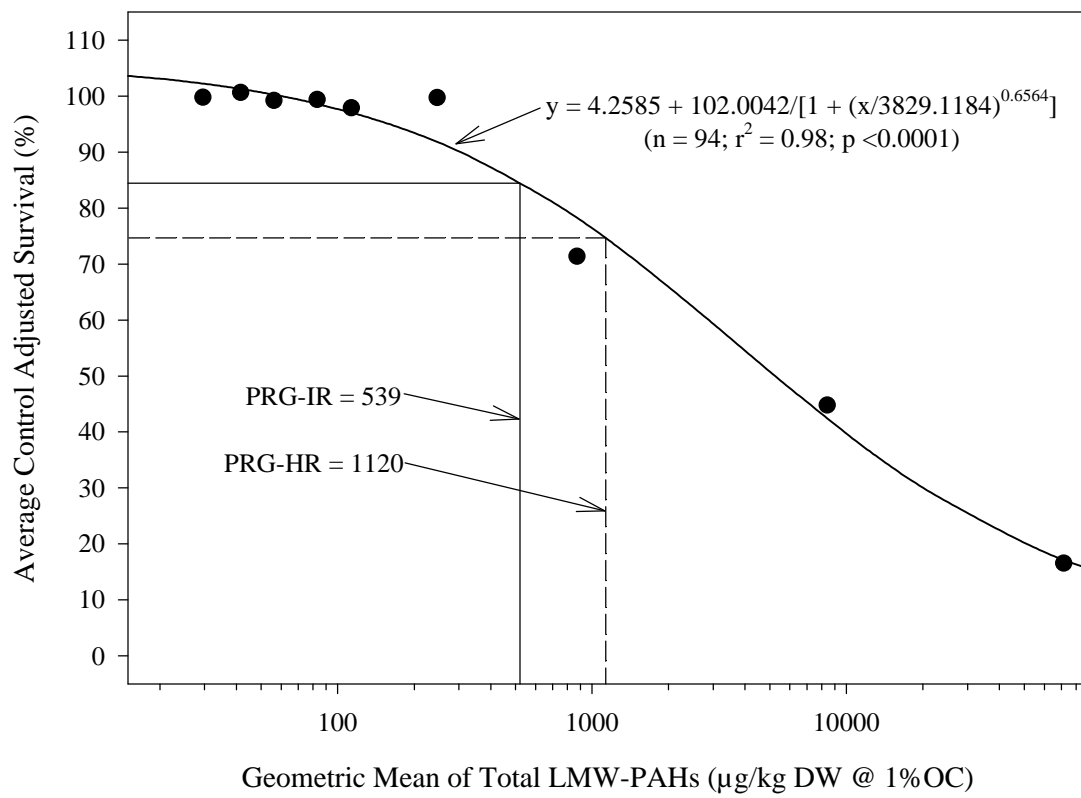


Figure 26. Relationship between the geometric mean of benz(a)anthracene concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

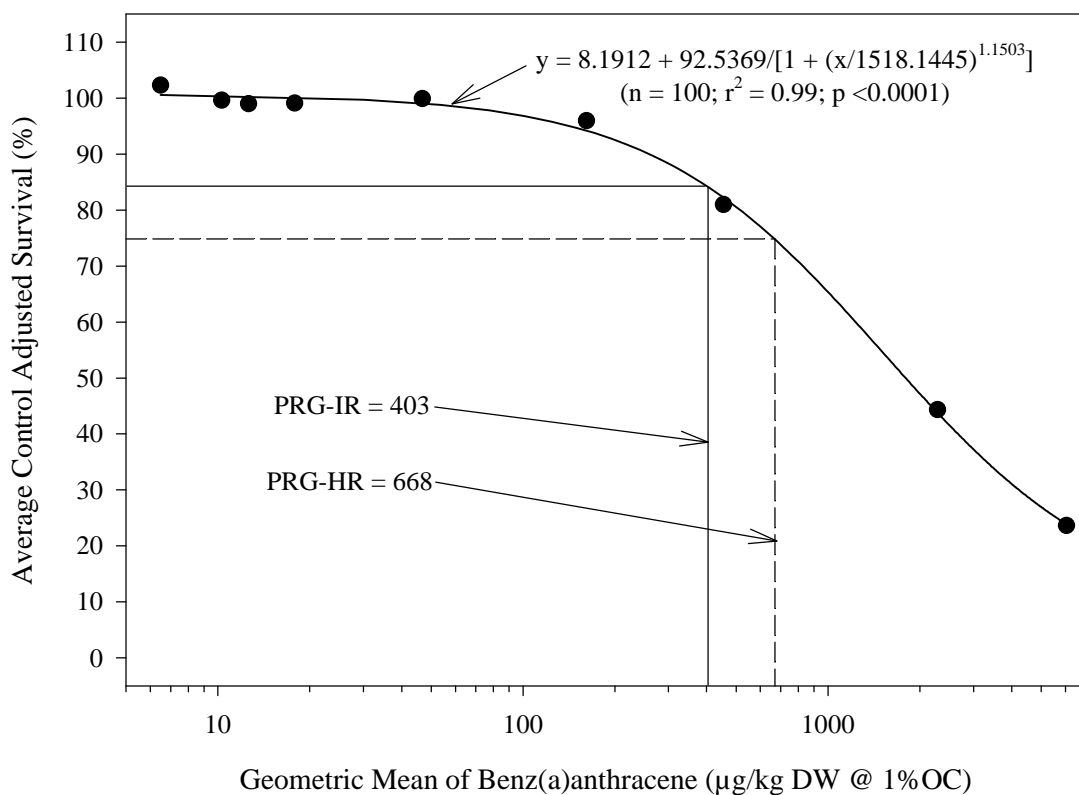


Figure 27. Relationship between the geometric mean of benzo(a)pyrene concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

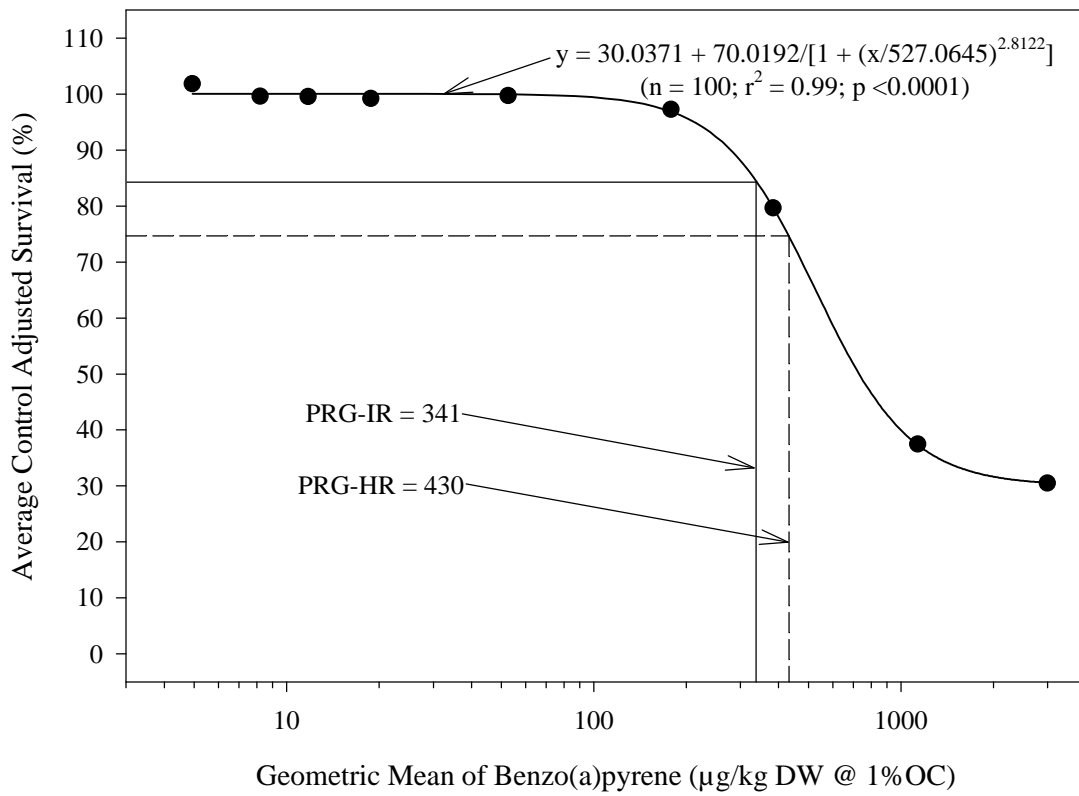


Figure 28. Relationship between the geometric mean of chrysene concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

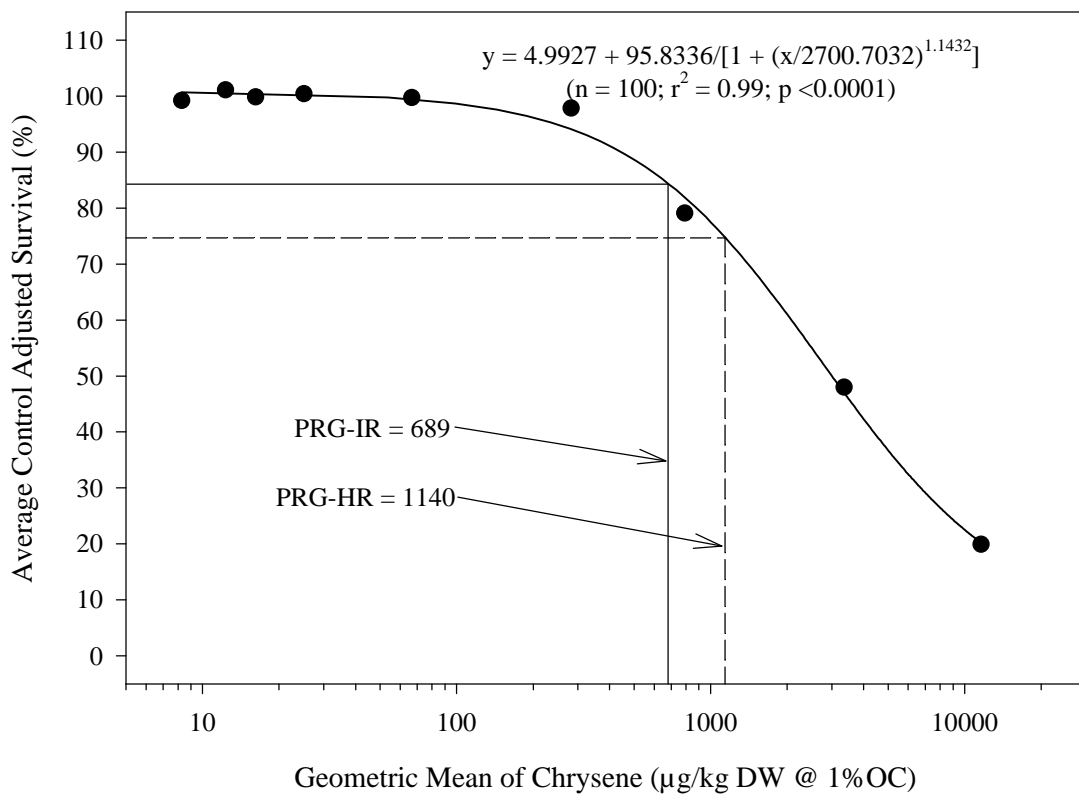


Figure 29. Relationship between the geometric mean of fluoranthrene concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

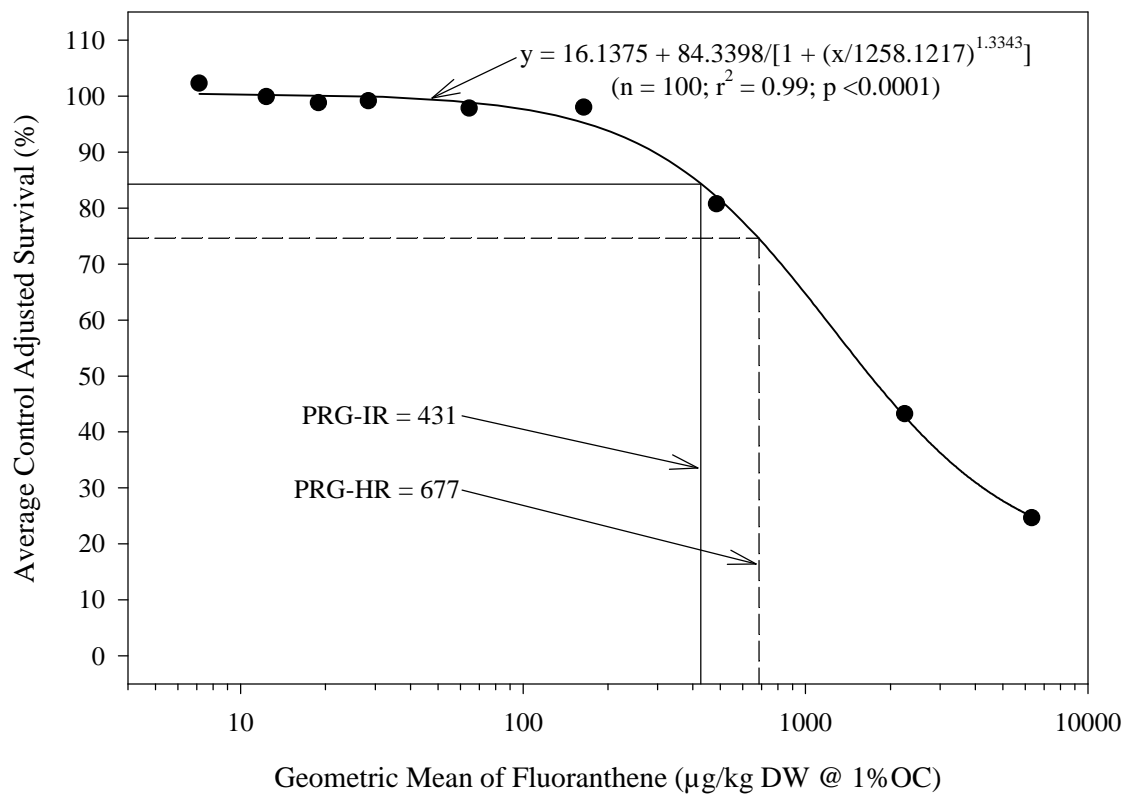


Figure 30. Relationship between the geometric mean of pyrene concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

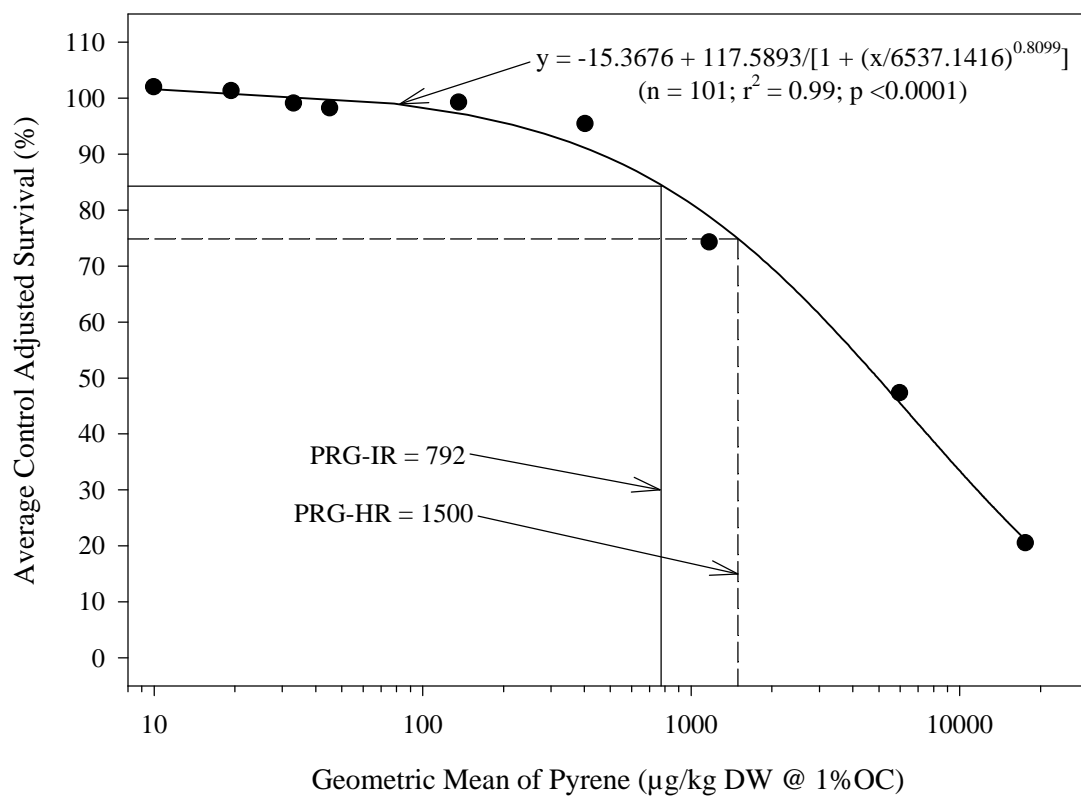


Figure 31. Relationship between the geometric mean of total high molecular weight-polycyclic aromatic hydrocarbon (HMW-PAH) concentration and average survival of the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

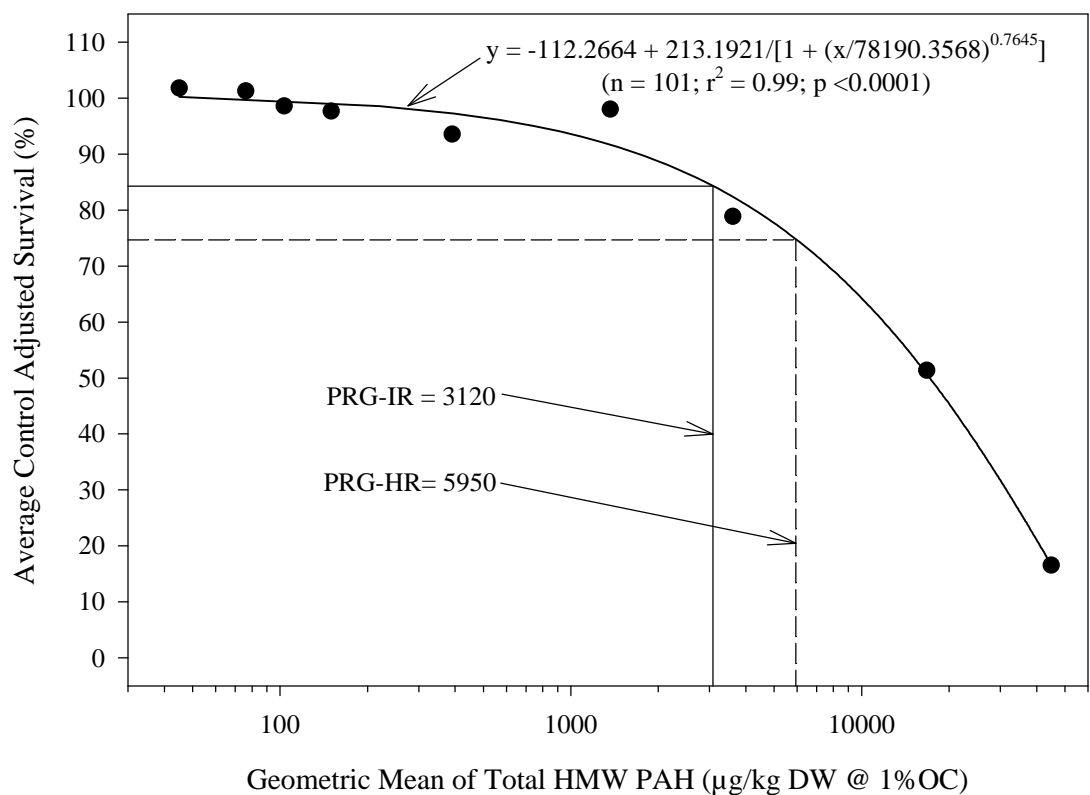


Figure 32. Relationship between the geometric mean of total polycyclic aromatic hydrocarbon (PAH) concentration and average survival of the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

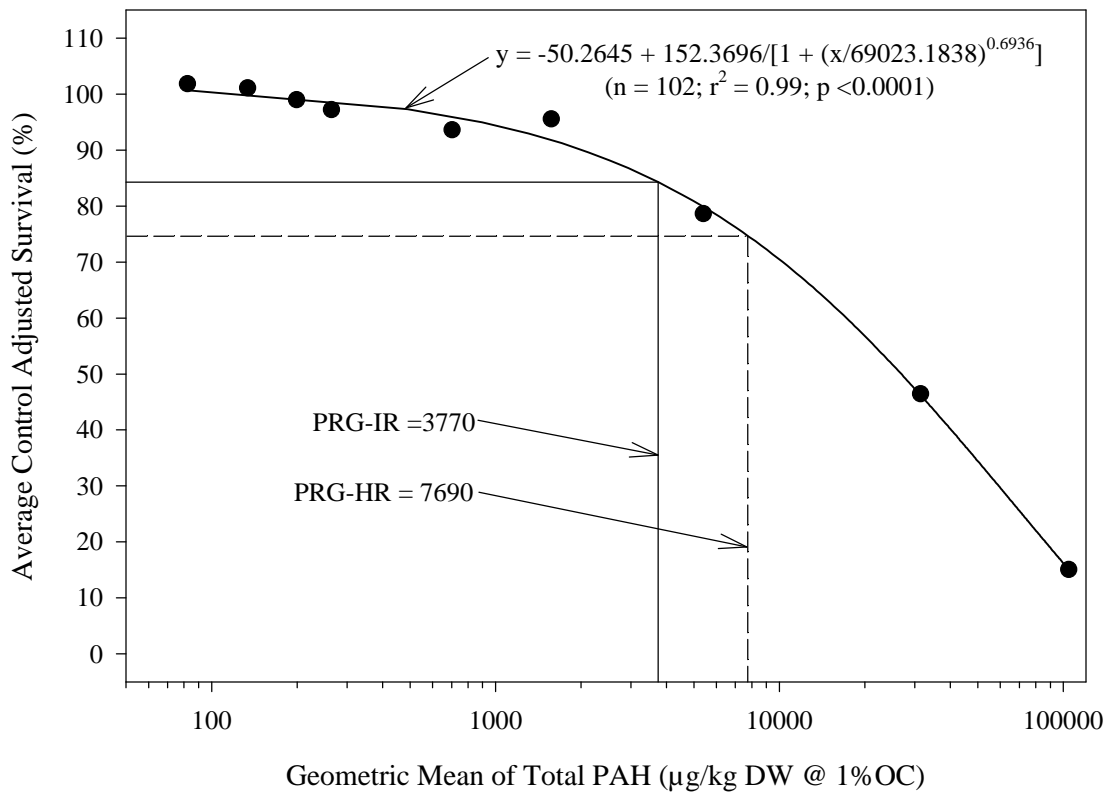


Figure 33. Relationship between the geometric mean of total polychlorinated biphenyl (PCB) concentration and average survival of the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests (i.e., magnitude of toxicity).

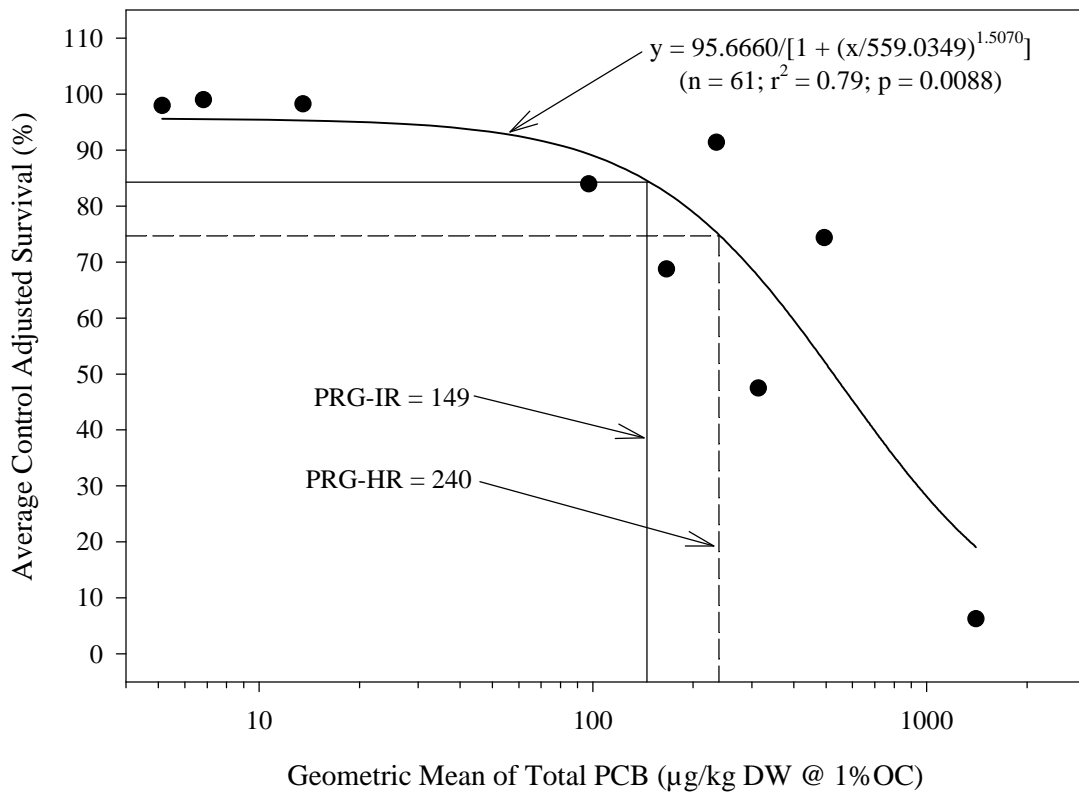


Figure 34. Relationship between the geometric mean of arsenic concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

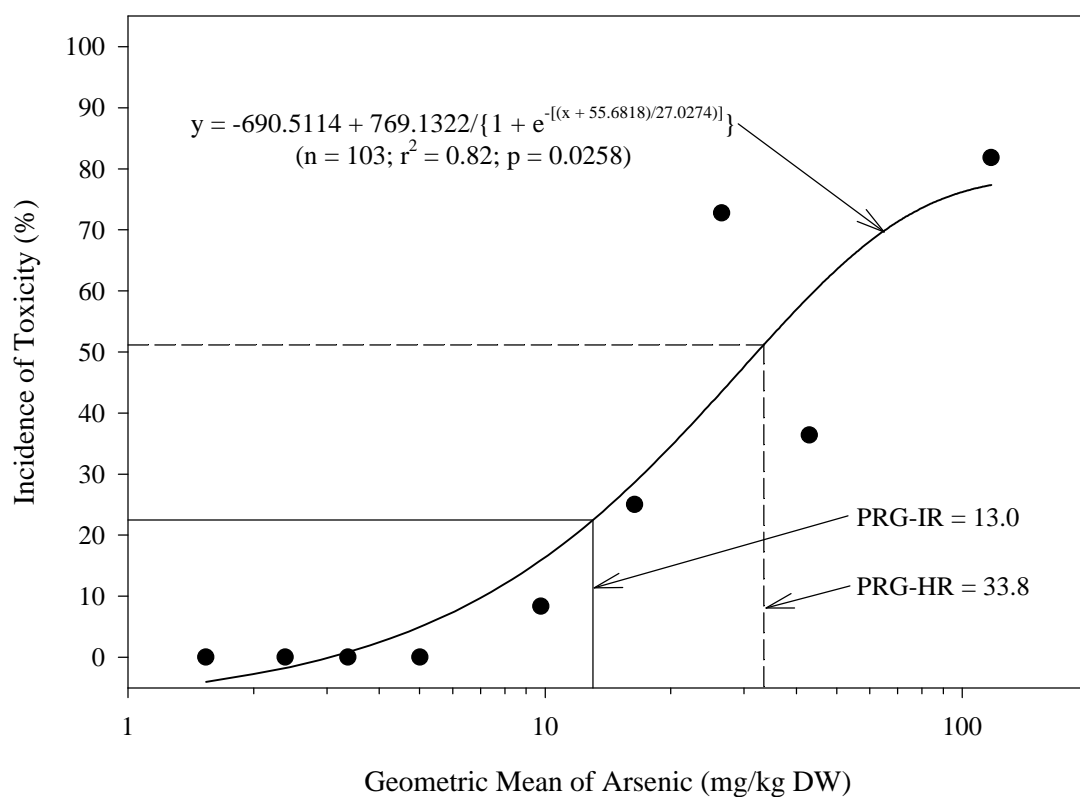


Figure 35. Relationship between the geometric mean of cadmium concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

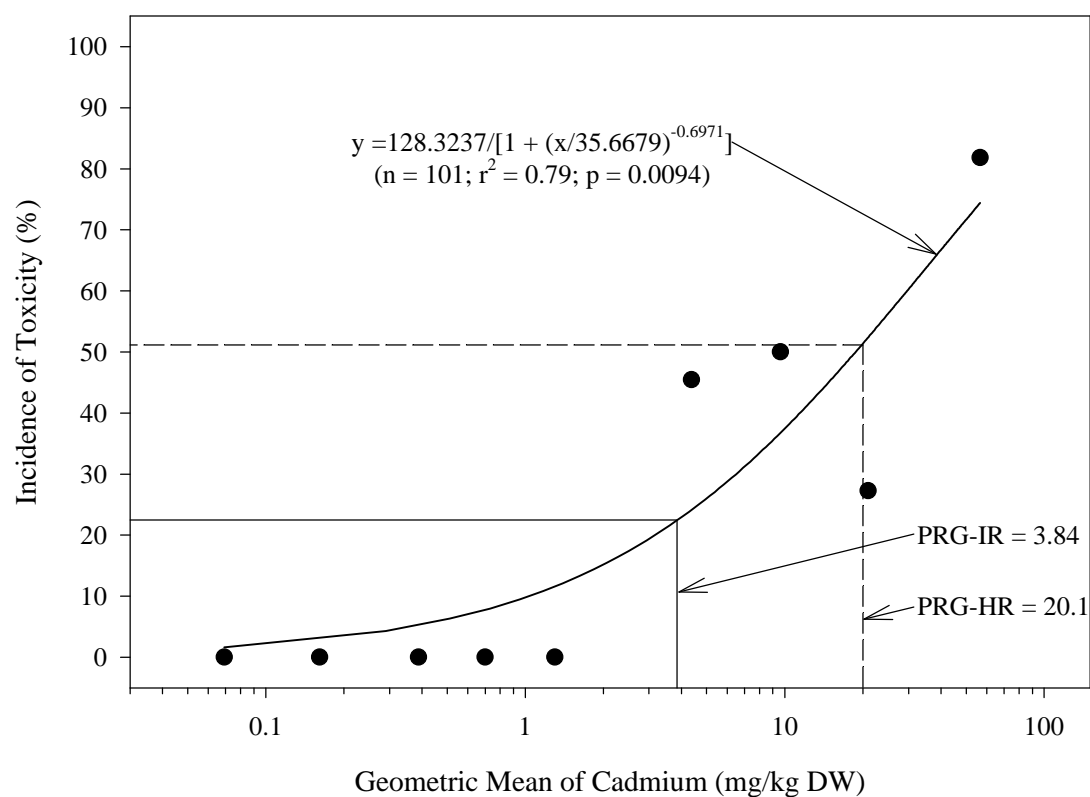


Figure 36. Relationship between the geometric mean of chromium concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

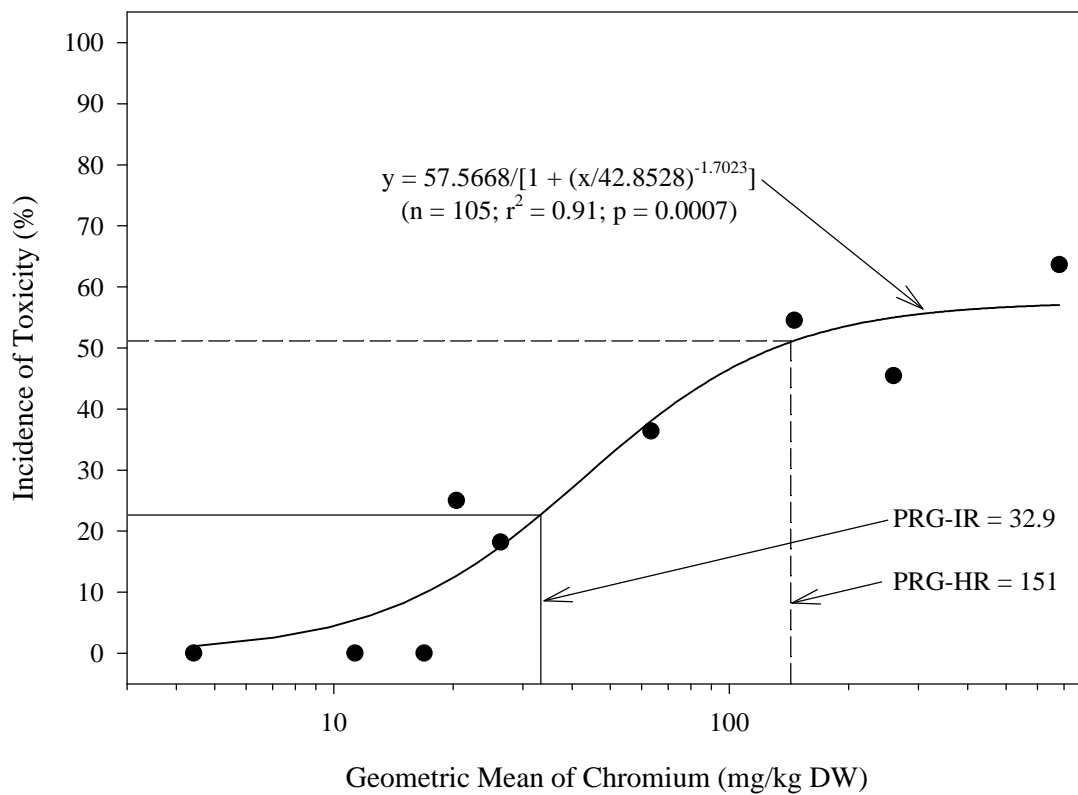


Figure 37. Relationship between the geometric mean of copper concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

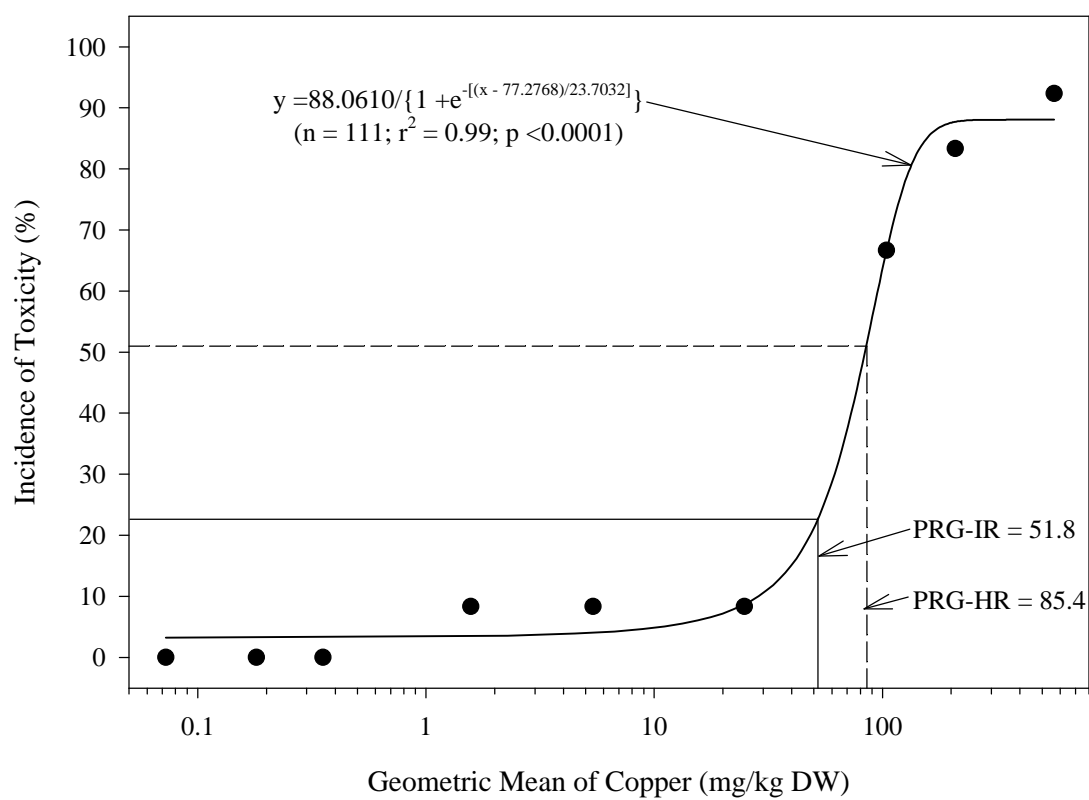


Figure 38. Relationship between the geometric mean of lead concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

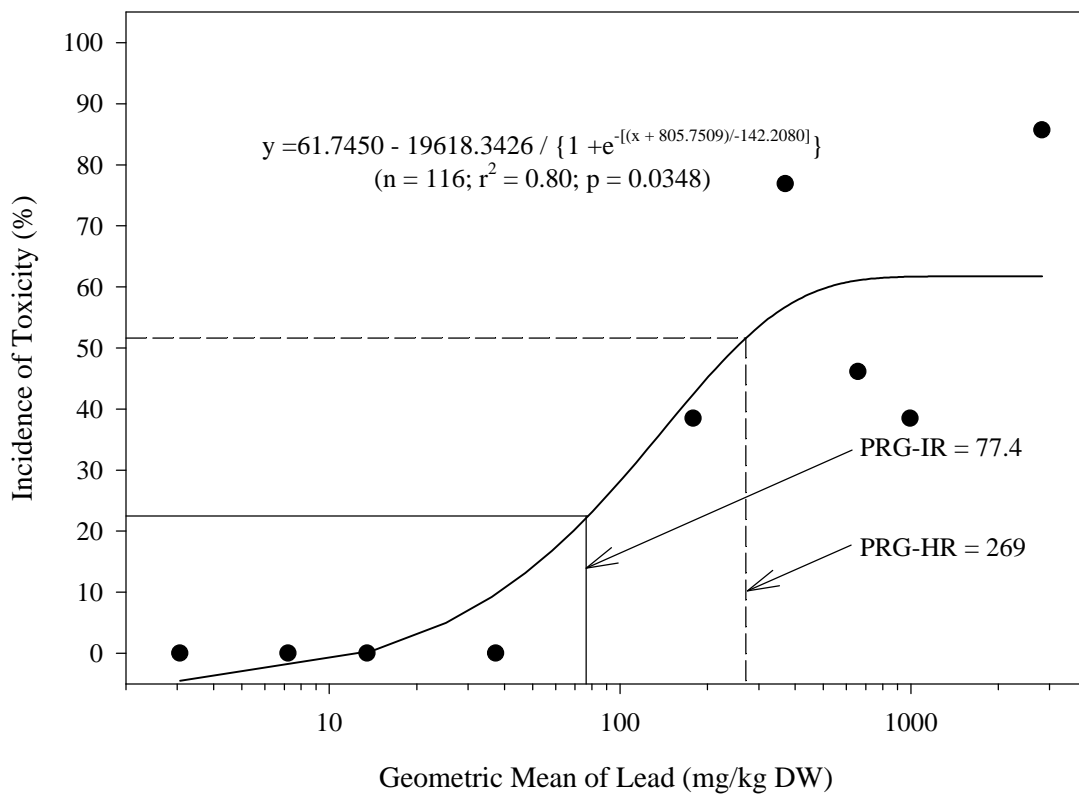


Figure 39. Relationship between the geometric mean of mercury concentration and the incidence of toxicity to the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests.

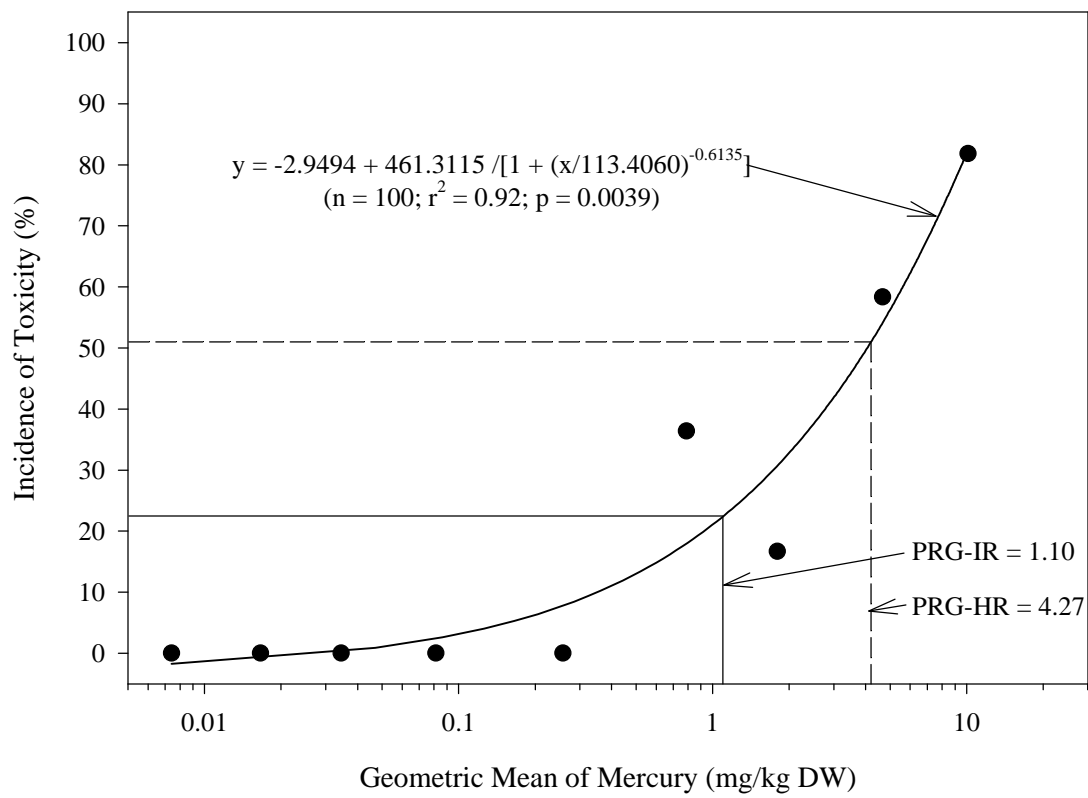


Figure 40. Relationship between the geometric mean of nickel concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

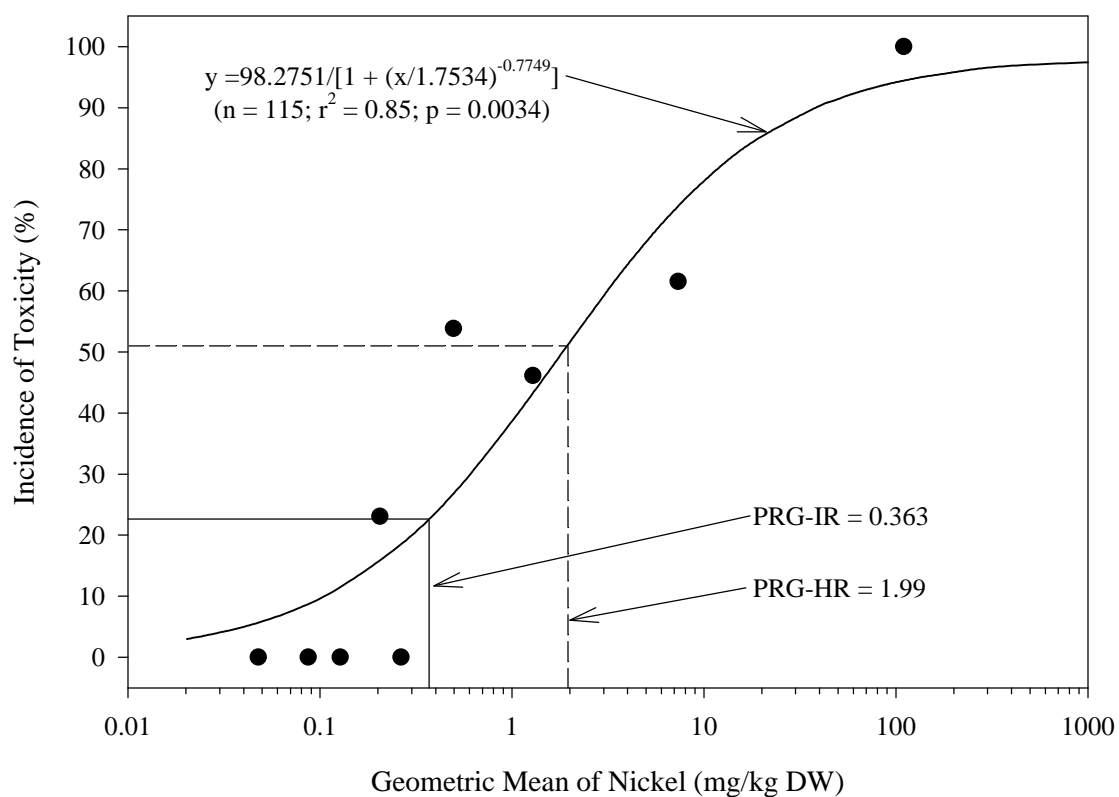


Figure 41. Relationship between the geometric mean of zinc concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

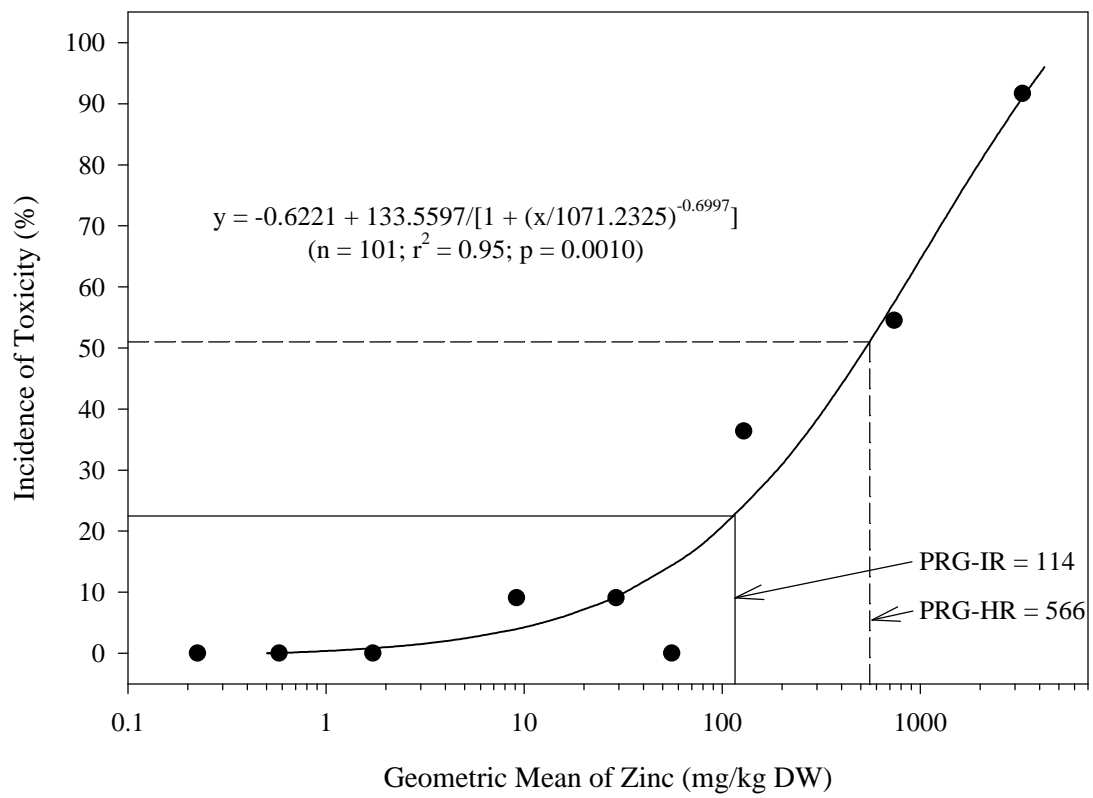


Figure 42. Relationship between the geometric mean of anthracene concentration and the incidence of toxicity to the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests.

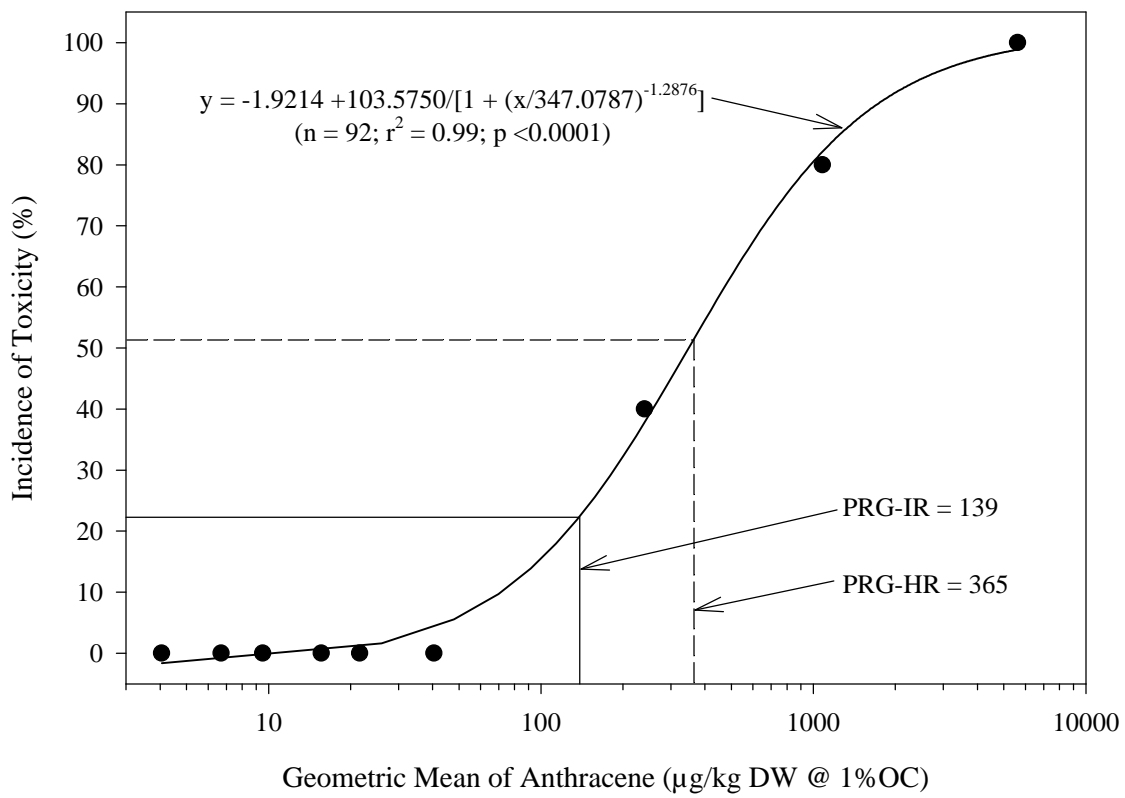


Figure 43. Relationship between the geometric mean of fluorene concentration and the incidence of toxicity to the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests.

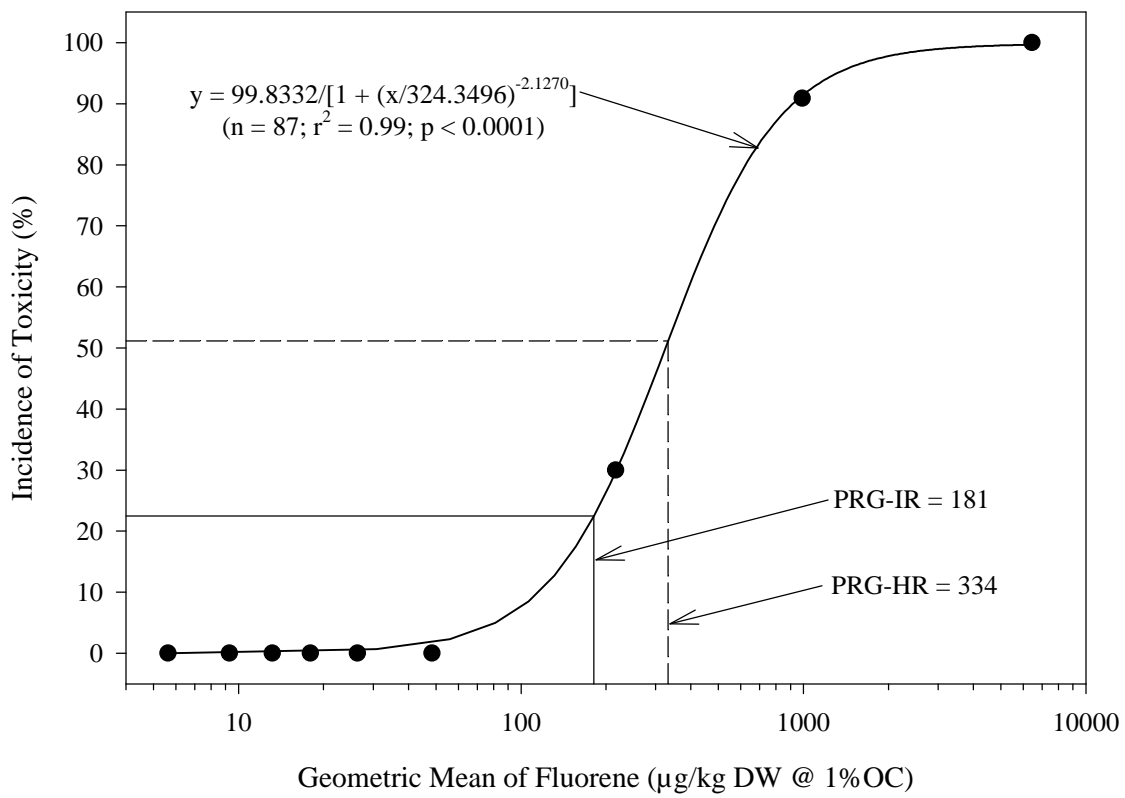


Figure 44. Relationship between the geometric mean of naphthalene concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

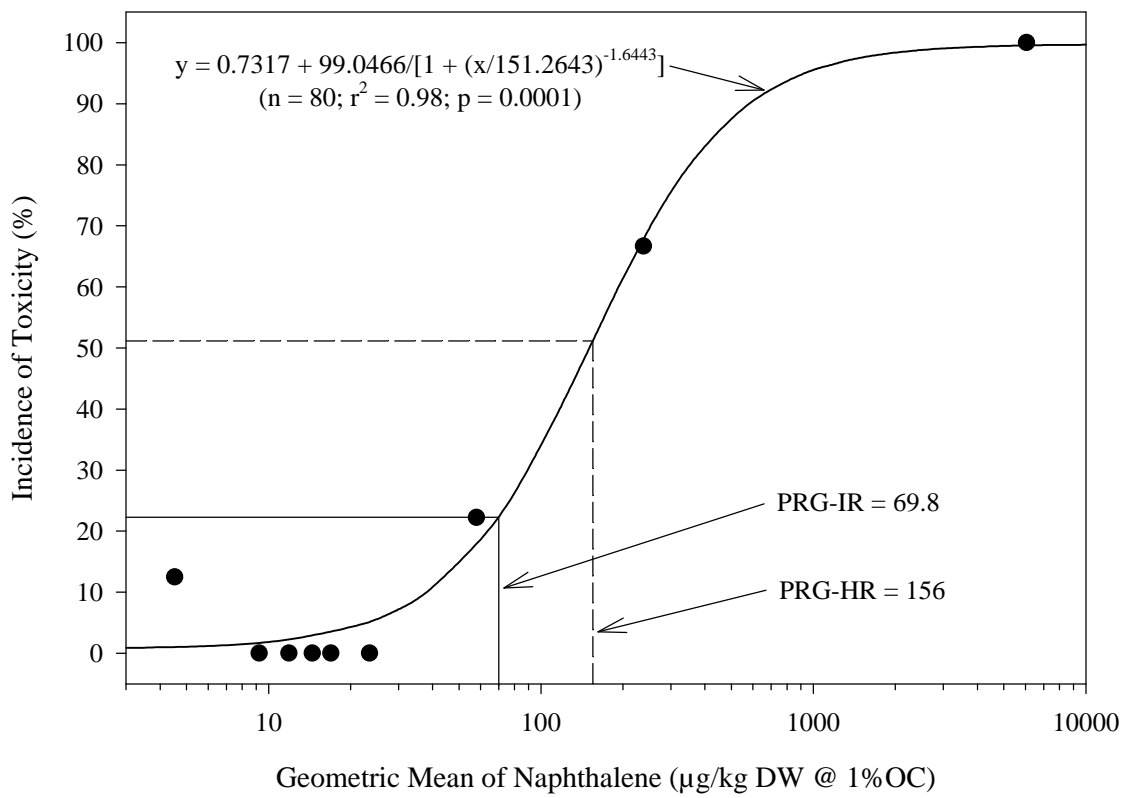


Figure 45. Relationship between the geometric mean of phenanthrene concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

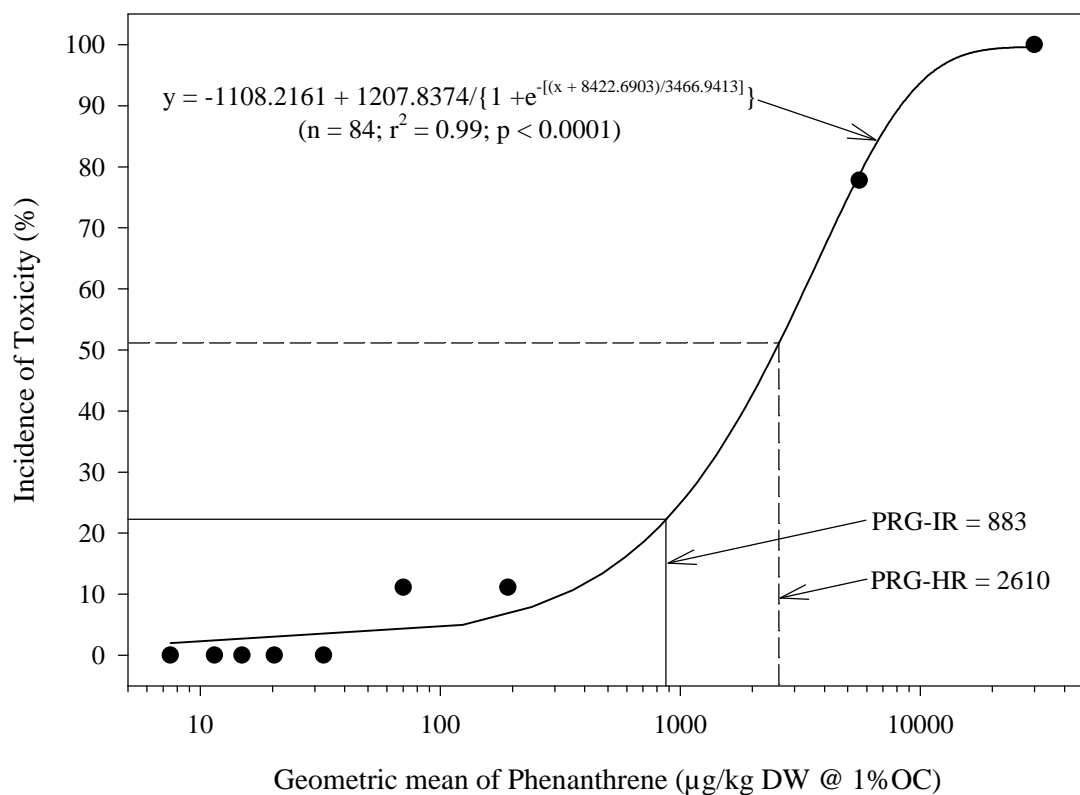


Figure 46. Relationship between the geometric mean of total low molecular weight polycyclic aromatic hydrocarbon (LMW-PAH) concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

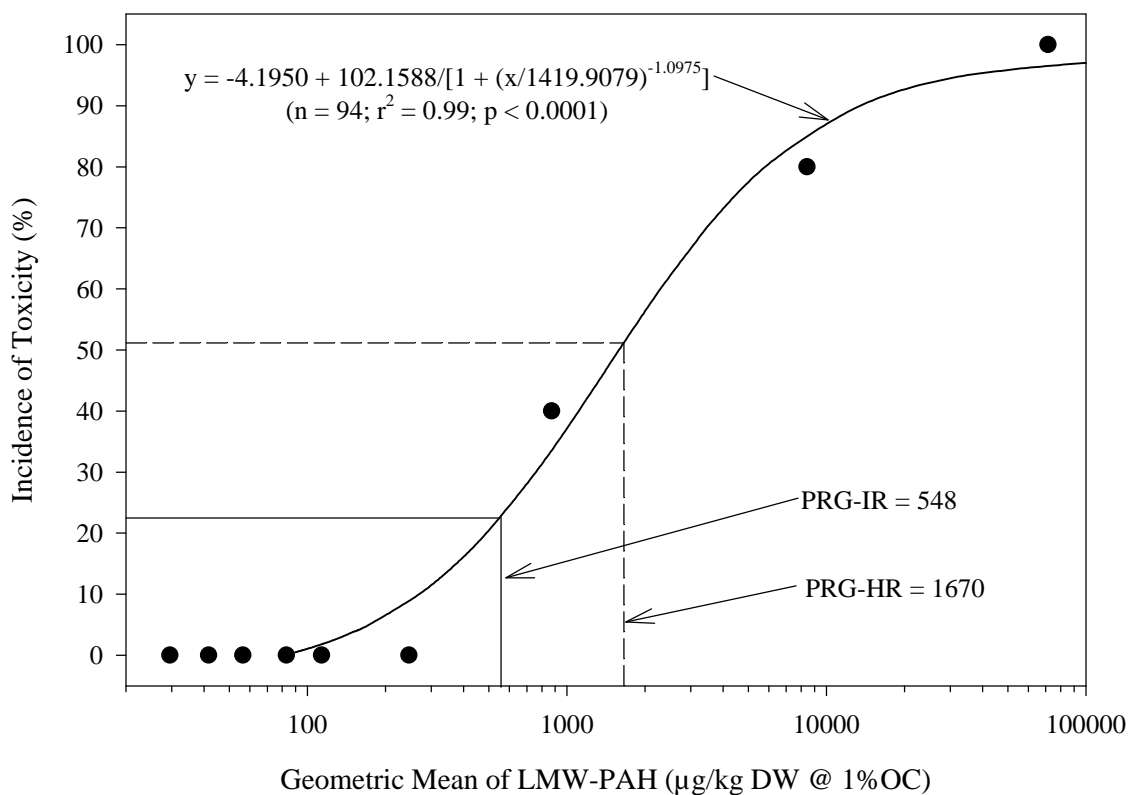


Figure 47. Relationship between the geometric mean of chrysene concentration and the incidence of toxicity to the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests.

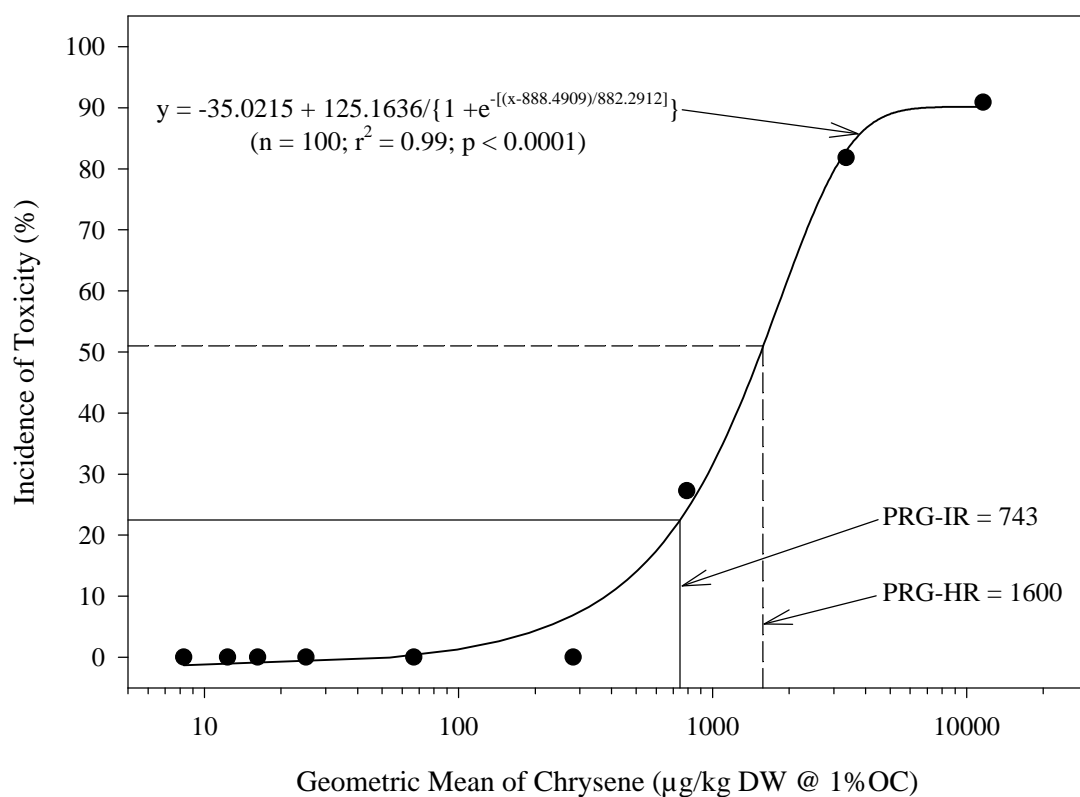


Figure 48. Relationship between the geometric mean of pyrene concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

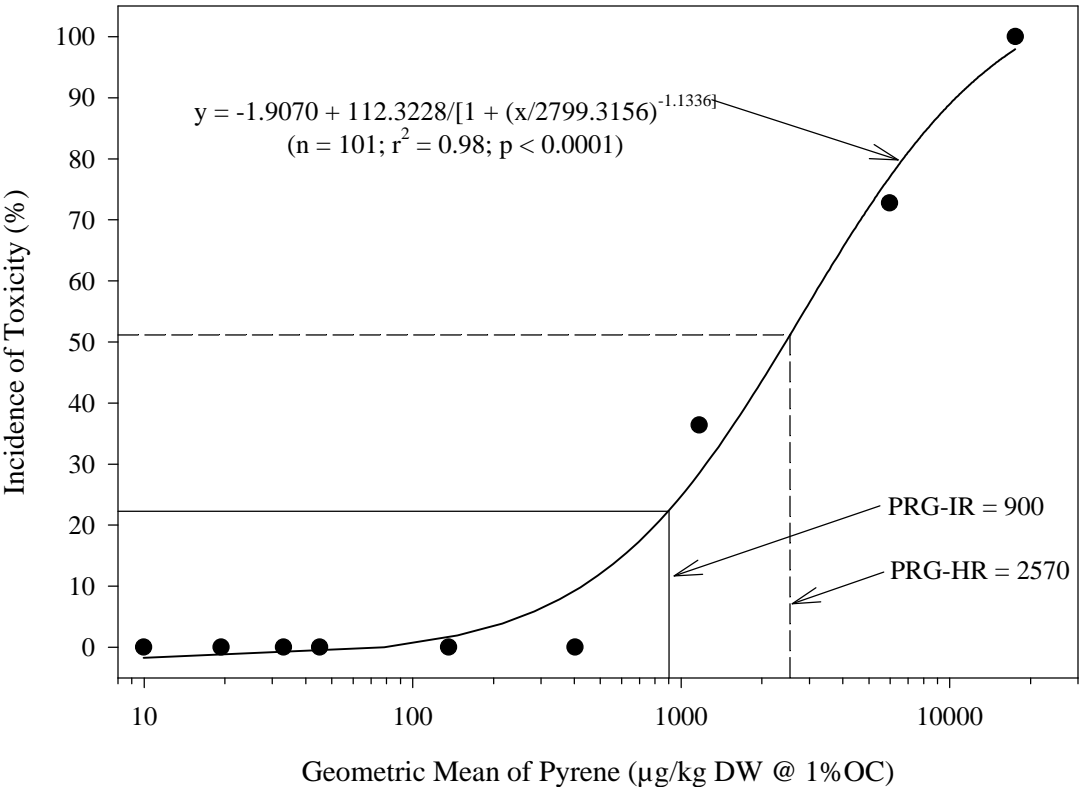


Figure 49. Relationship between the geometric mean of total high molecular weight polycyclic aromatic hydrocarbon (HMW-PAH) concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

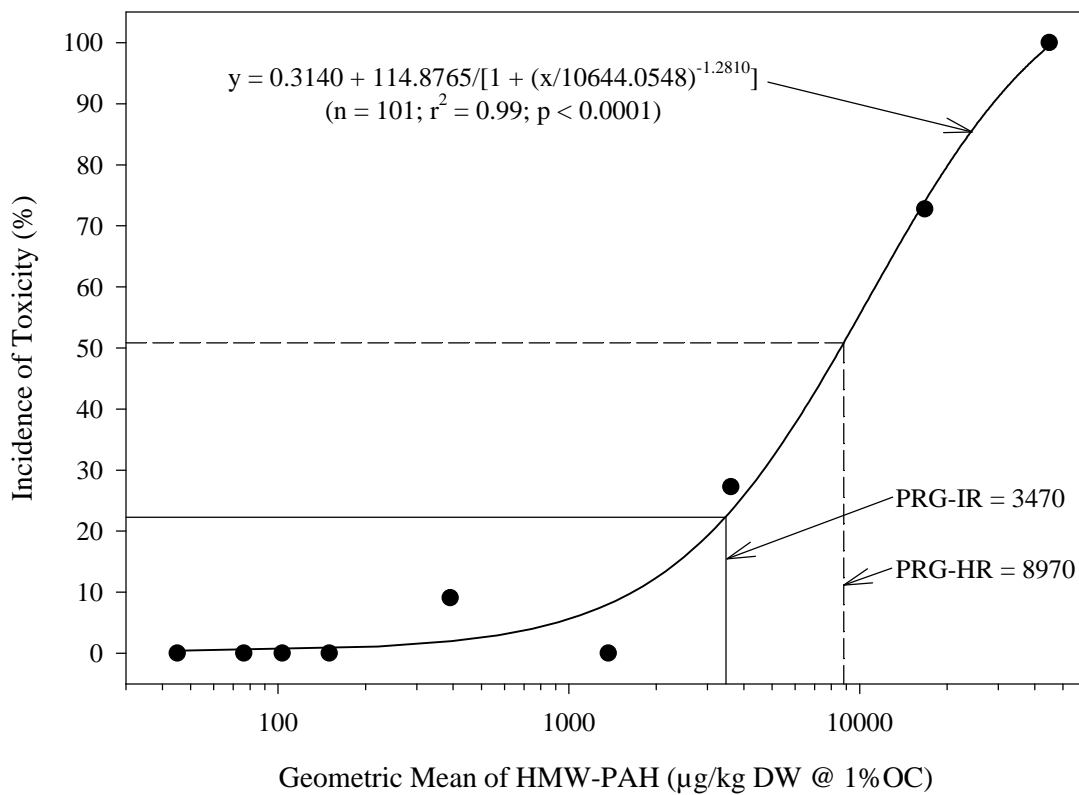


Figure 50. Relationship between the geometric mean of total polycyclic aromatic hydrocarbon (PAH) concentration and the incidence of toxicity to the freshwater amphipod, *Hyaella azteca*, in 28-d toxicity tests.

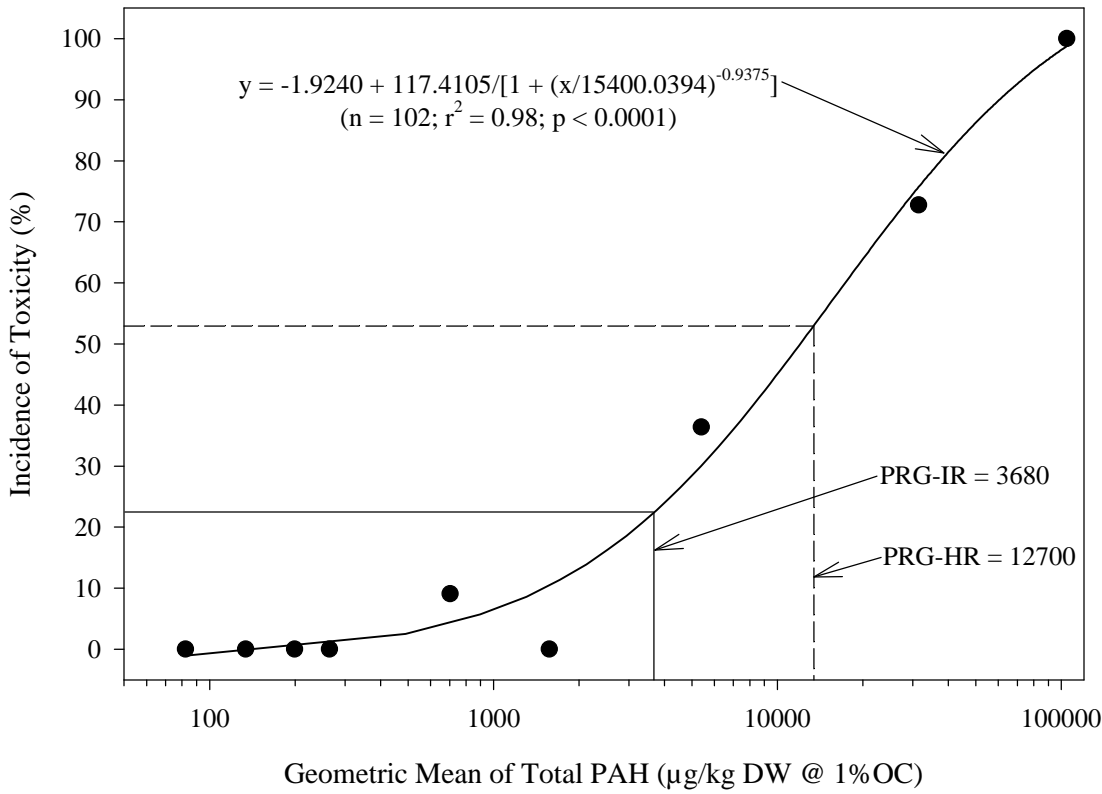


Figure 51. Relationship between the geometric mean of total polychlorinated biphenyl (PCB) concentration and the incidence of toxicity to the freshwater amphipod, *Hyalella azteca*, in 28-d toxicity tests.

